Turloughs: Hydrology, Ecology and Conservation

Edited by S. Waldren

This report details the findings and recommendations of a multidisciplinary project to investigate the hydrology, ecology and conservation status of Irish turloughs, temporary lakes in karst limestone. The project was funded by National Parks & Wildlife Service, with additional funding for Nova Sharkey's PhD project provided by the Environmental Protection Agency. The project was carried out by Principal Investigators and Researchers from the Departments of Botany, Zoology, Geology, Civil Structural and Environmental Engineering, and the Centre for the Environment at Trinity College Dublin.

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Cover Image:

Lough Gealain, in the Burren National Park, County Clare. One of the most important turloughs in Ireland, with exceptional water quality, important biological communities and no apparent pressures.

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Executive Summary

Scope

Turloughs are topographic depressions in karst that are intermittently inundated on an annual basis, mainly from groundwater, that drain without overland stream outflow, and that have a substrate and/or ecological communities that are characteristic of wetlands. They are listed as priority habitats of community concern under the EU Habitats Directive (92/43/EEC), which directs Member States to maintain these habitats in favourable conservation status. As the majority of turloughs globally occur within its territory, Ireland has an international obligation to conserve them. This report documents the outputs, findings, recommendations and synthesis from a project funded by the National Parks & Wildlife Service to research the hydrology, ecological functioning and conservation status of Irish turloughs. To achieve this, a multidisciplinary team based at Trinity College Dublin undertook an in-depth study of 22 selected turloughs.

Key Outputs

The following key outputs improve ecological understanding and conservation assessment of turloughs:

- *An improved understanding of turlough hydrology.* Turlough hydrology can be characterised by either flow through or surcharge tank models, which are able to accurately describe variation in eco-hydrological variables derived from continuously recorded flooding and rainfall data.
- *An evaluation of seasonal and annual changes in turlough hydrochemistry, algae and aquatic invertebrates*. Turlough aquatic communities resemble those of permanent lakes, but sometimes with limited development and with peaks of abundance that occur over the winter period rather than in spring or summer. Invertebrate seasonal patterns are set and modified by the onset of flooding.
- *Descriptions of terrestrial vegetation, soils, aquatic invertebrate and algal communities, and their relationships with hydrological, nutrient and landuse data*. The duration of flooding results in a characteristic zonation of turlough plant communities, but variability of flooding regimes across turloughs may hinder generalised models of vegetation zonation. Long-duration of flooding drives development of wetland communities, while the less-frequently flooded areas are typified by transitions to grassland, scrub and woodland communities.
- *A conceptual model of turlough ecological functioning, linking biological communities with hydrology, water and soil nutrient status, and landuse*. The project investigated many but by no means all aspects of this conceptual model.
- *A conservation assessment of the 22 sites, based on their ecological structure and function, identify specific pressures and threats, and the future prospects of these sites.* Biodiversity within turloughs is strongly influenced by an interaction between grazing and ambient nutrient status. Some of the low-nutrient status turloughs have little pressure from grazing livestock, with plant communities dominated by less palatable sedges.
- *A scheme for monitoring turloughs.* This will provide additional ecological information on turloughs and form the basis for future reporting obligations under Article 17 of the Habitats Directive.
- *Site reports for the 22 turloughs studied in detail, providing quantitative site-specific biological, hydrological and conservation data*. These data provide a baseline from which trends can be measured. These reports contain maps of vegetation, soils, turlough topography and estimated zones of groundwater contribution.

Key Findings

Many turloughs are of international conservation significance: Although the overall conservation status of turloughs in Ireland is *Unfavourable*, some of the oligotrophic turloughs that were monitored retained excellent ecological conditions, and could be considered as equivalents to the *High Status* water bodies under the E.U. Water Framework Directive (2000/60/EC). Maintaining the quality of the oligotrophic turloughs depends on both low intensity activities in the immediate vicinity of the turlough, and across a wider hydrological network supplying those turloughs. Special provision for the protection of these sites, similar to the needs of many Water Framework Directive (WFD) *High Status* water bodies, may require further policy development. Other potentially oligotrophic turloughs should be surveyed and monitored as a matter of urgency, and their conservation status determined.

Hydrology is the main ecological driver: The biological communities were shaped primarily by the depth, duration and rate of areal reduction in flooding. As a consequence, maintaining the hydrological functioning of turloughs is key to providing effective conservation status. Drainage to alleviate flooding seriously impairs ecological structure and function of turloughs, unless such drainage is restricted to the very upper-most parts of turloughs, thereby alleviating only the occasional extreme flooding events.

Turloughs exist as a hydrological and ecological continuum: All hydrological variables investigated showed a continuous range of variation, and biological communities were found to respond to this hydrological variation. There is no justification for categorizing turloughs into hydrological types. Instead, conservation management should be developed on a site-by-site basis.

Phosphorus concentration in the floodwater is the major pressure on turlough systems. Concentrations of phosphorus in floodwater varied considerably, and showed strong relationships with algal and aquatic invertebrate communities and terrestrial vegetation. Some turloughs had exceptionally good water quality (oligotrophic to ultra-oligotrophic) and these usually had the most interesting biological communities, with vegetation dominated by various sedges (*Carex* spp.); several of these turloughs occurred in the vicinity of the Burren. By contrast, turloughs with higher nutrient levels (mesotrophic) tended to have vegetation communities dominated by grasses and forbs. Other turloughs had very poor water quality (strongly eutrophic), often associated with degraded biological communities. In some cases poor water quality could be attributed to sources adjacent to or within the turlough, including fertilizer application, slurry spreading and effluent discharge. Turloughs, being in a karst landscape, are inherently sensitive to rapid transport of pollutants (including nutrients) from the surface via karst features which link directly down into the conduit network (e.g. dolines, swallow holes, sinking streams etc.), either from areas of autogenic recharge (i.e. on the karst) or from allogenic recharge from rivers draining off other bedrock types down into the karst, as is the case in the Gort lowlands chain. Some of the more oligotrophic turloughs have extreme pathway susceptibility, yet had very few sources of phosphorus pollution in their zones of groundwater contribution (ZOC); the complex relationships between source (particularly of phosphorus), pathways and receptor are poorly understood and require further investigation.

Inappropriate agricultural management is an important pressure in some turloughs: There was evidence that overgrazing had reduced biological diversity in some turloughs since previous vegetation surveys in the early 1990s. Grazing intensity was usually highest in the mesotrophic turloughs, probably because the vegetation was more palatable and nutritious than in the sedge-dominated oligotrophic turloughs; the latter often had low density grazing and one case (Lough Gealain) a complete absence of livestock. In some mesotrophic turloughs, low grazing intensity seems to have resulted in the development of taller, less diverse vegetation. In general, excessive sheep grazing was more detrimental to turlough swards than cattle or horse grazing. Some turloughs also showed signs of agricultural improvement, through fertilizer spreading, scrub clearance and probable reseeding with Perennial Ryegrass in the upper zones. Effluent discharge and the washing of agricultural machinery in some turloughs negatively affected turlough nutrient status.

Recommendations

Monitoring: Future monitoring should focus on changes from established baselines on a site-specific basis. Phosphorus should be directly measured in turlough floodwater at least once and preferably three times per year. Ongoing monitoring of biological communities, hydrology and hydrochemistry should continue in the 22 turloughs studied here, using the baseline information established by this project to assess future change. Other important turloughs should be added to this monitoring scheme, especially those thought to be oligotrophic and of high conservation importance; vegetation can be used to provide a field assessment of nutrient status in turloughs which lack hydrochemical data.

Research: Research should be undertaken to determine the relative contributions to turlough nutrient status of phosphorus sources in the zone of groundwater contribution (ZOC), sources adjacent to the turlough and sources within the turlough. Research should also investigate the relationship between phosphorus in floodwaters, soils and its uptake by vegetation. This would provide an informed basis to manage the nutrient status of turloughs and improve their conservation status.

Active Conservation: Efforts should be made to improve the conservation status of turloughs. For those already considered to be in favourable conservation status, this should involve on-going monitoring of the biological communities and the pressures, particularly phosphorus in floodwater. For other turloughs, more active conservation is required; some trial restorations could be attempted to improve their ecological status, mainly through grazing management and control of source inputs of nutrients, both locally and within the wider ZOC. Grazing management will involve reductions in grazing intensity in some turloughs, but increases in intensity in some under-utilised turloughs. This will involve development of management plans through close co-operation between State conservation and planning agencies and local landowners. Effective conservation of turloughs can be delivered while also ensuring that the livelihoods, land and property of local landowners are maintained. Karst features in ZOCs which link directly into the conduit network, and hence form important pathways for pollutant ingress to turloughs, should be identified and given special protection from potential pollution sources, similar to the source protection zone concept used by the Geological Survey of Ireland for water resources and the Environmental Protection Agency's Code of Practice for on-site systems which must be at least 15 m from a karst feature.

Policy Considerations

Like many high status sites, turloughs are subject to localised small scale, but extensive (ie within the wider ZOC) pressures, such as local pollution and drainage. These are not necessarily documented in the Significant Water Management Issues (SWMI) reports prepared for each River Basin District (RBD) as part of the drafting of the RBD management reports under the WFD. The Planning and Development (Amendment) Act 2010 strengthens the relationship with the WFD, providing a clearer requirement for local authorities to consider potential impacts on high status water bodies. While better planning for development including one-off housing and associated water treatment is required, and progress has been made, for example with the EPA's national inspection plan for domestic wastewater treatment systems, this does not address low level and localised impact from inappropriate land use. Impacts from agriculture on water quality are regulated by the European Communities (Good Agricultural Practice for Protection of Waters) Regulations S.I. No 31 of 2014 (following a series of other Regulations dating back to 2006).

Furthermore, the water requirements of groundwater-dependent terrestrial ecosystems (GWDTEs) such as turloughs must be protected under the WFD; to be achieved through the groundwater body classification process. Under the European Union (Water Policy) Regulations 2014 (S.I. NO. 350 of 2014), the Environmental Protection Agency is now responsible for leading the development of Programmes of Measures to implement the WFD in Ireland, and it will be important that measures for turloughs are considered in this context. Programmes of Measures already identified at a national scale in 2008 for implementation of the WFD could potentially facilitate conservation of turloughs, and it is important to ensure that further measures developed at both national and catchment scale consider this dimension. For example, existing measures to control point source and diffuse source discharges, and measures to protect direct discharges to groundwater could all help reduce the input of nutrients to turloughs. Similarly, specific measures listed under cross-compliance with the Habitats Directive include protection and restoration measures for sensitive habitats and species receptors, and indicate that management measures and codes of practice be developed and implemented for individual Natura 2000 sites, including adjustment of management to achieve and maintain favourable conservation status where needed. Other measures regulate agriculture, including, for example, a reduction of grazing where necessary. Further supplementary measures for High Status Sites could be used to ensure protection of the most important oligotrophic turloughs noted above. Further refinement of these measures might include additional protection for karst features in turlough ZOCs, as noted in the previous section.

Much of the policy framework to deliver turlough conservation therefore exists, though it is far from clear whether all of the documented measures are being applied. A Code of Practice, jointly developed by NPWS, EPA and relevant landowner organisations, could deliver a series of management recommendations that helps to deliver sustainable agriculture while also ensuring that the requirements of the Water Framework and Habitats Directive are met for turloughs.

Chapter 1. Introduction

S. Kimberley

East Burren landscape, with the Travaun-Skaghard-Cooloorta complex of turloughs in the middle distance, and Castle Lough beyond. *Photo: S. Waldren*

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1.1 Project Scope and Aims

The National Parks and Wildlife Service (NPWS) commissioned this interdisciplinary research project to provide a robust scientific foundation for assessing the conservation status of turloughs, which are karst wetlands characterised by dynamic hydrology, intermittently occurring terrestrial and aquatic phases and mosaics of management units. The EU Habitats Directive (HD) and Water Framework Directives (WFD) are the key legislative drivers of turlough conservation. The vast majority of turloughs occur in the western third of Ireland and this limited distribution induced their designation as an EU priority habitat under the HD. Conservation status, in the context of the HD, encompasses the sum of influences acting on turloughs that may affect their distribution and structures and functions, including the survival of typical species. The key objective of the HD is the maintenance of 'Favourable Conservation Status' (FCS) of priority habitats. The current understanding of turlough ecology is inadequate, however, for categorising the conservation status of specific structures and functions of the habitat. This inadequacy principally derive from a lack of extensive and integrated eco-hydrological research. To date, eco-hydrological research has focussed on a limited number of turloughs and extensive data often encompasses only one aspect of the habitat. Information on the spatial and temporal variation of ecological factors is sparse and, on a more fundamental level, there is currently almost a complete lack of baseline nutrient data for turloughs.

Turloughs are designated as groundwater-dependent terrestrial ecosystems (GWDTEs) under the WFD. The conservation focus in this context is on the linkage between the groundwater body and the turlough and the prevention of significant damage from anthropogenic pressures. Specific guidance on the definition of significant damage for GWDTEs is lacking and improved definition demands greater understanding of the impacts of groundwater pressures on wetlands (Kilroy *et al.*, 2008). This relationship is poorly understood for turloughs and demands an integrated, interdisciplinary research approach. Under the WFD, the relevant protected areas for conservation are those designated under the HD. Currently, however, there is no specific guidance on harmonising the conservation objectives of both the HD and WFD for habitats such as turloughs (Irvine, 2009), yet there is broad agreement that clarification is imperative and that the potential for the development of complementary assessment strategies should be explored.

The project research team comprised personnel from the School of Natural Sciences and the School of Engineering in Trinity College Dublin. The disciplines included were Zoology, Botany, Geology and Environmental Engineering. The aspects of turlough ecology under investigation were phytoplankton, aquatic invertebrates, hydrochemistry, vegetation, hydrology, soils and land-use. The steering group for this project was derived from the NPWS, the Environmental Protection Agency and consultant turlough experts, many of whom are members of the Irish WFD groundwater working group (GW-WG). This report presents outputs from the targeted research, conducted with a view to improving understanding of turlough ecological functioning. This report also aims to provide explicit links between the improved understanding of turlough ecology gained from the project and the HD and WFD.

The overall project aims were:

- To describe and classify vegetation, algal and aquatic invertebrate communities of turloughs.
- To integrate concomitant hydrological, biological, nutrient, soil and land-use data generated from a broad range of turloughs with a view to identifying key drivers of biological community distribution.
- To assess threats to key drivers of biological community distribution.
- To examine the spatial and temporal variation of various aspects of turlough ecology and to elucidate consequent implications for monitoring.
- To support the NPWS in assessment of the conservation status of turloughs by developing survey, monitoring strategies and management prescriptions to enable compliance with the HD and WFD.

1.2 Legislation Affecting Turlough Conservation

The National Parks and Wildlife Service (NPWS) is the part of the Department of Environment, Heritage and Local Government with responsibility for enforcing legislation concerning Irish habitat and species conservation. The Wildlife Act, 1976 and the Wildlife (Ammendment) Act, 2000 are the two most important pieces of national legislation driving habitat conservation and management in Ireland. The Wildlife Act, 1976 is the principal national legislation providing for the protection of ecologically interesting habitats, such as turloughs, and Natural Heritage Areas are the primary national designation. The Geological Survey of Ireland (GSI) is currently compiling a list of geological/geomorphological sites in need of protection through NHA designation. The GSI has completed its list of karst features which includes 364 turloughs, which will undergo a process of survey, reporting and review, to provide recommendations regarding NHA status or otherwise. Formal designation will proceed on a phased basis over the next few years, without reference to Europe, under the Wildlife (Ammendment) Act 2000, the main objective of which was to enhance the legal protection of NHAs and pNHAs by enforcing protection from the date of formal proposal. Turloughs with pNHA status alone are subject to limited protection in the form of obligatory Rural Environmental Protection Scheme (REPS) Plans and recognition of their ecological value by Planning and Licensing Authorities.

Turlough conservation has been fortified and extended by the EU Birds Directive (79/409/EEC), the EU Habitats Directive (92/43/EEC) and the EU Water Framework Directive (2000/60/EEC). The HD placed an obligation on Member States of the EU to establish the Natura 2000 network of important ecological sites. The network is made up of Special Protection Areas (SPAs), established under the Birds Directive (79/409/EEC), and Special Areas of Conservation (SACs) established under the HD itself. Habitats listed as priority habitats under Annex I must be protected within SACs and, consequently, many turloughs have been proposed for designation as Candidate Special Areas of Conservation. cSACs are chosen subject to criteria provided in Annex III of the Habitats Directive and turloughs were selected as candidates from the list of Areas of Scientific Interest and NHAs compiled in the 1970s and 1990s respectively, in conjunction with input from professional and amateur ecologists. To date 44 sites have been designated as Candidate Special Areas of Conservation (SACs) for turloughs in the Republic of Ireland, containing approximately 70 individual turloughs.

Some turloughs lie within cSAC complexes encompassing large areas of interspersed Annex 1 habitats whereas other turloughs are individually designated as cSACs. Farmers are encouraged, but not legally obliged, to manage cSAC areas in accordance with a conservation management plan drafted by NPWS and subject to review every 5 years. Landowners are legally obliged, however, to acquire consent from the Minister for the Environment Heritage and Local Government prior to implementing any potentially damaging changes (Notifiable Actions) (Government of Ireland, 2014).

EU members states are required to monitor and report on the conservation status of cSACs and their management must ensure their 'maintenance or restoration at a favourable conservation status'. For the purposes of the HD, conservation means a series of measures required to maintain or restore a natural habitat at a favourable status. Conservation status is considered favourable when the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future. Favourable conservation status also demands that the natural range, and area it covers within that range, are stable or increasing and that the ability of typical species to remain a viable component of the habitat is maintained (European Commission, 2006).

The EU Water Framework Directive (2000/60/EC) requires good water status for all European waters by 2015, to be achieved through river basin management planning and extensive monitoring and assessment (Mostert, 2003). Achieving good groundwater status includes preventing significant damage to associated GWDTEs such as turloughs (Kilroy *et al*., 2005). There is limited guidance, however, in the WFD guidance document on wetlands (European Commission, 2003) on the definition of significant damage for GWDTEs. For freshwaters in general, the issue of how to assess significant damage under the WFD is tackled by relating ecological quality to a baseline or reference state under minimal human influence (Solimini *et al*., 2006). Determining the ecological quality of hydrologically dynamic habitats is extremely challenging, as is the determination of baseline or reference conditions for turloughs. Kilroy *et al*. (2008) state that a better understanding of the relationships between groundwater pressures and impacts on turloughs is fundamental to achieving a better definition of significant damage. Such work will enable the identification of indicators of site condition and the development of significance thresholds.

There is significant overlap between the WFD and HD. Article 6 of the WFD requires preparation of a register of Protected Areas including Natura 2000 sites. This Article links the objectives of nature conservation legislation and objectives of good water status for the WFD. A programme of measures aiming to achieve good groundwater status, including the prevention of significant damage to GWDTEs, and will assist in the achievement of favourable conservation status under the Habitats Directive (Kilroy *et al*., 2005).

A daughter Groundwater Directive 2006/118/EC has also been developed in response to the requirements of Article 17 of the Water Framework Directive, which obliged the Commission to propose measures to achieve good groundwater chemical status. This new Directive sets underground water quality standards and introduces new measures to prevent or limit inputs of pollutants into groundwater. Additionally, Statutory Instrument (SI) 31 of 2014 (Good Agricultural Practice for Protection of Waters) gives further effect to a range of previous Directives for Waste (75/442/EEC), Dangerous Substances (76/464/EEC), Groundwater

(80/68/EEC), Nitrates (91/676/EEC), Water (2000/60/EC) and Public Participation (2003/35/EEC) (Government of Ireland, 2014).

1.3 Linking Turlough Ecology and Conservation

Sheehy Skeffington *et al.* (2006) provide a comprehensive review of recent understanding of turlough ecology and outline key ecological research that must be undertaken to facilitate adequate compliance with the HD and WFD. Effective conservation of any habitat is reliant on a solid understanding of its ecology. The HD embodies this concept by requiring an assessment of the conservation status of the structures, functions and typical species of priority habitats, central parameters of favourable conservation status. The terms 'structure' and 'functions' are not defined in the HD, however, and require careful interpretation in this context as ecosystem structure (i.e. system components) and function (i.e. system dynamics) are essentially synthetic concepts, incorporating many aspects of ecosystems (Jaeger Miehls *et al*., 2009). Structural characteristics of wetlands include relationships between physical habitat conditions, resources and species. Functional characteristics involve nutrient cycling, decomposition and photosynthesis (Sutton-Grier e*t al.*, 2010). Ecosystem structure and function can also incorporate the interrelationships between populations and communities (Gaedke, 1995) in addition to interrelationships between communities within foodwebs (Krause *et al*., 2003).

The relationship between ecosystem structure and function is a source of ongoing debate in ecology and is most fully understood with regards to natural succession (Sutton-Grier *et al*., 2010). Structure becomes more complex by an increase in the number of species and their ecological diversity and consequently function increases in terms of an increase in biomass and nutrient cycling (Bradshaw, 1984).

The complexity of the ecosystem structure and function concept and the application within the HD is briefly addressed in reporting guidelines which acknowledge that habitat structure and habitat function varies widely between different habitats (European Commission, 2006). Member States are directed to identify various components and processes essential for a habitat to be present and functioning for the habitat to be considered at FCS. Mehtala and Vuorisala (2007) discuss the usefulness of FCS as a measure of conservation success and the practical problems related to its application. The authors highlight the study of habitat specific structure and functions as one of the key problems with FCS and provide suggestions on how to deal with this issue. Potentially diagnostic habitat characteristics include species or functional group richness, species composition (including the presence of some indicator species) and physical conditions that limit the habitat range (Ebenman & Jonsson, 2005). Description and classification of turlough biological communities and research investigating the relationship between biological communities and environmental drivers is necessary for informed selection of appropriate habitat indicators for assessment and monitoring of turlough-specific structures and functions.

The WFD also embodies ecosystem based objectives for water resource management (Kallis & Butler, 2001) and has established the concept of Ecological Quality Status (EQS) as a way to assess the biological quality of surface waters. Solimini *et al*. (2006) provide a comprehensive review of proposed methods for WFD ecological status assessment. Under the WFD the ecological status of surface water is defined as "…*an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters, classified in accordance with Annex V*". This implies that ecological status classification systems should reflect changes in the structure of the biological communities and in the overall ecosystem functioning in response to anthropogenic pressures. There is a consequent need to identify biological indicators that have predictable responses to anthropogenic disturbance and allow classification of ecological quality based on functional relationships between pressures and indicators (Solimini *et al*., 2006).

The authors emphasise the importance of a solid understanding of ecosystem functioning for the development of ecological status assessment strategies. Turloughs lack the benefit of extensive international research and the understanding of turlough ecological functioning is embryonic relative to other freshwater habitats, a situation which can only be improved by interdisciplinary eco-hydrological research.

1.4 Pressures and Threats

The HD requires an assessment of the *Future Prospects* of turloughs involving an evaluation of impact of key pressures and threats (see Evans & Arvela, 2011). The HD makes a distinction between pressures and threats for assessment and reporting of conservation status. '*Pressures*' include past and present impacts whereas '*threats*' refer to foreseeable impacts. The primary contemporary pressures to turloughs are drainage, eutrophication and over-grazing. Key threats include these three pressures in addition to climate change and grazing absence.

Approximately one third of turloughs over 10 hectares have been irreversibly damaged by drainage (Coxon, 1986). The impact of land drainage on groundwater resources is particularly acute in karst areas owing to the unique characteristics of karst aquifers (Sheehy Skeffington *et al*., 2006). Large-scale drainage, now ceased, has resulted in lowering of water tables, drying up of turloughs and periodic groundwater contamination (Drew & Coxon, 1988). Drainage ditches often stretch across turloughs, created with a view to extending the period of favourable conditions for grazing. Increased winter precipitation (McElwain & Sweeney, 2006) may lead to increased flooding in karst areas, which could result in new demands for drainage schemes in response to local community pressure. Research detailing the explicit links between turlough biological communities and hydrological regime is needed to add weight to arguments against proposals for reintroducing large-scale drainage in the karst landscape.

Eutrophication of freshwaters is a pressure that has had a high profile since the early 1980s. Nutrients are a significant driver of productivity leading to increased growths of algae and aquatic plants (Solimini *et al*., 2006). The eutrophication processes within turloughs are under researched and currently there is very limited information on the drivers of the trophic status of turlough floodwaters. Karst catchments are characterised by an intimate surface-groundwater relationship and are capable of transporting large volumes of water at relatively high velocities compared to catchments in other geological settings.

Consequently, in karst aquifers there is less possibility of attenuation of contaminants, and nutrients may be more conservatively transported. Evaluating the link between nutrient pressures in turlough catchments and nutrient conditions and biological quality of the floodwaters is a key focus of the project. The assessment of pressures and impacts to freshwaters under the WFD adopts the DPSIR (*Drivers, Pressures, State, Impact, Response*) framework. The links between the components of this framework relate to an assessment of the risk of pollutant mobility, the effect of hydromorphological changes and the response of biological elements (Irvine *et al*., 2005). Such an approach is necessary for assessing the impact of eutrophication on turloughs.

Turloughs are an example of marginal grazing land with Priority Habitat Status (Visser *et al*., 2007) and grazing regime diversity within a turlough has been shown to be important for its biodiversity (Sheehy Skeffington *et al*., 2006). Over-grazing is a perceived pressure and threat to turloughs yet no specific research has been conducted to date to identify grazing regimes which cause retrogressive vegetation changes from a stated management objective in turloughs. A clear set of management objectives for turlough vegetation is a prerequisite for this research. Grazing absence, resulting from land abandonment owing to agricultural intensification, is also considered a threat to turlough biodiversity (Sheehy Skeffington *et al*., 2006). Grazing regimes on turloughs are extremely dynamic and notoriously difficult to quantify (Visser *et al.*, 2007) and research to date has focused on a very limited number of sites (Ní Bhriain *et al*., 2002, 2003; Moran *et al*., 2008; Ryder *et al*., 2005). Evaluating the potential impact of over-grazing and under-grazing on turlough vegetation requires an extensive evaluation of turlough grazing intensities and investigation of the effects of varying grazing intensities on vegetation community distribution across a range of turloughs.

1.5 Project and Reporting Structures

1.5.1 Project structure

A series of five work packages were employed to deliver the research and conservation assessment outputs. Key research aims and tasks relating to each work package are presented in Table 1.1. A conceptual model of turlough ecological functioning is presented in Figure 1.1. Elements under investigation are highlighted in the conceptual model.

Table 1.1 Work packages employed for the delivery of research and conservation assessment outputs relating to the project titled *Assessing the Conservation Status of Turloughs*.

Work Package	*Principal Investigator*	*Personnel*	*Key Research Aims*
1a Vegetation	Steve Waldren	Nova Sharkey Mark Murphy	• Describe, classify and map vegetation communities. • Investigate effects of hydrology, soils and land-use on vegetation community distribution.
1b Soils	Steve Waldren	Sarah Kimberley	• Describe, classify and map soil types. • Investigate effects of hydrology, grazing intensity and soil type on soil nutrient variation. • Investigate nutrient release from soils to the water column.
2 Hydrology	Paul Johnston Laurence Gill	Owen Naughton	• Construct models of hydrological functioning. • Derive ecologically relevant hydrological variables. • Delineate zones of groundwater contributing to turloughs.
3 Algae and hydrochemistry	Norman Allott Catherine Coxon	Helder Pereira	• Describe phytoplankton communities • Describe spatial and temporal variation in chemistry and algal communities. • Evaluate sources of nutrients to turloughs.
4 Aquatic Invertebrates	Ken Irvine	Gwen Porst	• Investigate effects of season, habitat, hydroperiod and water chemistry on the distribution of aquatic invertebrate communities.
5 Project Management	Steve Waldren	Sarah Kimberley	• Coordinate project logistics e.g. site selection, field work and data integration. • Organise meetings and prepare reports.

1.5.2 Structure of the final report

The report comprises thirteen chapters. Chapter 1 provides an introduction to the aims of the project and the legislative and conservation context of the research. Chapter 2 details the selection of study sites. Chapters 3-8 summarise the basic findings of the work relating to hydrology, algae, soils, vegetation, macroinvertebrates and land-use respectively. Chapter 9 details the integration of work packages and conceptual models of turlough ecological functioning. Chapter 10 deals with outputs relevant to the EU Habitats Directive and provides conservation assessment and a national assessment for turlough conservation status. Chapter 11 provides recommendations for the assessment and monitoring of significant damage to turloughs for EU Water Framework Directive compliance. Chapter 12 provides a recommended approach for future monitoring of turlough conservation status for the EU Habitats Directive, and finally Chapter 13 provides an overview of the conclusions and recommendations of the project.

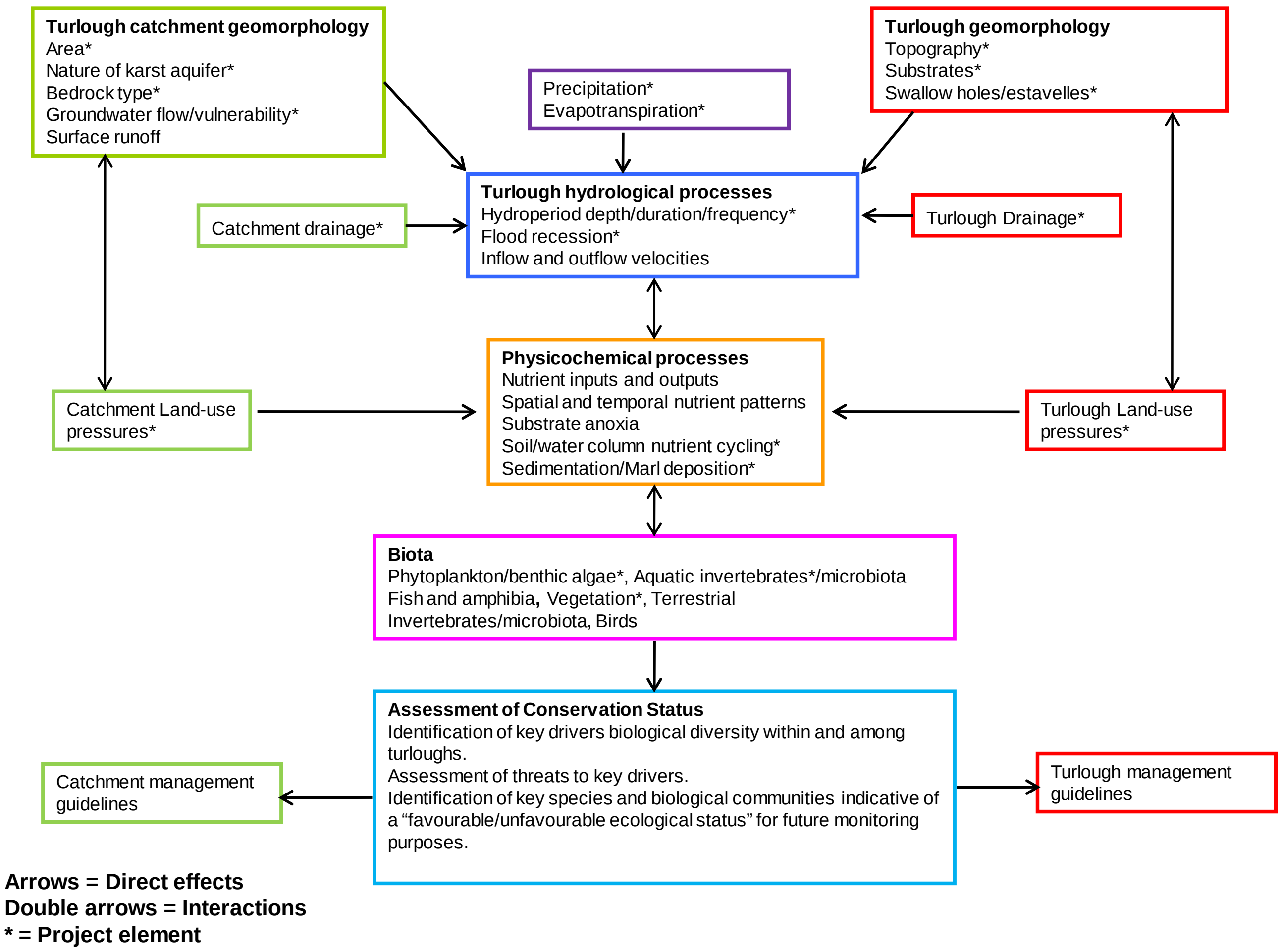

Figure 1.1 A conceptual model of turlough ecological functioning developed by the TCD research group. Elements under investigation as part of the research project are highlighted by *.

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Annex 1 contains a consolidated list of all references cited in the report.

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Chapter 2. Site Selection

S. Kimberley

Caherglassan. *Photo: S. Waldren*

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2.1 Selection of Sites for Extensive Study

Turlough distribution in Ireland is strongly controlled by the occurrence of well-bedded, pure, grey calcerenite susceptible to karstification, with or without shallow deposits of glacial till (Coxon, 1986). Consequently, the majority of the 304 turloughs listed in the Geological Survey Ireland Karst Database (2006) extend along the Western region of Ireland, from Co. Donegal to Co. Cork, with clusters of turloughs occurring in Co. Clare, Co. Galway, Co. Mayo and Co. Roscommon. The updated database of turloughs held by NPWS (Mayes, 2008) was not available at the time of site selection, and consequently was not used here. In 2006, hydrological and ecological information, of varying forms and standards, was available for 151 turloughs (Coxon, 1986; Tynan *et al*., 2007; Goodwillie, 1992; Southern Water Global, 1998); 90 turloughs had both some hydrological and ecological information available. Twenty-two turloughs spanning Co. Clare, Co. Galway, Co. Mayo and Co. Roscommon were selected for study from this subset of 151 to represent the hydrogeological and geographical range of the habitat (Table 2.1, Figure 2.1). As hydrology is thought to be the key determinant of the establishment and maintenance of wetland processes (Mitsch & Gosselink, 2000), site selection was primarily driven by the requirement for sites representative of the range of turlough hydrogeological variation. Site selection was initially based on the Karstic Flow System hypothesis, at the time the best available hypothesis of turlough hydrological function, which suggested that turloughs associated with specific types of karst and groundwater flow (i.e shallow epikarst or conduit) are associated with a specific range of ecologies (Tynan *et al*., 2007). No attempt was made to select a predetermined number of each type, sites were merely identified where groundwater flow could be reliably inferred as conduit or epikarst flow; 11 such sites with adequate hydrological evidence were identified. A further 11 sites were chosen by setting aside the Karstic Flow System hypothesis owing to inadequate evidence in the case of turloughs located in Co. Galway (East), Co. Mayo and Co. Roscommon. In this case, a further 11 sites were chosen using alternative hydrological criteria based on limited ecohydrogeological evidence from Coxon (1986). The mosses *Cinclidotus fontinaloides* and *Fontinalis antipyretica* were used as a surrogate for duration of flooding, and the height of *Cinclidotus fontinaloides* was used as a measure of depth of flooding. The 11 sites associated with shallow epikarst or conduit groundwater flow were assigned to groups based on depth and duration of flooding, as indicated by the aforementioned moss species, and gaps in the representation of the different groupings were identified (i.e. shallow and short duration, deep/variable depth and short duration, medium depth and intermediate duration, deep and intermediate duration, medium depth and long duration).

The availability of groundwater tracing data and information on deposits and swallow holes were considered as secondary criteria (see Table 2.1 for summary of alternative hydrogeological criteria for each site). Access to turloughs was clarified with landowners prior to the finalisation of the site selection. All selected turloughs, except Brierfield, Carrowreagh and, Rathnalluleagh are designated as Special Areas of Conservation (SAC) under the EU Habitats Directive (92/43/EEC) (European Commision, 1992).

Table 2.1. List of twenty-two turloughs studied including their site codes, location, area, information of associated karstic flow system and reference to source of hydrological information used for selection. Sites highlighted in grey were selected for more detailed spatial and temporal investigation of aquatic ecology.

Turlough	Site Code	Townland	Easting	Northing	County	Size (ha)	SAC/ NHA Code	RBD	Karstic Flow System	Alternative Hydrogeological Criteria	Hydrological Data Source
Ardkill	ARD	Ardkill	127360	262500	Mayo	16	000461	Western	n/a	Deep with intermediate duration flooding with peat, marl, peat-marl deposits.	Coxon (1986); David Drew (pers. comm.)
Ballindereen	BAL	Ballindereen Cartron	140092	215248	Galway	83	000606	Western	n/a	Shallow with short duration flooding and peat deposits.	Coxon (1986)
Blackrock	BLA	Turloughnacloghdoo	149780	208130	Galway	143	000318	Western	Conduit	Deep with short duration flooding and diamicton deposits.	Tynan et al. (2007)
Brierfield	BRI	Brierfield	181600	276560	Roscommon	52.9	000594	Shannon	n/a	Medium depth with intermediate duration flooding and peat, marl deposits.	Coxon (1986); David Drew (pers. comm.)
Caherglassan	CAH	Killomoran	141456	206290	Galway	68	000238	Western	Conduit	Medium depth with intermediate duration flooding with peat-marl and sand/silt deposits.	Tynan et al. (2007)
Caranavoodaun	CARA	Castletaylor	145109	215648	Galway	48	000242	Western	Shallow epikarst	Medium depth with intermediate duration flooding with peat-marl and sand/silt deposits.	Southern Water Global (1998); Tynan et al. (2007)
Carrowreagh	CARR	Carrowreagh	178378	275305	Roscommon	26.3	001624	Shannon	n/a	Variable depth with short duration flooding and diamicton deposits.	Coxon (1986); David Drew (pers. comm.)
Coolcam	COO	Coolcam	157420	271390	Roscommon	67.1	000218	Shannon	n/a	Medium depth with long duration flooding and peat, marl deposits.	Coxon (1986); David Drew (pers. comm.)
Croaghill	CRO	Croaghill	159680	270540	Galway	37.4	000255	Shannon	n/a	Variable depth with intermediate duration flooding and peat.	Coxon (1986); David Drew (pers. comm.)

Turlough	Site Code	Townland	Easting	Northing	County	Size (ha)	SAC/ NHA Code	RBD	Karstic Flow System	Alternative Hydrological Criteria	Hydrological Data Source
Garryland	GAR	Garryland Wood	141750	204050	Galway	25	000252*	Western	Conduit	n/a	Southern Water Global (1998)
Kilglassan	KIL	Kilglassan	127860	264550	Mayo	49.9	000504	Western	n/a	Medium depth with intermediate duration flooding and peat, marl deposits.	Coxon (1986); David Drew (pers. comm.)
Knockaunroe	KNO	Knockaunroe	130700	193450	Clare	42.5	001926	Shannon	Shallow epikarst	Medium depth with intermediate duration of flooding with peat, marl and peat-marl deposits.	Drew (1990)
Lisduff	LIS	Lisduff	184250	255500	Roscommon	54.1	000609	Shannon	n/a	Medium depth with long duration flooding and peat, marl, peat-marl deposits.	Coxon (1986); David Drew (pers. comm.)
Lough Aleenaun	ALE	Sheshymore	124740	195440	Clare	10.7	001926	Shannon	Shallow epikarst	Deep with short duration flooding and marl, peat-marl deposits.	Southern Water Global (1998); David Drew (pers. comm.)
Lough Coy	COY	Shanvally	148927	207255	Galway	36	002117	Western	Conduit	n/a	Southern Water Global (1998); Tynan et al. (2007)
Lough Gealain	GEA	Gortlecka	131450	194730	Clare	17.3	001926	Shannon	Shallow epikarst	n/a	David Drew (pers. comm.)
Rathnalulleagh	RAT	Rathnalulleagh	177710	273760	Roscommon	26.4	000613	Shannon	n/a	Variable depth with short duration flooding with diamicton deposits.	Coxon (1986); David Drew (pers. comm.)
Roo West	ROO	Roo	138627	202214	Galway	28	001926	Western	Shallow epikarst	n/a	Tynan et al. (2007)
Skealoghan	SKE	Skealoghan	124750	262900	Mayo	28	000541	Western	n/a	Medium depth with intermediate duration flooding with peat and sand/silt deposits.	Coxon (1986); David Drew (pers. comm.); Moran (2000)
Termon	TER	Termon	140920	197350	Galway/Clare	39	001321	Western	Shallow epikarst	Medium depth with intermediate duration flooding with marl deposits.	Southern Water Global (1998)

Turlough	Site Code	Townland	Easting	Northing	County	Size (ha)	SAC/ NHA Code	RBD	Karstic Flow System	Alternative Hydrological Criteria	Hydrological Data Source
Tullynafrankagh	TUL	Caherpeak West	143208	215339	Galway	20	000606	Western	Shallow epikarst	n/a	Southern Water Global (1998); Tynan et al. (2007)
Turloughmore	TUR	Turloughmore	134700	199800	Clare	21	001926	Shannon	n/a	Medium depth and short duration with sand/silt deposits.	Coxon (1986)

*Garryland turlough, as part of the Coole-Garryland complex, is also designated as a Special Protection Area (Code 004107).

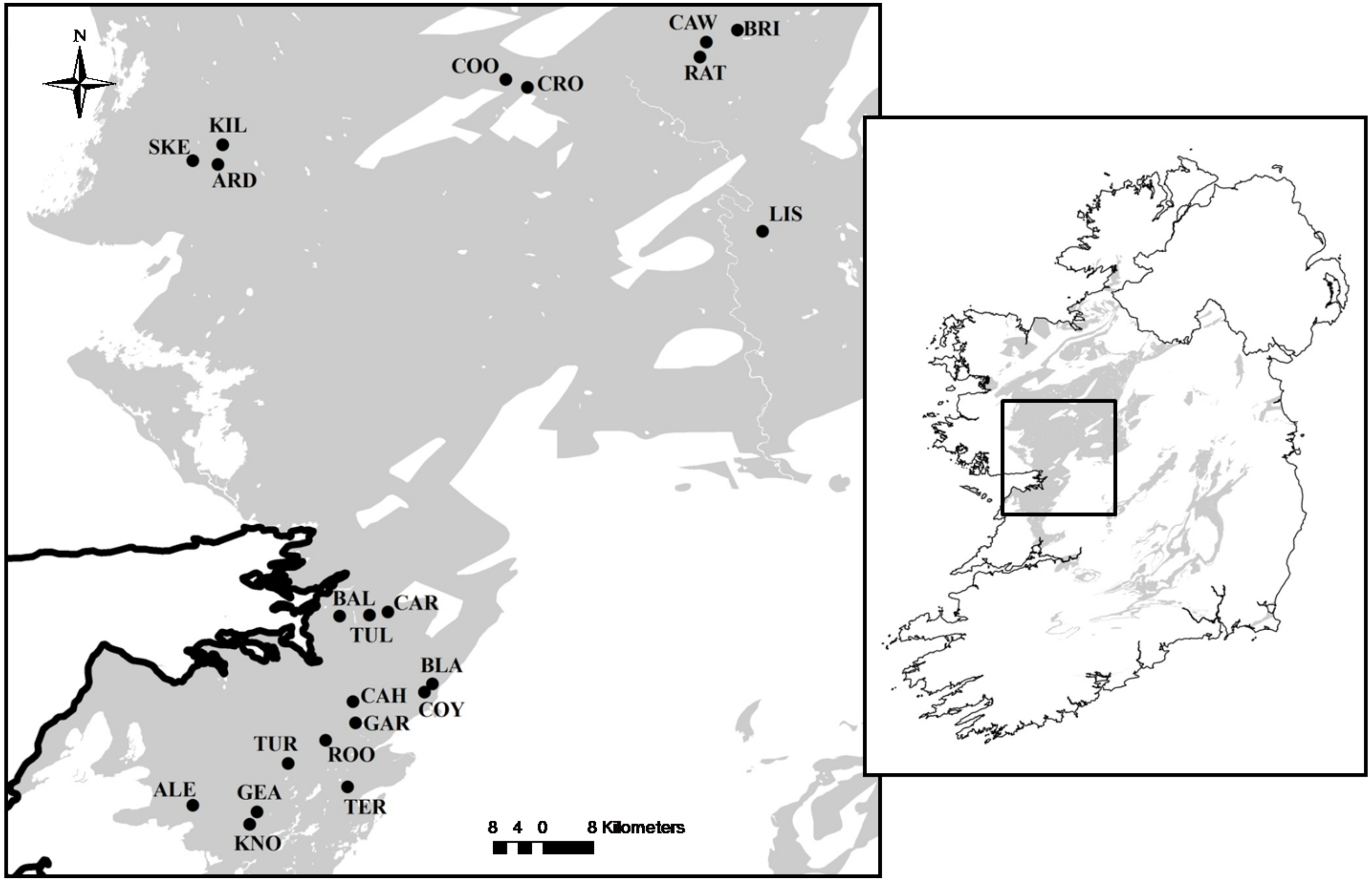

Figure 2.1 Geographical distribution of the 22 turloughs studied (abbreviations are explained in Table 1). Shaded areas correspond to areas of pure bedded limestone (geological data from the Geological Survey of Ireland Database: http://www.gsi.ie/Mapping.html).

Annex 2 contains a series of site reports which summarise data from the 22 selected turloughs on a site by site basis.

2.2 Selection of Sites for Intensive Study

Both the algal and aquatic invertebrate ecological studies aimed to elucidate the implications of within-turlough hydrochemical and biological community variation for habitat quality assessments. To achieve this, a sub-set of sites was selected for further intensive spatial and temporal investigations spanning 2007 and 2008. The terrestrial phase mapping work involved detailed spatial investigation of all 22 sites and time constraints did not allow for further spatial and temporal work on a sub-set of sites. Given the scale of field and laboratory work involved, it was decided to restrict the spatial and temporal algal ecology investigations to four sites. The aquatic invertebrate aspect of the project conducted some spatial and temporal work on eight selected turloughs during the 2006/2007 field season. Personnel working on this aspect of the project considered it important that the four sites be selected from the sub-set of eight sites to link with the previous spatial and temporal investigations (Termon, Roo West, Ballindereen, Caranavoodaun, Caherglassan, Kilglassan, Brierfield, Lisduff). These sites were previously selected to represent a gradient of total phosphorus (see Porst, 2009 for further details). The sites on this priority list were considered for selection and discussed in terms of their ZOCs, water nutrient status, hydrological response characteristics, presence of existing hydrological data and geographical distribution. Preference was given to sites with long-term hydrological datasets. Ballindereen, Kilglassan, Brierfield and Lisduff had hydrological data for only one year at the time and were therefore not considered suitable for more detailed work. Termon turlough was considered a selection priority to allow for the comparison of inter-annual variation of aquatic invertebrate community structure and composition. This turlough has a non-flashy hydrological regime and long-term hydrological data. Mean seasonal TP and Chl a concentrations indicate a mesotrophic nutrient status.

Caherglassan has an extremely large catchment area which would be very difficult to refine given the time and resources available. For these reasons, this site was excluded as a candidate for more detailed research. It was considered important, however, to include a turlough representative of conduit-type turloughs with a flashy hydrological regime with a eutrophic nutrient status. Blackrock and Lough Coy were considered as suitable examples, with a preference for Blackrock, as aquatic invertebrate spatial distribution data were available for this turlough.

Roo West was selected as a suitable site as it is an example of a shallow epikarst turlough, has a relatively flashy hydrological regime, with long-term hydrological data and an oligotrophic/mesotrophic nutrient status. Caranavoodaun was also considered as a suitable site as it presents an oligotrophic/mesotrophic condition, has long-term hydrological data and a non-flashy hydrological regime. Termon, Roo West, Caranavoodaun and Blackrock were consequently selected as the subset of sites for detailed spatial and temporal investigations of aquatic ecology (Table 2.1).

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Chapter 3. Hydrology

O. Naughton, P. Johnston, L. Gill

Swallow holes; Garryland, Co. Galway. *Photo: M. Murphy*

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3.1 Introduction

Turloughs are wetlands at the interface between groundwater and surface water and occur predominantly on the well-bedded, pure limestone regions in the western third of Ireland, forming a significant part of this region's hydrological cycle. They are transient lakes resulting from a combination of high rainfall and, accordingly, high groundwater levels in topographic depressions in karstified limestone terrain. They fill mainly by inflows of groundwater through estavelles and springs, in addition to some surface runoff; they also ultimately empty through estavelles and swallow-holes. The behaviour of a turlough as a wetland is fundamentally driven by its hydrology; the hydrological regime results in a characteristic ecology associated with the pattern of groundwater inundation.

Although turloughs are ephemeral lakes, they are essentially groundwater features and as such are classified as Groundwater Dependent Terrestrial Ecosystems (GWDTEs) under the Water Framework Directive (2000/60/EC), and as a Priority Habitat in Annex 1 of the EU Habitats Directive (92/43/EEC). Both EU directives necessitate the monitoring and management of these habitats to ensure that favourable conservation and groundwater status is achieved.

3.1.1 The Conceptual Framework of Karst Aquifers

The defining feature of karst terrains is the dominance of solution as a geomorphic agent, with solution and solutional transport the dominant process in the development and formation of karst (White, 1988). It is these solutional processes which produce the secondary porosity, in the form of dissolution conduits, which provide a low resistance pathway for groundwater flow and interact with the granular and fracture permeability of the karst rock (White, 2002). The permeability of a karst aquifer is comprised of a number of elements. The primary porosity is associated with intergranular permeability of the unfractured rock, while secondary porosity is caused by rock folding, fracturing and dissolution pathways, which themselves vary in size, carrying capacity and interconnectivity (Ford & Williams, 2007). Conceptually, karstic aquifers can be described using the triple permeability or triple porosity model, which is composed of matrix, fracture and conduit permeability (White, 2002):

Matrix Permeability:	The intergranular permeability of the unfractured rock
Fracture Permeability:	The mechanical joints, joint swarms and bedding plane partings all of which may be enlarged by solution
Conduit Permeability:	Pipe-like openings with apertures ranging from 1 cm to tens of metres

Matrix porosity is composed of the individual pores within the carbonate rock, and is characterised by high storage but low groundwater velocities and laminar flow conditions (Cheng & Chen, 2005). Fractures normally have apertures in the range 50-500 μm but can be up to 0.01m, and typically have a laminar flow regime but may have non-linear components (White & White, 2005). At the point where fractures exceed an aperture size of 0.01 m they are reclassified as conduits. Although some fractures can have apertures in excess of 0.01 m, they may not be continuous at this size and so not considered to be conduits (White & White, 2005). Conduits are solutionally enlarged flow paths through the karst aquifer. Conduit permeability is characterised by localised distribution, low storage and high groundwater velocities (Sauter & Liedl, 2000). Studies have identified that while almost all of the storage was within the rock matrix, the conduit system accommodated the vast majority of flow within the karst aquifer.

Karst aquifers are composed of a combination of matrix, fracture and conduit permeability, with the relative contribution of each to regional groundwater flow dependent upon the properties of the carbonate rock itself and the degree of karstification. As a result of this complexity the effective permeability of a karstic aquifer is highly scale-dependent. As highlighted by Worthington (2003), the vast majority of groundwater flow may be dominated by and contained within the conduit system, yet the conduits may only make up a minute percentage of the aquifer volume. Overflow conduit systems may also exist within the aquifer whose operation is intermittent and dependent upon prevailing hydrological conditions, thus adding a temporal variability to the already highly heterogeneous spatial nature of karst permeability (Ray, 1997).

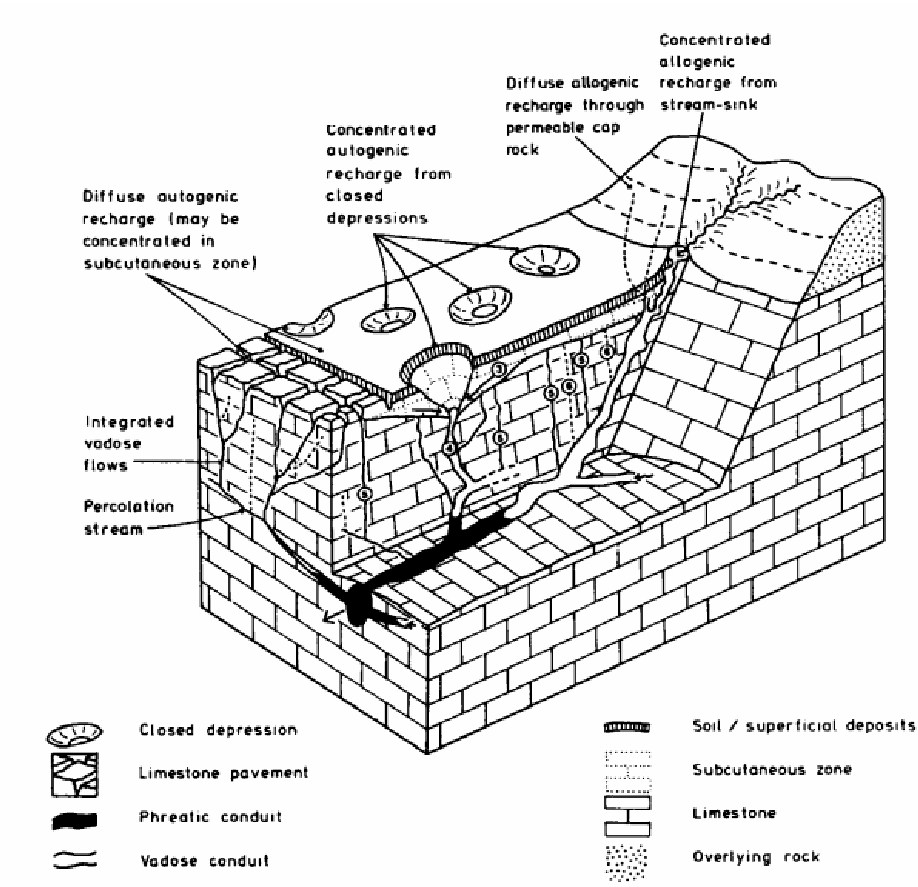


Figure 3.1 *A conceptual model for drainage in a karst area (from Gunn, 1986)*

Recharge derived from precipitation may enter a karst aquifer in a variety of forms. The range of recharge forms and pathways are shown in figure 3.1 (Gunn, 1986). Recharge can be divided into those sources which originate within the karst body (autogenic) and those that originate from outside the karst aquifer (allogenic).

3.1.1.1 Autogenic Recharge

Autogenic recharge is derived solely from precipitation falling directly onto the karst body, and can take the form of both point and diffuse recharge (Ford & Williams, 2007). Diffuse (or dispersed) infiltration consists of precipitation directly onto the karst surface. Where soil cover is present, this infiltration is governed by the same soil moisture processes as occur in non karstic aquifers. Rainfall exceeding the soil moisture capacity percolates downwards until it reaches the phreatic zone of the aquifer. In addition to the controls on recharge imposed by soil cover, karst recharge is further governed by the subcutaneous (or epikarst) zone.

The uppermost section of the karst bedrock, known as epikarst, can impact upon the rate and quantity of recharge entering the saturated karst aquifer. Epikarst is a term used to describe the unsaturated zone of carbonate rock near the upper surface where significant weathering, fracturing, solutional enlargement and storage may occur (Ford & Williams, 2007; Zhou, 2007). The epikarst is typically 3 to 10 m deep, often highly irregular and fractured with high secondary permeability due to the considerable chemical solution in the zone (Ford & Williams, 2007). Fracture widths reduce with depth before eventually giving way to the largely unweathered rock below (Williams, 1983; White, 2002; Ford & Williams, 2007). An example of this can clearly be seen in the Burren (Co. Clare) where the surface fractures are clearly visibly on the exposed limestone pavements. A close inspection of the extensive solutionally widened joints shows the reduction in dissolution with depth, as the fractures close to hairline cracks within a few metres of the surface (Williams, 1983).

The link between epikarst and the underlying regional water table is often limited to sporadic subcutaneous drains and vadose shafts (Quinlan, 1989). Due to the heterogeneous nature of karstification within the epikarstic zone, and the consequent reduction in permeability with depth, recharge is unable to percolate down directly into the phreatic zone (Williams, 1983). Because of this, the epikarst zone can operate as an important groundwater store with the development of a perched potentiometric surface. The potentiometric surface generates a gradient towards areas of high vertical permeability, inducing a major lateral flow component within the epikarst (Williams, 1983). In this way the transmission of diffuse recharge to the phreatic zone is concentrated within this subcutaneous zone. As a result, epikarst can act as a buffer between recharge events and the corresponding response within the phreatic zone, with the residence time of water ranging anywhere between a few hours to weeks reach the water table (White, 2002).

Point autogenic recharge occurs where precipitation is concentrated into internal runoff, generated when rainfall exceeds a given threshold and results in surface runoff (Gunn, 1983). This internal runoff is analogous to normal overland flow then enters the aquifer rapidly via surface depressions or dolines (White, 2002).

3.1.1.2 Allogenic Recharge

Allogenic recharge is derived from an adjacent non-carbonate catchment area and flows onto the karst body at a geological boundary (Ford & Williams, 2007). Precipitation is first concentrated into surface flow paths with then flow across the boundary onto an adjacent carbonate aquifer. Where this occurs, the stream or river can often sink abruptly via a doline or swallow holes, or be lost more gradually via a series of smaller swallow holes along the flow path. The quantity of allogenic recharge is obviously dependent upon the size and nature of the adjoining catchment. Chemically aggressive waters derived from non-carbonate catchment areas can often rapidly advance the development of substantial karst flow systems. An example of this can be seen in the Gort lowlands, Co. Galway where the acidic allogenic waters derived from the peat catchment of the Slieve Aughty Mountains has led to the development of a complex network of sinking streams, conduits and surface storages (turloughs).

The ability of the karst aquifer to accommodate concentrated recharge is dependent upon the level of connection between surface and subsurface flow systems, and the drainage capacity of the underlying conduit flow system. Where the conduit system is capable of accommodating the full allogenic recharge, no surface flow will be seen. However, where this capacity of the swallow hole is inadequate to accommodate the full point recharge, excess flow may continue as surface overflow or result in surface ponding around the surface water – groundwater interface, such as poljes and turloughs (White, 2002). Similarly, where the drainage capacity of the conduit flow path is reduced, either by physical constriction, sedimentation or human activity, comparable surface flooding can occur (Zhou, 2007).

3.1.1.3 Discharge

Karst aquifers generally discharge to springs, which represent the termination of the subterranean karst systems and account for the runoff from the entire karst catchment area (White, 2002; Ford & Williams, 2007). The rate of discharge, temperature and chemical composition from springs can vary substantially depending upon the supplying flow system. Discharge from conduit-driven springs can vary by many orders of magnitude, whereas the flow rate and hydrochemistry of springs derived from solutionally widened fracture swarms can remain constant irrespective of recharge events (White, 2002). Submarine springs have been recorded discharging both fresh and brackish water from some coastal karst aquifers. The Gort lowlands conduit system is an example of such a system, where the periodic sea level fluctuations have an effect upon the behaviour of springs at Kinvarra as well as exerting an influence over turloughs as much as 10 km inland (as discussed later).

3.1.2 Lowland Irish Karst

In the Irish context it is the Carboniferous Limestone which has undergone significant karstification. Unlike mainland Europe where most karst terrain is mountainous or plateau, over 90 percent of karst in Ireland is located in lowland areas of less than 150 mAOD (Drew, 2002; 2008). Lowland karst in Ireland exhibits relatively low hydraulic gradients estimated at 0.01 to 0.001 with groundwater flow velocities of between 5 and 250 m/h recorded. Lowland karst areas are characterised by a high level of interaction between ground and surface waters. Subterranean karst flow systems coexist with surface drainage leading to complex hydrological interactions (Coxon & Drew, 1998). Water is lost to and gained from groundwater sources via swallow holes, estavelles and springs depending on the prevailing hydrological conditions. Such complex and extensive interactions between surface and groundwater can make it extremely difficult to delineate the boundaries of contributing areas or accurately quantify recharge for karst groundwater bodies (Drew, 2008). Contributing areas can vary greatly in areal extent depending upon prevailing hydrological conditions. Coupled with this the heterogeneous nature of karst flow paths mean that aquifer vulnerability can vary substantially within a contributing area making it difficult to assign viable protection areas to springs and water supplies (Deakin, 2000).

Glacial action during the Quaternary period covered much of the limestone of Ireland with Pleistocene and early Holocene deposits (Drew & Daly, 1993; Mitchell & Ryan, 1998). It has also led to the infilling and/or destruction of many surface karst features such as dolines, swallow holes and conduits. This infilling of many karstic flow systems with glacial and fluvioglacial deposits may have rendered them inoperative or hydrologically separate from the contemporary system (Ford & Williams, 2007). Such systems are known as paleokarst. Over time groundwater flow can erode the choking sediments thereby reactivating the conduits, resulting in the reintegration of paleokarst into the active system. Drew and Daly (1993) suggest that the groundwater flow systems in the lowlands today may be a combination of newer, shallow epikarst systems developed during the Holocene and older reactivated paleokarstic systems. An example of such an interaction between surface and shallow groundwater flow systems and paleokarst exists south of Gort. The Beagh River sinks into a swallow hole known as the "Devils Punchbowl" and drops at least 50 m below ground level only to re-emerge from a cave less than 2 km away as the Cannahowna River (Southern Water Global 1998).

3.1.3 Turlough Hydrology

Turloughs are one of the characteristic features of the Irish karst landscape. They are transient lakes resulting from a combination of high rainfall and accordingly high groundwater levels in topographic depressions in the karst. A turlough is effectively a hydrogeological feature defined as *"A topographic depression in karst which is intermittently inundated on an annual basis, mainly from groundwater, and which has a substrate and/or ecological communities characteristic of wetlands"* (Tynan *et al*., 2007).

During extreme rainfall events, water levels can rise above traditional turlough boundaries and connect bordering turloughs to form open water bodies with areas far in excess of 260 ha. This occurred during the flooding of November 2009 where, for example, turloughs in the Coole/Garryland complex joined forming a massive continuous water body stretching from Ardrahan all the way to Caherglassan.

Turloughs are at the interface between groundwater and surface water. It is the nature of this interaction, the characteristic depth, duration and frequency of flooding, which drives the ecology and is responsible for the ecological diversity present within these unique Groundwater-Dependent Terrestrial Ecosystems (GWDTEs). They fill mainly by rising groundwater levels through estavelles and springs in addition to some surface runoff; and ultimately empty through estavelles and swallow holes (Coxon & Drew, 1986). Filling normally occurs in late autumn due to periods of intense or prolonged rainfall with emptying typically occurring from March onwards. The karst flow system, of which a turlough is a surface expression, possesses a flow capacity which is defined by the size and connectivity of the flow paths present within the rock (Drew & Daly, 1993). Rainfall of insufficient duration or intensity can be accommodated by subsurface flow paths; hence no surface flooding is visible in the turlough basin during these dry periods. However once the required combination of rainfall intensity and duration occurs the storage of the system is exceeded and flooding begins.

The hydrological regime of turloughs varies greatly across turlough sites, as shown in figure 3.2 which compares the water level profiles of two turloughs collected as part of this research. Some show a multimodal flooding regime with rapid response to rainfall events throughout the year. These turloughs represent a high disturbance habitat as they experience multiple distinct flood events throughout the winter and even summer flooding is relatively common. Other sites have a unimodal flooding regime characterised by a gradual filling and a lengthy recession. Turloughs can also show a high level of variability from year to year due to the lack of strong seasonal definition within the Irish climate.

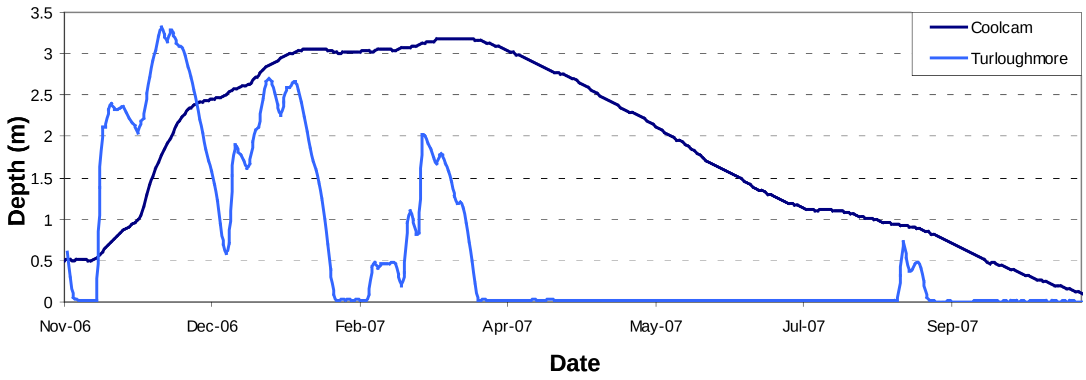


Figure 3.2 *Contrast between unimodal flood regime of Coolcam, Co. Galway and the multimodal regime of Turloughmore, Co. Clare*

The karst hydrological systems in which turloughs operate are dynamic and constantly changing. Due to the localised nature of karstic groundwater flow, the collapse of an active conduit or the reactivation of a paleokarstic system can rapidly and drastically alter the characteristic regime of a turlough and its response to excess precipitation. Evidence of such changes in flood regime has been provided in the form of lacustrine marl found in the basin of many turloughs (Coxon & Coxon, 1994). The present day hydrological regime of such turloughs does not facilitate the deposition of lacustrine marl implying that a fundamental shift has occurred in their hydrological operation.

Turloughs have been the continuing focus of research interest mainly due to the unique flora and fauna in this type of aquatic environment, but also from a more anthropogenic point of view, due to the risks of localised flooding. The present day drainage network in many of the karstic areas of western Ireland has been systematically modified by arterial drainage schemes designed to compensate for the lack of extensive surface drainage and reduce flooding in the area (Coxon & Drew, 1986). The key role that turloughs play as flood attenuation devices in the regional hydrological regime has often been poorly understood, and turlough inundation has often been seen as part of the problem rather than a beneficial natural flood attenuation system. Areas in which turloughs occur are characterised by little or no surface drainage, and so all effective rainfall in the area must be accommodated by subsurface karstic flow systems. These systems have finite flow capacities and turloughs are utilised to store the excess during periods of high and prolonged rainfall. When the system has drained sufficiently and head levels have dropped enough the temporary storage is fed back into the system.

Due to the localised nature of groundwater flow through karst aquifers they are particularly sensitive to activities which may interfere with these flow paths such as artificial drainage, disturbance of estavelles and quarrying. While drainage activities may benefit stakeholders on a local scale by extending the availability of pasture land within turloughs, on a regional scale these activities could have a negative effect by intensifying flooding in more economically or socially important areas. With the absence of natural channels to act as outlets to drainage schemes, drainage activities in upland areas tend to just prolong and exacerbate flooding down gradient.

3.2 Field Investigation and Data Collection

3.2.1 Site selection and description

The site selection process is detailed in *Chapter 2: Site Selection*. Water level monitoring continued in all sites throughout 2007/2008, and was continued into the summer of 2009.

3.2.2 Turlough catchment areas

Estimates of catchment areas for the 22 study sites were generated by members of the research team (see *Chapter Water Framework Directive Risk Assessment*). Existing information, data and catchment estimates were collated for the study sites. Catchment area estimates for the majority of sites had been generated in historic studies (Coxon, 1986; Coxon & Drew, 1986; Southern Water Global, 1998), as well as more recent work carried out for turloughs designated as SACs carried out under the Water Framework Directive (WFD) risk assessment. All catchment estimates were reassessed by the research team utilising individual experience, relevant hydrological research, topographic data, tracer studies and guidance documents used for the delineation of groundwater bodies (Working Group on Groundwater, 2005).

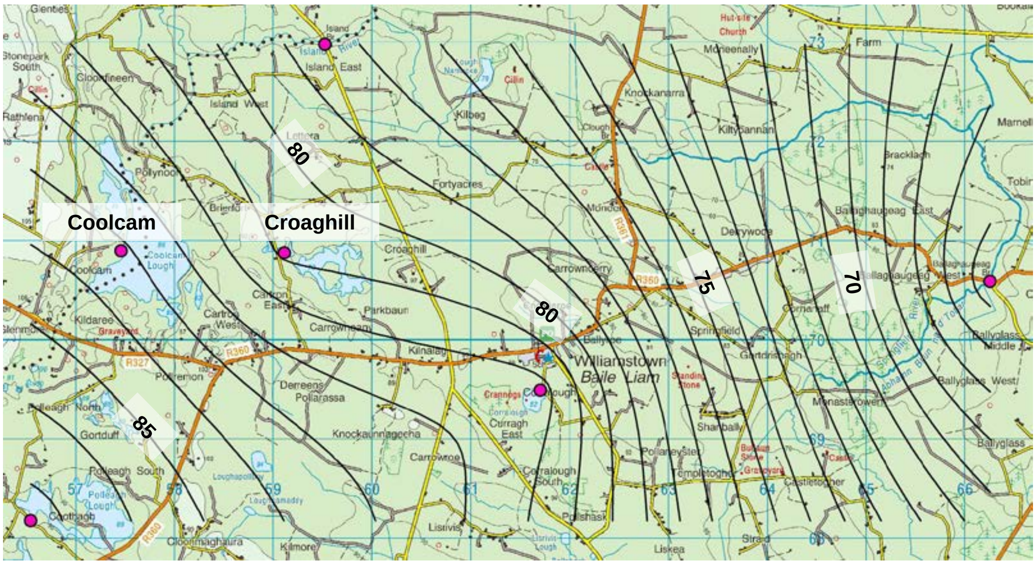


Figure 3.3 Water table map for area around Coolcam and Croaghill turloughs, Co. Galway

To aid in the process of catchment estimation and validation, water table mapping was also carried out. This work provided information on regional groundwater levels and gradients in areas which lacked existing catchment estimates. Water table mapping was confined to areas around the northern and north-eastern turloughs, as significant work existed for the South Galway and Mayo areas (Coxon & Drew, 1986; Southern Water Global, 1998). Spot water level measurements were taken (in mAOD) of any turloughs, surface water bodies and rivers in the area surrounding the study sites using a Trimble R6 Differential GPS. Water table maps were then generated using Surfer 8© and overlaid on topographic maps for the region as shown, for example, in figure 3.3. From this the general direction of regional groundwater flow was ascertained, which in turn helped to determine possible catchment area extent.

3.2.3 Water Level Monitoring

Sites were instrumented between September 2006 and January 2007, with monitoring continuing until July 2009. Water levels were recorded at hourly intervals using a variety of Schlumberger Divers® (Marton Geotechnical Ltd, Suffolk, UK) placed at or near the lowest point in each turlough. Divers measure the pressure of the water and air column above them, and from this the depth of water can be calculated. The majority of Divers used were Schlumberger Mini-Diver® models DL501 and DL502. The Mini-Diver® DI501 has a range of 10 m of water with an accuracy of 0.5 cm and resolution of 0.2 cm. For sites where the flooding range exceeded 10 m the Mini-Diver® DI502 was used, which has a range of 20 m of water, an accuracy of 1 cm and a resolution of 0.4 cm. Nineteen of the twenty two Divers used were equipped with temperature probes which recorded ambient water temperature at hourly intervals to an accuracy of 0.1°C. A CTD Diver was installed in Blackrock turlough which, in addition to depth and temperature sensors, has a conductivity sensor with a range of 0 to 80 mS/cm and so recorded conductivity on an hourly basis.

A concrete platform or paving slab was used to anchor the Divers in place (Fig. 3.4a). A length of rope was tied to the platform and a buoy attached to the other end to mark the position of the platform and enable recovery during inundation periods. However, in most cases the divers were left in position until the turloughs had receded enough to allow recovery on foot. Divers were downloaded roughly every six to nine months using a Reading Unit (Fig. 3.2b). The data was then imported into an Excel® spreadsheet format for further processing.

Figure 3.4 *Diver platform, Rathnalulleagh, Co. Roscommon (a), and downloading diver using Reading Unit, Garryland, Co. Galway (b)*

A summary of the water level monitoring periods for the twenty two study sites is given in table 3.1. Five equipment failures occurred during the monitoring program in Ardkill, Ballinderreen, Kilglassan, Lough Aleenaun and Roo West with a resultant loss in water level records.

Table 3.1 Summary of water level monitoring periods for 22 study sites

Turlough	*Start*	*End*	*Days Recorded*	*Failure*
Ardkill	05/11/2006	13/10/2008	708	13/10/2008 onwards
Ballindereen	05/11/2006	05/08/2009	557+294	From 15/5/2008 to 15/10/2008
Blackrock	05/11/2006	23/06/2009	961	
Brierfield	04/11/2006	08/07/2009	977	
Caherglassan	24/09/2006	05/08/2009	1046	
Carranavoodaun	24/09/2006	04/08/2009	1045	
Carrowreagh	04/11/2006	08/07/2009	977	
Coolcam	04/11/2006	06/08/2009	1006	
Croaghill	04/11/2006	06/08/2009	1006	
Garryland	10/01/2007	23/06/2009	895	
Kilglassan	04/02/2007	21/08/2008	564	21/8/2008 onwards
Knockaunroe	05/11/2006	05/08/2009	1004	
Lisduff	05/11/2006	08/07/2009	976	
Lough Aleenaun	06/11/2006	19/02/2009	836	19/02/2009
Lough Coy	24/09/2006	05/08/2009	1046	
Lough Gealain	11/01/2007	05/08/2009	937	
Rathnalulleagh	04/11/2006	08/07/2009	977	
Roo	27/09/2007	05/08/2009	678	Before 27/9/2007
Skealoghan	06/11/2006	08/04/2009	975	
Termon	05/11/2006	05/08/2009	1004	
Tullynafrankagh	01/10/2006	04/08/2009	1038	
Turloughmore	06/11/2006	24/06/2009	961	

In order to determine the water level accurately, compensation for the variation in prevailing air pressure was made by means of a combination of BaroDiver® (DI500) and Met Eireann synoptic station data. The air pressure readings were converted into equivalent water head and then taken away from the water levels recorded by the Divers. As air pressure varies exponentially with height according to the barometric data was adjusted prior to compensation to allow for the difference in elevation between the BaroDiver or Met station elevation and that of the Diver on site.

Diver and BaroDiver® elevations relative to ordnance datum Malin Head (mAOD) were obtained using differential GPS surveying techniques. In addition to the adjustment of barometric data for differences in site elevations, each Diver record had to be adjusted for differences in the Diver calibration itself (see Naughton, 2011 for details).

3.2.4 Temperature Profiling

Further to the integrated temperature probes housed within the Divers, a vertical array of temperature probes was installed in an estavelle in Caranavoodaun turlough, Co. Galway to measure the temporal variation in temperature with depth. A 1.5 m length of plastic pipe was attached vertically to a 75 kg concrete base. Five Campbell Scientific 109-L temperature probes were affixed at 0.25 m intervals inside the pipe using cable ties. The 109-L probe uses a thermistor to record ambient air and water temperature within the range of -10°C to 70°C with a maximum error of ±0.2°C. The probes were connected to a Campbell Scientific CR200 multi-channel data logger attached to a nearby tree above the maximum flood level.

3.2.5 Precipitation

Three ARG100 tipping bucket rain gauges (Environmental Measurement Ltd) were installed in Kilchreest (Fig. 3.5a) and Francis Gap (Fig. 3.5b) Co. Galway and Ballintober, Co. Roscommon. Their purpose was to provide detailed rainfall records and to supplement existing Irish Meteorological Service (Met Eireann) rainfall and synoptic stations. Precipitation was recorded at intervals of fifteen minutes; the data were then aggregated into hourly and daily totals from 0900UTC to 0900UTC and so are consistent with Met Eireann rainfall station records.

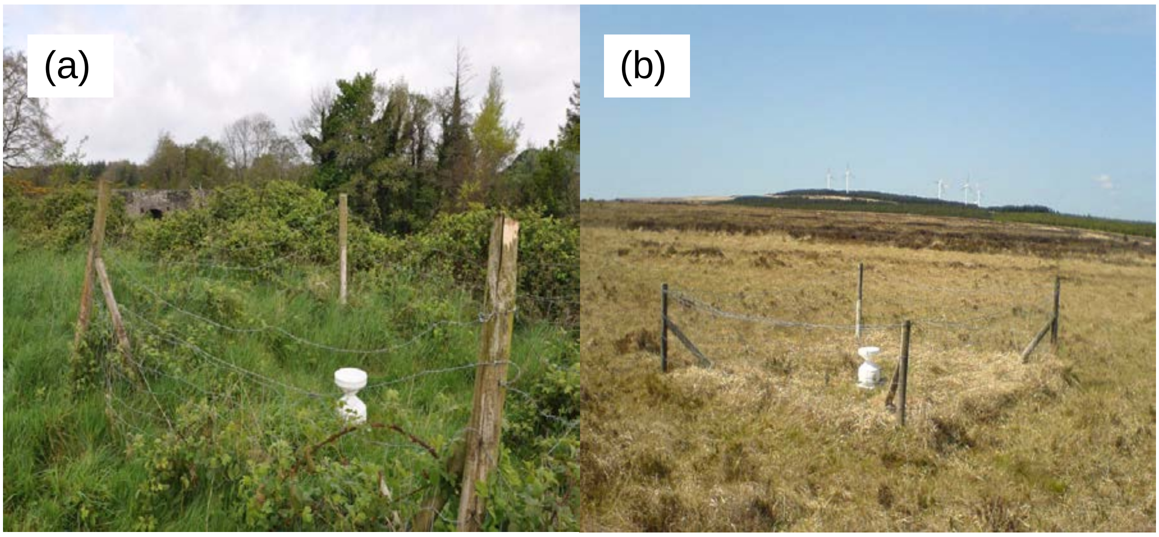


Figure 3.5 *Tipping bucket rain gauge at Kilchreest (a) and Francis Gap (b), Co. Galway*

A fence was erected around each gauge to prevent interference and damage from livestock. Rainfall records were downloaded every four to six months.

As a turlough's characteristic ecology is dependent on the long term hydrological regime, it was deemed more functional to base any hydrological modelling on long established precipitation records. Long term data were obtained for a number Met Eireann stations and utilised in the modelling process. A list of the Met Eireann stations from which meteorological data was obtained is given in table 3.2.

3.2.6 Evapotranspiration

Daily evapotranspiration data were obtained from Met Eireann synoptic stations located in Shannon Airport (Co. Clare), Knock Airport (Co. Mayo), and Birr (Co. Offaly). Met Eireann calculates potential evapotranspiration using the FAO Penman – Monteith equation.

Table 3.2 Met Eireann synoptic, climatic and rainfall stations from which meteorological data were obtained

Location	Station Type	Station Number	County	Elevation (mAOD)	Easting	Northing	Year Open
Shannon Airport	Synoptic	518	Clare	6	137900	160300	1937
Birr	Synoptic	4919	Offaly	73	207400	204400	1954
Claremorris	Climatic	2727	Mayo	71	134500	273900	1943
Ballinagare	Rainfall	7129	Roscommon	87	174700	287700	2003
Bayygar	Rainfall	2228	Galway	61	178400	252500	1969
Ballyvaughan	Rainfall	2321	Clare	23	121500	208300	1984
Carheeny Beg	Rainfall	2018	Galway	49	144400	194300	1993
Carron	Rainfall	1718	Clare	134	127700	198200	1974
Craughwell	Rainfall	2521	Galway	27	149800	220000	1985
Glenamaddy	Rainfall	3127	Galway	84	162900	261600	1944
Gort	Rainfall	2121	Galway	155	159700	201900	1982
Kikeeran	Rainfall	5127	Mayo	27	116400	272800	1994
Loughrea	Rainfall	2721	Galway	76	160100	218100	1998
Milltown	Rainfall	3027	Galway	50	141000	262800	1944
Roscommon	Rainfall	5829	Roscommon	58	186700	264100	1984
Strokestown	Rainfall	6329	Roscommon	52	192800	278200	1987

3.2.7 Sea Level Monitoring

As two turloughs lying in the Gort – Kinvarra conduit system (Garryland and Caherglassan) demonstrated a tidal influence at low stages, tide level data were obtained from the Marine Institute for analysis. The nearest Marine Institute tide gauges, Galway Port and Inishmore, consist of OTT Hydrometry CBS Bubbler water level gauges which record accurate tide levels at six minute intervals in mAOD. Comparison of the two datasets showed that the timing of high and low tide was synchronous but with Galway Port showing the greater high tide level by approximately 0.4 m. This is due to the tidal bore effect caused by incoming tidal waters entering Galway bay. Galway Port tide levels were used in the analysis with Inishmore levels used to compensate for any missing data points, suitably adjusted for the difference in maximum level. The tide level time series was reduced to hourly readings to allow comparison with hourly water level time series for Caherglassaun and Garryland. A plot of stage for Galway Port and Caherglassaun turlough for May and June 2008 is shown in figure 3.6. The variation in tide level maxima with spring and neap tides is clearly visible as well as the corresponding effect on water levels within the turlough.

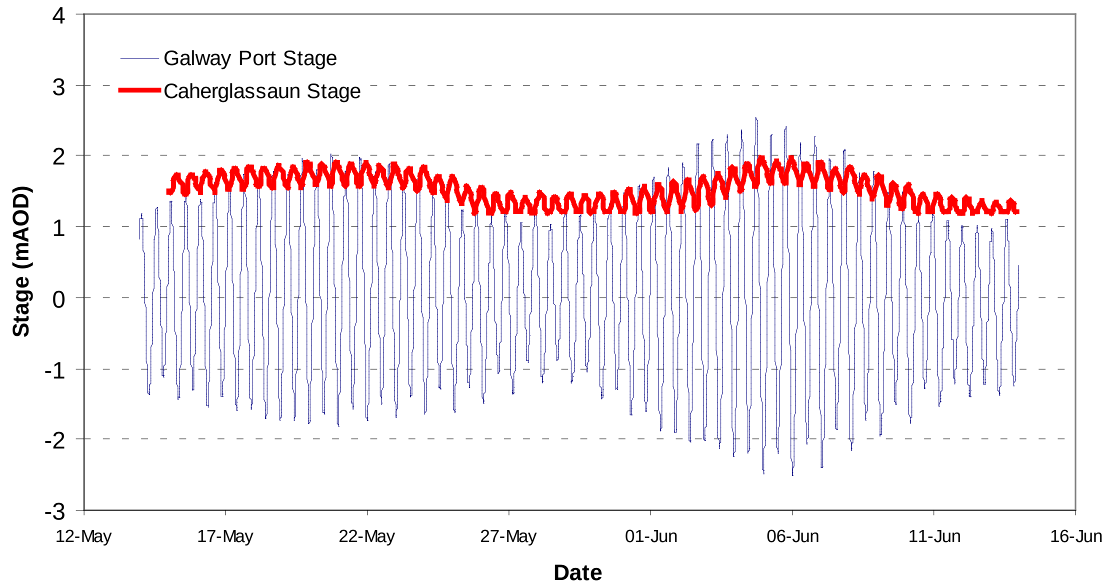


Figure 3.6 Variation in stage of Galway Port and Caherglassan turlough, Co. Galway

3.2.8 Visual Surveying

A great deal of insight into the hydrological regime and hydrogeology of each site was gained during the DGPS surveying process. Specific active hydrological features such as estavelles (Fig. 3.7), springs and swallow holes were identified at a number of sites. In total the location and nature of over one hundred previously undocumented karst features were identified and their position accurately surveyed. These features have been submitted for inclusion within the GSI karst database.

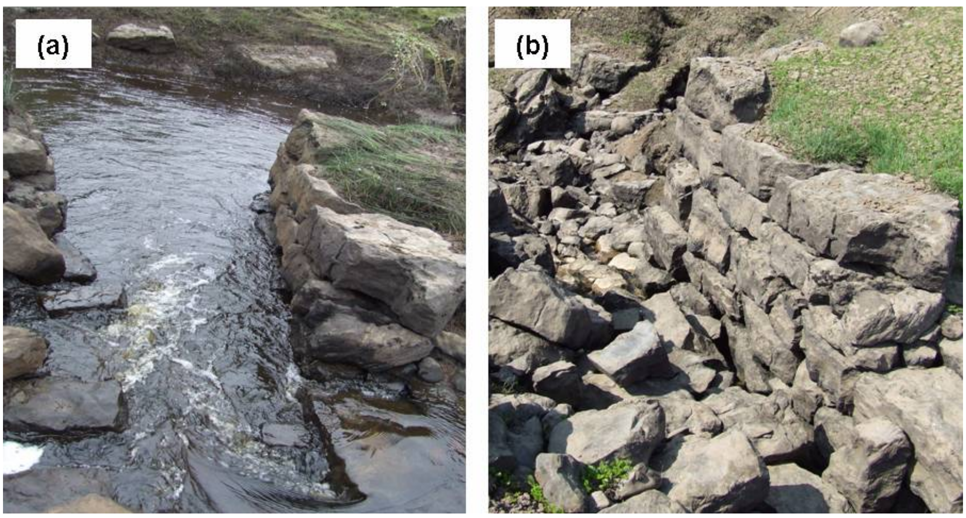


Figure 3.7 Estavelle in operation during turlough recession (a) and dry (b) in Lough Coy, Co. Galway

3.3 Surveying and Digital Terrain Modelling

3.3.1 Introduction

GPS surveys were carried out on all 21 monitoring sites in order to develop digital terrain models (DTMs) from which stage / volume / surface area relationships could be defined. Contour maps, stage – volume and stage – surface area relationships are produced from the turlough DTMs. The steps involved in the DTM process are shown in the flow chart below (Fig. 3.8).

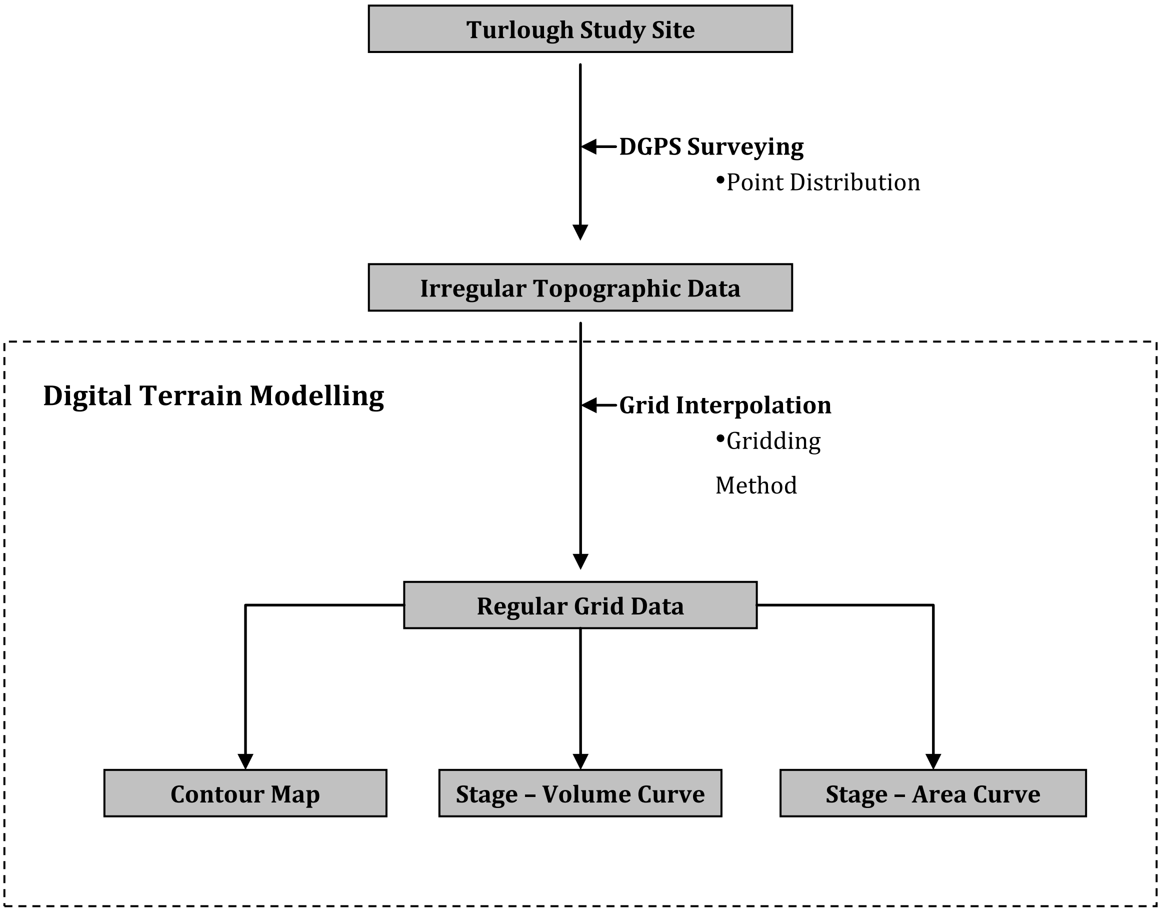


Figure 3.8 Flow chart for the turlough digital terrain modelling process

3.3.2 Global Positioning System Surveying

Global Positioning System (GPS) receivers use the satellite signals to pinpoint their coordinates on the earth's surface to within a few metres and, then, with the use of further methods such as differential GPS (DHPS), down to centimetre accuracy. DGPS involves the use of a stationary base receiver and one or more mobile rover receivers. As the location of the base receiver is precisely known, the timing errors for each satellite can be measured at this receiver using its known coordinates and from the accumulated errors a correction signal is generated. This signal is transmitted to the rover receiver thus allowing the rover position to be measured to a high degree of accuracy (Fig. 3.9).

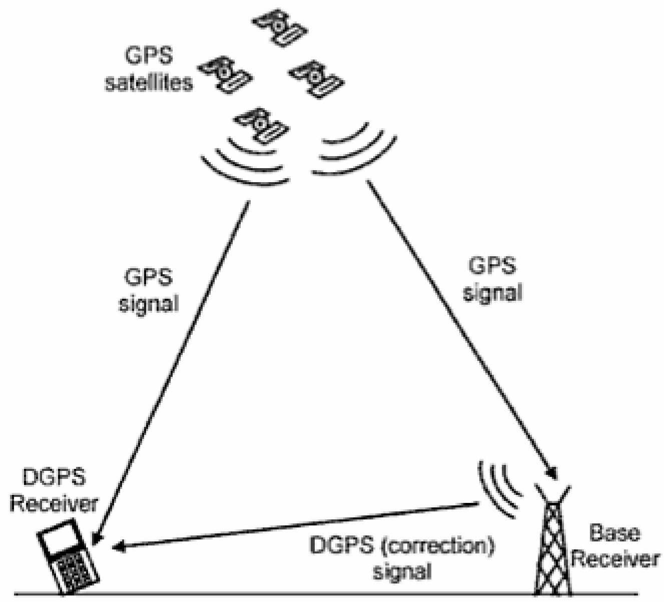


Figure 3.9 Conceptual operation of differential GPS surveying system (from Maini & Agrawal, 2007)

Using Real Time Kinematic (RTK) surveys, the corrections are transmitted in real time to the rover, allowing the immediate correction of GPS data and accuracies of up to one centimetre to be achieved on site without the need for post processing All GPS surveys carried out as part of this research used DGPS RTK surveying.

3.3.2.1 DGPS Field Surveying

During the summer of 2007 GPS surveying was carried out using a Trimble model 4700 GPS system (Fig. 3.10a). In early 2008 a Trimble R6 GPS System equipped with the Virtual Reference Station (VRS) hardware and software was purchased (Fig. 3.10b). This allowed all surveys to be referenced to the Irish National Grid without the need to locate existing benchmarks in the survey area. A combination of the R6 and 4700 GPS systems were used to carry out subsequent surveys. Both systems have identical levels of accuracy and so results obtained with each system were compatible.

(a) (b)

Figure 3.10 Trimble 4700 GPS system (a) and Trimble R6 GPS system (b)

The procedure used to carry out the GPS surveys is outlined in Naughton (2011). Point density depended on the terrain variability. Points were taken at approximately ten to fifteen metre intervals in areas of gentle undulation. In areas of greater topographic variation (such as estavelles) a spacing of as little as one metre was used. An example of point density for Blackrock turlough, county Galway can be seen in figure 3.11. Note how point spacing was much lower in area (a) than in area (b), as area (a) contained a steep-sided channel entering the turlough whereas area (b) consisted of gently undulating terrain.

The upper boundary of the survey was defined by the maximum water level recorded during the monitoring period. Often natural barriers such as woodland or impassable marl deposits were present within the boundary of the turlough, which prevented an area being surveyed in detail. Areas of open water shallower than 1.5 metres were surveyed using chest waders or a wetsuit if necessary. A canoe was used to take a limited number of points in areas of deeper water. When encountering woodland, points were taken at breaks in the canopy within the woodland, or transects in clear ground beyond it taken and used to define the upper bound. In total over twenty thousand topographic points were taken with an average of over one thousand points per turlough. A summary of the surveys is given in table 3.3.

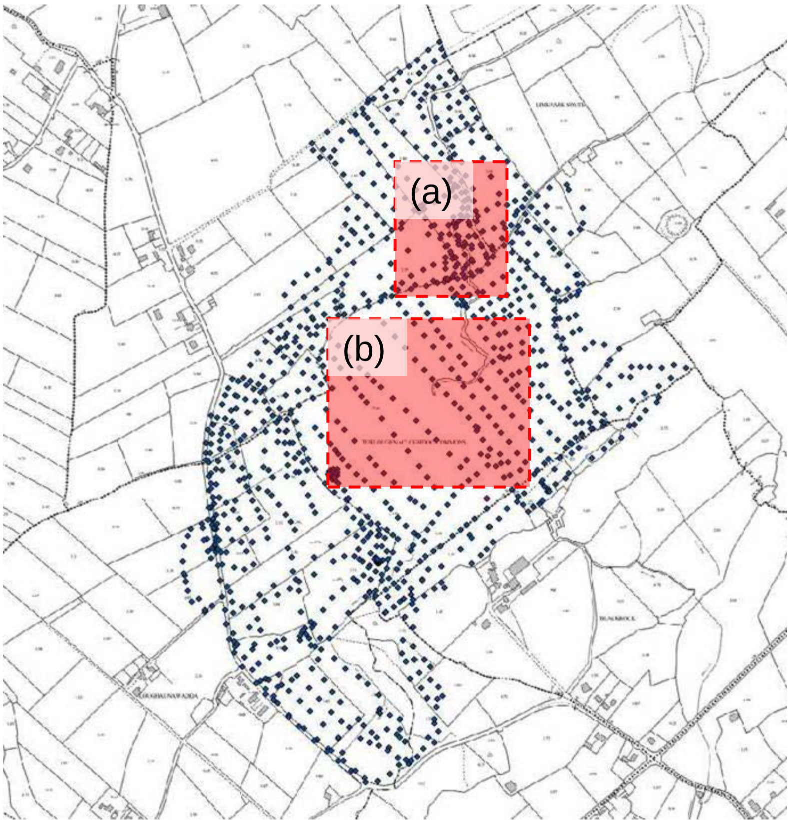


Figure 3.10 Areas of high point density (a) and of gently undulating terrain with low point density (b), Blackrock turlough, Co. Galway

Table 3.3 Summary of DGPS survey data

Site Name	Maximum Stage (mAOD)	Number of Points	Range (m)			Spacing	
			X	Y	Z	Mean (m)	Standard Deviation (m)
Ardkill	39.78	960	580.0	730.6	12.6	10.6	6.6
Ballinderreen	14.66	1571	1380.9	1208.3	9.3	12.8	8.5
Blackrock	26.40	1323	915.3	1344.2	19.9	12.2	8.2
Brierfield	92.53	1056	1269.0	1362.9	8.7	14.0	8.1
Caherglassaun	10.51	1554	1686.2	1077.1	19.4	11.3	7.4
Caranavoodaun	24.53	1043	1190.5	636.7	10.6	10.6	6.6
Carrowreagh	86.89	739	1436.5	814.5	12.9	15.5	8.4
Coolcam	84.94						
Croaghill	81.16	1091	1167.0	982.8	9.2	13.0	7.5
Garryland							
Kilglassaun	35.27	1028	1004.8	1785.0	12.1	13.3	8.0
Knockaunroe	30.46	1663	1540.1	1412.8	14.1	12.4	8.2
Lisduff	50.00	740	977.7	1326.1	4.8	17.2	8.7
Lough Aleenaun	78.32	880	909.2	427.0	16.5	9.1	6.4
Lough Coy	18.36	1011	635.9	815.3	16.6	8.5	6.0
Lough Gealain	30.90	1020	964.0	982.9	9.9	11.8	8.9
Rathnalulleagh	81.40	654	1125.3	713.1	12.0	12.5	8.0
Roo West	15.38	945	1124.8	863.5	11.3	12.7	7.3
Skealoghan	34.10	690	933.8	753.7	8.3	13.5	7.0
Termon	22.60	831	1115.5	992.5	10.2	13.7	6.9
Turloughmore	30.16	937	766.3	1399.1	10.1	12.0	7.6

3.3.2.2 Water Level Correction

The elevation of each Diver was surveyed to ensure accurate barometric compensation and adjustment of water level time series data to ordnance datum. Diver elevations during the 2006 / 2007 flooding period were tied in to the temporary bench mark (TBM) at each site using the Trimble 4700. The TBMs were later adjusted to mAOD using a Trimble R6 VRS survey. When a Diver was recovered during an inundation period the water level was recorded with the Trimble R6 to allow the alignment of the time series before and after recovery as it was impossible to replace the diver in the exact position.

3.3.3 Digital Terrain Modelling

Digital terrain modelling (DTM) provided a way to transform water level data into flooded areas, volumes and the associated flow rates. Ecologically, DTMs aid in the determination and representation of depth, duration and frequency of flooding, factors known to be of great importance to the diversity and characteristic ecology of wetlands.

The elements required for a DTM are a finite number of reference points such as GPS points. Interpolation or "gridding" is then used to predict or extrapolate the elevation at unobserved locations based on known elevations at a set of reference points. Much detailed analysis was carried out comparing eight different gridding methods (*Nearest Neighbour, Natural Neighbour, Kriging, Multiquadratic Interpolation, Triangulation with Linear Regression, Polynomial Regression, Local Polynomial and Minimum Curvature*) and appropriate grid resolutions, all covered in Naughton (2011). At the end of this process it was decided to use the kriging gridding method at a 2 m grid resolution for all DTM work.

3.3.3.1 Contour Maps

Once the surface has been computed the software was used to produce contour maps, as shown for Lough Gealain in figure 3.12. These were also combined with a wireframe plot to give a 3-D representation of each turlough (Fig. 3.12). The duration and frequency of flooding for each contour can be calculated from water level time series and combined to give duration and frequency maps. The contour plots and 3-D surfaces of all of the turloughs are given in Naughton (2011).

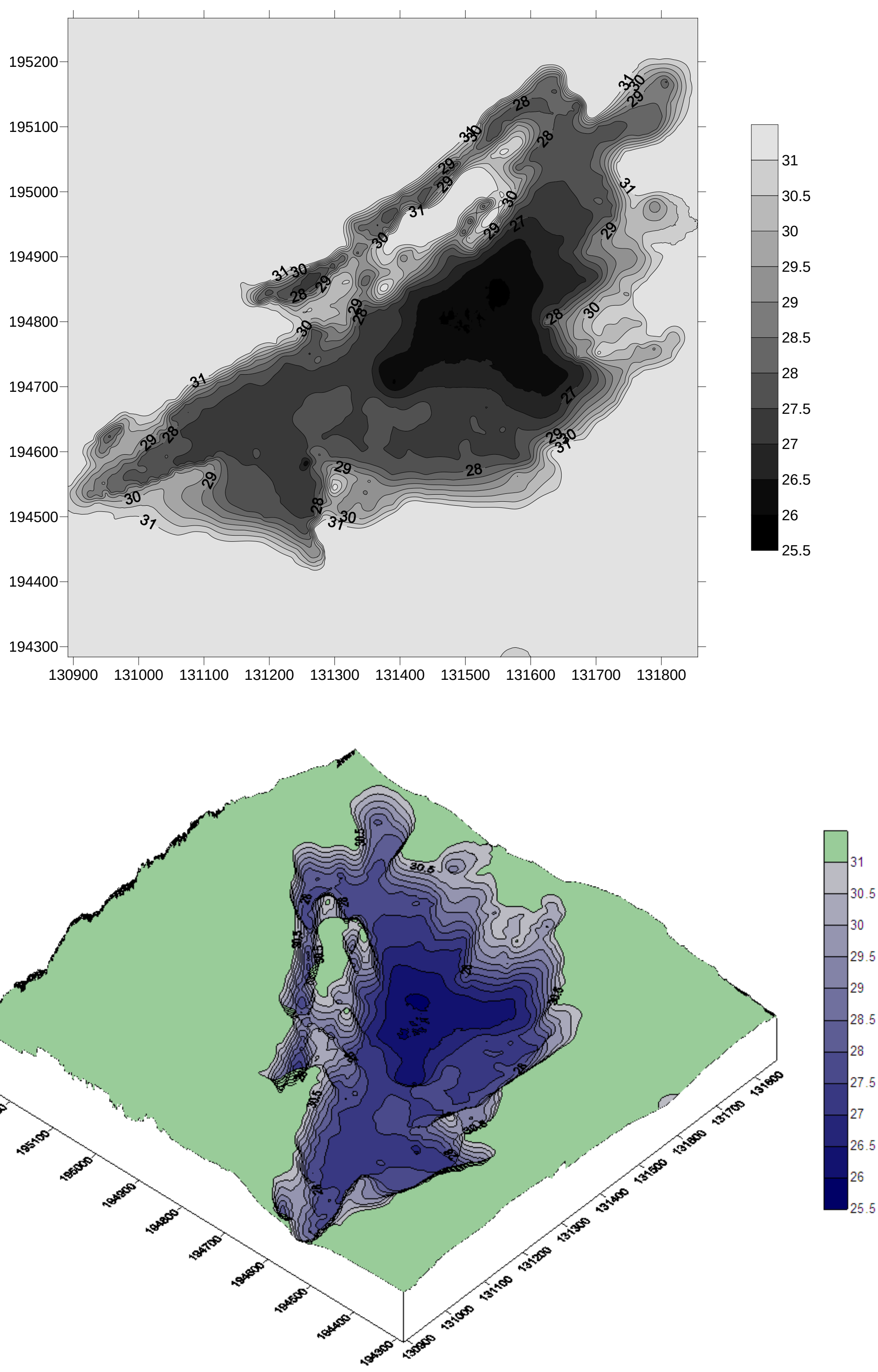


Figure 3.12 Contour map (top) and 3D terrain model (bottom) of Lough Gealain, Co. Clare

3.3.3.2 Stage Volume and Stage Area Curves

As the points at which inflow and outflow occur within the turlough are submerged during the period of inundation, direct measurement of flow rates is practically impossible. In the absence of direct measurements the volumes and net flows are derived by determining the changes in volume of the turlough across each time step. Stage volume relationships derived from digital terrain models were used to transform recorded water levels into volumes, thus allowing notional flow rates to be calculated. The ability of Surfer® 8 to compute volumes between two surfaces was utilised to achieve this. Surfer® carries out volume calculations on solids defined by an upper and lower surface. In this case the upper surface was a horizontal plane representing a specific water level while the lower was the turlough surface. Volume calculations were carried out on each grid cell. If the surface at either end of the grid column was tilted or irregular the volume is approximated by a prism (Fig. 3.13). The accuracy of the volume calculation increases with increasing grid resolution as the relative size of the approximated prism is reduced compared to the size of the associated column.

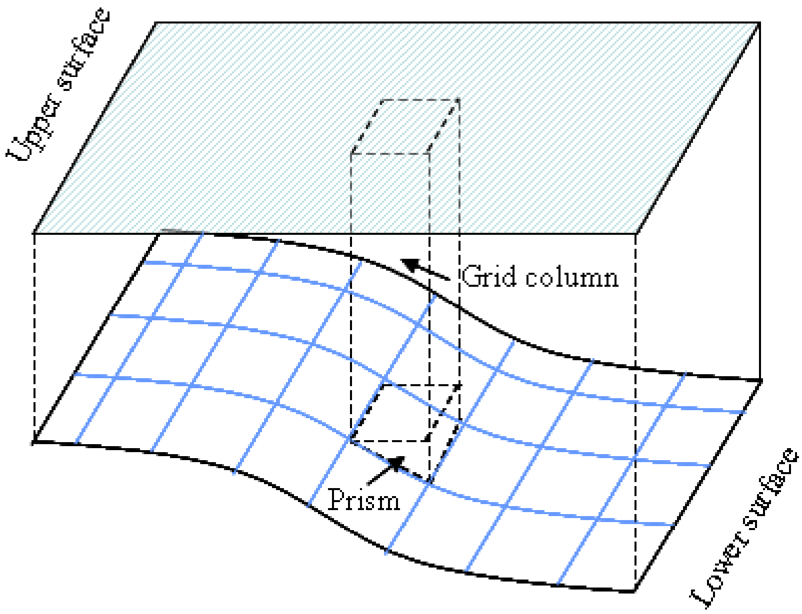


Figure 3.13 Solid used in volume calculation between surfaces for grid cell

Volume and surface area calculations were carried out at 2 cm intervals across the range of flooding to produce stage – volume curves (Fig. 3.14). A SurferScript program was written to automate this process and perform and record multiple calculations. The stage volume and stage area curves for each turlough are given in Naughton (2011).

Two methods were trialled for the application of the stage volume relation to water level time series: polynomial curve fitting and linear interpolation. Because of inaccuracy at low levels using polynomial curve fitting, linear interpolation was used to transform the recorded water level time series into corresponding volume and area time series. In the modelling process, polynomials were used to convert volume back into stage due to their ease of use.

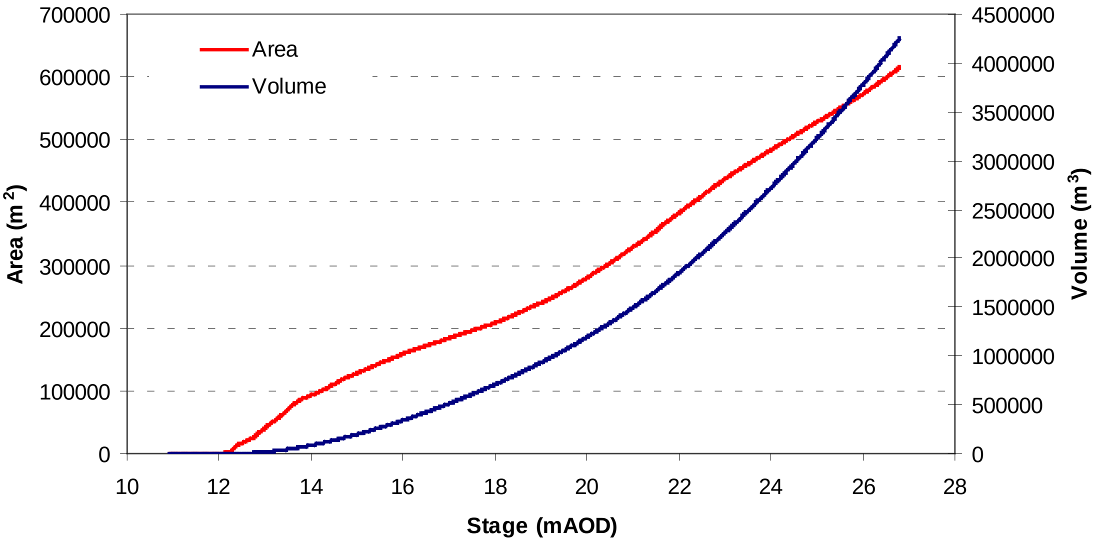


Figure 3.14 Stage area and stage volume curve for Blackrock turlough, Co. Galway

3.4 Data Analysis

3.4.1 Water Level Profiles

The first step in classifying and quantifying turlough hydrology is through the analysis of water level time series. The monitoring period consisted of the three hydrological years: 2006/2007, 2007/2008 and 2008/2009. The general water level profile recorded during the 2006/2007 and 2007/2008 hydrological years demonstrated what is often considered typical turlough flooding behaviour. In 2006 water levels began to rise in mid September, reaching a peak in December and another towards the end of January, with emptying occurring from April onwards. The highest water level recorded in the more flashy turloughs such as Lough Aleenaun, Turloughmore and Blackrock coincided with the first mid December peak, while the majority of the other sites displayed a seasonal maximum during late January. A low level flood event took place in July / August 2007 in a number of turloughs due to unusually high rainfall for the period, with floodwaters persisting until mid September 2007. The subsequent dry period caused a later onset of flooding in the 2007/2008 hydrological year whereby inundation began across all study sites at the end of November. Thereafter, flooding followed the typical pattern as in 2006/2007 year with most peak water levels taking place in February. In contrast the 2008/2009 hydrological year showed a distinct pattern with low level, long duration flooding consisting of several filling and emptying events taking place throughout the year.

While the maximum flood level over the entire monitoring period occurred during the 2006/2007 year in the majority of sites, others showed the highest overall level during 2007/2008. Turloughs located in the north of the study area, in counties Mayo, Roscommon and north Galway, as well as those in the Gort area, all recorded maximum levels in the 2006/2007 hydrological year. In contrast, turloughs in Co. Clare and around the Ardrahan area in Co. Galway showed maxima in 2007/2008. All sites showed the lowest yearly level of flooding in the 2008/2009 hydrological year.

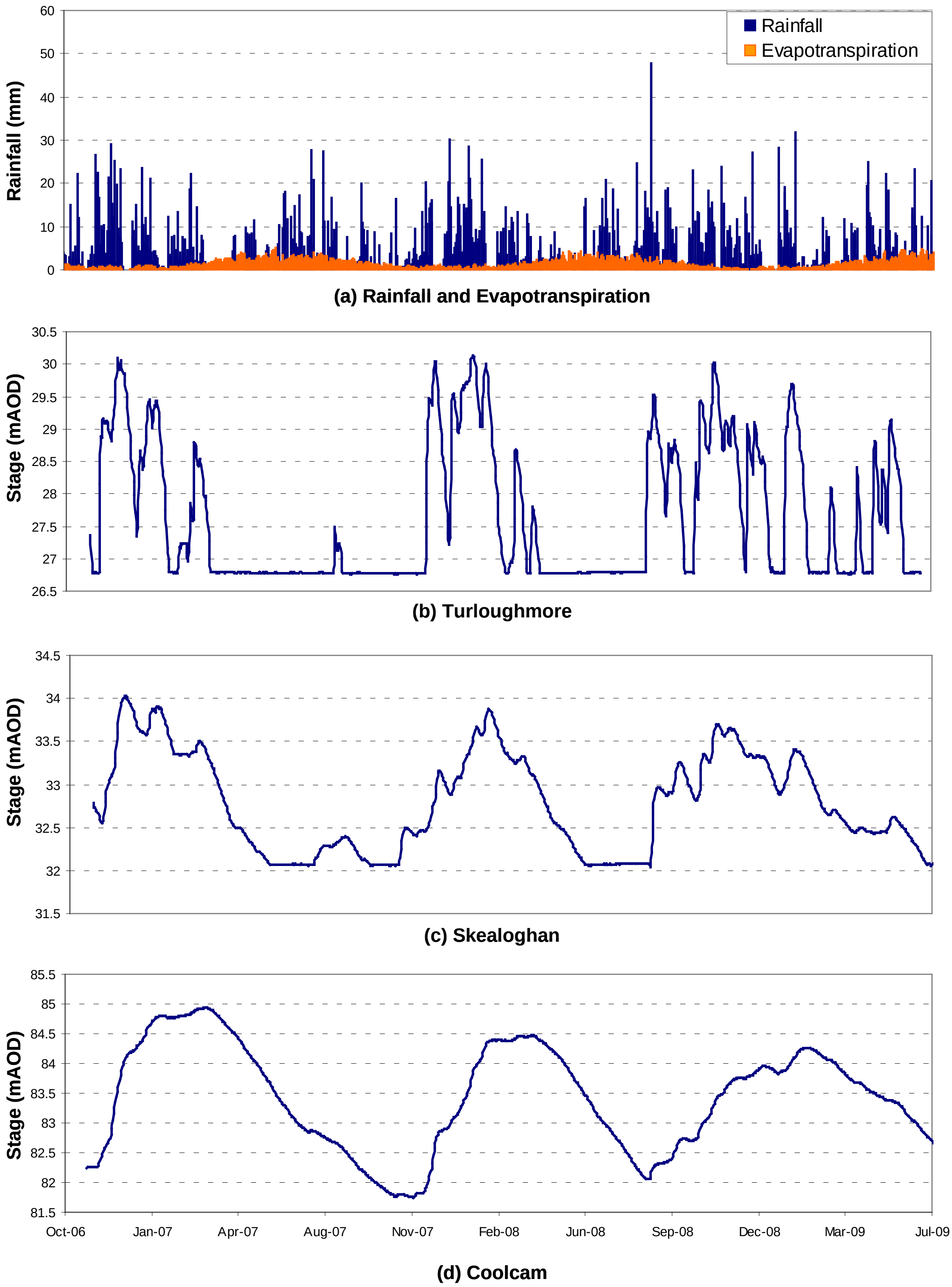


Figure 3.15 Rainfall and evapotranspiration for monitoring period from 2006 to 2009 (a), and water level time series plot for Coolcam (b), Skealoghan (c) and Turloughmore (d)

Within the broadly similar flooding patterns there are some stark contrasts between turloughs. A plot of water level time series from 2006 to 2009, illustrating the general seasonal pattern of flooding, can be seen in figure 3.15 b-d with representative rainfall and evapotranspiration records for the period shown in figure 3.15 a. The water level hydrographs demonstrate the range of flooding regimes observed across the monitored turloughs. At one end of the scale are sites like Turloughmore, Co. Clare (Fig. 3.15 b), which display a multimodal flooding regime consisting of a series of rapid filling and emptying events. At the other end of the flooding spectrum are sites such as Coolcam, Co. Galway, which show a single long duration flood event with an extended recession within each hydrological year (Fig. 3.15 d). The regimes of Skealoghan (Fig. 3.15 c) and many others lie somewhere in between these extremes, and possess a wide variety of depth, duration and frequency characteristics.

Some turlough pairs display practically identical water level profiles, such as Garryland and Caherglassan, Lough Gealain and Knockaunroe, and Rathnalulleagh and Carrowreagh. The sites that show the greatest level of similarity are geographically close to each other, suggesting the possibility of hydraulic connections between them allowing simultaneous responses to occur. Other sites within close proximity, such as Ardkill and Skealoghan, have substantially different regimes with Ardkill showing deeper flooding and markedly longer recession characteristics than Skealoghan.

A comparison of water level hydrographs with the rainfall record of the same period shows a strong relationship between rainfall and flood dynamics. Each filling event corresponds to a period of intense, prolonged rainfall while the recession limbs all occur during a period of little or no rainfall. This relationship is particularly strong during the winter months due to a combination of high rainfall and lower losses due to evapotranspiration. A clear example of this can be seen in the Turloughmore hydrograph (Fig. 3.15 b) as each distinct flood event has a corresponding set of rainfall events. Sufficiently intense rainfall during the summer period can also cause flooding to occur, but on a smaller scale due to the greater losses associated with higher evapotranspiration. The low antecedent rainfall conditions create a cumulative soil moisture deficit and storage within the aquifer itself, which further dampens the effect of rainfall during the summer months. For example, the rainfall events that occurred in mid 2007 had an effect on all three turloughs, but the form of this response varied depending on the flow dynamics of each system. Distinct flood events occurred in figure 3.15 b and c. However, flooding occurred earlier and had a longer duration in Skealoghan than in Turloughmore. Due to the long recession characteristics of Coolcam (Fig. 3.15 d) the turlough had not yet fully emptied and so the corresponding rainfall events halted the recession rather than causing fresh flooding.

Despite the clear differences in hydrological regime across the study sites, a comparison of peak levels shows similarities in the timing of response to rainfall events. Following the cessation of rainfall the net flow direction quickly becomes negative in flashy turloughs leading to a rapid fall in water levels. The result of this is a hydrograph characterised by number of clearly defined peaks and discrete flood events. This reversal of flow direction is a much slower process in turloughs like Coolcam. The lower recession rate means that sustained rainfall has a greater cumulative effect on the water level hydrograph in these sites. During a period of little or no rainfall the level in the turlough drops at a much slower rate than is witnessed in flashy turloughs, leaving the turlough at a relatively high level when rainfall resumes. Thus, while the timing of peak flood levels may be similar across a wide set of turloughs, the magnitude of the peaks themselves can differ greatly. A demonstration of this is shown using the peaks periods 1, 2 and 3 in the 2006/2007 hydrological year (Figure 3.16).

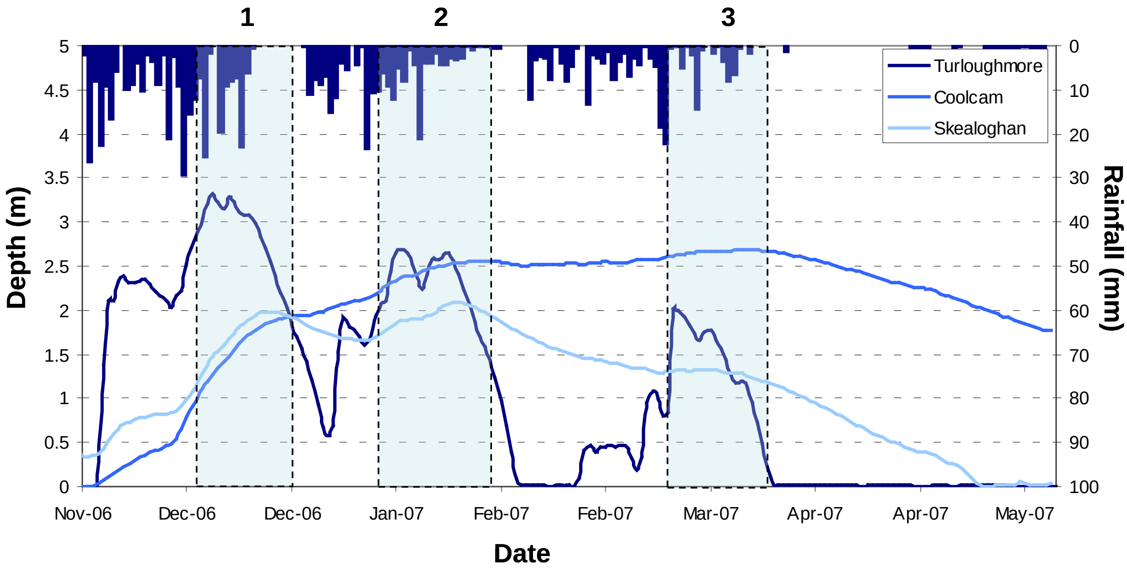


Figure 3.16 Magnitude of peak water levels during the 2006/2007 inundation period for Turloughmore, Skealoghan and Coolcam turloughs

While a peak or significant change in slope occurred in all turloughs during periods 1, 2 and 3 the relative magnitude of each peak was different for each turlough; the annual maximum level occurs in Turloughmore in period 1, in Skealoghan in period 2 and in Coolcam in period 3. Following peak 1 the higher drainage capacity of Turloughmore allowed the water level to drop sufficiently so that the causative rainfall for peak 2 resulted in a lower overall level. While the water level in Skealoghan also fell following peak 1, it was at a slower rate than that of Turloughmore and so when rainfall resumed it caused the highest recorded level in peak 2. Due to the slow recession rate of Coolcam, the water level scarcely dropped following both peaks 1 and 2 and so the cumulative effect of this led to the highest water level occurring during peak 3. This contemporaneous behaviour of peaks has implications for the nature of turlough flow systems. It implies a confined flow system where changes in pressure are rapidly felt throughout, rather than a phreatic system where a lag dependent upon the position of the turlough within the system would be expected. The relative timing of peak water levels is further investigated later in terms of the hydro-ecological indicators.

3.4.2 Depth-Volume-Area Analysis

The stage volume and stage area relationships derived from digital terrain models were used to transform water level time series into corresponding volume and area time series for each site. This allowed a detailed examination of turlough flow dynamics as the net flows into or out of the turlough can be calculated, as well as quantifying changes in flood extent. The plots of water level, volume and area are provided for all twenty one study sites in Naughton (2011). Summary statistics quantifying the turloughs in terms of maximum water depth, volume, area and average depth are given in table 3.3. Maximum water level fluctuation or flood depth was calculated as the difference between the lowest topographic point surveyed within the turlough and the maximum recorded water level. Average depth is the maximum volume divided by the maximum area.

The large range of flooding in terms of depth, volume and area demonstrates the great diversity in the characteristics of turloughs as hydrological entities. At one end of the scale lie shallow expansive basins such as Ballinderreen, where the average depth of flooding was only 0.85 metres across an area of almost 60 hectares. At the other extreme lie turloughs occupying steep sided depressions with substantial depths of flooding, such as Lough Coy. Covering only 25 hectares, Lough Coy was one of the smallest turloughs monitored in terms of area but when full contained approximately 1.5 million m^3 and reached maximum depths far in excess of those in Ballinderreen and many others.

Table 3.3 Summary statistics of maximum turlough flood depth, volume, area and average depth

Site ID	Site Name	Max Depth (m)	Max Volume ('000 m^3)	Max Area ('000 m^2)	Average Depth (m)
1	Skealoghan	3.2	382.2	326.8	1.17
2	Ardkill	7.7	652.6	233.4	2.8
3	Kilglassaun	4.9	809.6	510.4	1.59
4	Coolcam	4.5	1570.2	781.2	2.01
5	Croaghill	4.4	636	386.1	1.65
6	Rathnalulleagh	8.2	877.9	294.6	2.98
7	Carrowreagh	8.1	546.2	282.5	1.93
8	Brierfield	4.2	933.5	541	1.73
9	Lisduff	3.0	771.3	537.4	1.44
10	Caranavoodaun	3.8	498.5	345.5	1.44
11	Blackrock	15.4	4008.1	592.9	6.76
12	Lough Coy	10.6	1479.1	252.6	5.86
13	Garryland	10.9	2330.4	420.8	5.54
14	Caherglassaun	9.4	2998.9	626.1	4.79
15	Termon South	3.7	956	420	2.28
16	Roo West	5.5	1077.3	409.9	2.63
17	Turloughmore	3.5	416.5	307.9	1.35
18	Lough Gealain	4.9	919.9	357.9	2.57
19	Knockaunroe	5.8	1841.6	788.2	2.34
20	Lough Aleenaun	5.9	355.6	137.1	2.59
21	Ballinderreen	4.3	592.6	695.2	0.85
	Range	(3.0 – 15.4)	(355.6 – 4008.1)	(137.1 – 788.2)	(0.85 – 6.76)

3.4.2.1 Depth

Maximum depth of flooding varied substantially between monitored turloughs, reflecting the differences in characteristic flood regime and geomorphology of each site (Fig. 3.17). Flood depths ranged from 3.0 to 15.4 metres with Blackrock turlough, Co. Galway, displaying the greatest fluctuation and Lisduff, Co. Roscommon, showing the least. Broadly speaking the variation in flood depth reflects the topography of the flood basin. Sites showing a low range of flooding tended to be shallow extensive depressions with gentle side slopes, whereas turloughs with a greater flood depth were formed in steeper sided basins. The four highest flood depths were displayed by turloughs forming part of the Gort – Kinvarra chain, a conduit karst system running from the foot of the Slieve Aughty Mountains in the east to springs discharging into Kinvarra Bay in the west. This system combines large quantities of allogenic recharge, extensive catchment area, a high capacity conduit system and relatively deep surface depressions created the conditions for such a high flood range. As mentioned before and can be seen in figure 3.17 below, the year containing the highest overall flood level varied between turloughs, with the majority of sites recording a maximum in 2006/2007. All sites showed the lowest level of flooding in the 2008/2009 hydrological year.

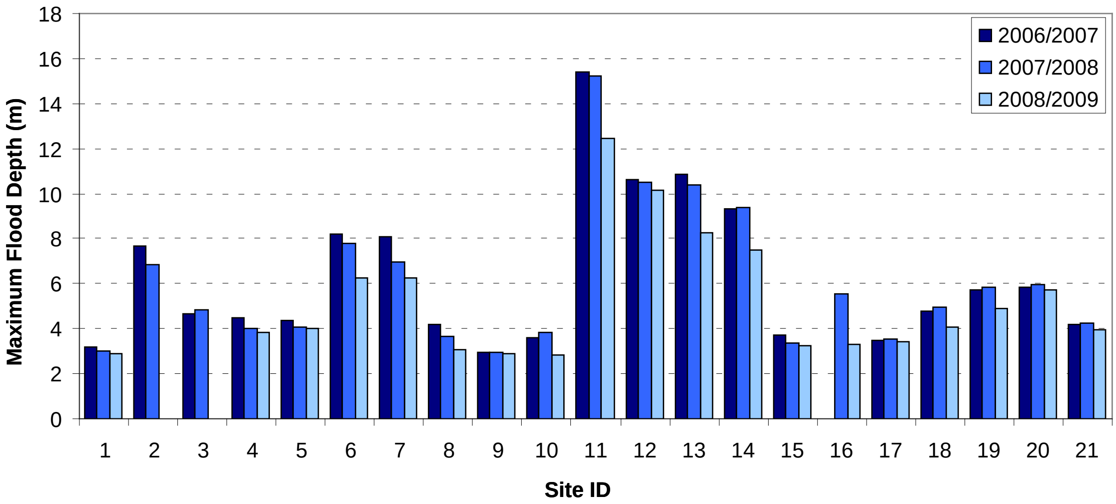


Figure 3.17 Maximum turlough flood depths recorded during the hydrological years 2006/2007, 2007/2008 and 2008/2009. Site ID is given in table 3.3 above.

3.4.2.2 Volume

The maximum recorded volume of each turlough for the 2006/2007, 2007/2008 and 2008/2009 hydrological years is shown in figure 3.18. There was a greater degree of variation in volume between the study sites than was witnessed between corresponding turlough depths. An order of magnitude difference existed between the largest and smallest sites volumetrically, with Lough Aleenaun filling to around 350,000m^3 compared to the 4 million m^3 of Blackrock. As with the depth data, the turloughs of the Gort – Kinvarra chain showed the highest maxima, with total volumes ranging from 1.5 million to 4 million m^3. The fluctuations in level and volume of Blackrock dwarf those of most other turloughs. In a three day period the water levels rose by approximately six metres with a corresponding inflow of 1.6 million m^3, equating to an average flow rate of 6m^3/s sustained for the entire 3 day period. As the range of volumes is so great, a second plot comparing turloughs whose mean volume was less than 1 million m^3 is given in figure 3.19.

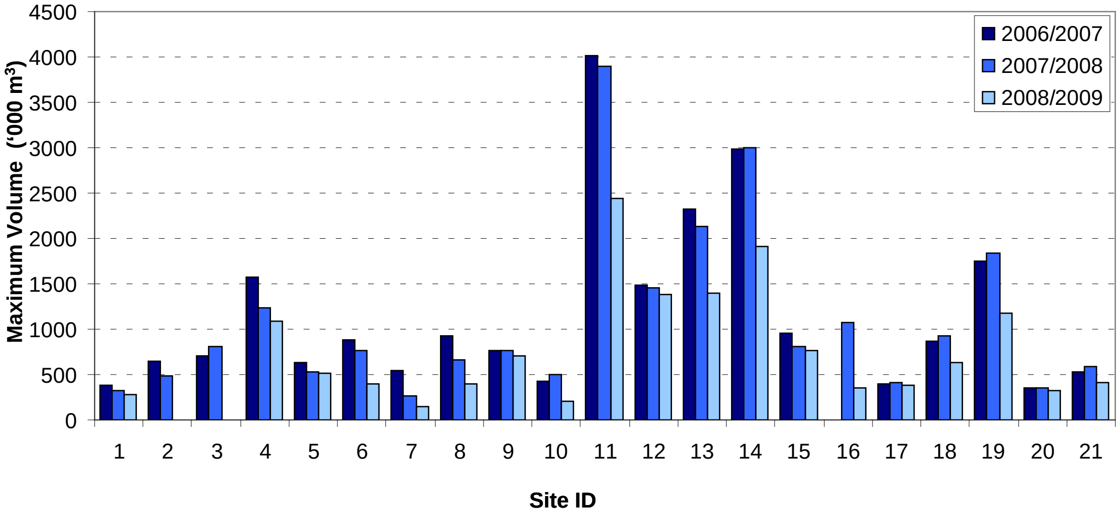


Figure 3.18 Maximum turlough flood volumes recorded during the hydrological years 2006/2007, 2007/2008 and 2008/2009

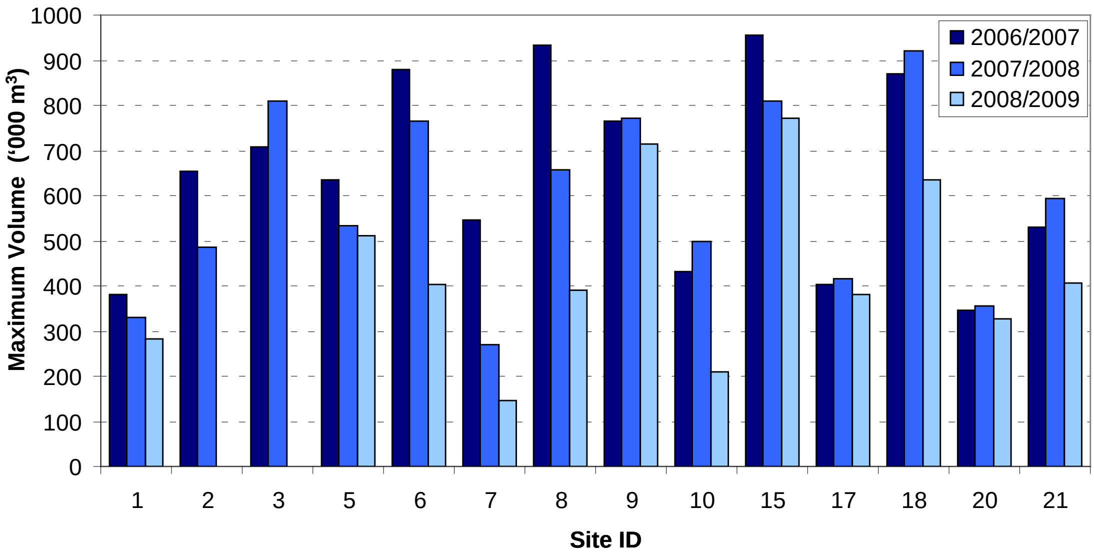


Figure 3.19 Maximum turlough flood volumes under 1 million m^3 recorded during the hydrological years 2006/2007, 2007/2008 and 2008/2009

The most noticeable yearly variation in maximum volume occurred in sites 6, 7 and 8, all sites within a 3 km radius of each other in Co. Roscommon. The yearly reduction was particularly acute in site 7, Carrowreagh, with the volume almost halving year on year. A comparison of cumulative rainfall from the Roscommon rainfall station gives some insight into the cause of this decline in maximum volumes. Cumulative rainfall was calculated starting just before the onset of flooding to just after the peak water level. The reason for the lowest flood volume occurring during 2008/2009 is clear as the cumulative rainfall over the period is significantly lower than the other two years (Fig. 3.20). It shows a high frequency of days with little or no rainfall (Fig. 3.21) where the turloughs had sufficient time to partially empty and for storage to build up within the system, thus lessening the effects of subsequent rainfall. While the 2006/2007 cumulative rainfall total of 500 mm was only marginally higher than that of 2007/2008, the rate at which this was reached was significantly faster occurring a full week earlier in 2006/2007 than 2007/2008. While all periods followed the characteristic J-distribution for daily rainfall frequencies, the period containing the 2007/2008 showed the highest frequency of days with no rainfall (Fig. 3.21). These dry periods, represented by horizontal sections within the cumulative rainfall plot, would have facilitated draining of the catchment storage and even partial outflow from the turlough itself, thereby dampening the effect of subsequent rainfall events. The timing of rainfall may also have impacted upon the maximum levels reached. 2008/2009 began in August, much earlier than the other 2 years, and so would have had higher evapotranspiration losses further reducing recharge available for flooding.

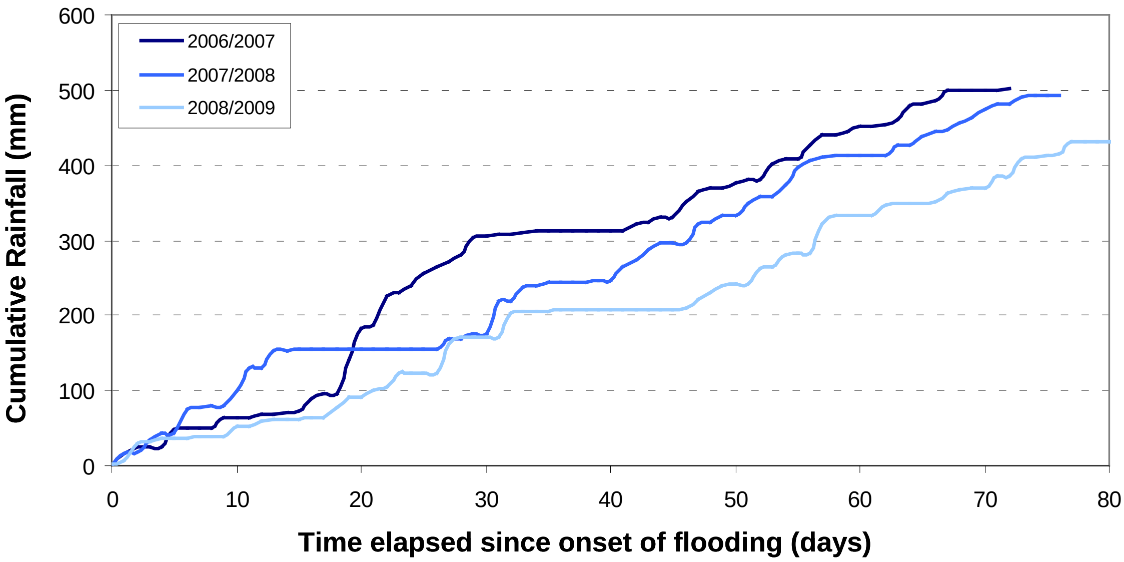


Figure 3.20 Cumulative rainfall plot for Roscommon rainfall station during major 2006/2007, 2007/2008 and 2008/2009 flooding events

Another contributing factor to relative levels in 2006/2007 and 2007/2008 was the antecedent flood conditions. The flood event resulting in the 2006/2007 maximum immediately followed a lesser flood event in September 2006. As a result of this previous event the system would have been close to saturation with little storage available to dampen the effects of subsequent rainfall events. In contrast the 2007/2008 flood event followed an extended dry period and so the drainage capacity of the flow systems would not necessarily have been operating at full capacity and a portion of effective recharge would have been taken up as storage within the system.

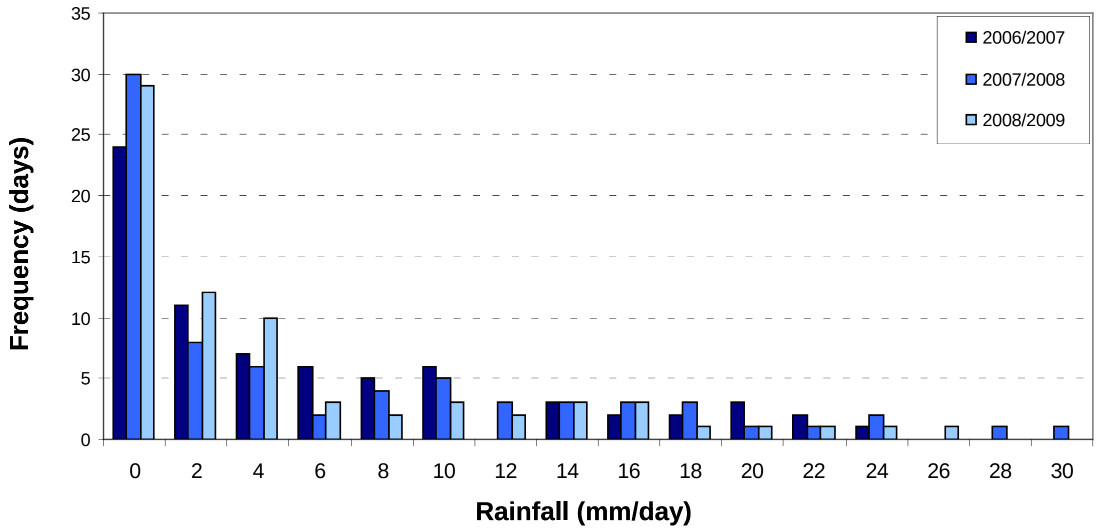


Figure 3.21 Daily rainfall frequency distribution for Roscommon rainfall station during major 2006/2007, 2007/2008 and 2008/2009 flooding events

3.4.2.3 Area

While sites showing the greatest depth generally corresponded to the largest turloughs volumetrically, a different set of sites showed the greatest flooded area (Fig. 3.22). Flooded area is a reflection of turlough basin topography and geomorphology, with the highest areas shown by those turloughs located in shallow expansive basins. The largest recorded area over the monitoring period was that of Knockaunroe, located in the Burren, Co. Clare, which covered almost 80 ha at its peak with an average depth of 2.34 m. Another Burren turlough, Lough Aleenaun, accounted for the smallest at only 13.7 ha. Here for the first time the turloughs of the Gort – Kinvarra chain are not the extreme case with Blackrock, the turlough considerably the largest in terms of depth and volume, ranking only fifth in terms of area.

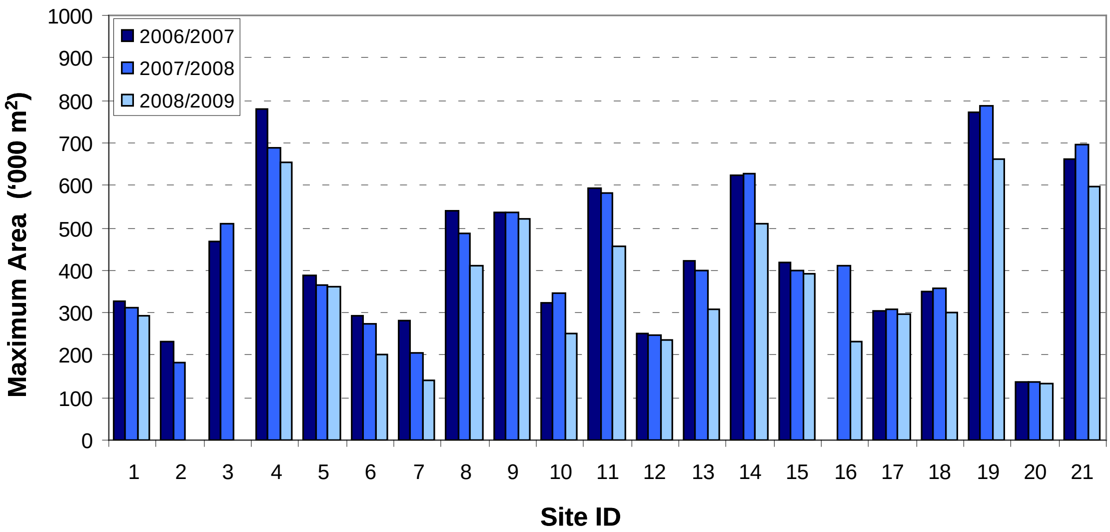


Figure 3.22 Maximum turlough flooded area recorded during the 2006/2007, 2007/2008 and 2008/2009 hydrological years

While area may seem the least important of the hydrological variables, it can be a controlling factor in terms of mixing, evaporation, direct rainfall, nutrient release and ecological disturbance. Shallow expansive turloughs are more likely to be completely mixed than smaller deeper sites as a greater surface area per unit volume is exposed to wind which induces turbulence in the water column as it drags across the water surface. A greater area potentially means higher levels of evaporation and direct rainfall, both important in the interpretation of stable isotope and water chemistry data. Turloughs covering large areas may also be more susceptible to nutrient release from subsoils, particularly those with a low average depth. The rate at which flooding expands or recedes is important for ecological communities. This can be a controlling factor for aquatic invertebrates as some species are not mobile enough to adapt to rapidly fluctuating conditions, and so the rate of areal change can be a limiting factor in community composition (e.g. aquatic invertebrates; see *Chapter 8: Aquatic Invertebrate Communities*).

3.4.3 Temporal Variability

Annual changes in precipitation will generate different responses in terms of timing, duration and frequency of turlough flooding. Significant yearly differences in maximum flood level could result in shifting boundaries between vegetation communities, as variable levels of disturbance are experienced by ecological communities in the upper reaches of turlough basins. The temporal variability of hydrological parameters was compared using the ratio of highest to lowest yearly maxima across the monitoring period (Fig. 3.23). Statistics for the maximum flood depth, volume and area are given in table 3.4. Volume was found to show the greatest variation between years with an average ratio of 1.67, meaning the highest recorded volume was 1.67 times greater than the lowest.

The three Roscommon turloughs, Rathnalulleagh, Carrowreagh and Brierfield, showed the greatest degree of yearly variation with the volume in Carrowreagh turlough reducing by a factor of over 3.5 between the inundation periods of 2006/2007 and 2008/2009. The mean area variability ratio was 1.26, while depth of flooding was the most stable parameter across the monitoring period with a mean ratio of 1.2. When the geomorphology and topography of turlough basins is considered, depth would intuitively be the least variable parameter. As depth of flooding increases the volume of water (and associated rainfall) required for each incremental rise in depth becomes greater, as shown in the stage / volume / area relationships (Naughton, 2011). Therefore while the difference in maximum flood levels may be small in terms of the overall flood depth, the increase in volume associated with this difference is proportionally much greater.

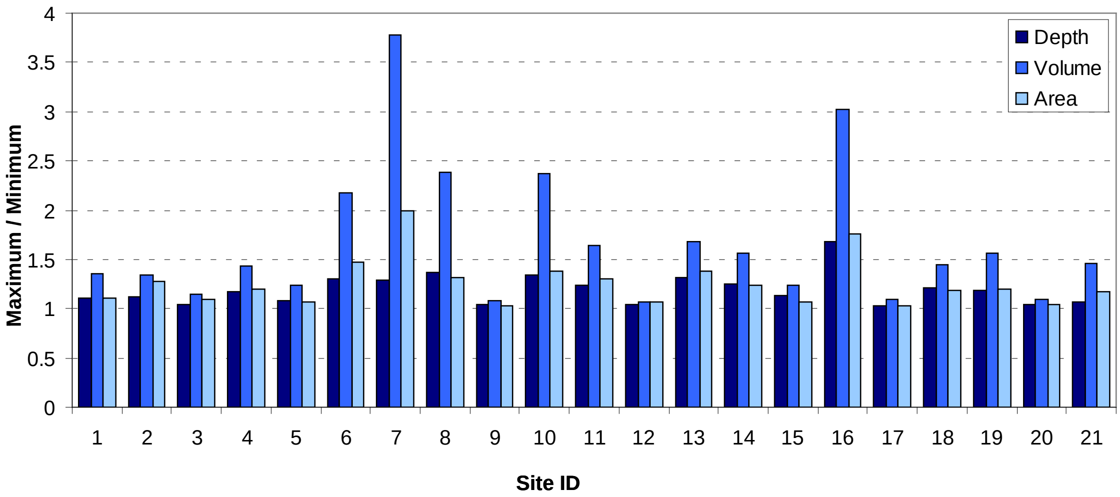


Figure 3.23 Ratio of highest to lowest yearly maximum for depth, volume and area for 21 study sites

Table 3.4 Ratio of highest to lowest yearly maxima for hydrological parameters of depth, volume and area

Site Name	*Depth*	*Volume*	*Area*
Carrowreagh	1.29	3.77	1.99
Roo West	1.68	3.02	1.76
Brierfield	1.37	2.38	1.32
Caranavoodaun	1.35	2.37	1.38
Rathnalulleagh	1.31	2.17	1.47
Garryland	1.31	1.68	1.37
Blackrock	1.24	1.64	1.3
Knockaunroe	1.19	1.56	1.19
Caherglassaun	1.26	1.56	1.23
Ballinderreen	1.07	1.46	1.17
Lough Gealain	1.21	1.45	1.19
Coolcam	1.17	1.44	1.2
Skealoghan	1.11	1.36	1.11
Ardkill	1.12	1.34	1.28
Croaghill	1.08	1.24	1.07
Termon South	1.14	1.24	1.07
Kilglassaun	1.05	1.14	1.1
Turloughmore	1.03	1.09	1.03
Lough Aleenaun	1.04	1.09	1.04
Lisduff	1.04	1.08	1.03
Lough Coy	1.04	1.07	1.06

Despite the distinct rainfall patterns that occurred within each hydrological year a number of turloughs displayed a remarkably consistent maximum flood extent across the entire monitoring period. The cause of this stability varies between sites. In some cases it is a result of the flooding regime whereas in others topographic features exert control on the flood level. Lough Aleenaun and Turloughmore, for example, have highly flashy flooding regimes, responding rapidly to rainfall events. While the seasonal rainfall pattern may have been different between years, each year incorporated a series of rainfall events of similar magnitude and duration that caused the maximum water level within that year. Thus while the frequency and duration of flooding may have varied depending upon the overall rainfall pattern, the maximum level remained steady. In the case of Lough Coy and Ballinderreen maximum flood levels are limited, artificially via a drainage channel in the case of Ballinderreen and naturally via a connection to an adjoining depression in Lough Coy. The reason for such consistency in Lisduff is unclear, but possibly the presence of an overflow connection to a neighbouring bog serves as a control at high water levels. Alternatively, perhaps at higher levels the flood waters interact with a distinct flow system which can accommodate the excess. The elevation of well established roads and farm buildings bordering the turlough supports the idea of a stable long term maximum flood level and an associated limiting factor to flood extent, as they are only slightly above the recorded maximum level.

3.5 Flow Dynamics

3.5.1 General

Through the analysis of net flows entering and exiting a turlough an insight into their hydrological operation as part of an integrated karst flow system can be gained. Initially the highest recorded average daily net inflow and outflow values were calculated for each site (Table 3.5). The inflow magnitude is indicative of the properties of a turlough's catchment area and flow capacity, while outflow is a function of the drainage capacity of the system. The relative magnitude of inflow and outflow values shows that all turloughs have the ability to fill significantly faster than they empty, with a maximum average daily inflow / outflow ratio of 2.91. As it is thought to be a lack of capacity or constriction within the system that causes turlough flooding, it is intuitive that maximum inflow values would exceed outflow. Water fed to the turlough via direct rainfall, overland flow and shallow groundwater flow would also serve to further increase the divergence between the recorded flow maxima.

Blackrock turlough showed the greatest average daily inflow of over 10 m^3/s which equates to an increase in volume of around 886000 m^3 in a single day, a figure greater than the maximum volume recorded in the majority of the other study sites. This inflow is also approximately 8 times higher than the maximum inflow in neighbouring Lough Coy. The main reason for this difference is the form of the connection between turlough and karst system. Blackrock and Lough Coy lie along the same conduit system which is fed by the predominantly allogenic Owenshree River running off the sandstone Slieve Aughty Mountains. At high flow rates the capacity of the conduit system flowing beneath Blackrock is exceeded causing the Owenshree River to discharge directly into the turlough. This does not occur in Lough Coy, which is isolated from any surface water inputs and solely fed via an estavelle joining the underlying conduit system. Therefore flow from the river which cannot be accommodated within the conduit, and thus cannot fill Lough Coy, can enter Blackrock directly causing the extremely high volume increase shown. A comparison of inflow/outflow ratio supports this, with Blackrock showing a ratio of over 5 while the Lough Coy ratio is only 1.58, as in Coy most flood waters enter and exit via connections to the conduit system.

Table 3.5 Maximum average daily net inflow and outflows, inflow: outflow ratio and inflow and outflow as a percentage of maximum volume for study sites

Site Name	*Site ID*	*Average Daily Inflow (m^3/s)*	*Average Daily Outflow (m^3/s)*	*Inflow / Outflow*	*Daily Inflow / Volume (%)*	*Daily Outflow / Volume (%)*
Skealoghan	1	0.500	-0.166	3.0	11.3	3.7
Ardkill	2	0.439	-0.086	5.1	5.8	1.1
Kilglassaun	3	1.626	-0.488	3.3	17.4	5.2
Coolcam	4	0.684	-0.193	3.6	3.7	1.1
Croaghill	5	0.496	-0.117	4.3	6.7	1.6
Rathnalulleagh	6	0.461	-0.325	1.4	4.5	3.2
Carrowreagh	7	0.523	-0.214	2.4	8.3	3.4
Brierfield	8	0.380	-0.134	2.8	3.5	1.2
Lisduff	9	0.341	-0.157	2.2	3.8	1.8
Caranavoodaun	10	0.309	-0.162	1.9	5.4	2.8
Blackrock	11	10.253	-2.018	5.1	22.1	4.4
Lough Coy	12	1.331	-0.842	1.6	7.8	4.9
Garryland	13	1.832	-0.626	2.9	6.8	2.3
Caherglassaun	14	2.496	-1.192	2.1	7.2	3.4
Termon South	15	0.254	-0.149	1.7	2.3	1.4
Roo West	16	0.995	-0.275	3.6	8	2.2
Turloughmore	17	1.746	-0.585	3.0	36.2	12.1
Lough Gealain	18	0.844	-0.222	3.8	7.9	2.1
Knockaunroe	19	1.333	-0.582	2.3	6.3	2.8
Lough Aleenaun	20	1.548	-0.555	2.8	37.6	13.5
Ballinderreen	21	0.594	-0.271	2.2	8.7	3.9
Mean				***2.91***	***10.5***	***3.7***
Standard Deviation				***1.05***	***9.9***	***3.3***

The higher flow rates did not consistently correspond to the largest estimated catchment areas (Fig. 3.24), but rather the ability of rainfall to rapidly enter and exit the turlough. The mechanism facilitating these rapid flows varies between sites. In Blackrock it is due to a combination of a major conduit system running beneath the turlough and a river feeding allogenic recharge directly into the turlough. The river and conduit system is capable of supplying water in large quantities following rainfall events due to the large catchment area. This catchment is comprised of steep sided, relatively impermeable bedrock of the Slieve Aughty Mountains. This enables rapid filling of the turlough, while the conduit system has sufficient capacity to drain this water with comparable speed following the cessation of rainfall. On a much smaller scale are the turloughs Lough Aleenaun and Turloughmore. In this case both turloughs are located in the Burren, an area of thin or absent soil cover which allows rainfall to enter the karst system almost immediately. Coupled with this both turloughs lie at the foot of steep hills which provides a high hydraulic gradient allowing rapid flow into the turloughs. The relative capacity of the outflow system is also extremely high, higher even than that of Blackrock, resulting in a hydrological regime characterised by frequent, distinct flood events.

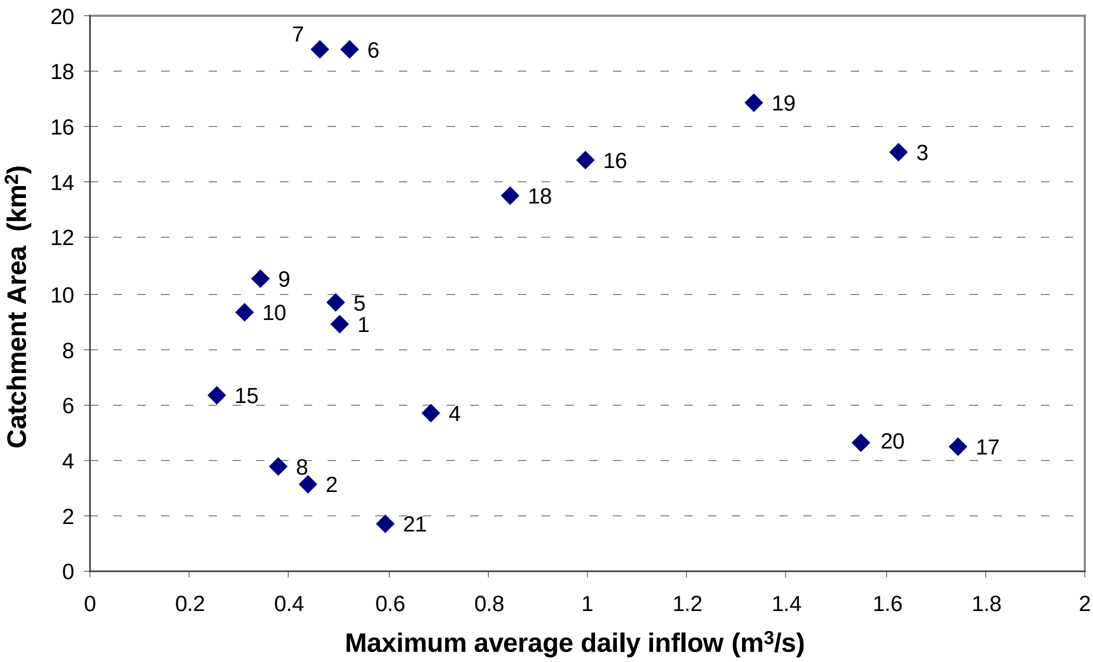


Figure 3.24 Plot of maximum average daily inflow against estimated catchment area for 17 monitoring sites

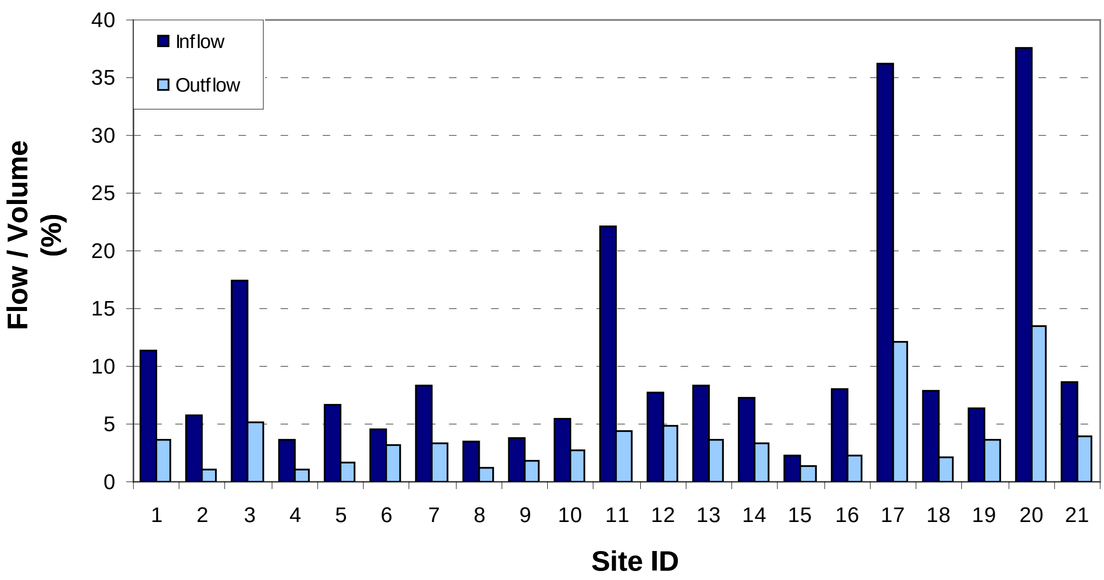


Figure 3.25 Ratio of maximum Inflow/ volume and maximum outflow/ volume for monitoring sites

To illustrate the relative scale of turlough flows, the maximum inflow and outflow values were calculated as a percentage of highest recorded volume over the monitoring period (Table 3.5, Fig. 3.25). Inflow ratios range from 2.3 to 37.6% while outflows were 1.1 to 13.5%. The ratios further demonstrate the continuum of temporal flooding behaviour from slow to fast. The lowest ratios are shown by those sites characterised by low frequency, long duration flooding with ratios increasing through intermediately responsive sites up to the flashy multimodal flooding regime of Lough Aleenaun.

The lowest inflow ratio was shown by Termon turlough, Co. Galway. The hydrograph of Termon reflects this with a longer than average filling period and maximum water level between 35 to 55 days later than the average across the study sites. The characteristic extended recession of Termon is also represented here with a low outflow/maximum volume percentage of 1.4%, which signifies that, even at maximum recorded outflow capacity, it would take 75 days for the turlough to empty. The hydrographs of other turloughs with similarly low outflow / volume percentages, such as Coolcam and Brierfield, also show lengthy recession limbs and corresponding long duration of flooding.

The inflow and outflow figures of Turloughmore (site 17) and Lough Aleenaun (site 20) are the most significant in terms of overall maximum volume. The highest daily increases of 150780 m^3 in Turloughmore and 133747 m^3 in Lough Aleenaun represent 36.2% and 37.6% of the total maximum recorded volume in each turlough. The corresponding outflow percentages of 12.1% and 13.5% are also the highest recorded within the study sites. As a result of this behaviour both sites show a highly fluctuating regime with numerous filling and emptying events. Lough Aleenaun was the archetypal example of this with 16 distinct flood events recorded during the monitoring period.

3.5.2 Inflow Analysis

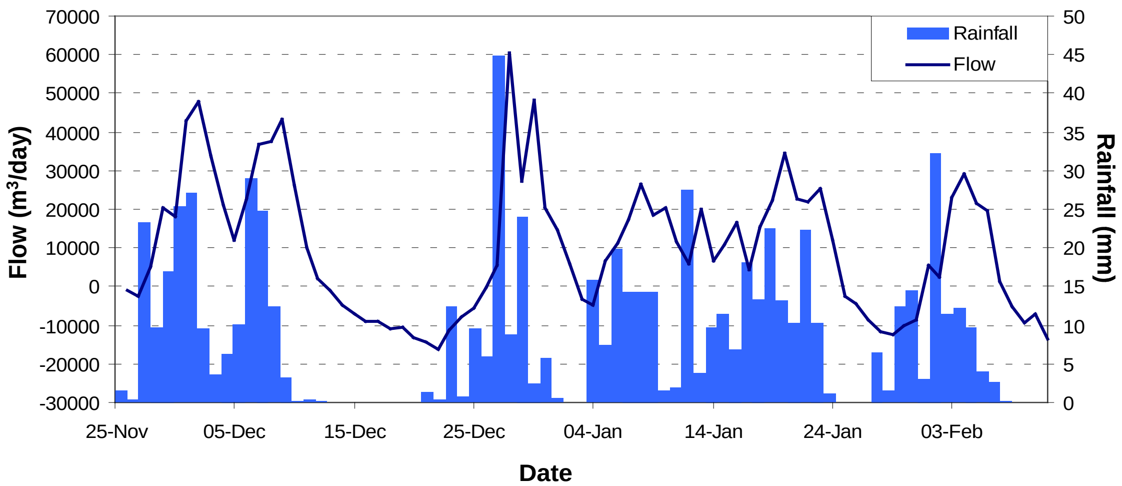


Figure 3.26 Plot of flow and rainfall for rising limb of volume hydrograph during 2007/2008 main flood event, Lough Gealain turlough, Co. Clare

To investigate the filling characteristics of turloughs and the link with rainfall in more detail, a subset of ten turloughs were selected representing the full range of hydrological regimes and spatial distribution of the study sites. As many turloughs showed comparable volume hydrographs and therefore similar inflow behaviour, particularly neighbouring sites such as Lough Gealain and Knockaunroe, a subset was chosen to avoid repetition of analysis in the initial stage of the investigation. The volume time series representing the main flood event during the 2007/2008 hydrological year and the corresponding precipitation time series from the nearest rainfall station were collated for all sites. The rising limb of the volume hydrograph was isolated within the time series and net daily flow rates calculated for each daily time step. A plot of flow and rainfall for the period from the onset of flooding until the highest volume recorded during the 2007/2008 hydrological year shows the general turlough flow behaviour and response to rainfall (Fig. 3.26).

As would be expected given the variations in turlough size and hydrological behaviour, the magnitude of inflow varied substantially but there were similarities in inflow behaviour between turloughs in the same geographical area (Fig. 3.27). Seven of the sites showed maximum average daily inflows of a similar scale in the range of 0.24 to 0.42 m^3/s, although the duration that the higher flow rates were sustained for was highly variable. No clear relationship existed between estimated catchment area and maximum net inflow, illustrating the dependence of inflow on properties other than the catchment area such as catchment gradient, flow system type, degree of karstification, and the nature of the connection between flow system and turlough.

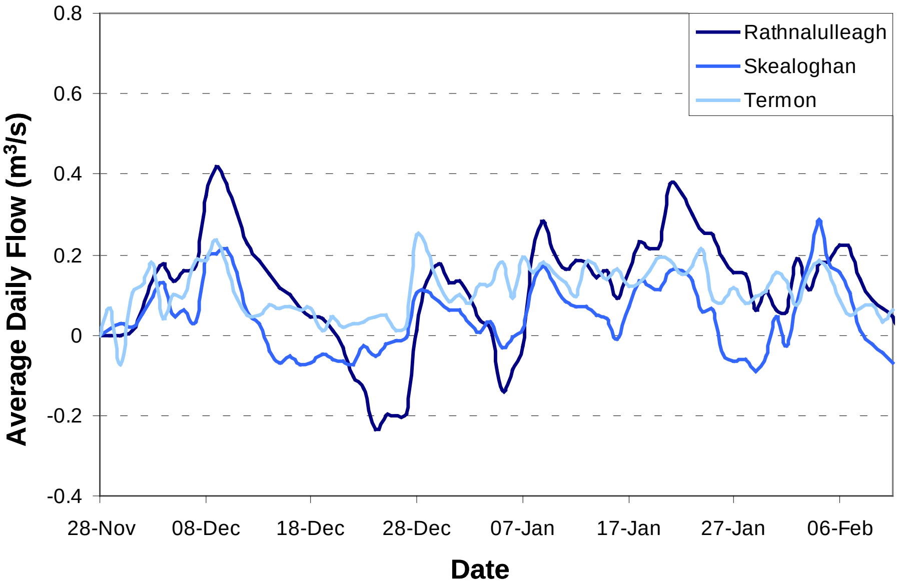


Figure 3.27 Average daily flow for three turloughs following the onset of flooding in 2007

The remaining three sites, Lough Coy, Turloughmore and Lough Gealain, showed larger flow rates of up to 1.74 m^3/s (Fig. 3.28). Turloughmore shows the highest net inflows but these were sustained only for a very short period. Of these three sites it has by far the smallest catchment, so there is insufficient area from which to derive recharge compared to the other two sites. However, the steepness of the catchment and the heavily karstified nature of the area allow a recharge and runoff rate sufficiently high enough to produce flows of comparable scale, which take the form of pulses of rainfall passing quickly through the system temporarily routed through the turlough. In comparison, Lough Coy did not reach the same maximum values but is able to maintain high inflows for a longer duration due to the greater catchment area drained by the karstic conduit system to which the turlough is linked.

An inconsistency can be seen after the 5th of January in Lough Coy where little or no flow appears to occur, compared to the highly fluctuating flows of the other two sites. This discrepancy is due to the interaction of Lough Coy with an adjoining basin at high stages. When the turlough reaches a threshold level it overflows across into an adjacent depression, limiting the maximum water level and causing an apparent flow cessation in the hydrological record. The exact role this additional storage plays in the hydrological regime of Lough Coy is unknown but is focus of ongoing research.

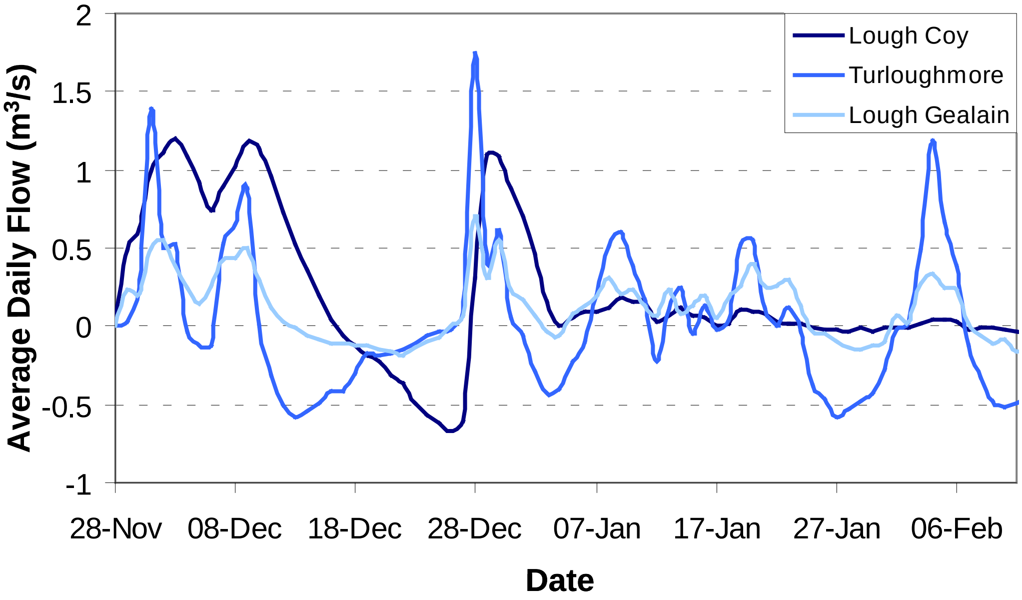


Figure 3.28 Average daily flow for Lough Coy, Turloughmore and Lough Gealain following the onset of flooding in 2007

3.5.2.1 Flow Transition

The turloughs within the analysis subset were highly variable in terms of their temporal flow behaviour. The time between the cessation of rainfall and the occurrence of flow transition or change in flow direction is indicative of the underlying karst flow system and was found to have a strong role in determining the characteristic hydrological regime of a turlough. While a few maintained a net inflow for most or all of the monitoring period, most sites fluctuated from net inflow to net outflow on a number of occasions in response to the prevailing rainfall conditions. The number of days of net inflow and net outflow recorded at the sites for the period 1/12/2007 to 31/1/2008 is shown in figure 3.29. This interval was chosen as it covered the major net inflow period between the flooding onset and maximum water levels for all sites, and so allowed the comparison of filling behaviour across a range of sites and in response to the same general rainfall signal. Taking into account local differences in rainfall, this reveals the general trend in transition time from inflow to outflow. Sites where this occurs quickly, such as Turloughmore and Skealoghan, have a higher frequency of flooding and the capacity of the flow system is high relative to the volume stored within the turlough. Sites where this occurred at a slower rate, such as Lisduff and Termon, were characterised by much longer duration, low frequency flooding and so represented a lower disturbance environment.

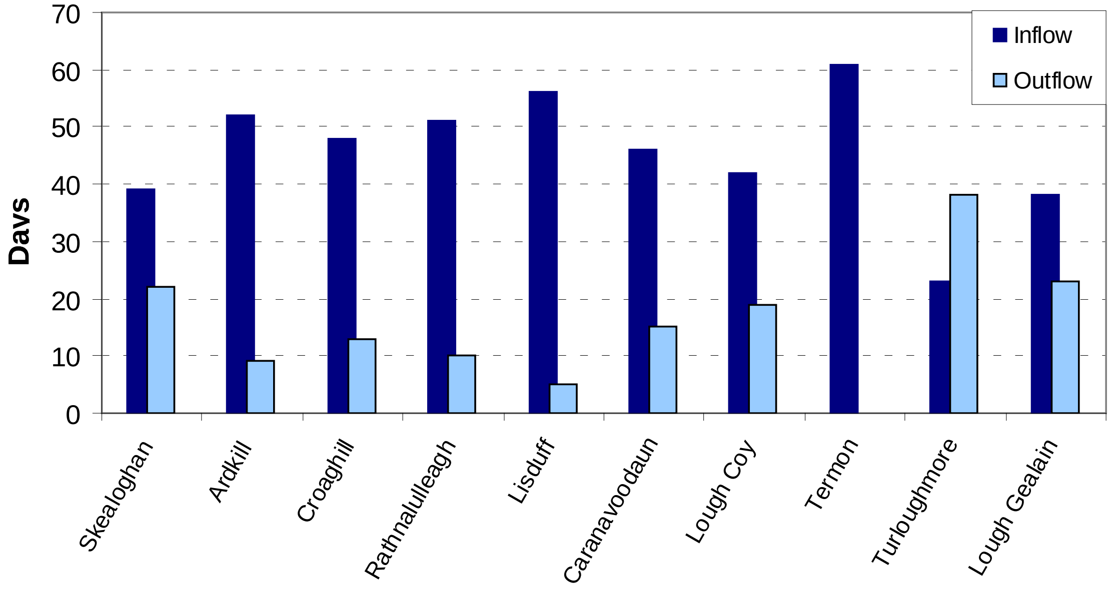


Figure 3.29 Number of days of net inflow and net outflow for flow analysis subset during the period 1/12/2007 to 31/1/2008

However, the duration of each flow type does not fully reflect the overall flow behaviour as there was a disparity between number of outflow days and the relative magnitude of the outflow during the analysis period, with some sites reaching far greater net outflows than others as demonstrated by the inflow to outflow ratios (Fig. 3.30). Despite Turloughmore experiencing a net outflow for 15 days more than a net inflow, the volumes over this period are approximately equal with a ratio of 1:1. Both Ardkill and Rathnalulleagh showed the same inflow and outflow durations, though the greater outflow capacity of Rathnalulleagh results in a ratio of 6:1 compared to only 18:1 in Ardkill.

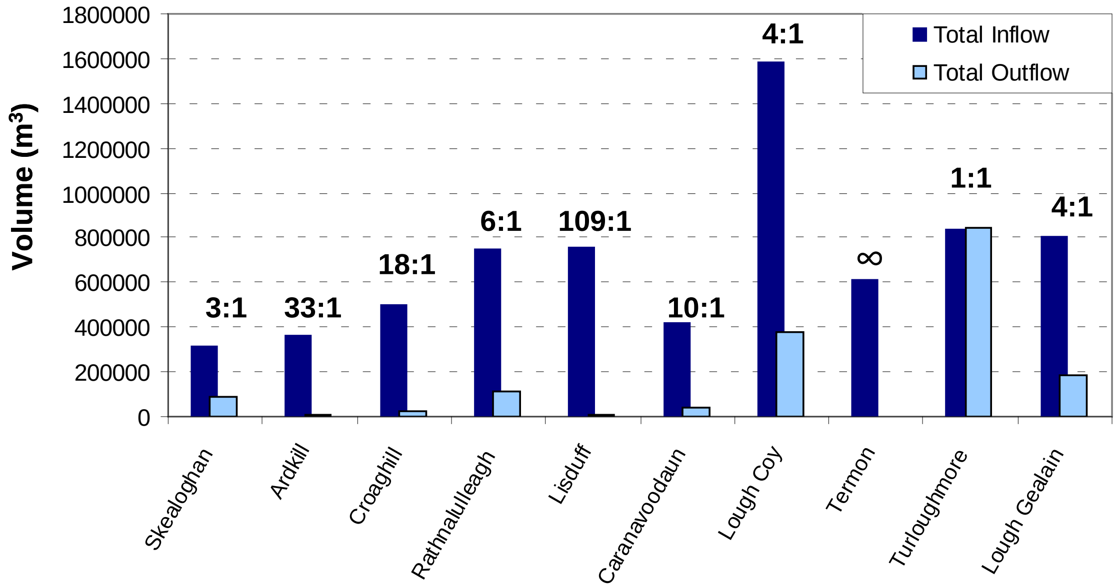


Figure 3.30 Sum of daily net inflow and net outflow including inflow: outflow ratio for flow analysis subset during the period 1/12/2007 to 31/1/2008

The effect of differences in flow behaviour is clearly demonstrated by comparing the net flows in the geographically close turloughs of Skealoghan and Ardkill (Fig. 3.31). Despite the estimated zone of contribution for Skealoghan being twice that of Ardkill, the two turloughs show remarkably similar inflow characteristics in terms of quantity and timing with coincident net inflow peaks occurring in both series. The major difference in flow behaviour occurs following the cessation of rainfall and the subsequent transition to net outflow. Skealoghan shows a much shorter transition time and displays a net outflow for 25 days of the analysis period, reaching a maximum average net outflow of 0.087 m^3/s. This compares with only 12 days of net outflow in Ardkill, and a maximum outflow of 0.027 m^3/day which equates to less than a third of that shown in Skealoghan. The cumulative effect of this, as shown in the lower plot, is a volume approximately 150000 m^3 greater in Ardkill than in Skealoghan at the end of the analysis period. This "easier" drainage for Skealoghan makes sense as it helps to offset the effect of a larger catchment area, i.e. if its drainage characteristics were similar to Ardkill, then the inflow characteristics would presumably not be so similar.

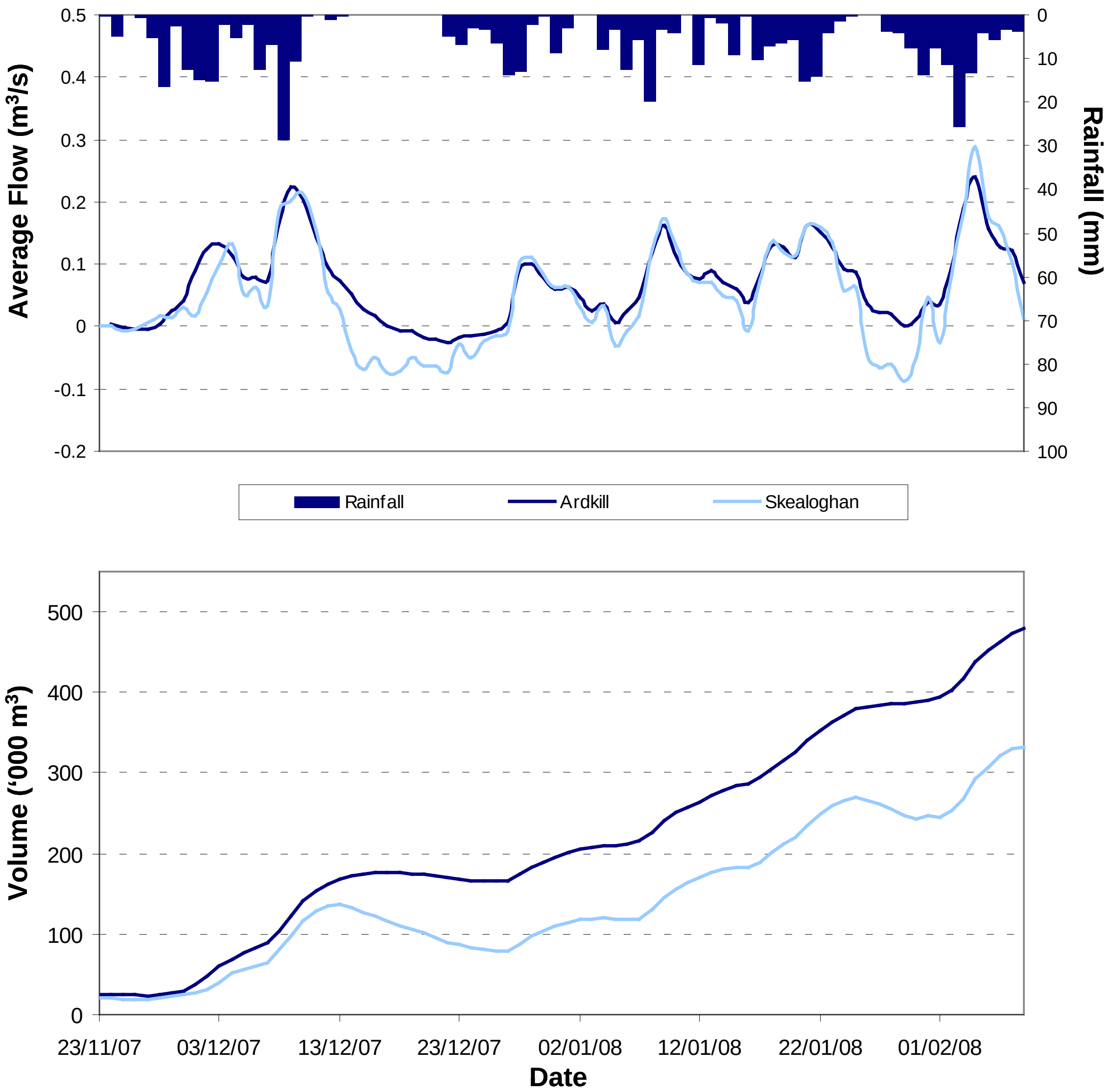


Figure 3.31 Net flow and volume for Skealoghan and Ardkill turloughs, Co. Mayo

Another interesting feature of the flow hydrograph is the behaviour of Skealoghan during the significant recession period in mid December 2007. Following the cessation of rainfall the net flow rate decreased, eventually reversing direction and becoming a net outflow. The net outflow rate then appears to plateau at approximately -0.07m^3/s. This behaviour was repeated in other turloughs that experienced significant recessions during the analysis period, and potentially points to a characteristic maximum outflow capacity limiting the recession and is further investigated later.

3.5.2.2 Inflow and Rainfall

The inflow time series and corresponding precipitation time series from the nearest rainfall station during the analysis period were collated for all sites. Plots of net inflow clearly show a strong relationship between net inflow and rainfall, with peaks in the inflow time series in evidence after each major rainfall event (Fig. 3.32). When rainfall ceased, the net inflow dropped eventually transitioning to a net outflow following sufficiently long dry spells. The time for this transition to occur differed greatly between the sites. Generally the highest inflows coincided with the greatest magnitude rainfall event, but this was not always the case. The rainfall–inflow relationship displayed a cumulative effect where high inflow rates were generated by a series of consecutive lower intensity rainfall events. Another factor affecting the association between rainfall and inflow was the preceding flow conditions. The flow response shown by turloughs to similar magnitude rainfall events was less following a recession period than following a prolonged filling period. It was also apparent that the length of the recession had an effect upon the level of inflow, with longer recessions further damping the inflow response.

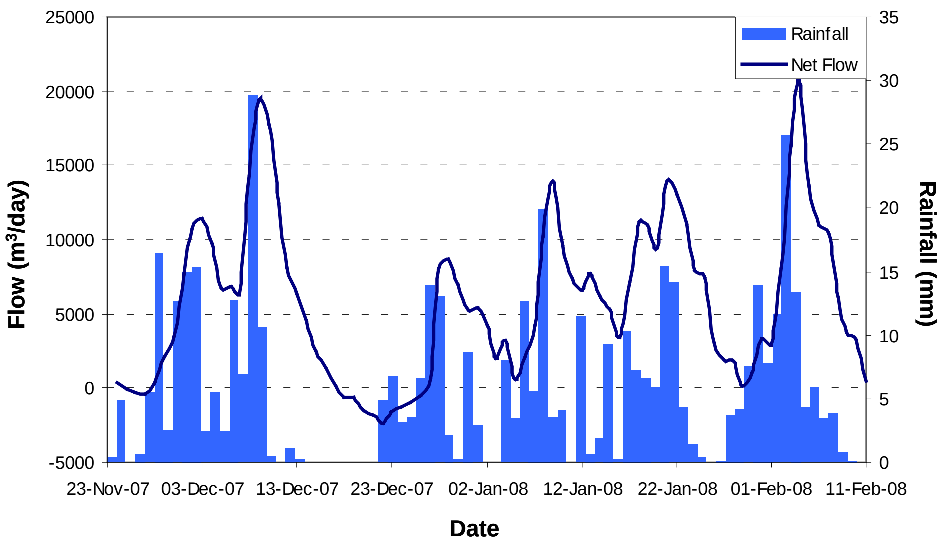


Figure 3.32 Plot of average daily flow and rainfall for rising limb of volume hydrograph during 2007/2008 main flood event for Ardkill, Co. Mayo

A clear delay can be seen between the rainfall event itself and the corresponding maximum inflow. This would be expected as it would take some time for rainfall-derived recharge to enter the karst system and thereafter the turlough. Time-lagged correlation was used to quantify the length of this delay for each turlough, whereby net flow values were correlated with rainfall offset by varying intervals; the lag corresponding to the maximum correlation coefficient was thus identified (Table 3.6). A number of individual lags were also checked manually and found to match those indicated by those of the time-lagged correlation. The delay, ranging from 1 to 3 days, showed little difference between sites and was not related to overall turlough hydrological regime, as turloughs with radically different flood durations and frequencies showed identical lag.

Table 3.6 Maximum inflow, time-lagged correlation coefficients and lag for flow – rainfall analysis

Site Name	*Site ID*	*Lag (days)*	*Lag Correlation*	*Averaging Interval n (days)*	*Interval Correlation*
Skealoghan	1	2	0.64	5	0.84
Ardkill	2	2	0.62	6	0.87
Kilglassaun	3	1	0.41	6	0.59
Coolcam	4	3	0.51	7	0.74
Croaghill	5	2	0.65	6	0.80
Rathnalulleagh	6	2	0.43	9	0.73
Carrowreagh	7	2	0.49	4	0.71
Brierfield	8	2	0.46	7	0.76
Lisduff	9	2	0.34	7	0.75
Caranavoodaun	10	3	0.56	9	0.67
Blackrock	11	1	0.67	3	0.74
Lough Coy	12	2	0.36	8	0.76
Garryland	13	3	0.56	8	0.79
Caherglassaun	14	1	0.59	6	0.72
Termon	15	1	0.67	7	0.73
Roo West	16	3	0.59	6	0.74
Turloughmore	17	1	0.76	4	0.79
Lough Gealain	18	1	0.78	5	0.89
Knockaunroe	19	3	0.69	7	0.88
Lough Aleenaun	20	1	0.80	3	0.77
Ballinderreen	21	1	0.54	3	0.67

The level of correlation could be improved by using average rather than time-lagged rainfall (Table 3.6). Average rainfall at time t, AR_t, is given by:

$$AR_t = \frac{\sum_{i=0}^{n} R_{t-i}}{n}$$

Where n is the averaging interval, is the number of preceding days rainfall is averaged over. Correlation was found to increase to a maximum after between four and nine days and then drop off, as shown for example in Ardkill turlough (Fig. 3.33). The averaging intervals corresponding to maximum correlation are given in table 3.6. The process of averaging rainfall is in effect applying an instantaneous unit hydrograph to the rainfall data, where the length of the unit hydrograph is defined by the interval with the highest correlation coefficient and an equal weight of 1/interval is applied to each ordinate of the hydrograph. The applicability of unit hydrographs for generating inflow from rainfall records shown here is further developed in the turlough modelling process as described later.

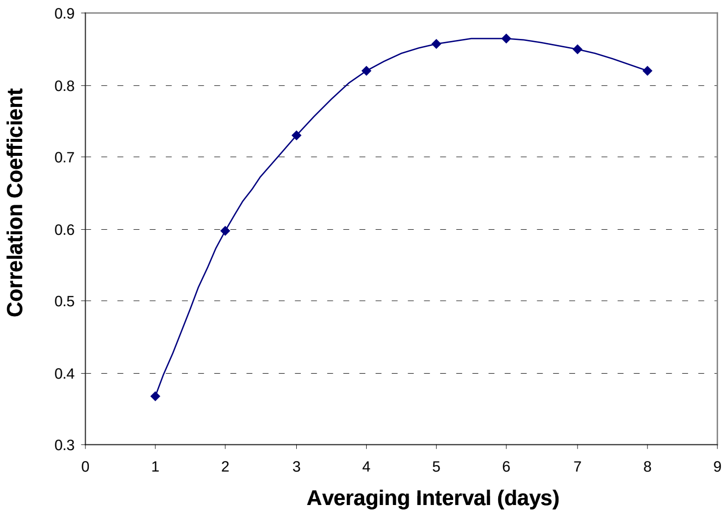


Figure 3.33 Correlation coefficient between inflow and average rainfall over varying averaging periods for Ardkill turlough, Co. Mayo

3.5.2.3 Cumulative Rainfall

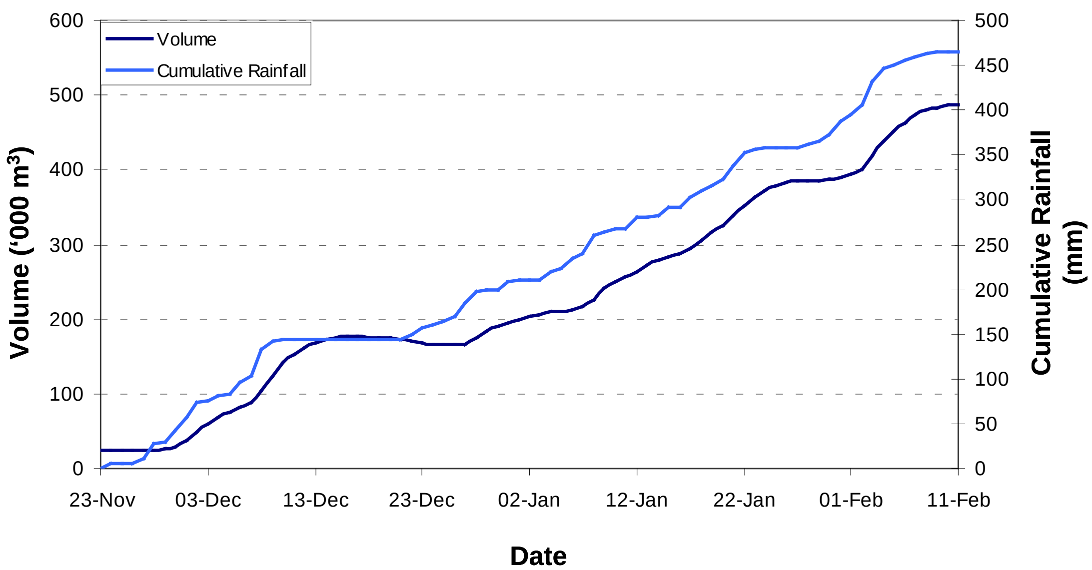


Figure 3.34 Plot of volume and cumulative rainfall for Ardkill turlough, Co. Mayo, for the period 23/11/2007 – 11/2/2008

Given the high correlation identified between rainfall and net inflow, the connection between turlough volume and cumulative rainfall was investigated to quantify this relationship on a level which is less sensitive to small-scale effects and data errors. A plot of cumulative rainfall was generated for each turlough within the subset from onset of flooding to maximum level and compared to corresponding volume data (see example from Ardkill, Fig. 3.34). Where sites displayed a significant recession during the analysis period the longest continuous phase of net inflow was extracted from the dataset and correlated with cumulative rainfall. The inflow duration and correlation coefficients between cumulative rainfall and volume are shown in table 3.7, with all sites in the subset showing high coefficients in excess of 0.95 and the gradient of the recession line denoted as the notional area.

Table 3.7 Correlation coefficients between cumulative rainfall and volume and notional zone of contribution areas for inflow analysis subset

Site Name	*Site ID*	*Inflow Duration (days)*	*Correlation Coefficient*	*Notional Area (km^2)*
Skealoghan	1	19	0.996	1.230
Ardkill	2	81	0.992	1.010
Croaghill	5	48	0.991	1.431
Rathnalulleagh	6	36	0.985	2.412
Lisduff	9	58	0.984	2.643
Caranavoodaun	10	48	0.977	1.383
Lough Coy	12	18	0.954	9.437
Termon	15	81	0.996	1.357
Turloughmore	17	6	0.952	4.603
Lough Gealain	18	21	0.984	1.351

Strong relationships for the longest duration were shown by those sites which maintained a net inflow throughout the analysis period, principally because there was insufficient time between rainfall events to allow flow transition to occur. For example, the plot for Ardkill turlough demonstrates the close match found between time series (Fig. 3.34), with a Pearson correlation coefficient of 0.991. In these sites, characterised by long transition times associated with low outflow capacity, turlough inflow remained approximately proportional to the rainfall intensity over the entire analysis period. In sites which displayed significant recessions during the analysis period, departure from the linear relationship occurred following rainfall cessation, represented by a horizontal line in the cumulative rainfall plot, and also during the onset of flooding immediately after a recession event. After a recession event the effect of rainfall on turlough volume was reduced for a time but regained approximate linearity after a few days. The reasons for this are twofold. Firstly, as shown in the comparison of inflow and rainfall, it takes a number of days for the full effect of a rainfall event to be felt within the turlough due to delays in recharge and transit time through the flow system. Secondly, the drainage of the karst aquifer during recession frees up storage and capacity within the bedrock system which can accommodate a component of subsequent rainfall thus lessening the amount of water passing to storage within the turlough.

One implication of the linear relationship identified between cumulative rainfall and volume is that during inflow periods a unit rainfall causes a unit increase in turlough volume. While the mechanisms and processes involved are inherently non-linear, the high correlations found show that it can be approximated as such for inflow periods. The constant of proportionality between rainfall and represents a notional catchment or contributing area. This constant is essentially the product of a mass balance and gives the absolute minimum area required to account for the recorded volume in the turlough. The actual catchment area will be substantially greater than this, as losses such as evapotranspiration are not accounted for. Also, considering the heterogeneous nature of karst systems, the actual contributing area may vary with changing hydrological conditions both within the catchment and the turlough itself. The strong relationship between cumulative rainfall and volume is expanded upon in the modelling processes detailed later.

3.5.3 Outflow Analysis

The analysis of turlough hydrology during draining or recession periods can yield key information about the nature and capacity of the underlying karst flow system. To elucidate this aspect of turlough behaviour major recession events for each site were studied and all recession information (in the form of days showing an average net outflow) collated and plotted against corresponding stage. A common temporal pattern was identified whereby the net outflow increased during the initial phase of recession as spare drainage capacity in the underlying system became available (Fig. 3.35). In the absence of rainfall, outflow continued to rise to a maximum value, the magnitude of which depended upon the capacity of the individual drainage system.

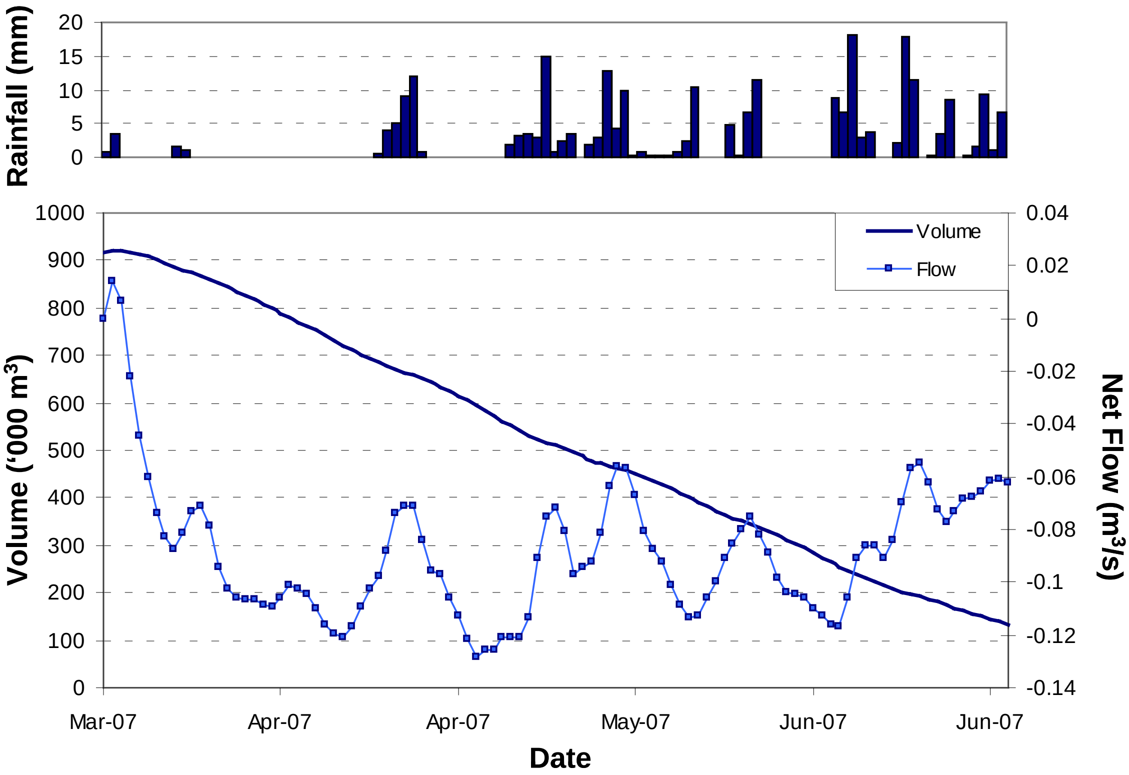


Figure 3.35 Recession volume and flow for Brierfield turlough, Co. Roscommon

The time taken to reach the maximum outflow varied depending upon system outflow capacity and rainfall conditions. Peak outflow was quickly reached in some sites within the first few days of recession which thus enabled the rapid drainage of floodwaters. Other slower responding sites took far longer to reach the maximum discharge. Generally it was found that the higher the outflow capacity, the shorter the delay between onset of recession and peak outflow. Rainfall during the recession period reduces the outflow rate and so delayed the onset of maximum outflow. Rainfall events in figure 3.35 can be seen to clearly correspond with a decrease in net outflow. Significant rainfall reduces the outflow rate by raising the head within the underlying flow system, where the outflow from the turlough is reduced due to a higher proportion of the total drainage capacity of the system being taken up with contribution from the underlying system. The net outflow rate also falls due to inflow entering the turlough directly via rainfall onto the turlough surface and runoff from the immediate surroundings. The relative importance of each element varies between turloughs and is dependent upon the hydrological operation of the turlough, and the nature of the connection between turlough and underlying system.

The nature of the relationship between stage and outflow was derived from stage-discharge plots generated for each site. It was shown that a stage-discharge curve defining a turlough's maximum drainage capacity was formed by the maximum outflow values across the flooding range (Fig. 3.36). This curve defines the characteristic relationship between stage and turlough discharge at peak outflow conditions. During the initial recession phase, turlough outflow increases until it reaches a maximum value on the stage-discharge curve ("Recession Events", Fig. 3.36). Thereafter outflow decreases with falling water level, as would be expected in a reservoir. The underlying assumption here is that points on the stage-discharge curve represent the actual outflow from the turlough. In other words, there is no inflow occurring at this time and so net

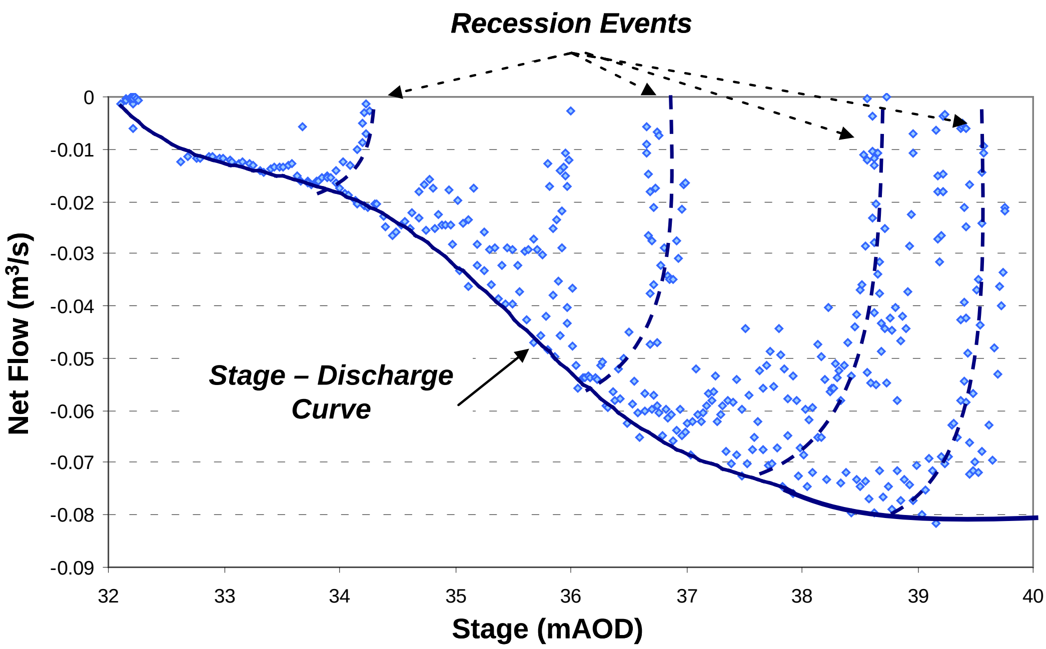


Figure 3.36 Plot of net outflow against stage with indicated stage – discharge curve for Ardkill turlough, Co. Mayo

The majority of outflow values fall short of the maximum as defined by this curve, as shown by the wide scattering of points above the curve in the outflow plots (Fig. 3.36). These points are made up of outflows during two scenarios:

a) Increasing net outflows during the initial recession period when flow is in a state of transition

b) Reduced outflow caused by rainfall events during the recession

The stage-discharge curves of studied turloughs took an array of forms. Most sites showed a continuous smooth curve across most or all of the flood range, such as Turloughmore, Co. Clare (Fig. 3.37 a). Others, such as Skealoghan, Co. Mayo, had a number of discontinuities in the stage-discharge relationship, with distinctive discharge curves applying within different flood ranges (Fig. 3.37 b). This discontinuous behaviour may represent the operation of distinct systems within the turlough basin, with additional outflow capacity available at higher flood levels.

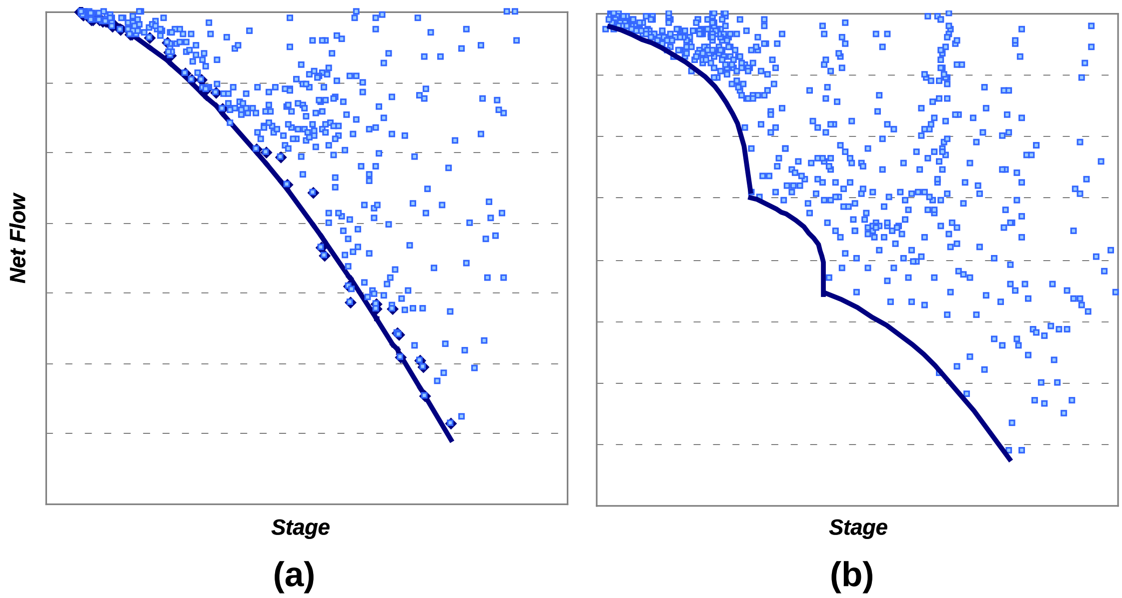


Figure 3.37 Continuous stage – discharge curve of Turloughmore, Co. Clare (a) and discontinuous curve for Skealoghan, Co. Mayo (b)

In such cases a threshold water level is required within the turlough to maintain outflow at the upper maximum capacity. As the water levels fall below this threshold the upper system becomes inaccessible, thus reducing the total outflow capacity available to the turlough and dropping the overall outflow capacity to that of the lower system. Similar behaviour definitely occurs in many turloughs at low water levels, as estavelles located above the base of the depression become isolated from the main water body. Consequently, the estavelles cease to operate as outflow points and the outflow rate drops severely. In some cases, outflow effectively ceases at low flood level leaving a shallow permanent water body at the base of the turlough.

A number of sites showed a maximum outflow capacity independent of water level in the upper range of flooding. Rather than a reduction in outflow with falling head within the turlough, as would be expected in a raised tank draining out through an orifice into the underlying system, the outflow is limited by a single maximum value across a range of stages (Fig. 3.38). This trait is prevalent in turloughs characterised by long duration, low frequency flooding such as Brierfield, Termon and Coolcam.

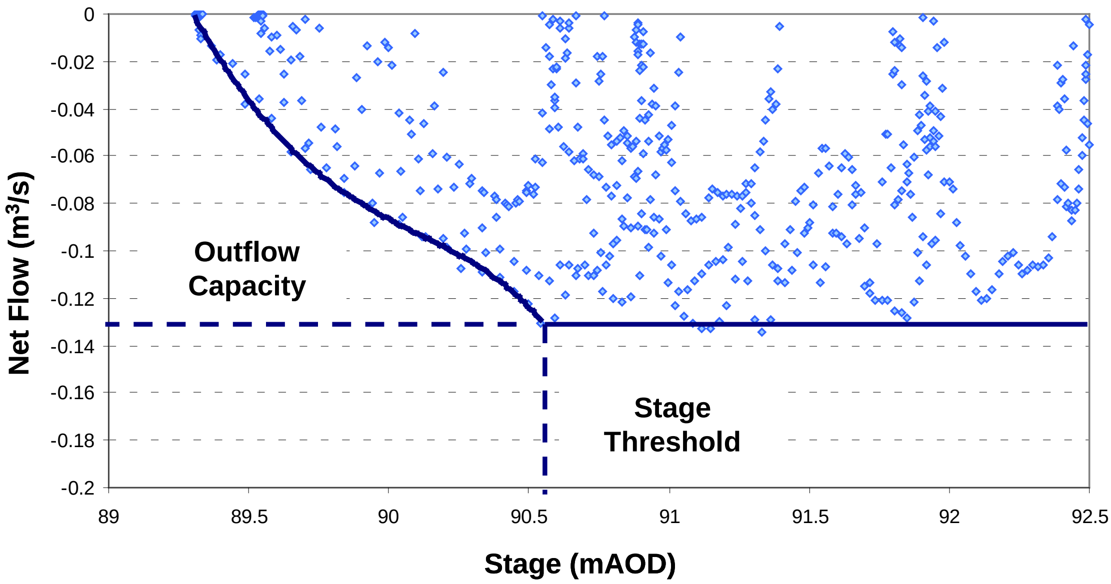


Figure 3.38 Stage – discharge relationship indicating maximum outflow capacity and stage threshold for Brierfield turlough, Co. Roscommon

This constant outflow rate may represent the maximum drainage capacity of the system in equilibrium conditions. When levels fall below the threshold required to maintain outflow at maximum capacity the controlling factor on discharge becomes water level and the turlough is draining more or less freely, where outflow is regulated by the system's discharge orifice. These slower turloughs can be seen to take significantly longer to reach maximum outflow for a given stage, and in many cases there is insufficient time between rainfall events for outflow capacity to be reached. Consequently, turlough outflow operates below capacity for substantial periods of the recession resulting in prolonged flood duration.

In this interpretation, the total capacity of the karst flow system is composed of two elements: catchment flow and turlough flow. The proportion of each element within this total is controlled by their relative heads. During the initial recession phase the underlying catchment flow is preferentially accommodated with a resultant fall in catchment head. Due to this drop, the proportion of turlough flow increases as the recession progresses with the head of both turlough and catchment flow system reaching an equilibrium condition. When this occurs the outflow from the turlough ceases to rise and the proportion of turlough outflow to underlying flow remains stable. When this equilibrium condition is reached while flow is still at system capacity, the discharge from the turlough remains constant (Fig. 3.39 a). When the head had dropped below the threshold required to maintain system capacity, turlough discharge drops in line with the stage-discharge curve. When the recession is of insufficient duration for the equilibrium state to be reached, the outflow from the turlough will increase to a peak before declining with falling head (Fig. 3.39 b).

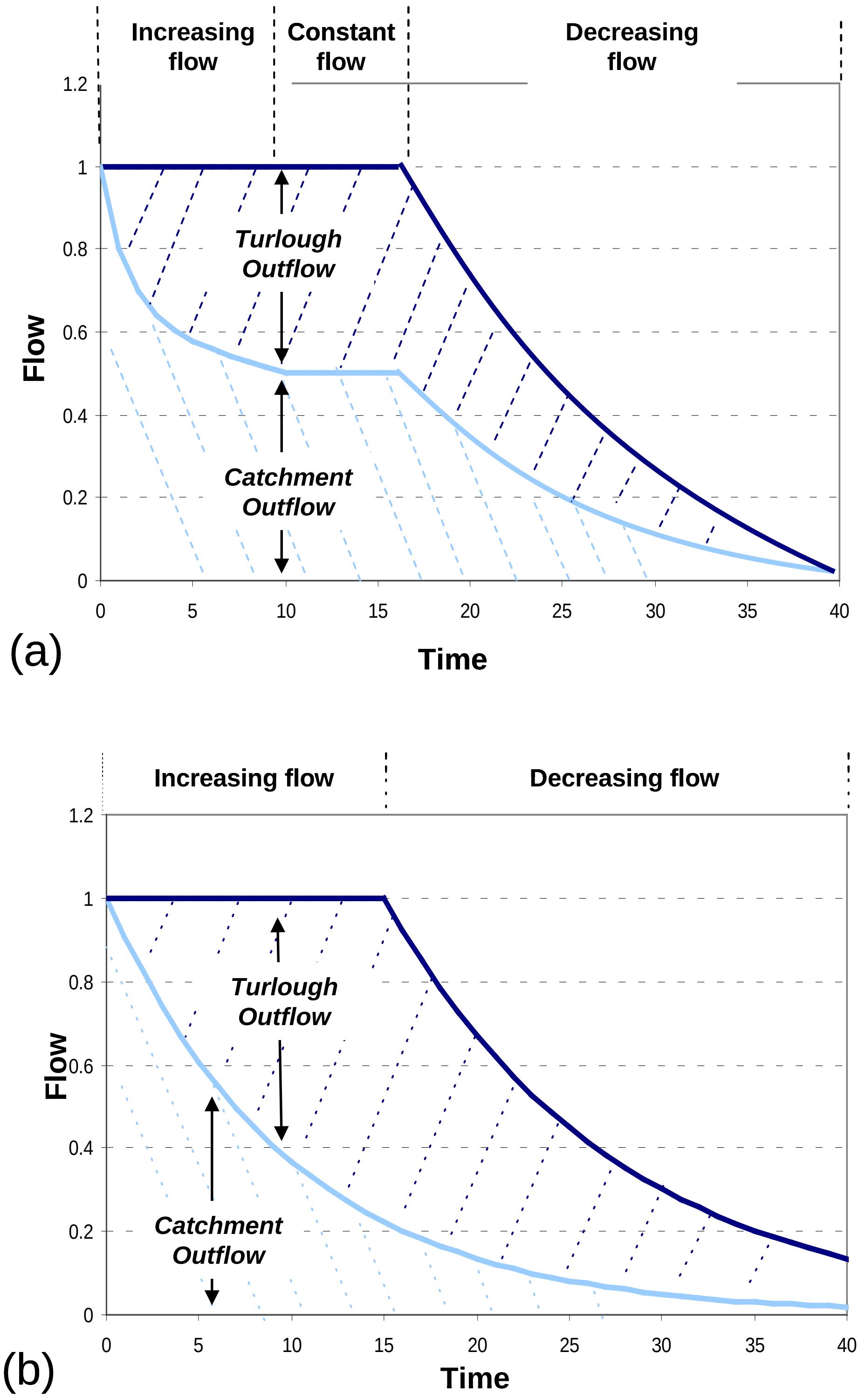


Figure 3.39 Illustration of proportion of flows in underground network during turlough recession for (a) case where system outflow capacity is reached during recession and (b) where system outflow capacity is not reached

The outflow rates of Blackrock turlough, the largest site volumetrically, show a unique stage-discharge relationship as well as an interesting temporal pattern in terms of the highest recorded outflows. Unlike other turloughs, the highest average daily outflows from Blackrock did not coincide with the highest flood levels, but instead occurred in the mid range of flooding, at a stage of around 20 mAOD (Fig. 3.40). Intuitively the greatest outflows would result from one or more of the following scenarios:

– At relatively high flood levels thus providing the maximum head to drive flow from the turlough

– With a high hydraulic gradient between Blackrock and the flow system down gradient, in this case Lough Coy

– Following an extended dry period thus allowing outflow to reach maximum system capacity

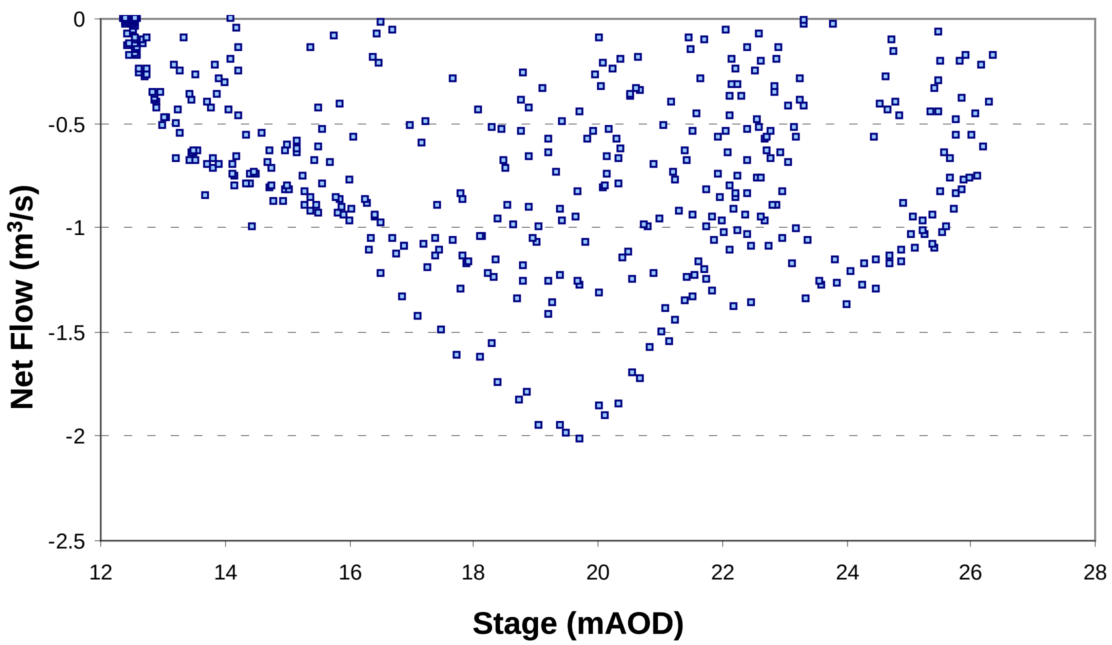


Figure 3.40 Stage-discharge plot for Blackrock turlough, Co. Galway

The stage at which maximum outflow occurred did not correspond with any of these scenarios. Instead the common trait across the three recessions containing the highest recorded outflows is that they follow periods of low or absent levels of flooding. One possible explanation for this is that in the early phase of flooding, significant storage exists lower down the system which is able to accommodate higher outflow quantities from Blackrock. Later in the season, when the system has reached equilibrium, the outflow from Blackrock is limited and does not exceed the threshold of around 1.4 m^3/s. The riverine nature of Blackrock must also be highly influential in determining flow behaviour. Blackrock is the only riverine turlough within the study group, with the Owenshree River discharging directly into the basin at high flood levels. As the highest flood levels coincide with the greatest flow in the river, it may be that the actual outflow from Blackrock is much greater at higher stages than is indicated by the net outflow figures due to continuous, direct inflow from the Owenshree River.

3.5.3.1 Stage-discharge Curve Derivation

The derivation of a stage-discharge relationship is complicated by the occurrence of rainfall events within the recession period. The maximum outflow events were extracted from the outflow dataset and used in the derivation of the stage-discharge curves. The simplest form of the stage-discharge curve is present where turlough outflow changes continuously with stage without any distinct changes in flow behaviour (Fig. 3.41). In this case the stage-discharge relation is comprised of a single curve where the outflow $\boldsymbol{Q}$ is given by the equations:

$$Q = a(H - H_0)^b \qquad \textit{where } Q_0 = 0$$

$$Q = q + a(H - H_0)^b \qquad \textit{where } Q_0 > 0$$

Where:

- $\boldsymbol{Q_0}$ is the outflow at stage H_0 (m^3/s)
- $\boldsymbol{Q}$ is the outflow (m^3/s)
- $\boldsymbol{a}$ is the scaling coefficient
- $\boldsymbol{b}$ is the orifice coefficient
- $\boldsymbol{H}$ is turlough stage (mAOD)
- $\boldsymbol{H_0}$ is turlough base level (mAOD)
- $\boldsymbol{q}$ is the outflow rate at lowest recorded stage (m^3/s)

The additional flow term $\boldsymbol{q}$ is required where the Diver was located slightly above the lowest level within the turlough. In this case there would still be outflow at stage $\boldsymbol{H_0}$, and therefore the stage-discharge curve must to be offset by an amount $\boldsymbol{q}$ during derivation.

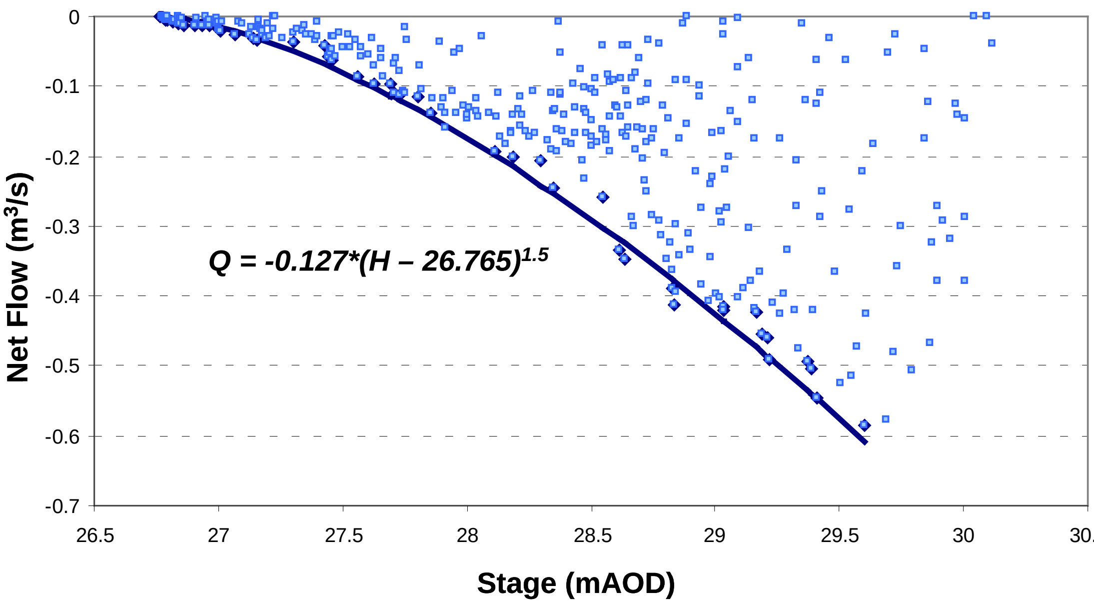


Figure 3.41 Stage-discharge curve for Turloughmore, Co. Clare

The second variation on the stage-discharge relationship is for those sites which display a maximum outflow capacity above a certain stage threshold, but below this have a consistent stage-discharge relationship (Fig. 3.42). Here the stage-discharge relationship consists of two parts covering constant and varying outflow, and the outflow ***Q*** is given by:

For $H < H_t$ **:**
$$\begin{cases} Q = a(H - H_0)^b \\ Q = q + a(H - H_0)^b \end{cases}$$

For $H \geq H_t$ **:**
$$Q = Q_{max}$$

Where:

H_t is the threshold stage above which outflow is at maximum capacity (mAOD)

Q_{max} is the maximum outflow capacity

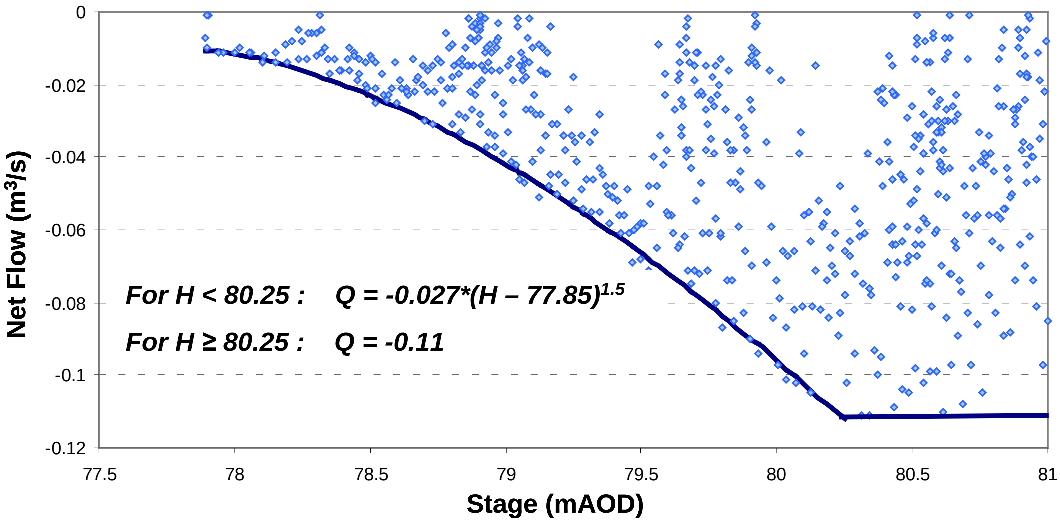


Figure 3.42 Stage-discharge curve for Croaghill turlough, Co. Galway

The final stage-discharge type is for those turloughs which demonstrated differing outflow behaviours with changing stage, either due to the complex interaction and operation of distinct flow systems at different levels within the basin, or the lack of sufficient outflow data to clearly define a continuous relation. In such cases, a number of individual curves were fitted to represent all identifiable outflow behaviours accurately (Fig. 3.43).

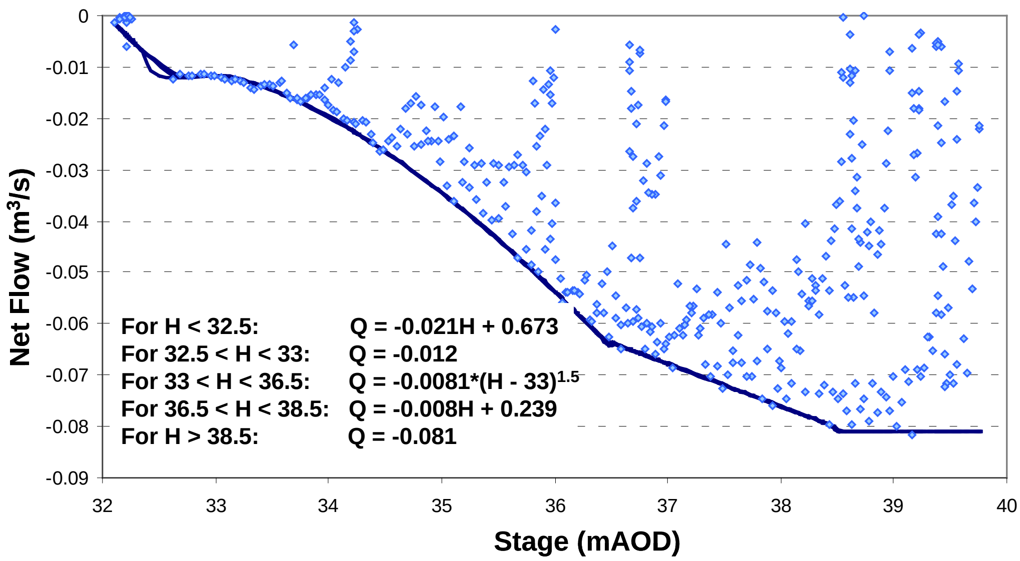


Figure 3.43 Stage-discharge curve for Ardkill turlough, Co. Mayo

3.5.3.2 Recession Approximation

As shown previously, the recession behaviour of turloughs can be a complex one, with different stage-discharge relationships often applicable within different flood ranges. This diversity makes it difficult to directly compare turlough outflow characteristics, or generate a standard metric for quantifying turlough recessions. The most obvious solution to this is to use the maximum drainage capacity or a variant thereof which was identified for the majority of turloughs. The capacity value allows direct comparison between turlough flow systems and, by dividing the maximum recorded volume, it also provides a hydrological indicator for recession duration. This figure represents a notional minimum time it would take for the turlough to drain from full. While this time will obviously be less than the actual recession duration, as flow rates drop at lower stages, it does provide an indicative hydrological indicator for turlough recession for use in the interpretation of ecological data.

To ensure consistency in analysis, and to compensate for the lack of a clearly defined outflow capacity in a number of turloughs, a standard method for deriving a constant turlough recession rate was devised. This method utilised a common feature of turlough volume hydrographs, namely that substantial portions of the recession limb could be approximated with a straight line (Fig. 3.44). This approximation removes many of the small-scale effects shown in the flow records themselves. In turloughs with a high level of outflow constriction, this linear approximation represents the actual recorded capacity outflow rate. In turloughs which do not show a clearly defined maximum capacity, it represents an average flow rate during the phase when outflow shows only a relatively small decrease with falling water level. As flow is defined as dV/dT, the rate of change in volume, the constant flow rate can be derived from the slope of the recession limb of the volume hydrograph (Fig 3.34). Thus, by using linear regression on sections of the volume hydrograph, an average drainage capacity was derived for each turlough.

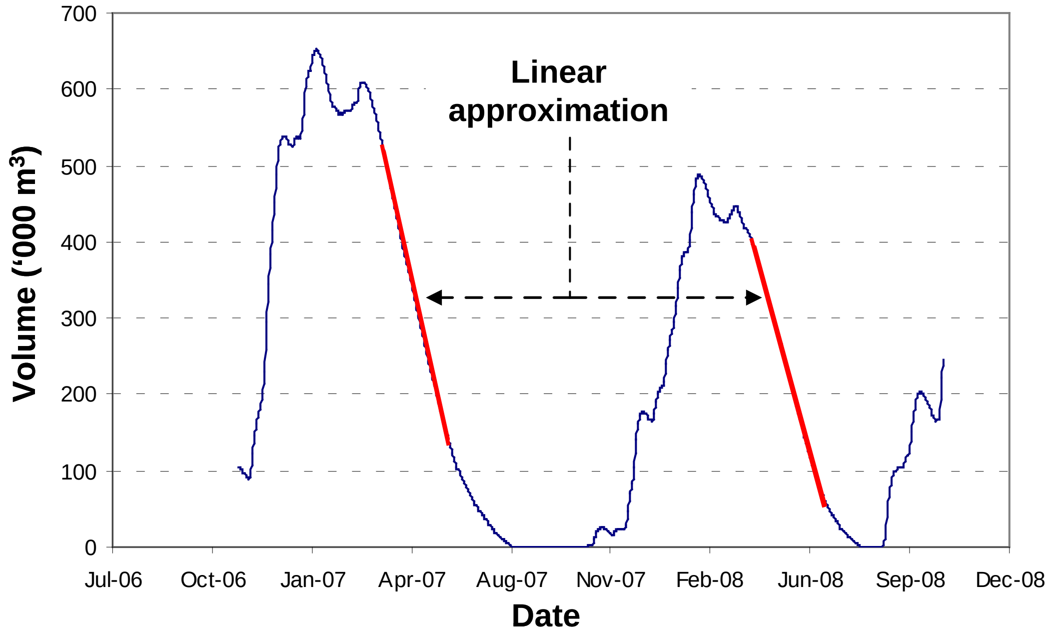


Figure 3.44 Linear approximation of volume recession, Ardkill turlough, Co. Mayo

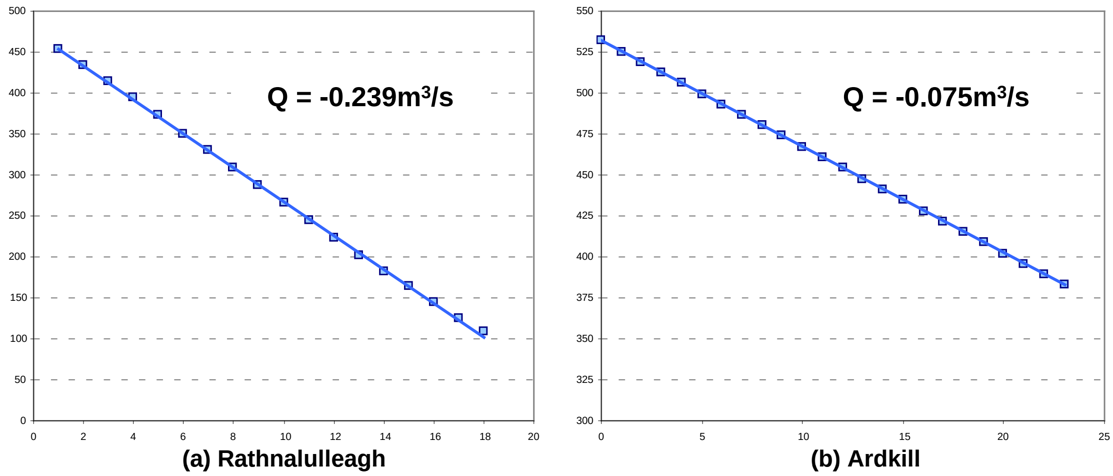


Figure 3.45 Regression analysis of volume recessions for Rathnalulleagh turlough (a) and Ardkill turlough (b)

The notional drainage capacity can be clearly defined only when there is little or no rainfall during the recession period. To limit the effect of rainfall during the recession, regression analysis was carried out on data from mid March to late April 2007, a period where little or no rainfall fell across all study sites. A few fast responding turloughs such as Turloughmore and Lough Aleenaun had fully receded prior this period. In these cases multiple recession events were isolated from the volume time series and regression analysis carried out on all recessions. The highest recorded rate was taken as the maximum recession capacity. R^2 values of at least 0.98 were achieved in all regressions showing the validity of the approximation.

The drainage capacity and recession rates and notional minimum recession durations are shown in figure 3.46. The drainage capacities ranged from 0.070 to 1.152m³/s, with a median value of 0.154 m³/s. These values put turlough outflows far in excess of the majority of recorded Irish karst springs (Drew & Chance, 2007). The mean turlough recession duration was 64.8 days, indicating that on average turloughs could take just over two months to empty at the maximum emptying rate.

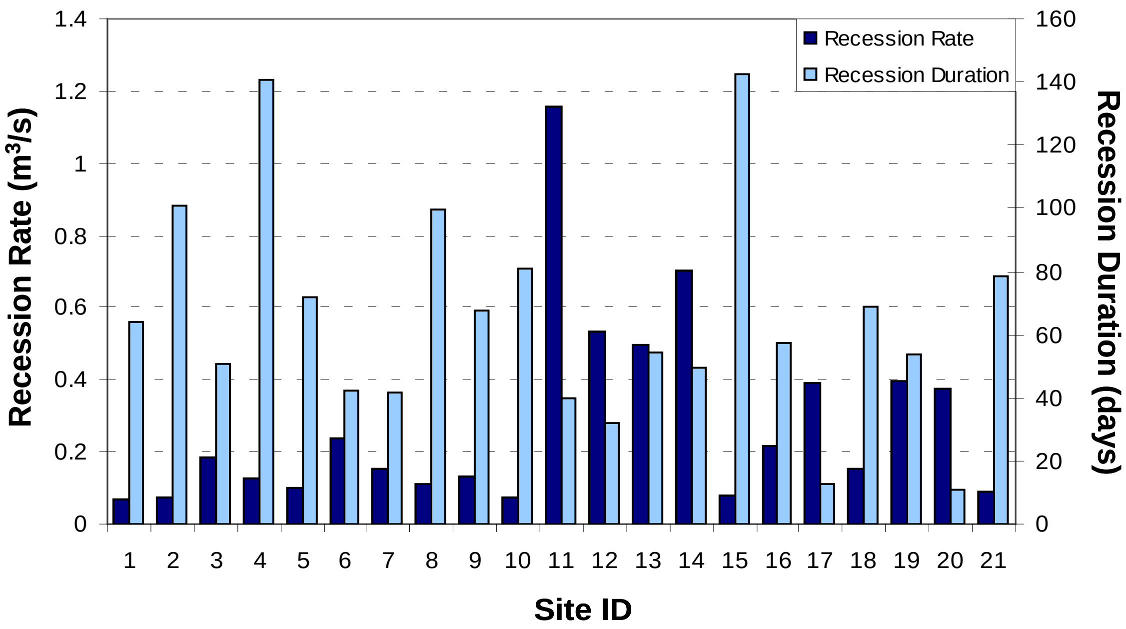


Figure 3.46 Approximated drainage capacity and notional recession duration for 21 monitored turloughs

As found in earlier analysis, the turloughs of the Gort-Kinvarra chain (sites 11 to 14) showed the greatest outflow capacity, accounting for the four highest values. This is thought to be due to a well developed conduit system and its ability to accommodate large flows. Interestingly, Lough Coy displayed lower notional recession duration than Blackrock, despite the fact that Blackrock consistently empties before Lough Coy. This anomaly can be explained by considering the configuration of the flow system, where due to their relative gradients and connection to the underlying conduit system, Blackrock drains preferentially to Lough Coy. This preferential drainage prevents Lough Coy from emptying at a high rate until Blackrock has already dropped significantly, thus causing Blackrock to empty before Lough Coy. As a fraction of overall volume, however, the drainage capacities of Lough Aleenaun and Turloughmore are by far the greatest. This is reflected in the low recession durations of 11 and 12.4 days respectively for these sites (Table 3.8).

Table 3.8 Approximated drainage capacity and recession duration for study sites

Site Name	*Site ID*	*Drainage Capacity (m^3/s)*	*Recession Duration (days)*
Lough Aleenaun	20	0.374	11
Turloughmore	17	0.39	12.4
Lough Coy	12	0.535	32
Blackrock	11	1.156	40.1
Carrowreagh	7	0.152	41.6
Rathnalulleagh	6	0.239	42.4
Caherglassaun	14	0.701	49.5
Kilglassaun	3	0.185	50.7
Knockaunroe	19	0.396	53.8
Garryland	13	0.496	54.4
Roo West	16	0.218	57.3
Skealoghan	1	0.069	64.1
Lisduff	9	0.132	67.5
Lough Gealain	18	0.154	69.1
Croaghill	5	0.103	71.8
Ballinderreen	21	0.088	78.3
Caranavoodaun	10	0.072	80.7
Brierfield	8	0.109	99.4
Ardkill	2	0.075	100.6
Coolcam	4	0.129	140.9
Termon	15	0.078	142.5

3.5.4 Indirect Flow Estimation

Flows calculated based on volume time series give the net flow rates rather than actual flows, although depending upon the modus operandi of the flow system these may be one and the same. The direct measurement of flow within turloughs is an extremely difficult task, as the points at which inflow and outflow occur within the turlough are not well confined and are submerged during the period of inundation. However, the identification of inflow periods would provide a greater understanding of turlough hydrological operation, as well as elucidate the relationship between net flow and actual flow. In order to achieve this, a number of potential methods to identify the presence of inflow were considered.

Direct flow measurement using electromagnetic current sensors and specialised loggers could provide an in-situ means of velocity measurement, but were found to be prohibitively expensive under this project. The use of thermal imaging or thermography could potentially identify the locations of inflow points due to differences in water temperature between surface and groundwater (Bogle & Loy, 1995). Ideally two sets of images would be taken during both the filling and emptying phases, and if possible during cold weather maximising the temperature differential. This too was prohibitively expensive and outside the scope of the project. However, as a surrogate for thermal imaging, an array of temperature probes was installed in an estavelle in Caranavoodaun, Co. Galway.

3.6 Time Series Analysis

3.6.1 Simple Correlation Analysis

Table 3.9 Maximum and minimum correlation coefficients

Site ID	Site Name	Maximum Correlation		Minimum Correlation		Average Correlation
		Value	Corresponding Site ID	Value	Corresponding Site ID	
1	Skealoghan	0.972	10	0.548	4	0.846
2	Ardkill	0.975	5	0.303	20	0.758
3	Kilglassan	0.950	14	0.538	4	0.839
4	Coolcam	0.990	15	0.048	20	0.608
5	Croaghill	0.975	2	0.303	20	0.785
6	Rathnalulleagh	0.978	7	0.537	20	0.846
7	Carrowreagh	0.978	6	0.516	20	0.820
8	Brierfield	0.946	5	0.213	20	0.721
9	Lisduff	0.952	16	0.413	20	0.838
10	Caranavoodaun	0.988	16	0.516	20	0.857
11	Blackrock	0.952	12	0.292	4	0.757
12	Lough Coy	0.973	14	0.325	4	0.770
13	Garryland	0.995	14	0.502	4	0.844
14	Caherglassan	0.995	13	0.465	4	0.833
15	Termon	0.990	4	0.096	20	0.649
16	Roo West	0.988	10	0.541	20	0.867
17	Turloughmore	0.863	20	0.101	4	0.602
18	Lough Gealain	0.996	19	0.603	4	0.866
19	Knockaunroe	0.996	18	0.611	4	0.862
20	Lough Aleenaun	0.863	17	0.048	4	0.531

To examine initial similarities between different turlough water level profiles, correlation analysis was carried out on water level time series. The maximum, minimum, and average correlation coefficients between the hourly water level time series for all turloughs for the period October 1st 2007 to 30th September 2008 are shown in Table 3.9, with the full correlation matrix given in Naughton (2011). The range of coefficients, from 0.996 to 0.048, shows the diversity of hydrological regimes and the continuum that exist across turlough ecosystems. Generally there is a good level of correlation between time series with high average coefficients, indicating a broadly similar flooding regime across the study sites corresponding to the seasonal inundation pattern. Some sites showed an extremely high level of correlation, with values approaching 1 derived for several turlough pairs: 0.995 between Garryland and Caherglassaun, and 0.996 between Lough Gealain and Knockaunroe. These pairs are geographically adjacent, with hydrograph comparisons showing them to be almost identical in terms of level and response time, with virtually simultaneous changes in water levels. Such close correlations would be expected if direct, relatively unrestricted connections existed between the water bodies or, in the absence of a direct linkage, a connection to a common groundwater flow system with both sites responding similarly to changing hydrological conditions. Alternatively, given that adjacent turloughs receive identical rainfall inputs, a similar modus operandi could result in highly correlated hydrological regimes even if each site operated in isolation. The relationships between geographically bordering, possibly hydraulically linked sites are further investigated later.

Some of the highest values correspond to sites that occur in completely different regions of the study area. Termon shows a high correlation of 0.99 with Coolcam, which is located approximately 70 km to the north. The similarities between the flooding characteristics are clearly demonstrated in the plot of water levels normalised with respect to maximum depth (Fig. 3.47). In contrast, Termon has a relatively low correlation of around 0.5 with nearby sites Garryland and Caherglassaun, again emphasising the spatial heterogeneity that can exist in flow properties within karst systems.

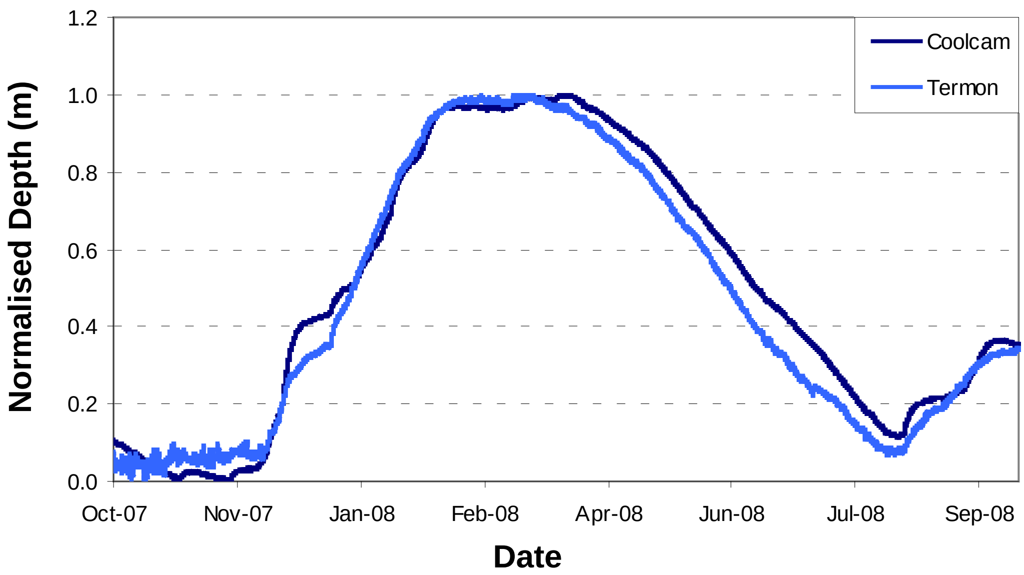


Figure 3.47 Normalised depth plot for Coolcam and Termon turloughs, Co. Galway

While there is a wide spatial variation in the sites corresponding to maximum correlation, it is interesting to note that only two sites account for all of the lowest correlations evaluated: Coolcam (site 4) and Lough Aleenaun (Site 20). As identified in previous analyses, these turloughs represent the extremes of turlough hydrological behaviour. Coolcam's regime consists of a single long duration flood event with gentle rising and recession hydrograph limbs, resulting in a low level of ecological disturbance. Lough Aleenaun displays a multimodal flooding regime with seven distinct flooding events within the same period (Fig. 3.48). In contrast to Coolcam, the rapid responses to rainfall events and highly fluctuating water levels throughout the year represent a high level of disturbance.

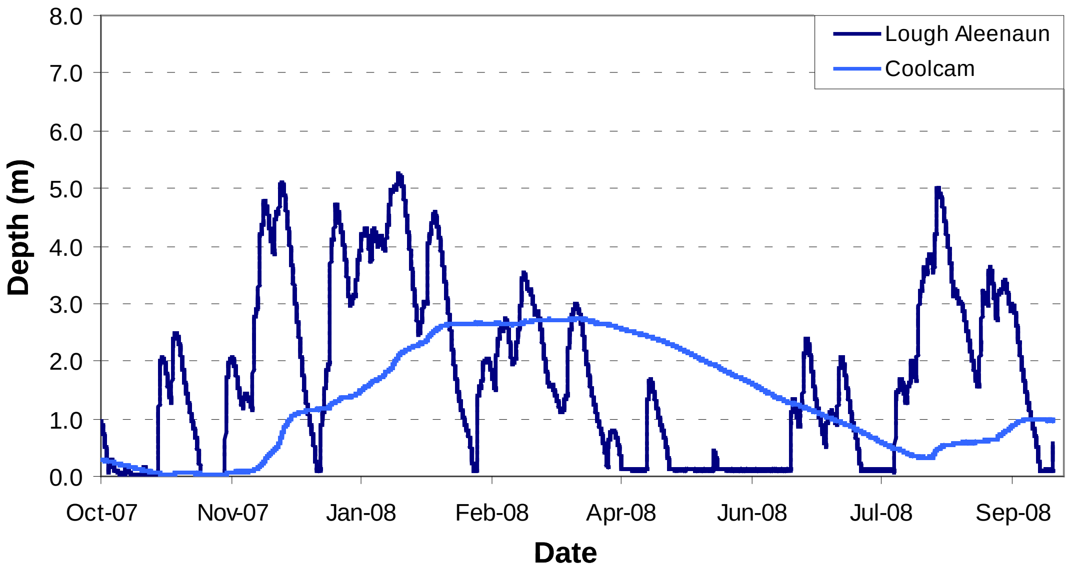


Figure 3.48 Comparison of stage depth hydrographs for Coolcam turlough, Co. Galway and Lough Aleenaun, Co. Clare

By using the behaviour of Coolcam and Aleenaun as benchmarks, an indication as to the nature of a turlough's hydrological regime and the scale of disturbance it represents can be established. A minimum correlation with Coolcam implies a higher level of disturbance with faster and more responsive flooding, whereas a minimum correlation with Aleenaun is indicative of a unimodal flood regime with low disturbance. The minimum correlation ID specifies which end of the disturbance spectrum a site tends towards, with Coolcam signifying a higher level and Aleenaun a lower level. The value of the minimum correlation coefficient itself indicates how far along the spectrum the turlough is, with lower values implying a more extreme regime and vice versa.

A plot of correlation coefficient with Coolcam versus the corresponding Aleenaun coefficient for each turlough shows the relative distribution of disturbance (Fig. 3.49). Sites plotted in the lower left corner (Coolcam, Termon, Brierfield, Ardkill and Croaghill) represent the slower responding turloughs with lower levels of disturbance while those in the upper right corner (Lough Aleenaun and Turloughmore) correspond to those sites with highly fluctuating levels and high disturbance. The wide distribution of points from low to high disturbance clearly represents the range of hydrological behaviours that exist within the study sites and across turlough habitats as a whole. It is this variability which results in the high level of habitat and ecological diversity found between sites. Correlation analysis was then carried out on water level time series of 16 turloughs for the 2006/2007 hydrological year and the correlation coefficients superimposed on the plot for 2007/2008 (Fig. 3.49). As can be seen in figure 3.49, both years showed a similar distribution and the relative position of sites within the spectrum very similar in both years. Another interesting trend is the upward shift of the 2007/2008 distribution relative to 2006/2007, highlighting the drier year experienced by many sites in 2007/2008. This upward shift indicates that during this period, many sites moved further from the long duration flooding characteristic of Coolcam due to the shorter duration of flooding.

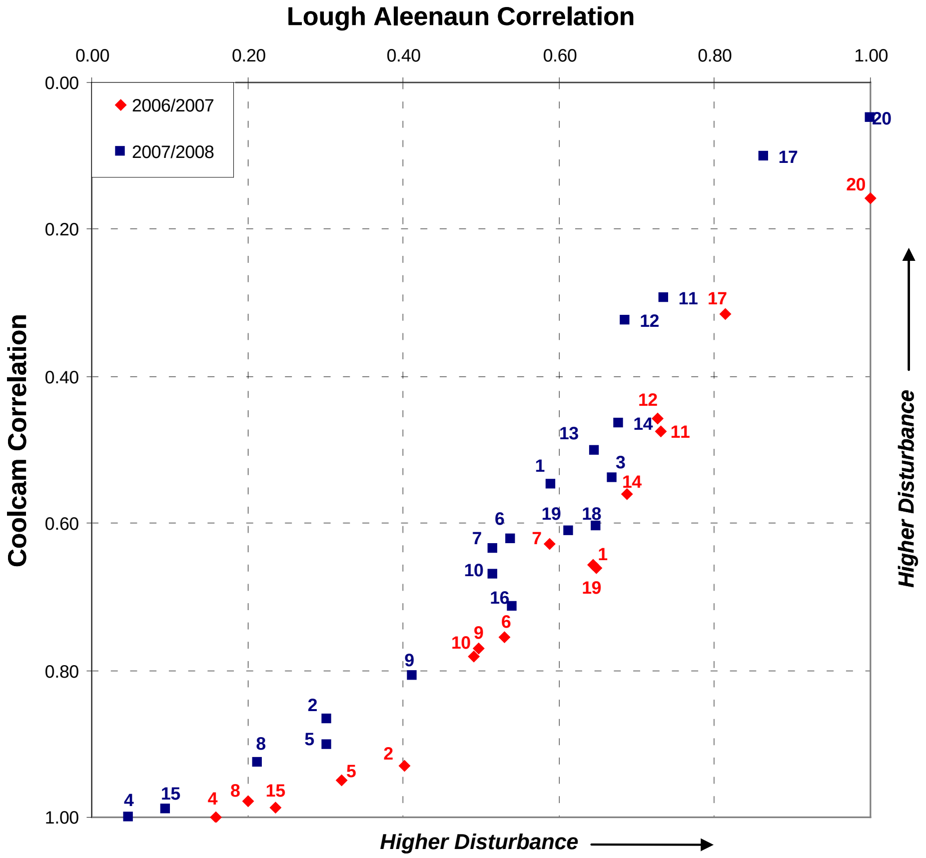


Figure 3.49 A plot of correlation with Lough Aleenaun versus the corresponding correlation with Coolcam for each turlough for the 2006/2007 and 2007/2008 hydrological years

3.6.2 Autocorrelation

Autocorrelation is a widely used method for analysing time series data used in the time domain. The autocorrelation function provides a normalized measure of the linear dependence of successive values within a time series, and allows the quantification of the memory effect in the system (Padilla & Pulido-Bosch, 1995; Box *et al*., 2008). In the analysis of karst systems, the correlogram provides information on the level of karstification and storage within the aquifer (Labat *et al*., 2000; Panagopoulos & Lambrakis, 2006; Bailly-Comte *et al*., 2008). The autocorrelation function itself is described in Naughton (2011).

The autocorrelation function can be interpreted using two metrics; the slope of the correlogram and the decorrelation lag time. The rate at which the autocorrelation function decreases as the time lag is increased, or its slope, differs depending on the characteristics of the karst system. The memory of the system is quantified using a parameter known as the decorrelation lag time. This is defined as the lag at which the autocorrelation function has fallen a predetermined value (Panagopoulos & Lambrakis, 2006). The exact magnitude of this value is somewhat arbitrary, but is usually between 0.1 and 0.2 as below this the memory effect of the system is adjudged to be indistinguishable from signal noise (Valdes *et al*., 2007). Where the karst system is poorly developed and has major groundwater storage, the correlogram will have a relatively gentle slope and consequently a high decorrelation lag time (Padilla & Pulido-Bosch, 1995; Larocque *et al*., 1998). Where the system demonstrates more rapid drainage characteristics the correlogram will have a much steeper slope and correspondingly lower decorrelation lag time.

While classically the storage within a karst aquifer is considered to consist of groundwater held within the matrix, fractures and conduit permeability, in the case of lowland Irish karst systems there is additional storage provided in the form of turlough basins. The autocorrelation function characterises the manner in which this storage is utilised by the karst flow system and from this, information about the nature of the flow system itself can be inferred.

3.6.2.1 Stage Autocorrelation

Autocorrelation analyses were carried out on the hydrological year from 1st October 2007 to 30th September 2008, as it represented a consistent interval with similar rainfall inputs over which autocorrelation functions could be generated and compared. The longest continuous water level time series available for each site was also analysed to identify potential longer term effects. Examples of the autocorrelation functions produced are shown in figure 3.50, with the complete set of stage correlograms given in Naughton (2011).

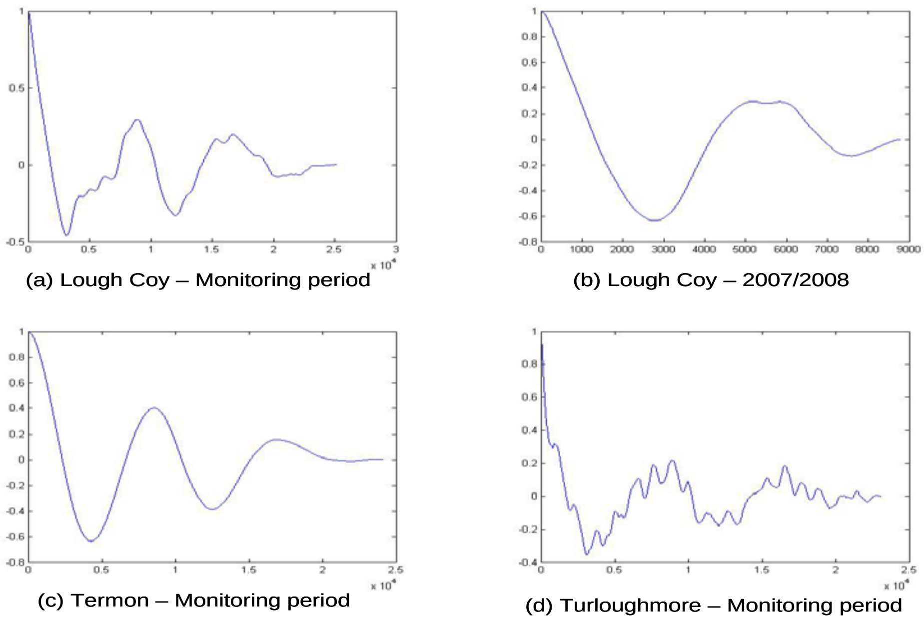


Figure 3.50 Autocorrelation functions for (a) Lough Coy (b) Lough Coy for 2007/2008 hydrological year, (c) Termon (d) Turloughmore (Time in days on horizontal axis, correlation coefficient on vertical axis)

A cursory look at the correlograms reveals that the seasonality of turlough flooding associated with the annual recharge cycle of the aquifer is clearly visible, with positive r(k) peaks occurring at lags roughly coinciding with flooding events during the winters of 2007/2008 and 2008/2009 (Fig. 3.50 a). The smoothest correlograms with the slowest slope changes are shown by sites characterised by long duration, low frequency flooding such as Brierfield, Coolcam and Termon (Fig. 3.50 c). The slope changes of more responsive turloughs show far more variability and changes in autocorrelation slope, such as Lough Aleenaun and Turloughmore (Fig. 3.50 d). Between these lay a continuum of behaviours such as that shown by Lough Coy (Fig. 3.50 a, b) with increasing regularity of the autocorrelation function implying greater temporal stability in water levels.

Table 3.10 Decorrelation lag times (in days) for stage and flow time series

	Stage Autocorrelation			*Flow Autocorrelation*	
Analysis Period	***2007/2008***	***2007/2008***	***Full***	***2007/2008***	***Full***
Decor. Level	***0.2***	***0.4***	***0.2***	***0.2***	***0.2***
Turloughmore	38.9	27.2	55.9	3	3
Lough Aleenaun	41.3	12.2	46.5	3	2
Blackrock	44.4	34.5	59.3	4	5
Lough Coy	45.1	35.1	59.6	10	8
Caherglassan	49	39.2	65.3	11	10
Garryland	49.9	40	61.3	9	10
Ardkill	52.8	41	80.2	45	46
Knockaunroe	53.4	43.9	67.5	11	10
Lough Gealain	53.7	43.6	63.6	8	7
Skealoghan	53.8	42.5	71.8	6	7
Croaghill	54	43.1	73.1	30	20
Lisduff	55.1	44.9	73.1	40	33
Rathnalulleagh	55.5	44	62.4	19	13
Caranavoodaun	55.5	44.6	69.8	13	14
Roo West	55.7	45.6	56.2	8	6
Carrowreagh	57.3	44.3	72.8	7	12
Brierfield	60.6	49.8	78.1	33	22
Coolcam	62.5	51.5	75.5	59	58
Termon	62.5	51.7	82.4	55	61
Mean	***52.7***	***41***	***67.1***	***19.7***	***18.3***
Standard Deviation	***6.6***	***9.1***	***9.4***	***18.2***	***18.1***

Decorrelation lag times were initially identified for all sites using a decorrelation level of 0.2 (Table 3.10). As expected a range of lag times was identified, with the lower values representing turloughs with highly fluctuating regimes, while higher values signified sites with more slowly responding regimes. The continuum of flooding behaviour was repeated here. There was a relatively low range of lag times, with standard deviations of 6.6 and 9.4 days for the two analysis period showing the similarity between many of the turlough flooding regimes. Interestingly, despite showing the steepest initial slope on the correlogram Lough Aleenaun does not show the lowest decorrelation lag; instead, it is Turloughmore with the lowest lag time at 38.9 days, compared to 41.3 days for Lough Aleenaun. This anomalous result is due the chosen decorrelation level of 0.2. A visual inspection of the Lough Aleenaun correlogram confirms this, with a clear change in slope of the autocorrelation function at r(k) values around 0.25 (Fig. 3.51 a). Lough Aleenaun fills and empties far more frequently compared to Turloughmore. While the two sites show similar regimes during the winter months, Turloughmore shows a damped response to summer rainfall events and thus has a lower frequency of flooding. This may be due to the additional storage available within the Turloughmore karst system compared to that of Lough Aleenaun. This extra storage is able to accommodate flows generated by precipitation events during the summer months without the onset of turlough flooding, whereas the low storage capacity of the Aleenaun system results in the onset of flooding in response to rainfall throughout the year.

To assess the sensitivity of lag time to decorrelation level, and how it affected the interpretation of stage time series, lag times were recalculated for decorrelation level of 0.4 and plotted against 0.2 lag time (Fig. 3.51 b). This showed an approximately linear relationship between the two lag times with one exception: Lough Aleenaun. Generally the correlograms showed a smooth, continuous decrease in r(k) with increasing lag but, in the correlogram for Lough Aleenaun, the autocorrelation function levels out for lags between 25 and 40 days before falling off thereafter. Therefore it is important to consider the shape of the autocorrelation function and any distinct changes in slope when interpreting turlough correlograms.

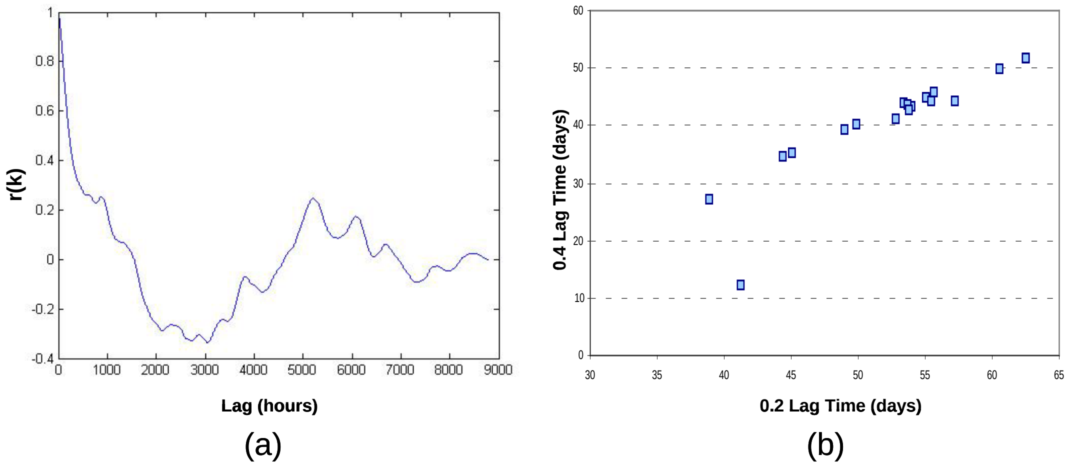


Figure 3.51 Autocorrelation function for Lough Aleenaun using 2007/2008 stage data (a) and plot of 0.2 lag time against 0.4 lag time for autocorrelation analyses carried out using 2007/2008 stage data (b)

3.6.2.2 Flow Autocorrelation

Autocorrelation was also carried out on net daily flow rate time series. As with the stage time series, analyses was carried out using data from the 2007/2008 hydrological year as well as the longest available record. The flow correlograms are provided in appendix C and the decorrelation lag times for the flow time series are shown in Table 3.10. There was a greater distinction between flow correlograms and corresponding lag times compared to that found during the stage analyses. The lag times varied by order of magnitude, from 3 days for Lough Aleenaun to 59 days for Coolcam, while the standard deviation of 18.2 days for 2007/2008 hydrological year is also far higher than the figure of 6.6 days for stage correlograms over the same period. It is also relatively high when compared to the mean lag time across the study sites of 19.7 days. This would be expected, since turlough flows are a response to the shorter-term events, namely precipitation, whereas the turlough water level represents a more long term response of the aquifer to the excess recharge during the winter period.

An example of the differences in flow behaviour is clearly demonstrated in figure 3.52. Figure 3.52 a shows the correlogram for Lisduff. Here, the correlogram shows a gentle slope with the 0.2 lag time of 40 days is far above the mean of 19 days. This links in well with the direct analyses of flow rates carried out in Section 3.5, where a net inflow rate was sustained in Lisduff over a long period, and is indicative of the long-term effects of rainfall events felt within the system. This behaviour is replicated in the other slow draining turloughs of Coolcam, Termon and Ardkill with lag times of 59, 55 and 45 days respectively. In contrast, the slope of the correlogram for Blackrock falls steeply, reaching the 0.2 decorrelation level after only 4 days (Fig. 3.52 b).

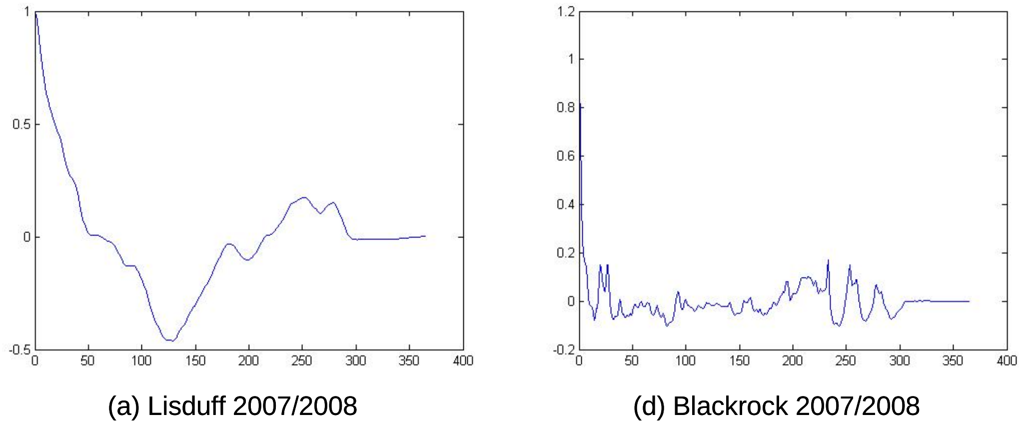


Figure 3.52 Autocorrelation functions for Lisduff (a) and Blackrock (b) using 2007/2008 daily flow data

3.6.3 Cross Correlation

The flow behaviour was further investigated using cross correlation with precipitation records. Details of the cross correlation function itself are given in Naughton (2011).

The time delay, defined as the lag at which the maximum value of the cross correlation function $r_{xy}(k)$ occurs, indicates the level of development or karstification of the system (Padilla & Pulido-Bosch, 1995). The direction of the relationship is given by the sign of the delay, with a positive delay indicating that the output y_t shows a response to the input signal x_t. A shorter delay represents a more rapid transfer of the input through the system, and in studies of karst springs is generally associated with well developed flow systems (Panagopoulos & Lambrakis, 2006). As can be seen in Table 3.11, all flow delays were positive, showing the intuitive relationship that turlough flow reacts to precipitation events. However, the delay is fairly constant across the study sites and shows a very low range of between 1 and 4 days, thus provides little information on the relative operation of the systems. Part of the reason for this ambiguity can be ascribed to features of a turlough flow time series and the role turloughs occupy within karst systems compared to that occupied by springs.

Table 3.11 Results from cross-correlation analyses between net daily turlough flow and precipitation (all delays given in days)

Site Name	2007/2008			Full		
	Max R	Delay	R=0 Delay	Max R	Delay	R=0 Delay
Lough Aleenaun	0.56	1	4	0.56	1	4
Turloughmore	0.44	1	6	0.44	1	6
Blackrock	0.5	2	11	0.5	2	12
Skealoghan	0.43	2	14	0.43	2	13
Carrowreagh	0.33	2	16	0.33	2	17
Knockaunroe	0.51	3	16	0.51	2	16
Lough Gealain	0.61	1	16	0.61	1	12
Lough Coy	0.44	2	17	0.44	2	14
Caherglassan	0.48	1	18	0.48	1	15
Rathnalulleagh	0.28	3	18	0.28	3	20
Garryland	0.45	2	19	0.45	2	14
Caranavoodaun	0.41	2	30	0.41	1	26
Roo West	0.42	1	30	0.42	1	23
Brierfield	0.34	2	49	0.34	2	52
Lisduff	0.39	4	51	0.39	3	31
Croaghill	0.47	2	59	0.47	1	32
Ardkill	0.46	2	70	0.46	1	48
Termon	0.4	1	70	0.4	1	67
Coolcam	0.35	1	73	0.35	1	58
Average	***0.44***	***1.8***	***30.9***	***0.44***	***1.6***	***25.3***
Standard Deviation	***0.08***	***0.8***	***23.2***	***0.08***	***0.7***	***18.3***

A karst spring represents the output from the karst system; the cross correlation function is the product of all processes which transform precipitation within the aquifer including storage effects. In contrast, a turlough forms an integral part of the storage within a karst system rather than a system output. The turlough flow cross correlation function represents an element of the internal processes which transforms precipitation within the karst system. Turlough flow is a function of both the input signal (precipitation) and also state of the system, i.e. the relative heads within the turlough itself and the underlying aquifer. In addition to the contributing factors of flow path development and degree of karstification, the hydrological state of the overall system determines the effect rainfall will have on turlough flow. It may cause a positive flow into the turlough, or alternatively just decrease the rate of net outflow if the turlough is in recession. If fact, during dryer periods it may have no effect at all on the turlough as the flow system is able to accommodate the recharge completely without utilising turlough storage.

A useful indicator generated from the cross correlation function is the delay between a lag of zero and the time at which $r_{xy}(k)$ drops to 0. This metric gives a general indication as to the period during which a precipitation event has a positive effect on net flow. This variable ranged from a low of just 4 days for Lough Aleenaun to 73 in Coolcam during the 2007/2008 hydrological year. This variation is reflected visually in the cross correlation functions and the number and degree of slope changes shown, with an increasing irregularity indicating a shorter rainfall effect (Fig. 3.53 a-d).

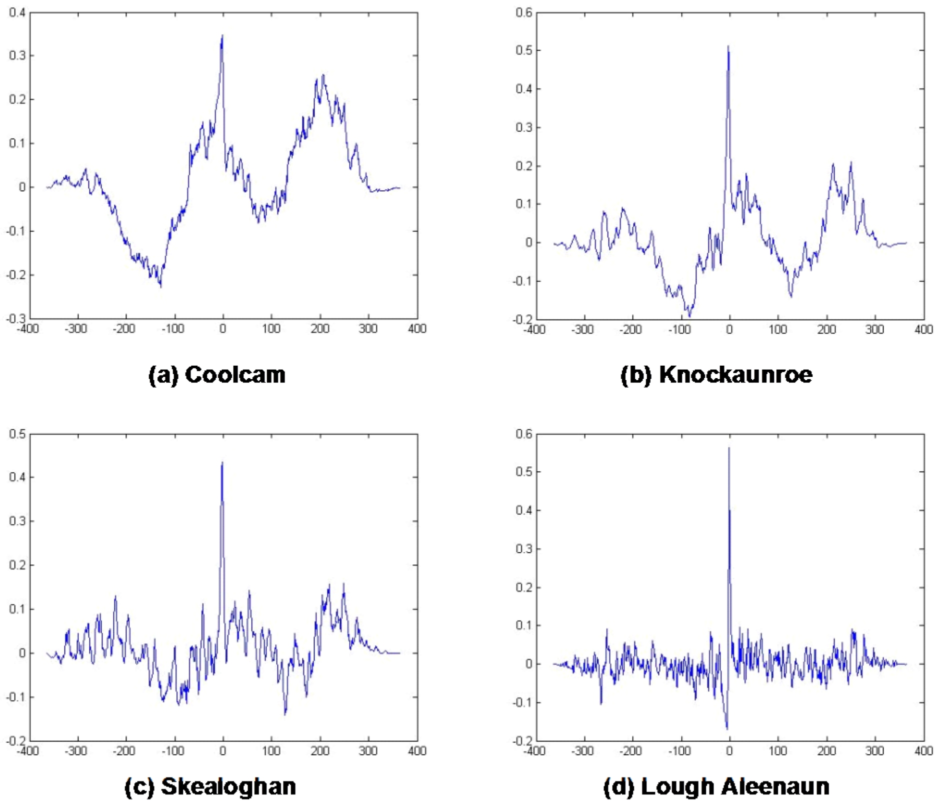


Figure 3.53 Cross-correlation functions using daily net flow and precipitation data from 2007/2008 hydrological year for (a) Lisduff, (b) Knockaunroe, (c) Skealoghan and (d) Turloughmore

3.6.4 Time-lagged Correlation

In order to investigate turlough dynamics and provide relevant information concerning the nature of site interconnectivity, time-lagged correlation was performed on turlough water level time series. Time-lagged correlation involves offsetting one time series relative to the other and identifying the time lag at which the maximum correlation occurs. The direction of the lag between two sites indicates which reacts more readily to rainfall, while the value of the lag quantifies the temporal difference in response time. Four subsets of study sites were based on geographical location, denoted subset 1 to 4 (Table 3.12). A comparison of their respective flooding regimes would be helpful in the understanding of one extreme in turlough behaviour. Within each subset time-lagged correlation was carried out using both the entire 2007/2008 hydrological year dataset and the shortest continuous period of inundation of any site within the subset.

Table 3.12 Geographically close site subsets

Subset 1: Mayo	Subset 2: Williamstown
Skealoghan	Coolcam
Ardkill	Croaghill
Kilglassaun	

Subset 3: Roscommon	Subset 4: Burren
Rathnalulleagh	Lough Gealain
Carrowreagh	Knockaunroe
Brierfield	

During the analysis process it was observed that, while differences in recession duration were correctly identified, in many cases the shorter lag time between actual water level peaks was overestimated. When comparing sites with similar duration flooding regimes, such as in the Burren subset, the delay between peak water levels was accurately represented. However where sites exhibited comparable filling patterns but distinctive recession durations, such as in the Roscommon subset, similarities in the maxima were masked by large disparities in recession duration. In order to ascertain the relative timing of peaks, clearly defined maxima in the water level time series were manually isolated within each subset and the lag measured. A positive lag in *site A vs. site B* implies the peak level occurred in *site A* earlier than *site B*. A negative lag implies the reverse, with the *site B* maxima preceding that of *site A*. Each maximum represents a point at which the flow direction changes from net inflow to net outflow. As sites in the same geographical location are generally subject to common rainfall patterns and events, a comparison of peak water level across each subset can give an insight into the temporal dynamics of the flow systems. Through the interpretation of these relative delays together with local hydraulic gradients, the determining factors affecting turlough hydrology on a local level can be explored.

3.6.4.1 Subset 1: Mayo

The Mayo subset consists of the three turloughs Skealoghan, Ardkill and Kilglassan and is located approximately 8 km east of Ballinrobe. Morphologically, Ardkill is located in a deep depression while the other two sites have much flatter topographies consisting of shallow basins surrounded by gentle side slopes. The water level hydrographs for each site are shown in figure 3.54. As can be seen from the plot, the bases of Skealoghan and Ardkill lie at approximately the same level with that of Kilglassan around a metre higher. Visually the hydrographs of Skealoghan and Kilglassan show a similar flooding pattern with maximum flood depths of 1.9 and 2.2 m respectively, but with a slower recession in Skealoghan. Ardkill displays a far greater range of flooding with a maximum recorded depth of close to 7 m, and a recession limb far in excess of that shown by either Skealoghan or Kilglassan. This divergence in recession behaviour was identified earlier, with Ardkill showing one of the lowest lag times 45 days compared to only 6 for Skealoghan.

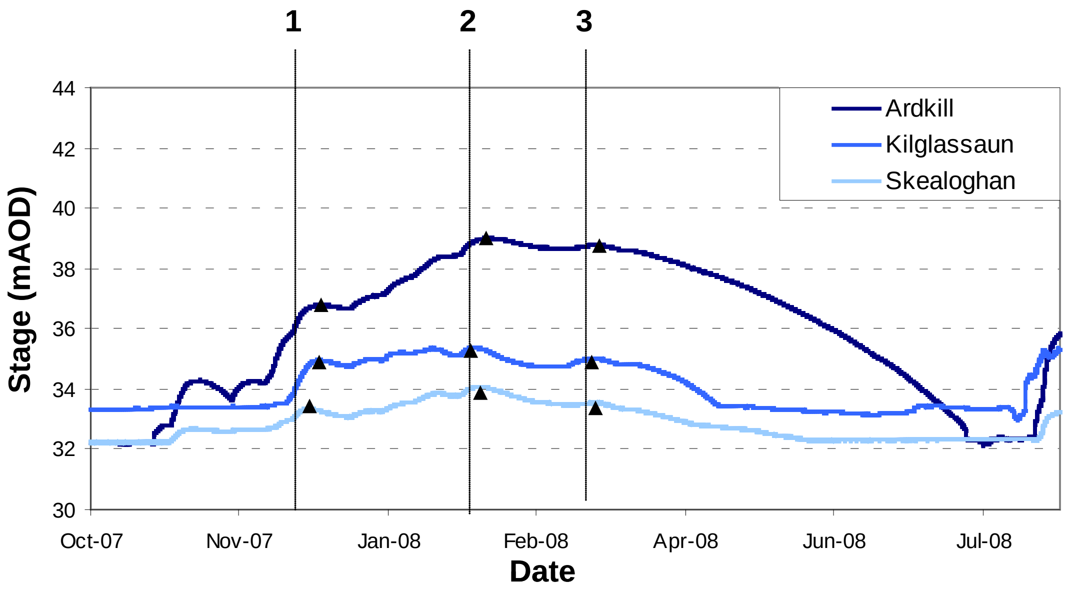


Figure 3.54 Plot of water levels as mAOD, rainfall and computed maxima for Subset 1: Mayo

The differences in recession duration are clearly picked up in the time-lagged correlation. The maximum correlation between Skealoghan and Ardkill occurred with a positive lag of 689 hours or 29.7 days (Table 3.13, Fig. 3.55). When assessed over the inundation period this dropped to 418 hours (17.5 days), but with Ardkill still lagging considerably behind Skealoghan. Skealoghan in turn was found to lag behind Kilglassan, but on a smaller scale with a negative lag of 108 hours across the hydrological year. This reflects the extended recession of Skealoghan compared to that of Kilglassan.

Table 3.13 Results of time-lagged correlation and manual comparison of maxima for Subset 1: Mayo

Correlated Sites	*Hydrological Year*		*Inundation Period*		*Peak 1*	*Peak 2*	*Peak 3*
	Lag (hrs)	*Correlation*	*Lag (hrs)*	*Correlation*	*Lag (hrs)*	*Lag (hrs)*	*Lag (hrs)*
Skealoghan vs. Ardkill	689	0.908	418	0.760	94	53	43
Skealoghan vs. Kilglassan	-108	0.937	-28	0.832	73	-69	-27
Ardkill vs. Kilglassan	-723	0.871	-675	0.664	-21	-122	-70

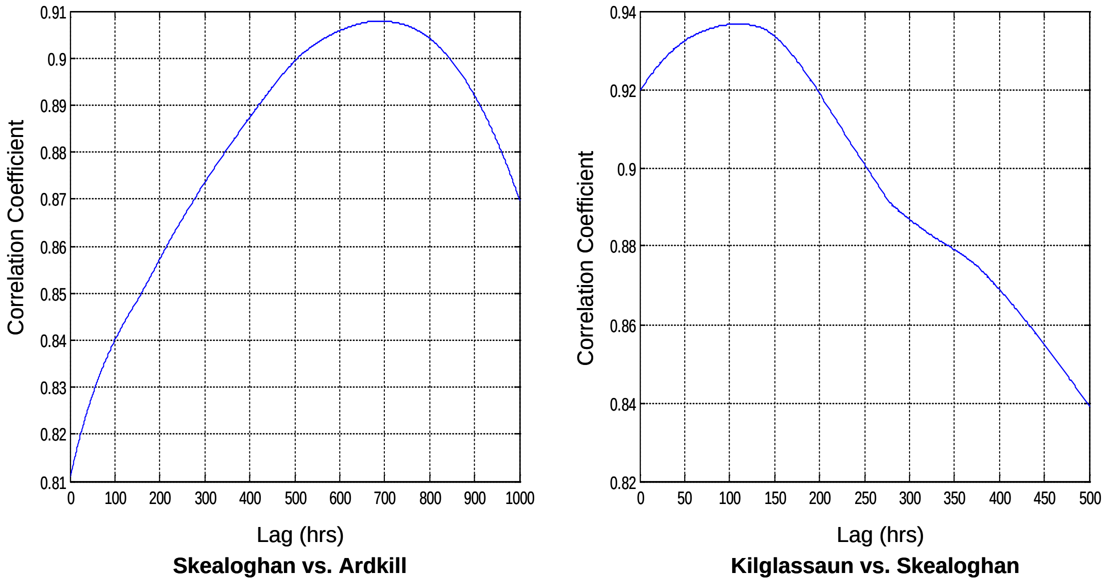


Figure 3.55 Time-lagged correlations for Skealoghan vs. Ardkill and Kilglassaun vs. Skealoghan (hydrological year)

Three water level maxima were identified, labelled 1 to 3 in figure 3.54, and the relative time delays between them determined. Despite the large variation in flood duration, depth and recession characteristics present within the subset, the water level maxima all occurred within a relatively short interval. The initial maxima in Skealoghan preceded that of Kilglassan by almost 3 days, but later in the season this pattern was reversed with Kilglassan peaking first. While the peak in Ardkill water levels consistently occurred after that of the other two sites, the delay of between 2 to 4 days was far shorter than what might be expected given the contrasting hydrological regimes.

When the maximum water level events are compared with the rainfall record they all follow periods of little or no rainfall, as expected. It is interesting to note that despite the differences in net flow rates and recession duration, the time it takes for this process to begin is remarkably consistent across the sites within the subset. If the controlling factor governing turlough hydrology was the filling process, a far greater difference would be expected between sites such as those within subset 1.

3.6.4.2 Subset 2: Williamstown

Coolcam and Croaghill turloughs lie to the west of Williamstown, north Co. Galway. The topography of the area is dominated by glacial deposits and eskers. Coolcam lies to the west of Croaghill and has a basin floor level of around 80 mAOD compared to 78 mAOD of Croaghill, with water levels showing a regional gradient from west to east. The hydrographs of Coolcam and Croaghill show comparable filling and emptying characteristics with a high correlation of over 0.9. The maximum flood depths are also similar at around 3 m.

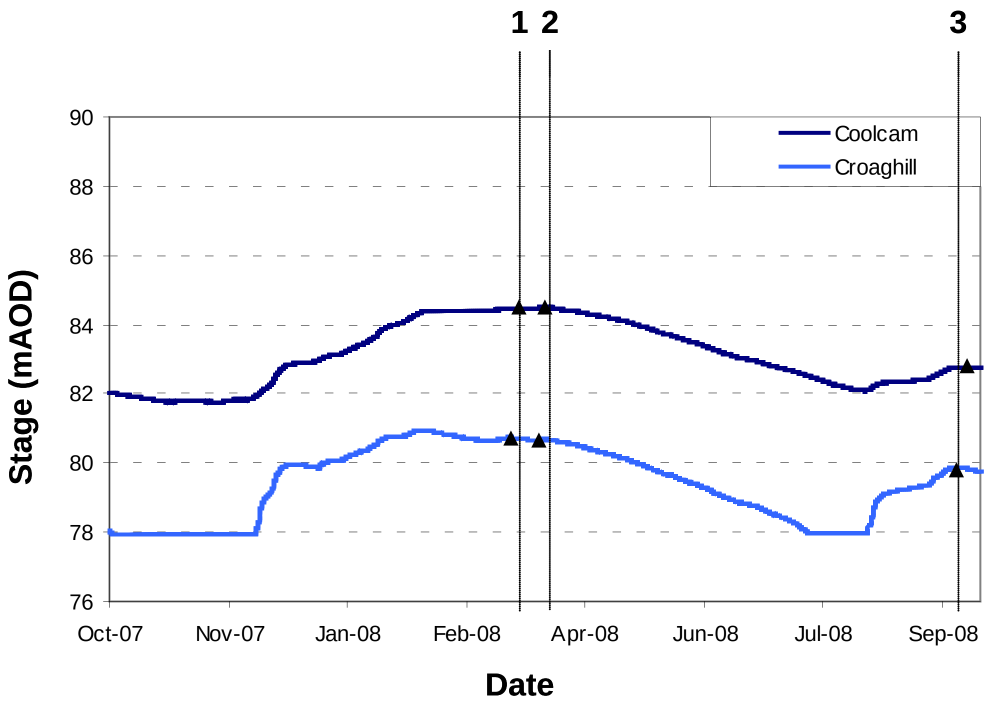


Figure 3.56 Plot of water levels as mAOD, rainfall and computed maxima for Subset 2: Williamstown

The time-lagged correlation results indicate Coolcam lagging behind Croaghill by 17 days (Table 3.14) across the hydrological year, a similar lag as that found between Skealoghan and Ardkill in subset 1. As with subset 1, this reflects the relative difference in recession durations. A comparison of water level maxima shows a lag in Coolcam with respect to Croaghill in the order of 3 days. Again, as with subset 1, this is a considerably shorter period than was indicated by the time-lagged correlation.

Table 3.14 Results of time-lagged correlation and manual comparison of maxima for Subset 2: Williamstown

Correlated Sites	*Hydrological Year*		*Inundation Period*		*Peak 1*	*Peak 2*	*Peak 3*
	Lag (hrs)	*Correlation*	*Lag (hrs)*	*Correlation*	*Lag (hrs)*	*Lag (hrs)*	*Lag (hrs)*
Coolcam vs. Croaghill	-406	0.963	-463	0.968	-94	-91	-64

Despite the short time lag between corresponding maxima, the highest water level recorded in Coolcam during the inundation period occurred almost 52 days after the highest in Croaghill. The disparity between these two values can be explained by a greater level of restriction or lower capacity of the outflow from Coolcam than is present in Croaghill. During an extended period of low or no rainfall, the greater drainage capacity of Croaghill allows its water level to drop significantly more than that which occurs in Coolcam during the same period. This difference in drainage capacity has a cumulative effect across the flooding period, with the result that the renewed flooding begins from a relatively higher level in Coolcam than it does in Croaghill when rainfall recommences. Thus while there are corresponding peaks in both time series their relative levels within the series can be different.

3.6.4.3 Subset 3: Roscommon

The Roscommon subset, located 3km to the southeast of Castleplunket, contains the turloughs Rathnalulleagh, Carrowreagh and Brierfield. In terms of elevation Brierfield is the uppermost turlough, followed by Carrowreagh with Rathnalulleagh the lowest (Fig. 3.57). An initial examination of the hydrographs shows some level of similarity between all sites within the subset, with a simultaneous onset of flooding across the sites and peak water levels occurring at approximately the same time. There is a strong resemblance between Rathnalulleagh and Carrowreagh with parallel filling and emptying characteristics in evidence, as would be expected given the correlation of 0.978 (Table 3.15). Brierfield, in contrast, displays a longer period of inundation with a recession far in excess of that demonstrated by either Carrowreagh or Rathnalulleagh. At 3.6 m the maximum flooded depth of Brierfield is also significantly less than that of either Rathnalulleagh or Carrowreagh, which have maximum depths of 7.8 and 7 m respectively.

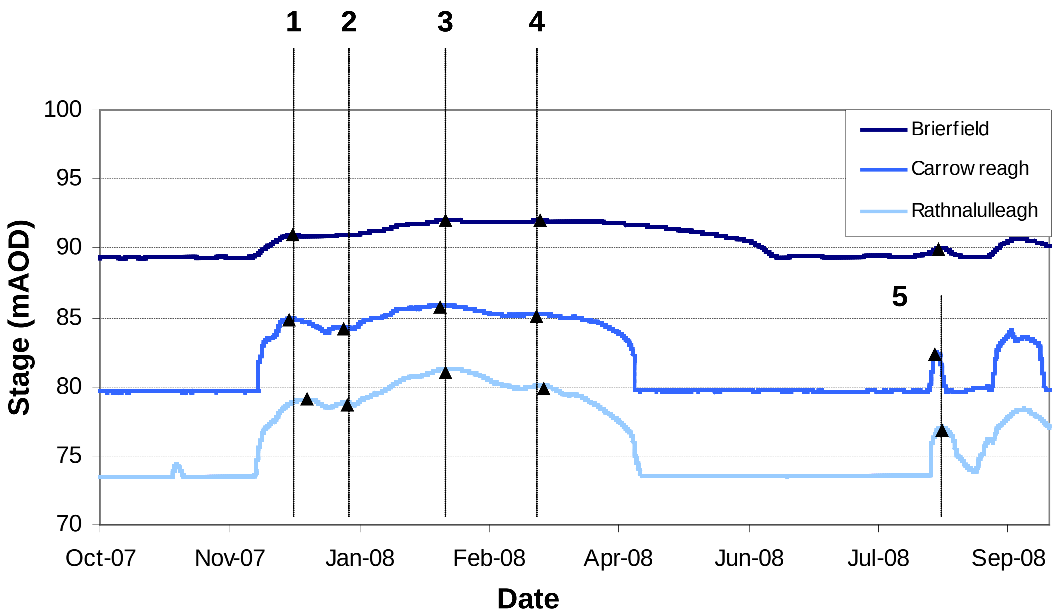


Figure 3.57 Plot of water levels as mAOD and computed maxima for Subset 3: Roscommon

Table 3.15 Results of time-lagged correlation and manual comparison of maxima for Subset 3: Roscommon

Correlated Sites	*Hydrological Year*		*Inundation Period*	
	Lag (hrs)	*Correlation*	*Lag (hrs)*	*Correlation*
Rathnalulleagh vs. Carrowreagh	-16	0.979	-4	0.992
Rathnalulleagh vs. Brierfield	707	0.901	904	0.925
Carrowreagh vs. Brierfield	728	0.892	938	0.916

	Peak 1	*Peak 2*	*Peak 3*	*Peak 4*	*Peak 5*
Correlated Sites	**Lag (hrs)**	**Lag (hrs)**	**Lag (hrs)**	**Lag (hrs)**	**Lag (hrs)**
Rathnalulleagh vs. Carrowreagh	-168	-43	-63	-63	-66
Rathnalulleagh vs. Brierfield	-145	-	-9	-37	-30
Carrowreagh vs. Brierfield	23	128	54	26	36

The turloughs of subset 3 follow a similar pattern as that identified in subset 1 and 2. The disparity in flood duration between the sites is clearly identified using the time-lagged correlation method, in this case with Brierfield showing a maximum correlation when lagged by 707 hours (29 days) behind Rathnalulleagh (Table 3.15). The difference in final emptying dates between these sites was greater still at just over 50 days. Rathnalulleagh was found to marginally lag behind Carrowreagh with less than a day offset required to maximise correlation, further highlighting the contemporaneous behaviours of these sites. The timing of flood maxima followed the same trend identified in subsets 1 and 2, with peak levels in all sites occurring in a short interval irrespective of the relative lengths of the recession. In this case Rathnalulleagh was preceded by both Carrowreagh and Brierfield with the lag remaining fairly constant for peaks 2 to 4, but showing a noticeably longer delay of a full week during peak 1. This could be due to the relative positions of each turlough within their particular flow system. The probable hydrological configuration of these sites has Rathnalulleagh and Carrowreagh forming part of the same flow system, with Carrowreagh at the upper end of the catchment, while Brierfield forms part of a separate system. This would explain the similar peak times between Brierfield and Carrowreagh, while the delay experienced in Rathnalulleagh is caused by the damping effect of Carrowreagh located up gradient in the system.

3.6.4.4 Subset 4: Burren

The sites of subset 4, Lough Gealain and Knockaunroe, border each other on the limestone pavement at the foot of Mullaghmore. If a purely flow-through turlough system existed it would be in this locale that one would expect it, as the bare rock outcrops which characterise the area would present ideal conditions for the distributed flow system throughout the epikarst. Despite this there are still obvious swallow holes present in both turlough basins, with water clearly draining to a depression in Lough Gealain witnessed during this study. It appears that the deposition of marl within the basins have formed low permeability barriers covering much of the epikarst, thus promoting the development of larger flow systems.

The correlation and lag time remained consistent across the periods of analysis, with Knockaunroe consistently lagging behind Lough Gealain by approximately 24 hours (Fig. 3.58). The manual analyses uncovered a slightly greater delay between maximum water levels, but with Lough Gealain still preceding Knockaunroe. The main flood events themselves during the year, peaks 3 and 4, showed a similar lag of 77 and 61 hours respectively (Table 3.16). This is similar to the relationship identified between Carrowreagh and Rathnalulleagh in Subset 3. The upper turlough (Lough Gealain) has a damping effect on the impulse response to recharge, causing a delay to be felt in the lower turlough (Knockaunroe) further down the system. The preferential drainage of the upper turlough also helps to maintain a positive gradient into lower turlough, thus causing a lag in peak time.

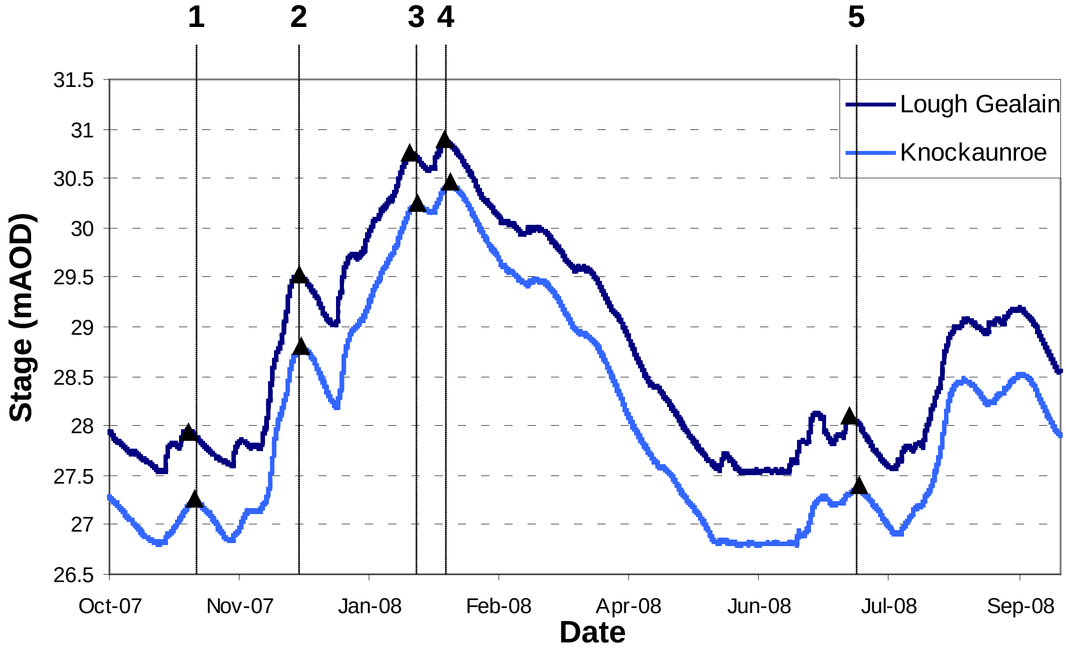


Figure 3.58 Plot of water levels as mAOD and computed maxima for Subset 4: Burren 1

Table 3.16 Results of time-lagged correlation and manual comparison of maxima for Subset 4: Burren

Correlated Sites	*Hydrological Year*		*Inundation Period*	
	Lag (hrs)	*Correlation*	*Lag (hrs)*	*Correlation*
Lough Gealain vs. Knockaunroe	23	0.997	26	0.997

	Peak 1	*Peak 2*	*Peak 3*	*Peak 4*	*Peak 5*
Correlated Sites	*Lag (hrs)*	*Lag (hrs)*	*Lag (hrs)*	*Lag (hrs)*	*Lag (hrs)*
Lough Gealain vs. Knockaunroe	48	7	77	61	90

3.6.5 Frequency Analysis

3.6.5.1 Fast Fourier Transform (FFT) Analysis

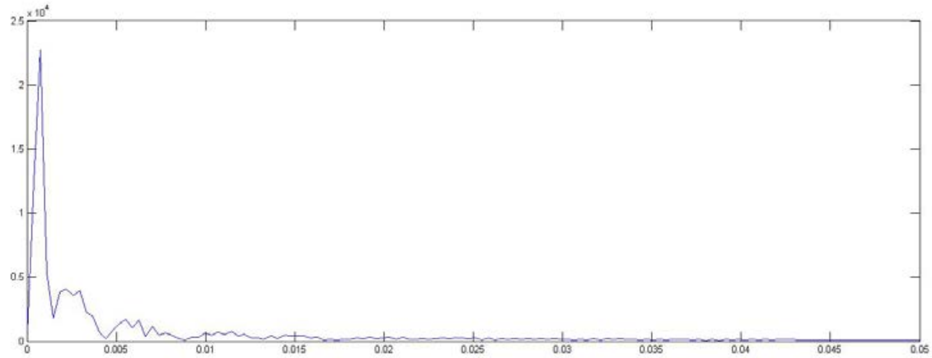
To complement the analysis of data in the time domain, stage and flow time series were also analysed in the frequency domain using the technique of Fourier analysis. The principle of Fourier analysis is covered in Naughton (2011). Frequency analyses were carried out using the Fast Fourier Transform (FFT), an efficient algorithm for the calculation of the Discrete Fourier Transform (DFT).

Stage time series datasets comprising the longest continuous monitoring period for each turlough were analysed using FFT in the MatLab software package (version r2008a). The data were detrended to remove any long term drift and then transformed into the frequency domain using the FFT. The first ten peaks were extracted from the FFT results. Peaks corresponding to the length of the analysed dataset were then discarded, and the remaining peaks sorted in descending order of energy.

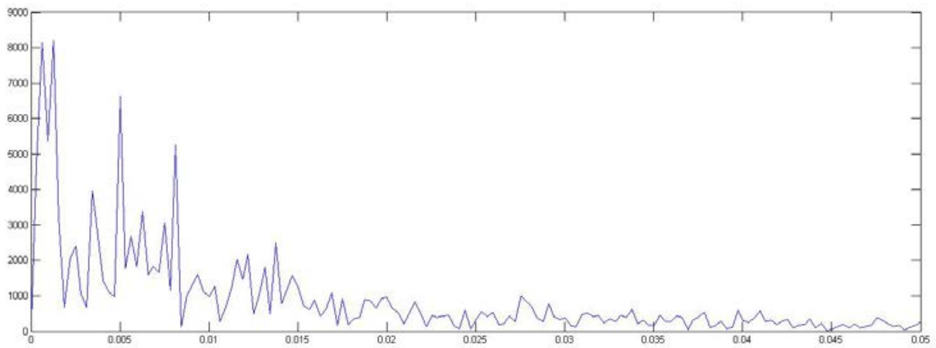
The annual pattern of inundation was identified in the FFT analysis of the full monitoring period, with the highest energy for each turlough corresponding to frequencies ranging from 312 to 355 days (Table 3.17

). The one exception to this was Lough Aleenaun, which showed the greatest energy at 209 days. This demonstrates the less significant impact the annual recharge cycle has on the flooding regime of Lough Aleenaun. This turlough regularly floods in response to heavy rainfall events throughout the year, and so the flooding regime is more sensitive to short term rainfall patterns and the effect of the annual recharge cycle is less pronounced.

In turloughs with unimodal flooding regimes, such as Ardkill, Coolcam and Termon, the dominant frequency is that of the annual flooding pattern (Fig. 3.59 a). In such cases the vast majority of signal energy is associated with lower frequencies representing the seasonal flooding pattern, and as the frequency is increased the peaks become poorly defined and greatly reduced in magnitude. In contrast, turloughs showing multimodal flooding regimes such as Lough Aleenaun had a more even distribution of energy across the frequency spectrum, with clearly defined peaked of comparable magnitude (Fig. 3.59 b). This reflects the greater frequency of flooding driven by higher flow capacities and lower transmission time within the aquifer.



(a) Ardkill



(b) Lough Aleenaun

Figure 3.59 FFT results for Ardkill (a) and Lough Aleenaun (b) analysed over entire monitoring period

The largest energy peaks were shown by those sites that experienced the greatest range of flooding, such as Blackrock, Caherglassan and Lough Coy, whereas shallower turloughs tended to have lower energy more evenly distributed across a range of frequencies. In order to quantify and compare the energy distribution across frequencies, the ratio of energy between the first and fifth peak was calculated. Table 3.17 shows the study sites arranged in order of descending energy ratio.

Table 3.17 Results of FFT analysis on longest available stage time series for 19 turloughs

Site Name	*Period (days)*		*Energy*		*Ratio of Energy 1st : 5th*
	1st Order	*5th Order*	*1st Order*	*5th Order*	
Termon	335	77.3	11316	568	19.9
Coolcam	335.9	53	12839	732	17.5
Lisduff	325.7	54.3	9607	559	17.2
Croaghill	335.6	91.5	13246	905	14.6
Ardkill	354.6	41.7	22704	1632	13.9
Brierfield	326	139.7	13368	1198	11.2
Roo West	339.5	45.3	9746	993	9.8
Rathnalulleagh	326	61.1	34638	3609	9.6
Skealoghan	325.3	54.2	7302	789	9.3
Caherglassan	349	65.4	34885	3900	8.9
Caranavoodaun	348.9	87.2	8244	1016	8.1
Knockaunroe	335	77.3	13295	1776	7.5
Lough Gealain	312.7	52.1	10917	1459	7.5
Carrowreagh	326	75.2	32431	4299	7.5
Lough Coy	349	65.4	39749	5355	7.4
Garryland	298.3	63.9	30391	4865	6.2
Blackrock	320.6	120.2	48214	10720	4.5
Turloughmore	320.6	120.2	9762	2546	3.8
Lough Aleenaun	209.2	41.8	8193	3371	2.4

This found that sites characterised by long duration flooding, such as Coolcam, Termon and Lisduff, showed the highest ratios, whilst sites which displayed a more disturbed regime, such as Lough Aleenaun and Turloughmore, the energy was more evenly distributed and so the ratio was substantially lower. This is as would be expected as in unimodal flooding regimes; the majority of energy is contained at low frequencies as the dominant flooding pattern is that of seasonal increase in recharge. In contrast, when the flood regime consists of more frequent flood events, the energy within the signal is understandably distributed across a greater range of flood frequencies. The ranking of sites using this ratio also corresponds well to the correlation analysis carried out earlier, where the correlation coefficients for Lough Aleenaun and Coolcam were used to plot the relative distribution of disturbance. Here, the rate at which energy dissipates at higher frequencies, given in the form of the ratio of 1st to 5th peak, provides a similar indicator of disturbance.

3.6.5.2 Tidal Effects on Turlough Water Level

The stage records of two turloughs in the Gort-Kinvarra chain, Garryland and Caherglassan, displayed a clear tidal response at lower water levels (Fig. 3.60). This tidal effect does not represent direct flow of seawater into the turlough, but rather a decrease in the hydraulic gradient in the system with the tide level even exceeding the turlough stage for brief periods. This was picked up in some of the springs in Kinvarra following high tide where the conductivity of water emerging from the springs rose significantly due to the cyclical saltwater intrusion into the system. To quantify this phenomenon and determine its extent across the flooding range, specific analyses were carried out on water level time series in 0.5 m depth intervals using FFT. Here, the frequency of interest is that of the tidal cycle which is typically 12 hours and 26 minutes which corresponds to a frequency of approximately 0.5 rads/hr. To limit the effects of noise caused by rainfall-induced recharge impulses travelling down the system, sections of the recession curve were extracted representing different ranges of flooding and analysed using FFT.

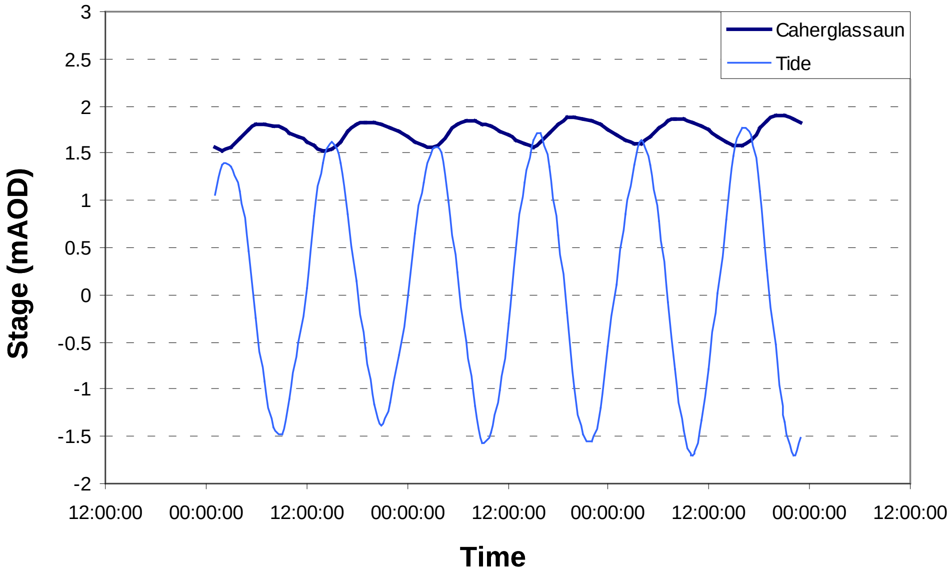
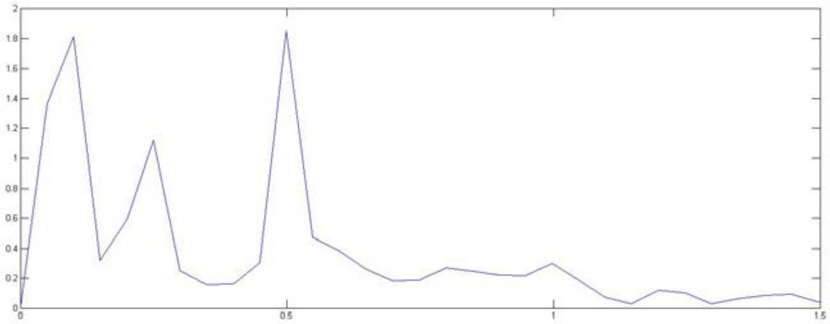
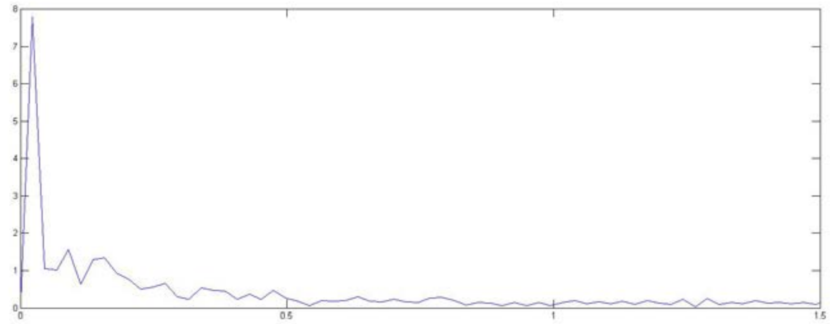


Figure 3.60 Comparison of water level in Caherglassan turlough and tide level

Caherglassan itself is located 8 km inland. Here, the power of the tidal frequency drops with increasing flood depth, representing the lessening effect tidal fluctuations have on turlough water level. A peak in the FFT plot at the tidal frequency of 0.5 rads/hr is clear in the lower range of depths, such as 2 to 2.5 mAOD (Fig. 3.61 a). At flood levels of above 6 mAOD the tidal effect is not clearly identified and so this was taken as the upper extent of tidal influence (Fig. 3.61 b). To determine the lag between the tidal cycles and water fluctuations within the turloughs themselves, time-lagged correlation was carried out between water level and tide time series using the sections of the time series where the tidal effect was most clear, namely the shallower flood depths. The maximum correlation coincided with a lag time of 5 hours, indicating the level of attenuation by the conduit system.



(a) 2 – 2.5 mAOD



(b) 6 – 6.5 mAOD

Figure 3.61 FFT data for Caherglassaun recession data for for 2 – 2.5 mAOD flood depth (a) and 6 – 6.5 mAOD flood depth (b)

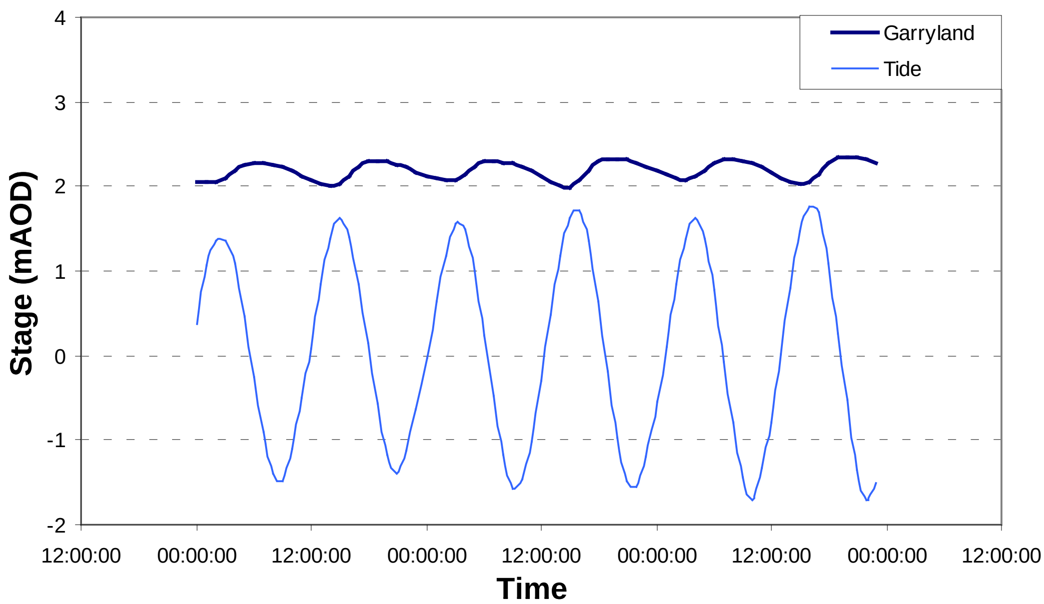


Figure 3.62 Comparison of water level in Garryland turlough and tide level in Galway Bay

Garryland is located up gradient of Caherglassan and approximately 10km away from Kinvarra, but also shows a marked tidal effect at low water levels (Fig. 3.62). FFT analyses on depth intervals revealed the upper limit on tidal effects to be approximately 6 mAOD, as was found for Caherglassan. A greater time lag was identified for Garryland than in Caherglassan, with the water level signal lagging behind the tide by 8 hours. This increase in lag time represents the extra degree of attenuation caused by the conduit system between Caherglassan and Garryland.

3.7 Modelling

3.7.1 Introduction

Turlough hydrology is driven by rainfall. Identifying the nature of the relationship between rainfall and water level is the primary objective of the hydrological modelling process. The aim of the modelling aspect of this research was to devise a generic hydrological model, capable of generating water level time series from rainfall and evapotranspiration records. Such a model, when used in conjunction with ecological and management data, can be used to evaluate the conservation status of turloughs as groundwater dependent terrestrial ecosystems (GWDTE). Long-term hydrological records can be synthesised from historic rainfall data and can be used to identify and quantitatively describe the critical long term hydrological factors which influence biological diversity within and among turloughs. By inference this allows ecological 'damage' or risk to be assessed. The models developed also have applications in flood risk assessment in karst areas,

Of necessity a decisive factor for any turlough hydrological model is minimal data requirements. Long term monitoring of turlough hydrology is limited to a group of turloughs around the Gort area, and even amongst this group continuous, consistent records are scarce. In general, there are little or no existing data for use in the generation or calibration of any long term hydrological model. Therefore the approach was to devise a conceptual model of turlough functioning based on data collected during this research and to use this as a basis for the generic model formulation. Firstly, a simple soil moisture deficit (SMD) model was developed to simulate the soil reservoir and evapotranspiration effects. Following this, two modelling techniques were devised to predict turlough water level using the output from the SMD model and parameters based upon field data and analysis: the *aggregated rainfall* model and the *general reservoir* model.

3.7.2 Model Efficiency

The specific criterion used to determine model efficiency or measures of fit, is dependent upon the requirements of the model in question. For example, the focus of the model may be to predict the peak, the duration of flooding or the recession behaviour. A number of performance statistics exist for assessing the goodness of fit of a hydrological model, as discussed in Naughton (2011). However, as the primary purpose of the modelling carried out as part of this research is to produce a reasonably good fit across the full range of flooding, rather than say the high water levels as would be used in flood risk assessment, the main model performance indicator used in this research is the Nash–Sutcliffe criterion for efficiency.

3.7.3 Soil Moisture Deficit Model

Soil cover within a catchment controls the quantity and rate at which infiltration occurs into the karst aquifer system. Water is contributed to the system in the form of precipitation, and is lost through a combination of evaporation and transpiration by vegetation cover, i.e. evapotranspiration (E_t). The soil itself can retain a certain amount of water under gravity, known as its field capacity. When the water supplied to the soil exceeds the field capacity the soil becomes saturated, with excess precipitation converted into overland flow or percolation. If there is insufficient rainfall to replenish the soil moisture lost over time through E_t, a deficit develops within the soil. This is known as soil moisture deficit (SMD) and is defined as the amount of rainfall required to restore the soil to field capacity (Shaw, 1994).

Evapotranspiration (E_t) does not always occur at the potential rate but decreases with increasing SMD. As the moisture level in the soil drops it is no longer available to plants with shallower root systems and so the rate of E_t reduces accordingly. Penman (1950) introduced the idea of a root constant which defined the amount of moisture that could be extracted without difficulty by a given vegetation type (Shaw, 1994). Different vegetation types were assigned root constants based on root depth and their ability to easily extract soil moisture. For example, permanent grassland has a root constant of 75 mm while woodland, with its associated deeper root systems, has a root constant of 200 mm. It is assumed that E_t occurs at the potential rate for a given vegetation type while the SMD is less than the root constant plus 25 mm. As the SMD increases it becomes more difficult for vegetation to obtain water from the soil leading to actual ET eventually dropping to zero. If SMD reaches a critical value, known as the permanent wilting point, the vegetation wilts and dies.

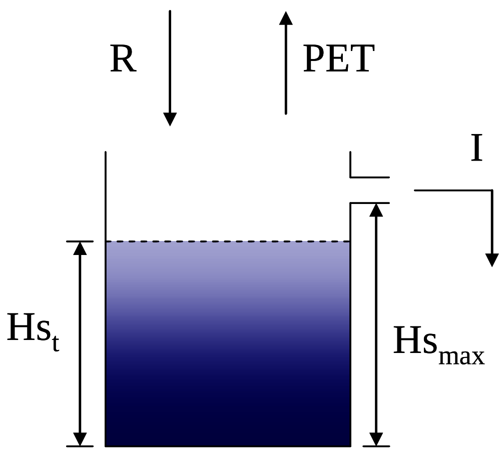


Figure 3.63 Conceptual SMD reservoir model

Where:

Hs_t is the level in the reservoir at time t (mm)
Hs_{max} is the soil field capacity (mm)
R is rainfall (mm)
PET is potential evapotranspiration (mm)
I is infiltration/percolation (mm)

An SMD reservoir model provides a simple way to represent the differences in soil moisture conditions throughout the year and to calculate percolation to groundwater (Fleury *et al.*, 2007). This is conceptually represented as a linear reservoir with the fluctuation in levels dependent on the reservoir inputs and outputs, namely rainfall as input and potential evapotranspiration and percolation as outputs. A level of zero corresponds to the base of the reservoir (Fig. 3.63). The reservoir has a maximum level that is defined by the soil field capacity parameter Hs_{max}. Hs_{max} is regarded as a characteristic of the catchment and varies with overburden thickness, soil and vegetation type. For example in areas where rock outcrop is close to or at the surface, such as in the Burren, the value of Hs_{max} would be close to zero as the soil would have very little capacity for storing moisture, and so a high percentage of rainfall percolates throughout the year. If the level in the reservoir exceeds the soil capacity

($Hs_t > Hs_{max}$), the amount by which it is exceeded equates to the percolation. As the lower limit of the soil reservoir is zero, Hs_{max} also limits the maximum soil moisture deficit that may exist, thus preventing the reservoir from becoming excessively under-saturated.

The reservoir level at time t (Hs_t) is calculated by a mass balance for each time step and given by:

$$Hs_t = Hs_{t-1} + R - PET - I \qquad \textbf{(Equation 3.1)}$$

The operation of the soil reservoir is demonstrated in the scenarios shown in figure 3.64 a and b. In figure 3.64 a the reservoir level Hs_{t-1} at 50 mm is below field capacity. Given rainfall and PET during the time step are 20 mm and 5 mm respectively, the change in level ΔHs_t is +15mm. As the new level is still less than Hs_{max} infiltration is zero. In figure 3.64 b the reservoir level Hs_{t-1} is equal to Hs_{max} at the beginning of the time step. Again, the change in level is +15 mm. As this would exceed the upper limit of the reservoir, the excess becomes an infiltration, or percolation to groundwater, of 15 mm.

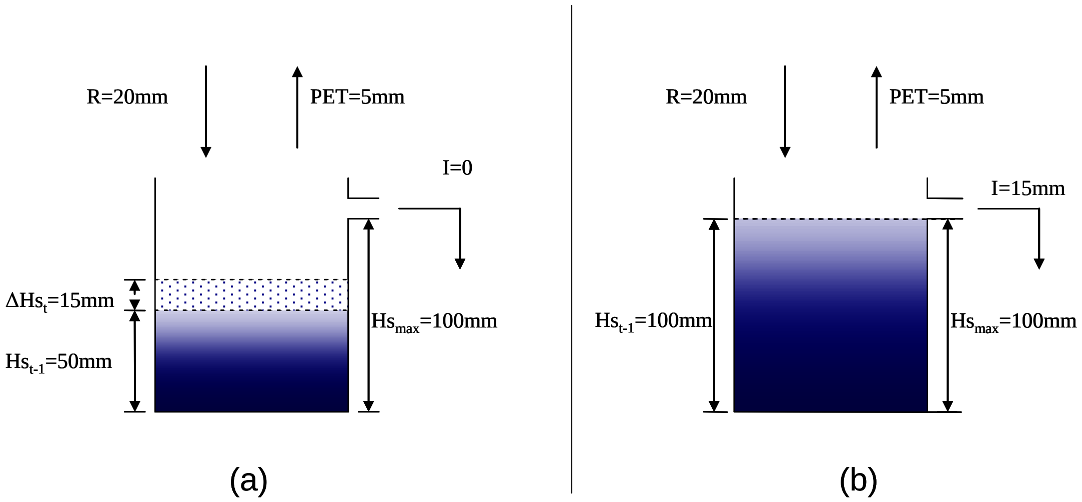


Figure 3.64 Operation of the soil reservoir under soil moisture deficit (a) and field capacity conditions (b)

Once the soil reservoir is near capacity, typically during the winter months in temperate climates, the value of Hs_{max} has little impact on the net infiltration. Where Hs_{max} has a greater effect is during dry periods. A low value for Hs_{max} can result in the model predicting more numerous low level flood events, as relatively little rainfall is required to produce infiltration which in turn causes flooding. Similarly, the onset of flooding would be predicted to occur earlier in the turlough basin for lower Hs_{max} as less rainfall is required to bring the soil reservoir up to field capacity. Hs_{max} has little or no buffering during the inundation period as dry periods are too short and PET too low for the deficit to become significant. The value of Hs_{max} for each turlough which produced effective runoff coincident with the onset of flooding, and also gave the highest model efficiency, was used throughout the modelling process.

Daily potential evapotranspiration (PET) data calculated using the FAO Penman-Monteith equation were obtained from Met Eireann synoptic stations located in Shannon Airport (Co. Clare), Knock Airport (Co. Mayo), and Birr (Co. Offaly). Knock data were taken to be representative of evapotranspiration conditions for the northern turloughs while Birr PET data were used for turloughs located in counties Galway and Clare. A program to simulate the operation of the SMD model was written in MATLAB.

3.7.4 Aggregated Rainfall Model

Previous analysis has shown a strong relationship between cumulative rainfall and volume during the filling period, with Pearson Product Moment correlations of >0.95 established. Consequent to this relationship, the possibility of using cumulative rainfall as the basis for a generic turlough hydrological model was explored. While this relationship was strong during the filling phase, cumulative rainfall continuously increases and so a method was required to incorporate a recession element into the cumulative rainfall model. The methodology devised is based on the idea that the filled turlough volume is dependent on the cumulative rainfall over a defined period, hereafter referred as to as the aggregation period $\boldsymbol{T}$. Thus, the aggregated rainfall model is founded on the notion that volume in the turlough at time $\boldsymbol{t}$ is a function of the cumulative rainfall over the preceding $\boldsymbol{T}$ days.

The modelling methodology consists of summing rainfall over successive consecutive intervals, and correlating the subsequent time series with volume. The period over which the rainfall is summed is the aggregation period $\boldsymbol{T}$. It was found that the correlation coefficient increased with increasing $\boldsymbol{T}$ towards a maximum value, and then decreased for higher values of $\boldsymbol{T}$. A linear regression between the aggregated rainfall and turlough volume time series gives a linear equation of the form:

$$V = S + \alpha * AR \qquad \textbf{(Equation 3.2)}$$

Where:

$\boldsymbol{V}$ is modelled volume (m^3)
$\boldsymbol{S}$ is karst storage capacity (m^3)
$\boldsymbol{\alpha}$ is contributing area (m^2)
$\boldsymbol{AR}$ is aggregated daily rainfall (m)

This methodology produces three characteristic parameters for each turlough:

***Aggregation period T*:** An indicator of the memory of the system, or how long water is retained within the turlough, and so provides an indirect measure of flood duration. A large aggregation period implies long flood duration with a lengthy recession, while a smaller value indicates a hydrological regime with rapid filling and emptying.

***Storage capacity S*:** This is the volume of water required to have built up in the karst flow system before flooding occurs in the turlough basin. The storage capacity represents both the storage and the flow capacity of the underlying flow system, and is a characteristic of the karst aquifer in which the turlough is located as well as being indicative of the hydrological operation of the turlough. A high storage capacity implies that significant quantities of rainfall falling within the turlough contributing area do not actually enter the turlough, but are taken up by storage or accommodated by the karst flow system. The reverse of this, a low storage capacity value, implies that the vast majority of rainfall within the contributing area passes directly through the turlough. In this scenario the turlough would operate like a surface reservoir, with discrete input and output points whose operation are dependent upon the prevailing hydrological conditions such as rainfall and water level within the turlough.

***Contributing area α*:** The contributing area $\boldsymbol{\alpha}$ defines the minimum magnitude of the zone of contribution and so provides a lower limit for the required catchment area. This is the minimum topographic area required to supply the recorded water volume within the turlough. The actual scale of the catchment area could be much greater than that specified by the contributing area α, as it is assumed that all effective rainfall within this area enters the turlough. It is a fitted parameter of the model. This would not be the case, as some recharge would be retained in storage within the matrix and fracture porosity of the karst bedrock. Depending upon the hydrological operation of the turlough and the associated karst flow system, the groundwater entering the turlough may only represent a fraction of the total recharge with the remainder potentially bypassing the turlough basin altogether.

A number of simplifying assumptions are made to assist in the application of this modelling methodology. The first is that of linearity; it is assumed that a direct proportional relationship exists between rainfall and volume, i.e. that 1 mm of rainfall at time t results in an increase in volume of α m^3 (0.01 x α) irrespective of existing hydraulic conditions. Similarly at time $t + T$ the volume decreases by α m^3 (Fig. 3.63 a).

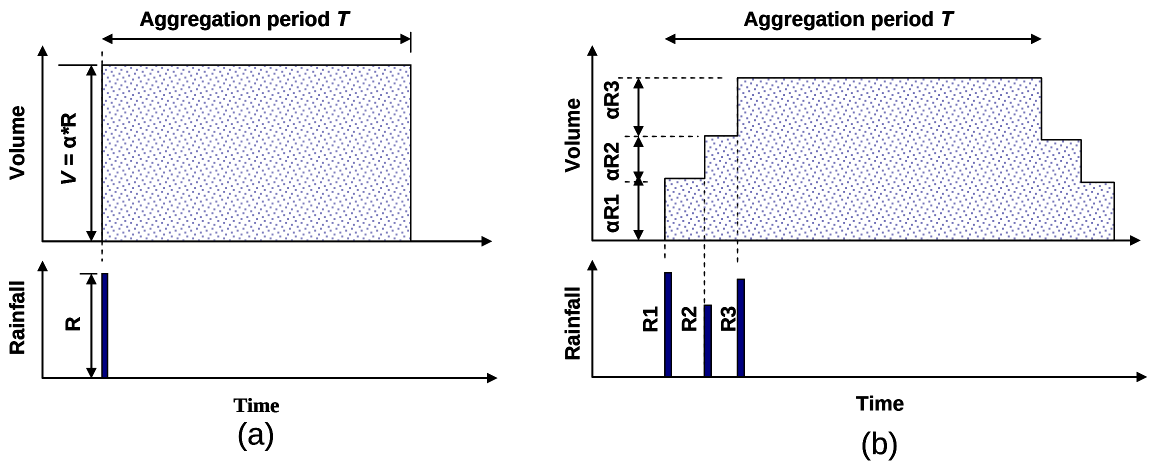


Figure 3.63 Linear relationship between rainfall and volume (a) and the principles of instantaneous inflow and superposition (b) used in the rainfall aggregation model

The second assumption is that of instantaneous inflow, where 100% of rainfall enters the turlough during the time step in which it occurred. This means that the rising limb of the hydrograph increases in a series of steps, with the magnitude of each volume step proportional to the magnitude of the associated rainfall event (Fig. 3.63 b). Due to the heterogeneous nature of karst aquifers, rainfall will infiltrate much faster in highly karstified areas than in adjacent, perhaps less karstified areas. The result of this characteristic is a lag between a rainfall event and its full extent being realised within the turloughs, shown in the delay between a rainfall event and the associated peak water level. The parallel assumption for the recession limb means that once a rainfall event is no longer within the aggregation period, it is not included in the regression. As a result, the recession limb of the volume hydrograph drops in a series of discrete steps as the aggregation period for each rainfall event elapses (Fig. 3.63 b).

It is assumed that the contributing area remains the same for all hydrological conditions, and that once the karst storage capacity has been reached, 100% of effective rainfall in the contributing area enters the turlough. Catchment areas in karst regions can vary significantly with changing hydrological conditions, as various flow systems may only be operational within a certain range of water levels. This situation may often not be the case within karst aquifers, with multiple groundwater flow systems operating and interacting during different hydrological conditions, and even may include the amalgamation of adjacent catchment areas during periods of high groundwater levels. This may also occur within the basin itself; an example being estavelles located above the base of a turlough no longer functioning as sinks once the water level recedes below their threshold. Also, where a flow system exists beneath the turlough a significant proportion of the flow potentially bypasses the turlough altogether, and so the contributing area represents a fraction of the area from which total floodwater is derived.

3.7.4.1 Modelling Methodology

Initial trials of this modelling technique were carried out for all turlough topographies using daily rainfall data as the input. The modelling methodology is discussed in detail in Naughton (2011).

The first model run was carried out using rainfall data as the input for all study sites. This run gave an average maximum correlation of 0.78 and standard deviation of 0.1. The range of aggregation period values showed the diversity in hydrological regimes, from a low of 12 days for rapidly responding Lough Aleenaun up to 203 days for much slower Termon Lough. In terms of modelling performance, this run yielded mixed results, with Nash – Sutcliffe efficiencies varying greatly from only 32% for Brierfield, Co. Roscommon, to 81.9% for Lough Aleenaun, Co. Clare (Fig. 3.66 d). Despite these low efficiency values, the general seasonal pattern of flooding was picked up across the range of flooding regimes, with major flood events generated during the winters and individual peaks associated with heavy rainfall events visible in the modelled output (Fig. 3.66 a-d). However, large errors were shown in the relative magnitudes of the peaks, both within each flooding season and between flooding years. Also, as would be expected since the effects of evapotranspiration were not considered, substantial flood events were predicted during the summer where no such event took place (Fig. 3.66 b, c).

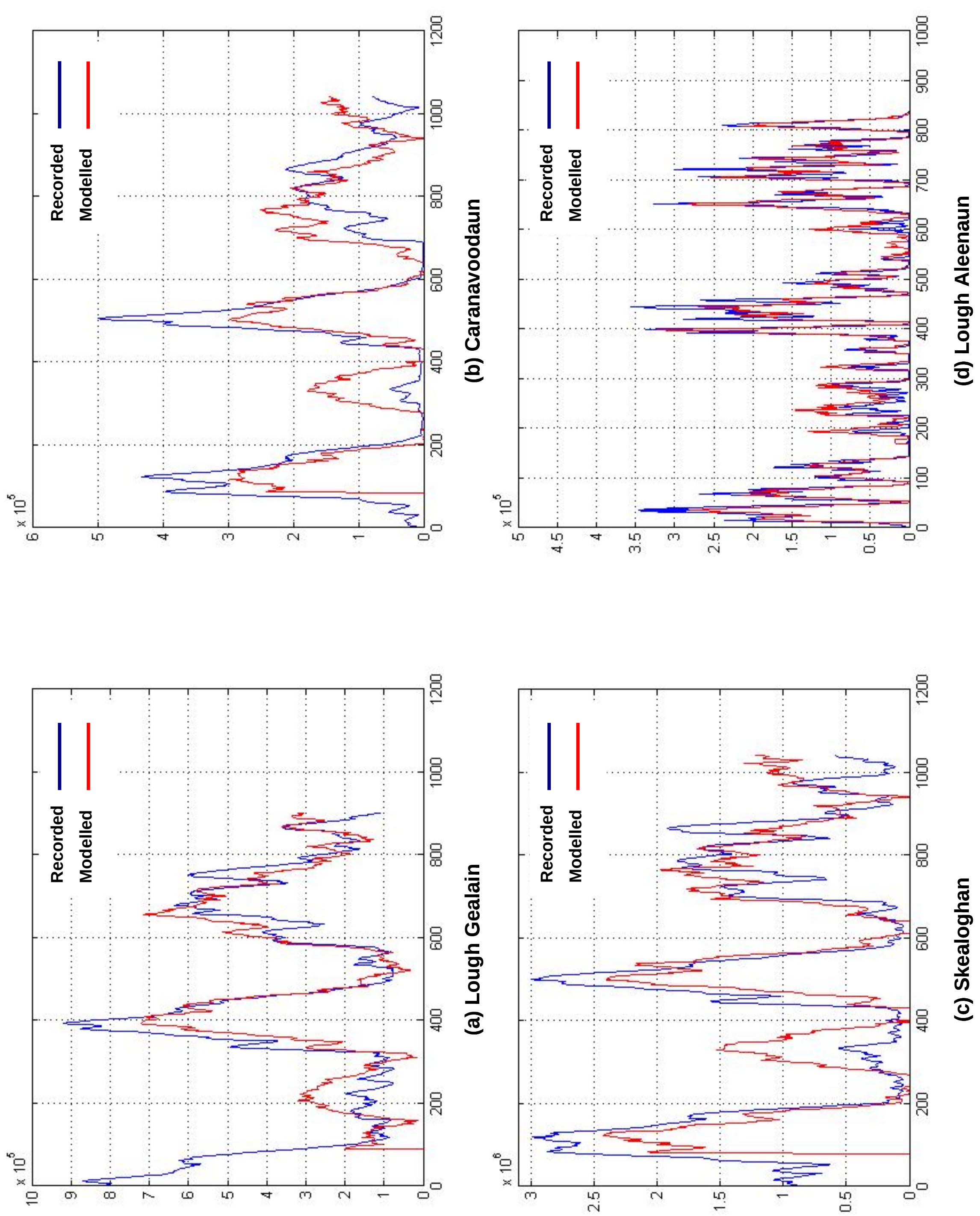


Figure 3.66 Aggregated rainfall model for Lough Gealain (a), Caranavoodaun (b), Skealoghan (c) and Lough Aleenaun (d)

The modelling process was then repeated using effective rainfall (rainfall – potential evapotranspiration) as the model input. This resulted in an average model efficiency increase of approximately 16%, up to a mean of 77.7%. In the case of Coolcam and Croaghill, the increases were as much as 43% and 37% respectively. The inclusion of evapotranspiration effects served to damp the response to rainfall during the warmer months, and so reduced the appearance of anomalous flood events during the summer. As this also increased the magnitude of the higher peaks relative to the lower ones, the peak volume error following regression was also reduced. This can be seen in the example shown for Caranavoodaun turlough, Co. Galway (Fig. 3.67 a, b). A large over-prediction error can be seen in the model using rainfall as input due to the predicted summer flood event after approximately 300 days (Fig. 3.67 a). The error associated with the same event is greatly reduced when effective rainfall is used as input (Fig. 3.67 b). Improvements can also been seen in both peak volume and timing estimation.

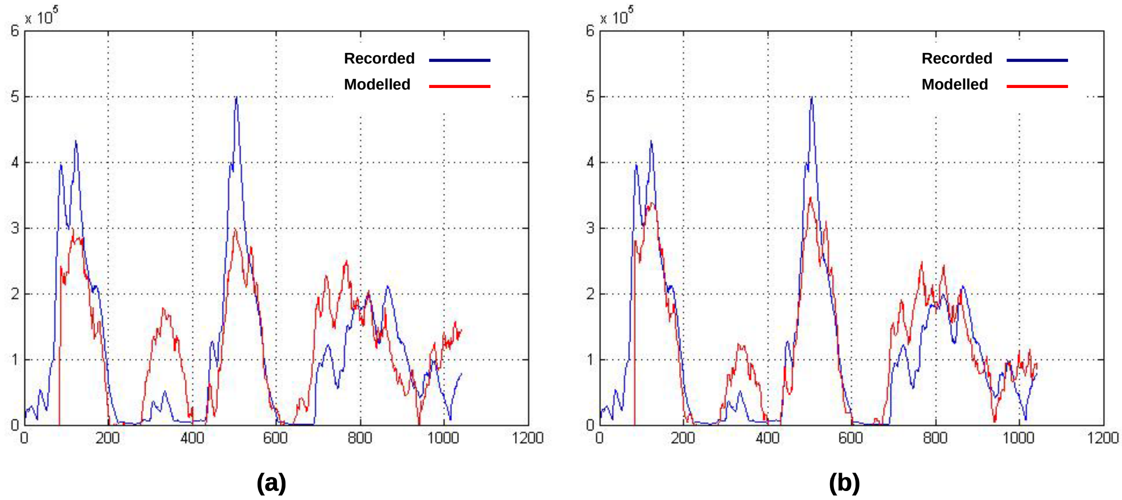


Figure 3.67 Aggregated rainfall model for Caranavoodaun using (a) rainfall and (b) effective rainfall as input

Next, infiltration time series were generated for each turlough using the SMD model for Hs_{max} values from 10 up to 60 mm, in increments of 10 mm. The revised form of the modelling equation thus becomes:

$$V = S + \alpha * AI_{Hs\,max} \quad \textbf{(Equation 3.3)}$$

where ***AI*** is the aggregated infiltration generated using a maximum allowable SMD of Hs_{max}. It was unnecessary to test values above 60 mm as deficits rarely if ever reached this level using the SMD model. Also, with Hs_{max} below 10 mm the SMD reservoir output rapidly approaches effective rainfall which had already been used. The variation in Hs_{max} had little impact on the turlough behaviour during the winter months, as high rainfall and low evapotranspiration meant that only a minimal soil moisture deficit build up during this period and rarely reached the defined maximum. The main changes in flooding behaviour were shown during the summer months. Lower values of Hs_{max} caused a slightly higher flooding frequency, but the increase in storage capacity generated during the regression tended to partially counteract this. It is also clear that the role of evapotranspiration in turlough response decreases with the more rapid response to rainfall.

3.7.4.2 Model Results

The best-fit model parameters for all turloughs using the longest available hydrological record, in descending order of efficiency, are given in Table 3.18**Error! Reference source not found.**. Average efficiency gave a mean of just over 81%, which rose to 86% when the turloughs around Castleplunket, Co. Roscommon were discounted (Rathnalulleagh, Carrowreagh and Brierfield). The Hs_{max} values which corresponded to best model fit varied from 10 up to 60 mm, while the aggregation periods ranged from 10 to 173 days. Plots showing recorded and predicted volume time series are given in Naughton (2011).

Table 3.18 Best-fit aggregated rainfall model results with corresponding maximum soil moisture deficit Hs_{max}, aggregation period T, storage capacity S and contributing area α

Site Name	*Max Correlation Coefficient*	*Max Efficiency (%)*	*Hs_{max} (mm)*	*T (days)*	*S (m^3)*	*α (m^2)*
Coolcam	0.97	93.4	40	163	-267581	3113
Ardkill	0.96	92.6	10	135	-135397	1075
Croaghill	0.95	91.4	50	120	-79572	1481
Knockaunroe	0.94	89.7	20	82	-286320	2720
Lough Gealain	0.94	89.2	10	81	-53264	1297
Lisduff	0.94	89	60	90	-45514	2013
Skealoghan	0.93	88.6	10	73	-57898	827
Lough Aleenaun	0.94	88.6	30	10	-6972	2070
Caranavoodaun	0.93	87.9	60	80	-63696	767
Caherglassan	0.93	87.7	20	66	-425394	6849
Termon	0.94	87.7	60	176	-219354	1342
Garryland	0.91	83.9	20	67	-336211	4542
Lough Coy	0.91	82.2	60	44	-19709	5215
Blackrock	0.88	79.9	10	38	-677436	13127
Turloughmore	0.85	75.9	30	15	-36222	1620
Roo West	0.85	73.6	30	82	-148322	1197
Rathnalulleagh	0.80	66	20	85	-154359	1399
Brierfield	0.74	54.2	50	144	-182895	1616
Carrowreagh	0.70	49.3	10	108	-69695	470

The aggregated rainfall model showed some good results for every type of turlough flooding regime. The highest efficiency was shown by Coolcam, Co. Galway, a turlough with one of the longest flood durations of any site (Fig. 3.77). The modelled volume hydrograph shows a good general fit for as well as picking up the timing and magnitude of volume peaks in all three hydrological years.

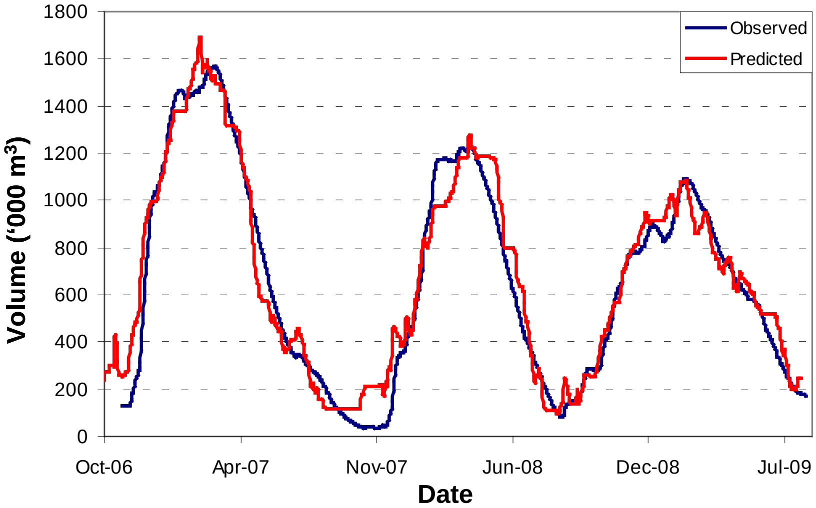


Figure 3.77 Aggregated rainfall model results for Coolcam turlough, Co. Galway

Skealoghan turlough, Co. Mayo, has a flooding regime somewhere in the mid range of frequency and duration. The efficiency of 88.6% shows the general pattern of flooding was clearly picked up (Fig. 3.78). However, the length of the best-fit aggregation period, at 73 days, meant that the modelling procedure was unable to accurately represent the short-term level fluctuations shown by the turlough. While peaks do exist within the modelled time series that correspond to the recorded peaks, the lack of sensitivity means that the model underestimates the rate of recession following the maxima. The effect is less prominent during the main recession, but did lead to substantially smaller predicted peaks in 2006/2007 and 2008/2009. In effect the model may be over – simplifying the recharge process in this case.

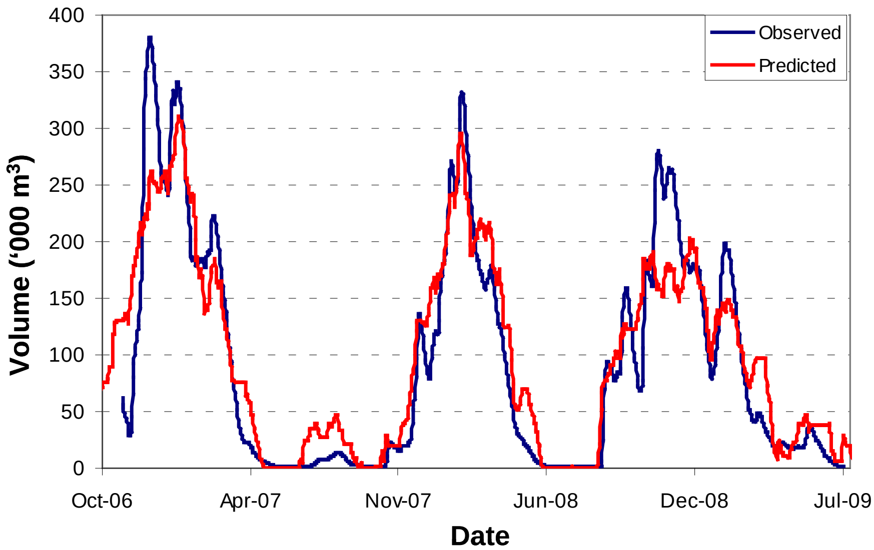


Figure 3.78 Aggregated rainfall model results for Skealoghan turlough, Co. Galway

As the aggregation period was further reduced for the more responsive sites, the predicted response was able to pick up short term fluctuations in volume. The best example of this is shown by Lough Aleenaun, Co. Clare. Here, the low aggregation period of 10 days allows the high frequency flooding events to be represented within the predicted hydrograph (Fig. 3.79). It also showed the low memory of the system which is indicative of low residence times within the turlough basin.

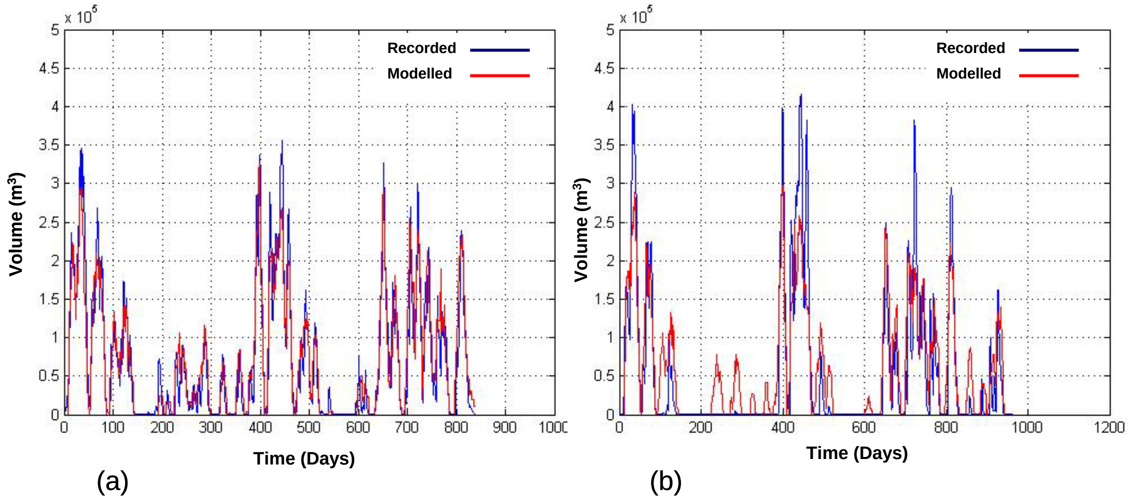


Figure 3.79 Aggregated rainfall model for Lough Aleenaun, Co. Clare (a) and Turloughmore, Co. Clare (b)

The modelling process has highlighted a key difference in the operation of the two most responsive turloughs, Turloughmore and Lough Aleenaun. Both turloughs show a comparable aggregation period, 10 days for Aleenaun and 15 days for Turloughmore, but model efficiency is substantially higher for Aleenaun at 88.6% compared to 75.9%. The cause of this is clearly visible in plots of the modelled results (Fig. 3.79 a, b). These turloughs show very similar hydrological behaviour during the main flooding season, with rapid filling and emptying occurring in response to heavy rainfall events. However, their behaviour diverges during the drier summer months. Lough Aleenaun shows a flood response to rainfall events throughout the year (Fig. 3.79 a); whereas Turloughmore has a much lower frequency of flooding during dry periods (Fig. 3.79 b). The magnitudes of the higher volume peaks are also substantially under-predicted while flood frequency is over-predicted in the case of Turloughmore.

This distinction in behaviour points to a difference in the flow capacity of the respective systems underlying each turlough. The response of Lough Aleenaun to all major rainfall events suggests an extremely low bypass flow capacity, or even its operation as a reservoir with distinct inputs and outputs. The flow system containing Turloughmore, in contrast, is able to accommodate considerable flow before Turloughmore becomes flooded. The presence of additional storage within the Turloughmore system is demonstrated by the higher storage capacity value of 36222 m^3, compared to only 6972 m^3 for Lough Aleenaun. This is supported by features observed within and surrounding each turlough. In Lough Aleenaun, a channel runs in an arc from the base of the central rock spring rises at the base of the central rocky outcrop on the eastern side before sinking at the western end of the outcrop (Fig. 3.80). When flooding occurs it expands out from this channel until the entire basin is inundated. This channel is also the last area to drain, and often retains a small amount of water throughout the year.

Figure 3.80 Arcing channel within Lough Aleenaun, Co. Clare

In Turloughmore, there are no such features indicating a continuous inflow of water into or through the turlough during dry periods. The behaviour of a depression directly beside Turloughmore, which has a lower base elevation, gives an insight into the groundwater flow conditions in the vicinity of the turlough. Flooding has been observed in the adjoining depression both in the summer, when no flooding occurred in Turloughmore, and during the winter after complete recession has occurred in Turloughmore. The summer flooding demonstrates the existence of a flow path that bypasses Turloughmore and feeds directly into this depression during lower flow periods. This depression acts as additional storage within the system, offsetting the effects of rainfall and limiting the occurrence of flooding within Turloughmore. During the winter, the depression damps the effects of rainfall during the initial filling phase, but when it reaches capacity later it ceases to damp the inflow signal and so the flow response into Turloughmore increases. Therefore, as the aggregated rainfall model represents the behaviour of the turlough using a single linear relationship, the overall effect of the neighbouring depression is to over-predict flood events and under-predict inflow at higher volumes. In Lough Aleenaun there is no such storage capacity, and so flooding occurs more frequently and the linear relationship between rainfall and inflow provides a better approximation throughout the year.

Clearly, the worst results achieved were shown by the subset of turloughs located near Ballintober, Co. Roscommon. As all three used data from the same rain gauge, the data integrity of the rainfall record was first checked to ensure this was not the cause of the errors. The rainfall time series used was from a rain gauge installed as part of this project, located only 3 km away from the sites. This was compared to data from the Met Eireann station in nearby Roscommon Town, and both showed extremely similar rainfall patterns and intensities so that data error did not explain the poor model performance. The Roscommon subset showed among the highest levels of temporal variation in volume. Carrowreagh, for example, showed a 50% reduction in maximum volume year on year during the monitoring period. The yearly decrease in depth was relatively much less, with only a 14% decrease from 2006/2007 to 2007/2008 and 10% from 2007/2008 to 2008/2009.

A possible explanation here is that the level in the turloughs, and associated volumes, are responding to the head within the subsurface flow systems and the interactions between the turloughs. In order for a turlough to fill, there must be a hydraulic gradient towards the turlough. The rate at which the turlough fills, and the level to which it rises, is dependent upon the interaction and the head. If this were the case, a smaller decrease in head would cause a proportionally much greater change in volume due to the depth-volume characteristics of each turlough. The water entering from the underlying system would depend upon the relative levels of the two. But the consequential effect is a massively lower volume within the turlough, as draining occurs.

3.7.4.3 Conclusion

The aggregated rainfall model showed that reasonable results could be obtained using a simple generic model based upon the correlation between turlough volume and rainfall. Despite it limitations, it provided a reasonable estimate of turlough water volume, and associated stage, based upon rainfall and evapotranspiration records and demonstrated that, at least during the rising limb of the volume hydrograph, the interaction between effective rainfall and volume could be relatively successfully modelled using a linear relationship. The methodology also generated a set of characteristic hydrological parameters for each turlough. These descriptors for the first time allow the comparison of turloughs as hydrological entities, based on quantitative recorded data rather than qualitative descriptions. The low data requirements and simplicity of use of this model also makes it suitable for use as a classification system for turlough hydrology. Moreover, the model demonstrates the strong correlation between net rainfall and water level response confirming the relatively rapid recharge as a characteristic feature of turlough hydrology. Simple though it is, the model also encapsulates and supports the basic conceptualisation of a turlough as a reservoir.

3.7.5 Reservoir Modelling

Using the insights gained during the hydrological analysis process, a more refined version of the reservoir modelling technique was utilised for a subset of turlough sites. Reservoir ("storage-release") modelling is particularly well suited to the modelling of turloughs, as they physically act as reservoirs for excess recharge during the winter months. This approach conceptualises the turlough as a reservoir with the same physical characteristics as the turlough being modelled (stage-volume-area relationships), and where the hydrological signature of the turlough is controlled by the nature and functioning of the reservoir inflows and outflows. The objective of this modelling approach is to identify the characteristic equations governing the flow rates, and therefore the volume and stage, and to enumerate the relationship these hold with rainfall in order to accurately predict turlough hydrological regimes. Figure 3.81 outlines the elements of the modelling process:

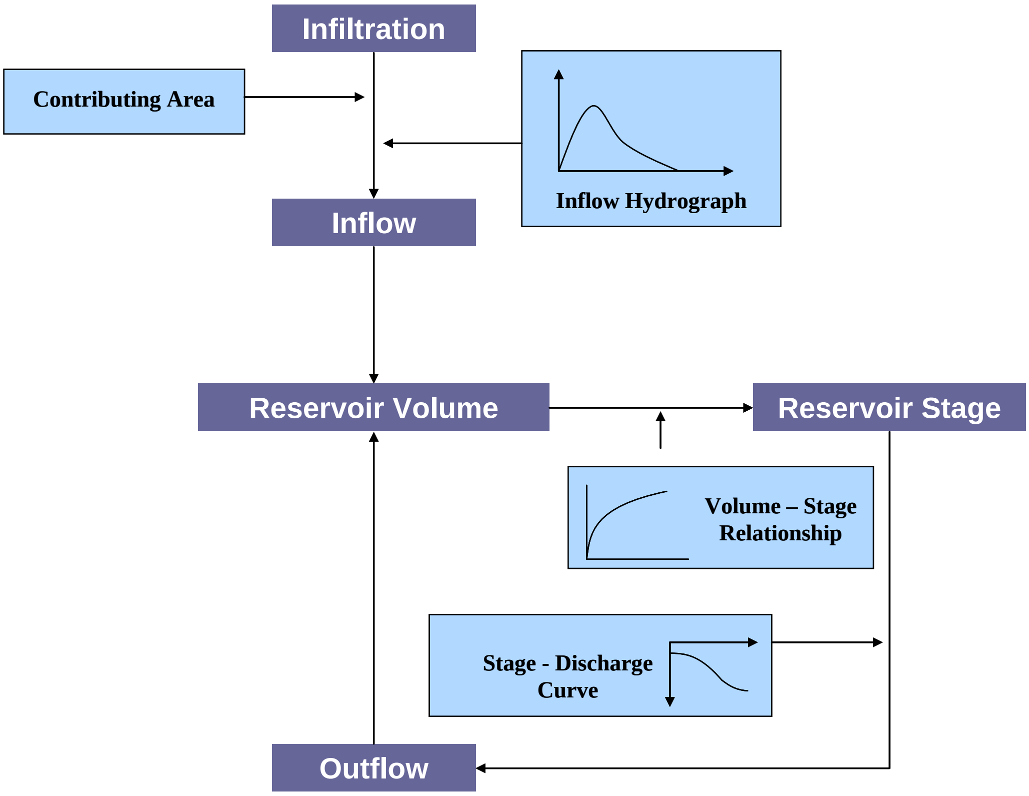


Figure 3.81 Flow chart for reservoir modelling methodology

The light blue boxes in figure 3.81 highlight the parameters that control the operation of the reservoir at each time step. The contributing area and inflow hydrograph transform infiltration or groundwater recharge into reservoir inflow. Reservoir outflow is a function of stage, and so a volume–stage relationship is required to transform volume into stage. The outflow itself is then calculated using the stage–discharge curve, and used to calculate the volume at the next time step. The derivation of these parameters begins with reservoir outflow and the stage–discharge curve.

3.7.5.1 Reservoir Outflow

The first step in the modelling process was the identification of the equations governing reservoir drainage or outflow. This was based upon the outflow analyses carried out in Section 3.5, where it was shown that a stage - discharge curve defining a turlough's maximum drainage capacity was formed by the maximum outflow values across the flooding range. This curve defines the characteristic relationship between stage and turlough discharge at peak outflow conditions (Fig. 3.82). Using this relationship, a potential outflow time series was calculated by applying the stage - discharge relation to the stage time series. This outflow time series represents the hypothetical maximum outflow that would occur given the water level recorded within the turlough.

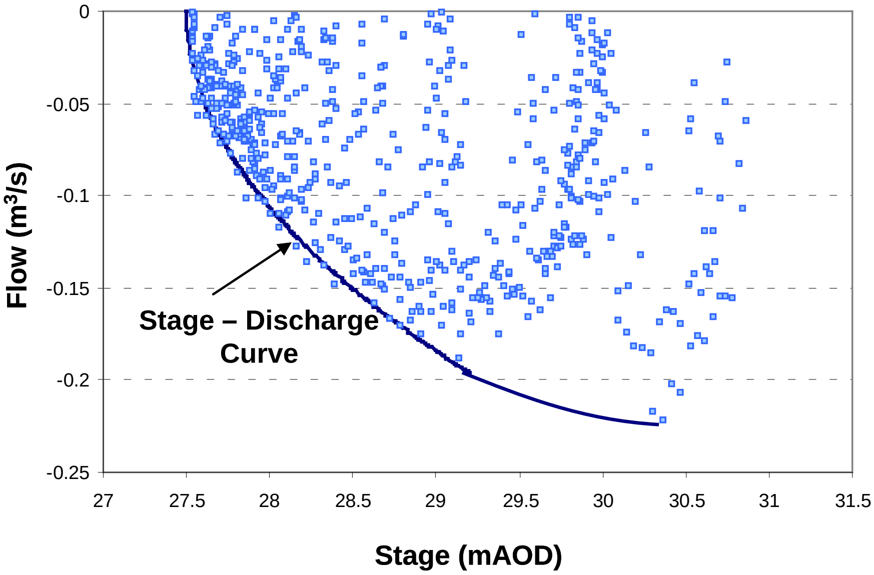


Figure 3.82 Stage-discharge curve for Lough Gealain, Co. Clare

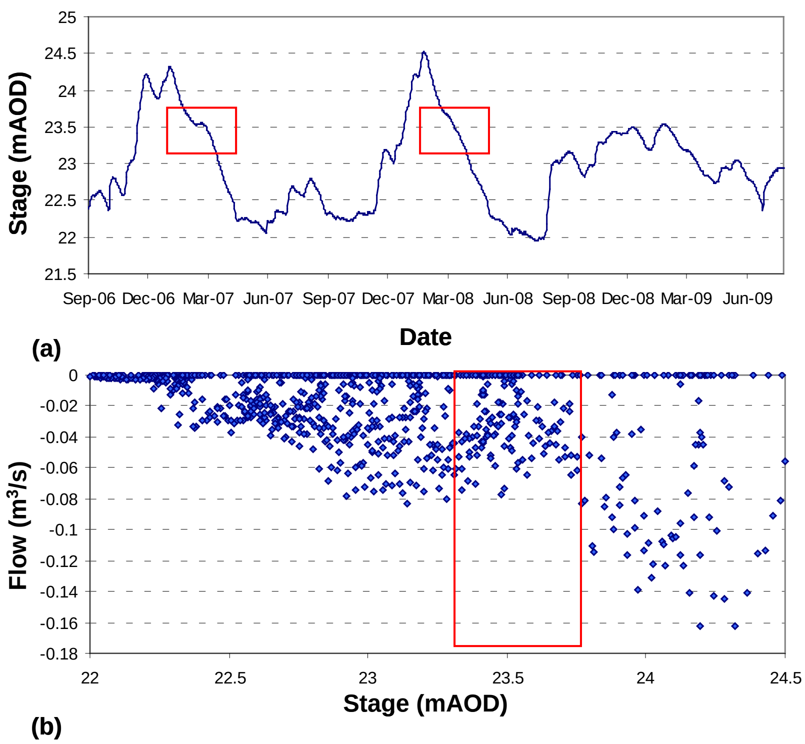


Figure 3.83 Stage time series (a) and associated stage-discharge plot (b) for Caranavoodaun turlough, Co. Galway

As described in Section 3.5, the complexity of stage - discharge curves varied significantly between turloughs. The form of the curve itself also varied, with some showing a convex (stage power less than 1) and others a concave (stage power greater than 1) curve. Some sites, such as Lough Gealain and Ardkill, showed a smooth, well defined stage-discharge curve across the full range of flooding. Other turloughs had a number of discontinuities in the curve, with distinctive discharge curves applying within different flood ranges. These discontinuities are possibly indicative of multiple zones of groundwater flow in operation at different levels within the turlough basin, for example where a swallow hole ceases to operate at lower water levels when it becomes disconnected from the main water body. Another cause of discontinuities in the curve is a lack of data at certain intervals within the range of flooding. An example of this can be seen in Caranavoodaun (Fig. 3.83 a, b). During both the 2006/2007 and 2007/2008 hydrological years, rainfall events disrupted the recession in the stage interval centred around 23.5 mAOD (Fig. 3.83 a). This resulted in a lack of definition in the stage-discharge curve at (Fig. 3.83 b).

3.7.5.2 Reservoir Inflow

The next step in the reservoir modelling process was the derivation of a relationship between effective rainfall or infiltration and turlough inflow. The basic principle on which this step is based is that the volume response recorded in the turlough is the resultant of a combination of inflow and outflow signals. It follows then, that since the net change in volume (ΔV) at each time step (Δt) is the sum of inflow (Q_{in}) and outflow (Q_{out}) during that step, and with the stage-discharge curve defining the maximum possible outflow at each time step, then inflow is given by:

$$\frac{\Delta V}{\Delta t} + Q_{out} = Q_{in} \quad \textbf{(Equation 3.4)}$$

As is clear from the above equation and can be seen in figure 3.84, the inflow signal follows closely that of the net flow signal, but is offset upwards at each time step by the magnitude of the outflow.

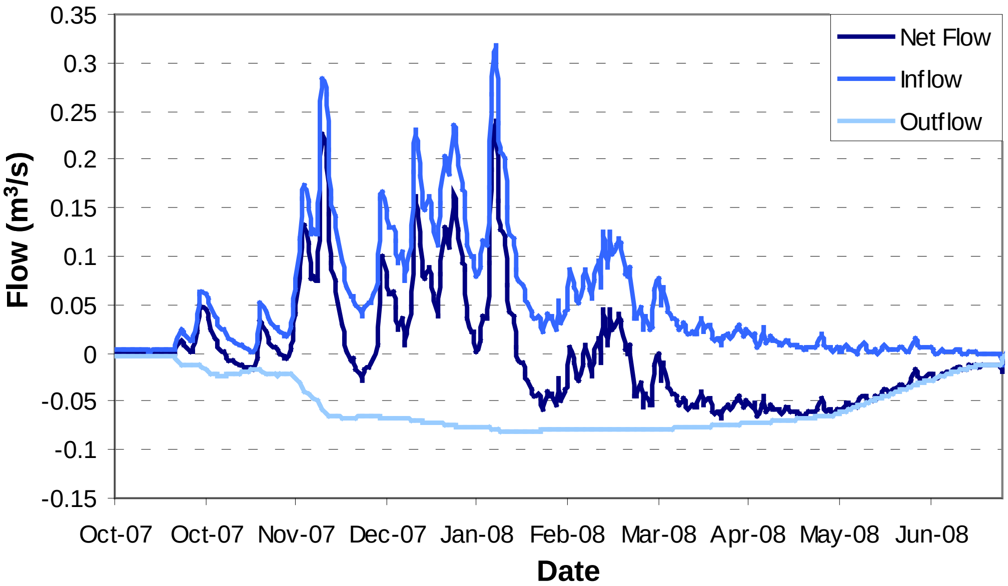


Figure 3.84 Plot of net flow, hypothetical outflow and inflow for Ardkill turlough, Co. Mayo

The next step was to derive a connection between infiltration and this notional inflow. To achieve this, a development on the strong correlation between cumulative rainfall and net inflow identified in Section 6 was utilised. Rather than using gross rainfall as an input, the

SMD reservoir model was once again employed here since, as well as providing a more realistic representation of infiltration, it was shown to greatly improve the results from previous hydrological analyses and modelling outcomes. The same SMD parameters were used for each turlough as were identified in the aggregated rainfall modelling procedure earlier.

First, the cumulative inflow and SMD infiltration was calculated over the calibration period (Fig. 3.85 a). Next, a linear regression was carried out between cumulative infiltration and inflow (Fig. 3.85 b), with the slope of the regression line giving the contributing area. This contributing area, measured in $m^2 * 10^3$ where infiltration is in mm, represents the area required to generate sufficient infiltration as to the account for hypothetical inflow over the corresponding period. It is similar to the contributing area defined in the aggregated rainfall model, except that it defines the relationship between infiltration and flow rather than infiltration and volume.

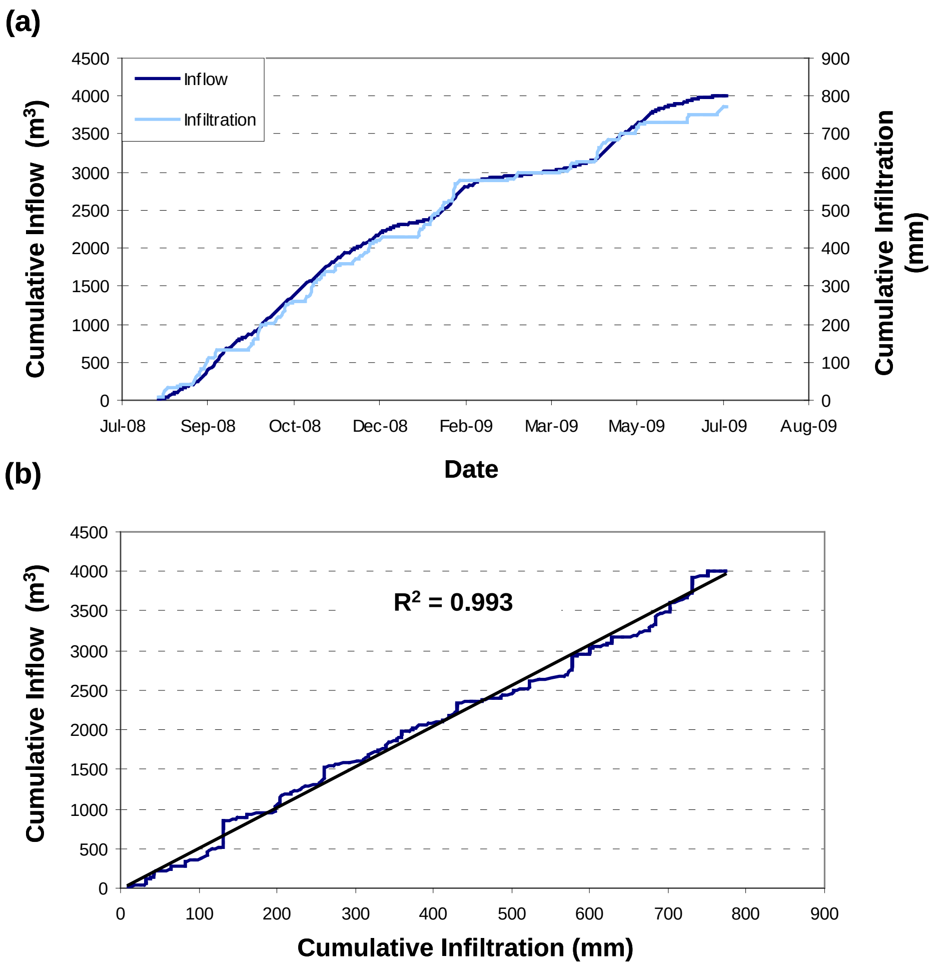


Figure 3.85 Plot of cumulative infiltration and cumulative inflow for the 2008/2009 flooding period (a) and plot of cumulative infiltration versus cumulative inflow (b) for Lisduff turlough, Co. Roscommon

This method of inflow prediction is a lumped parameter method, in that it represents all inflow processes with a single parameter and does not differentiate between the different sources of inflow such as direct rainfall versus conduit flow, or matrix versus conduit driven groundwater flow. However, adding additional parameters to represent the relative fractions would be somewhat arbitrary due to the limitations of the data available, but could be a possible future development if used in single site studies where more detailed hydrological information were available.

During the modelling process it was found that using the contributing area often led to significant over or under estimation of modelled volume. The methodology outlined above provided an initial estimate for the contributing area, which then could be altered during the calibration process to give the best overall result. The calibration process involved initially changing the contributing area manually to improve performance, followed by an iterative optimisation to maximise model efficiency using the Solver tool within Microsoft Excel.

3.7.5.3 Inflow Hydrograph

Earlier investigations found that significant improvements in relationships between rainfall and net inflow could be achieved simply by averaging the rainfall over increasing intervals, and selecting the interval which showed the best match. A development on this process is the use of a unit hydrograph or transfer function. One widely used model for the generation of unit hydrographs in surface water modelling is the Nash cascade (Beven, 2000) which is dicussed in more detail in Naughton (2011). The advantage of this model is its flexibility, with different values of the parameters (N and K) combining to give a wide range of unit hydrograph shapes (Fig. 3.86). In the context of this study, the Nash reservoirs are used to transform effective rainfall into recharge, with the conceptual reservoirs representing storage present within the epikarst and underlying karst flow system. The flexibility of the Nash model allows the inflowing water entering the turlough derived from a combination of sources (storages) to be combined into a single inflow hydrograph. The hydrograph parameters are N and K together with the number of intervals or length (duration) of the hydrograph. Varying lengths of hydrograph were trialled during the modelling process. As no significant improvement was seen in model performance for lengths greater than 14 days, this figure was used for all modelled turloughs. This does not impact on those sites with a shorter response time as all coefficients after the response time would be set to zero in the parameter fitting process. The coefficients N and K were optimised using the Least Squares method under the restriction that the sum of all coefficients was unity.

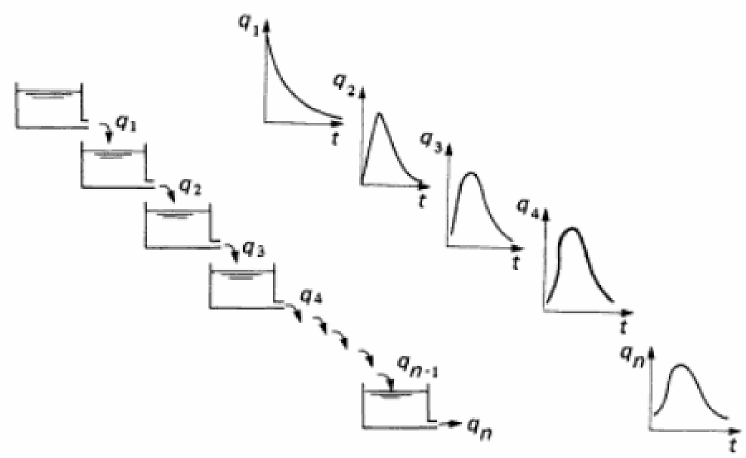


Figure 3.86 Unit hydrographs associated with routing of instantaneous flow through series of linear reservoirs (Shaw, 1994)

There are a number of assumptions associated with unit hydrograph theory: linearity, superposition and invariance (Shaw, 1994). Linearity supposes that there is a direct proportional relationship between input and output, in this case infiltration and inflow, so that a unit input produces a unit output. The second assumption, namely superposition, states that the combined output from a series of inputs is the sum of the component hydrographs. The third assumption is that the relationship between input and output does not alter with time. Given the complexities and inherent non-linearity of karst flow systems it is unlikely that all of these assumptions holds true. However, the unit hydrograph does provide a relatively simple tool for simulating the complex natural processes involved, given the data limitations involved in this modelling process and the improvements in the model performance, was deemed the acceptable for use here. Nevertheless, the apparently linear response of turlough water level to cumulative rainfall provided strong support for the application of the linear reservoir modelling approach.

3.7.5.4. Volume-Stage Relationship

The purpose of the reservoir modelling process is to accurately predict the volume, rather than stage, response in the reservoir to a given precipitation input. The reservoir water level can then be ascertained using the depth volume characteristics of the turlough basin in question. However, as outflow is a function of stage (i.e. hydraulic head); there was a requirement to transform the predicted volume into stage continuously at each time step. This can be achieved using the stage–volume data derived from the digital terrain modelling in Section 3.4.

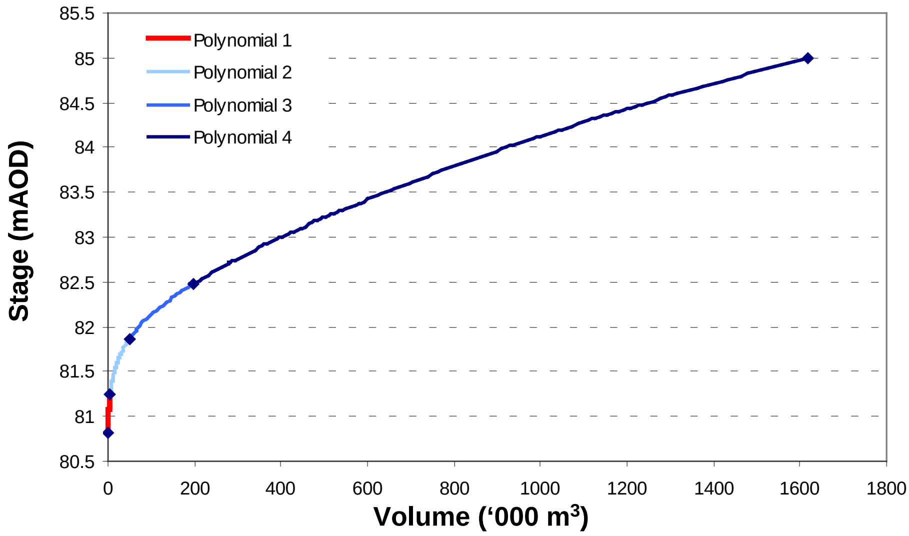


Figure 3.87 Volume – stage curve for Coolcam turlough, Co. Roscommon

In the initial data processing phase, stage was transformed into volume using linear interpolation of data points at 0.02 m intervals. While interpolation could be used to represent this transformation, the method is cumbersome and difficult to code. Instead, polynomials were generated and fitted covering the range of flooding experienced by the turlough, thus facilitating conversion. Due to discontinuities in the relationship, curves were broken up into intervals and polynomials of 2nd and 5th order were generated for each interval (Fig. 3.87). The polynomials were fitted using the Least Squares method in MATLAB (R2008a). The maximum error in the conversion process was set at 2 cm, in line with instrumentation accuracy, and the order of the polynomial adjusted on a trial and error basis until an acceptable fit was achieved. For each site, between two and four volume–stage polynomials were required to give an accurate conversion across the full range of flooding.

Care had to be taken when defining the relationship for the upper extremes of flooding. In some cases the oscillatory nature of the polynomials resulted in unrealistic predicted behaviour, such as a decrease in stage with increasing volume. To prevent this, each volume – stage curve was generated using data above the highest recorded water level. This additional data came directly from the DTM, as the level to which the turloughs was surveyed was substantially above the highest recorded water level. However, if the models were to be used for the prediction of extreme flood levels, details of the basin topography would have to be extended upwards. This could be achieved with additional GPS surveying or, on a larger scale, by utilising contours from GIS/DTM datasets such as those maintained by the Ordnance Survey.

3.7.5.5 Modelling Results

Reservoir modelling was carried out on eight turloughs with reasonably well defined stage–discharge curves and representing the spectrum of turlough hydrological behaviours. The subset consisted of Lough Gealain, Lough Aleenaun, Turloughmore, Lisduff, Ardkill, Coolcam, Croaghill, and Skealoghan, with table 3.19 summarising the results for each site. The specific performance of this technique and notable aspects of the modelling procedure are detailed for each site in the following sections.

Table 3.19 Reservoir modelling results

Site Name	*Contributing Area (km^2)*	*Model Efficiency (%)*			
		2006/2007	*2007/2008*	*2008/2009*	*Overall*
Lough Gealain	3.25	97.6	98.6	89.7	96.7
Lough Aleenaun	5.01	88.2	92.8	-	90.5
Coolcam	6.40	96.1	95.1	69.6	92.7
Croaghill	3.40	93.9	93.9	56.9	86.9
Lisduff	5.70	98.7	96.3	91.5	96.7
Ardkill	2.12	97.7	97.2	-	96.6
Skealoghan	2.78	96	80.6	91.4	90.7
Turloughmore	5.41	86.7	85.6	75.8	83.9

Lough Gealain

Lough Gealain was selected as the first suitable candidate for this modelling approach for a variety of reasons. Firstly, it is located at the upper end of its catchment in the Burren, an area of thin or absent subsoils. As such there are no substantial water bodies, extensive flow systems, or significant depths of overburden adding complexity to the system and affecting the rainfall response. Another decisive factor was the presence of a major spring in the northern end of the turlough, which was identified during field investigations. Based on observations of the spring flows it was deemed possible that the majority of the recharge entering the turlough was from this source. This would match well with the simplest interpretation of the reservoir, with unconnected inflow and outflow points. This is supported by diving carried out by Byrne and Reynolds (1982), where no evidence of conduits or water movement apart a small, shallow, debris filled trench were identified within the basin. The stage – discharge curve of the turlough was also well defined across the flood range and so the outflow calculations could be carried out with some degree of certainty. The final reason for this site selection was the good performance of the turlough's aggregated rainfall model. As the aggregated rainfall technique is a more simplistic version of the reservoir modelling attempted here, the high efficiency shown indicates good promise for more detailed modelling.

As described in the modelling methodology, the first step involved the derivation of the stage–discharge curve. Two different relations were defined within the Lough Gealain curve, one for those stages above 29.2 mAOD and second for those below. The relevant equations gave the outflow Q_{out} (in m^3/day) by:

H < 29.2 mAOD: $$Q_{out} = -13000(H - 27.5)^{0.5}$$

H ≥ 29.2 mAOD: $$Q_{out} = -2289H + 50482$$

The next step was to calculate the inflow time series and the associated contributing area. Outflow values were calculated for the stage time series, using the above equations, for the 2007/2008 hydrological year. This outflow time series was then subtracted from the net flow to give the required notional inflow time series (Fig. 3.88). Inflow values were added over the calibration period to give the cumulative inflow time series. Linear regression of the inflow and cumulative infiltration time series gave an initial contributing area of 3.7 km^2. It is interesting that this area is far smaller than the estimated catchment area of over 13 km^2.

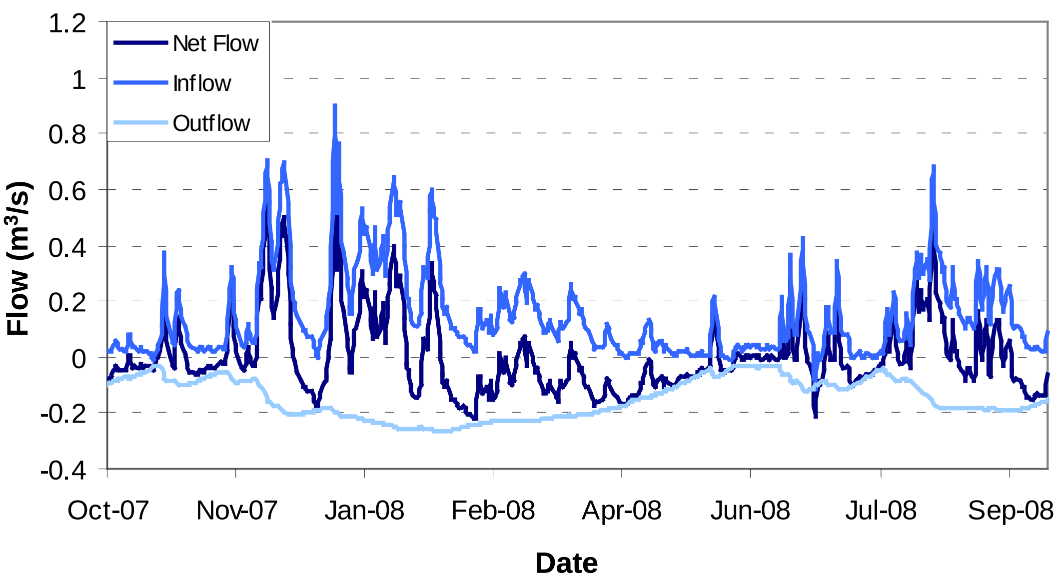


Figure 3.88 Inflow, outflow and net flow time series during the main 2007/2008 flooding period for Lough Gealain, Co. Clare

Next, the volume–stage relationship was derived from the turlough's DTM data. Two 2nd order polynomials were required to accurately transform volumes across the full flooding range, one for volumes below 75000 m^3 and a second for those above. All the relevant parameters were then entered into the modelling spreadsheet.

Rainfall and evapotranspiration records beginning in January 2006 were input into the SMD model to produce the infiltration time series for the model input. During the calibration process it was found that a contributing area of 3.7 km^2 produced excessive inflow into the turlough, and so this was reduced down to 3.2 km^2 to produce a better fit. The model showed an excellent performance during both filling and recession phases, with predicted peak magnitudes and times corresponding very closely with recorded values (Figure). This is reflected in the model performance statistics, with the overall efficiency coming in at 96.7%.

The greatest deviations between model and recorded time series were found in the 2008/2009 year, which showed an efficiency of 89.7%, compared to almost 98% for the 2006/2007 and 2007/2008 hydrological years. One reason for this is the nature of the flooding pattern during this period. The flooding season was far longer in the 2008/2009 year than in previous years, with a greater number of filling and recession events. Small errors over this phase had a cumulative effect. The higher recession rate of the model during February 2009 lead to a downward offset of the model volume for the remaining monitoring period, with a greater degree of storage occurring within the turlough basin than was predicted.

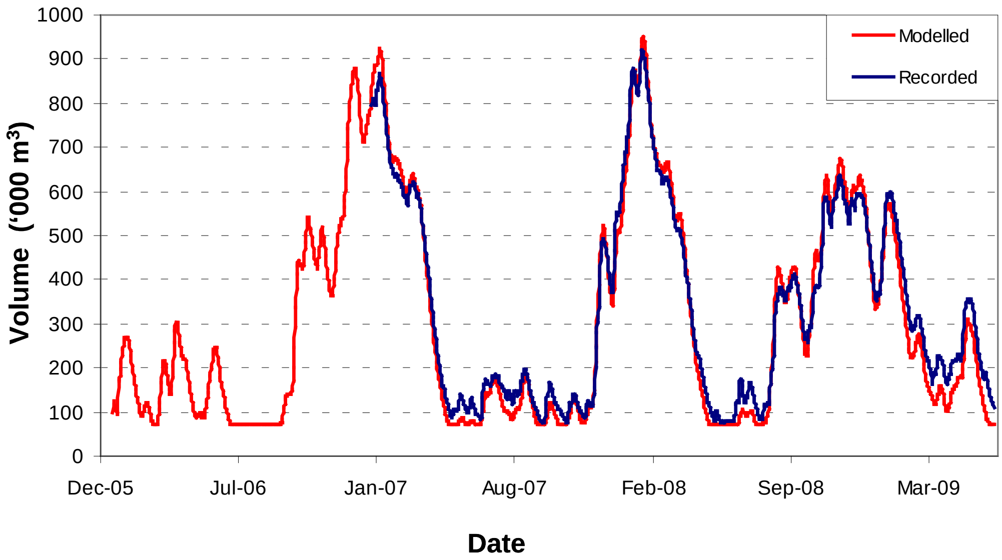


Figure 3.89 Plot of recorded and modelled volume for Lough Gealain, Co. Clare

A comparison of recorded versus modelled stage also yields a good fit for all years (Fig. 3.90). As it is stage, rather than volume, which is used in the derivation of hydroecological variables such as duration and frequency of inundation, this shows the use of the model for the long-term characterisation of Lough Gealain's hydrological regime.

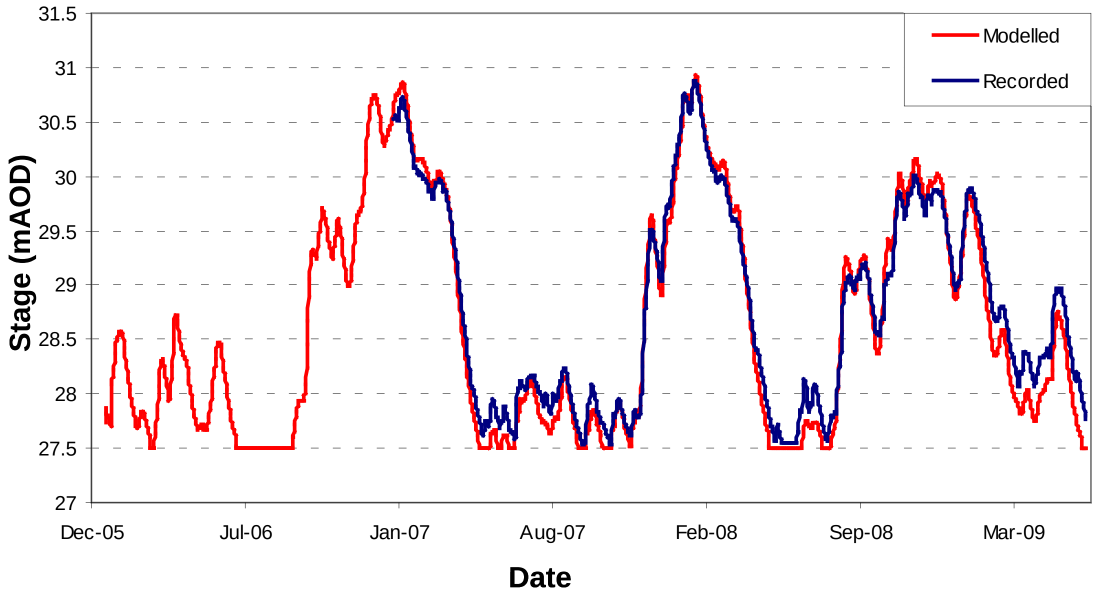


Figure 3.90 Plot of recorded and modelled stage for Lough Gealain, Co. Clare

Lough Aleenaun

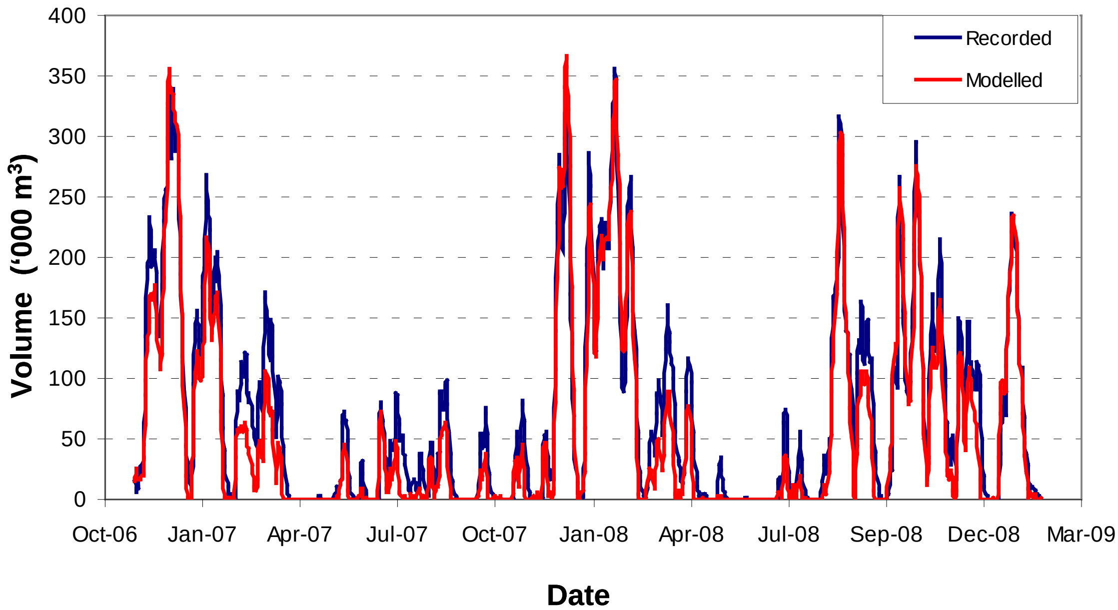


Figure 3.91 Plot of recorded and modelled volume for Lough Aleenaun, Co. Clare

Like Lough Gealain, Lough Aleenaun is a promising turlough for reservoir modelling due to its location in the Burren plateau, its potential flow through operation and also the good performance of the aggregated rainfall method. However unlike Lough Gealain, which would be in the mid range in terms of flooding response, Lough Aleenaun shows the highest flood frequency of any monitored site. Despite these differences in hydrological regime the reservoir model produced excellent results for Lough Aleenaun, with an overall model efficiency of 90.5%. While the highest peaks showed a good fit across the monitoring period, the subsequent lesser peaks tended to be notably lower than the corresponding recorded values (Fig. 3.91). This, again, indicates a greater amount of flood retention than was predicted by the purely flow through model. However, a modification of the stage-discharge relation by decreasing the outflow at lower volumes while increasing the outflow at higher volumes could also correct this behaviour.

The estimated contributing area at 5.01 km^2 is greater than the previous estimate based on topography of 4.6 km^2. This implies that there may be groundwater flow entering the turlough from outside the immediate topographic catchment of the turlough. This supports a hypothesis suggested by D. Drew (*Pers. Comm.*), which stated that when groundwater conditions are high, Lough Aleenaun may receive groundwater recharge from an adjacent catchment to the north.

Turloughmore

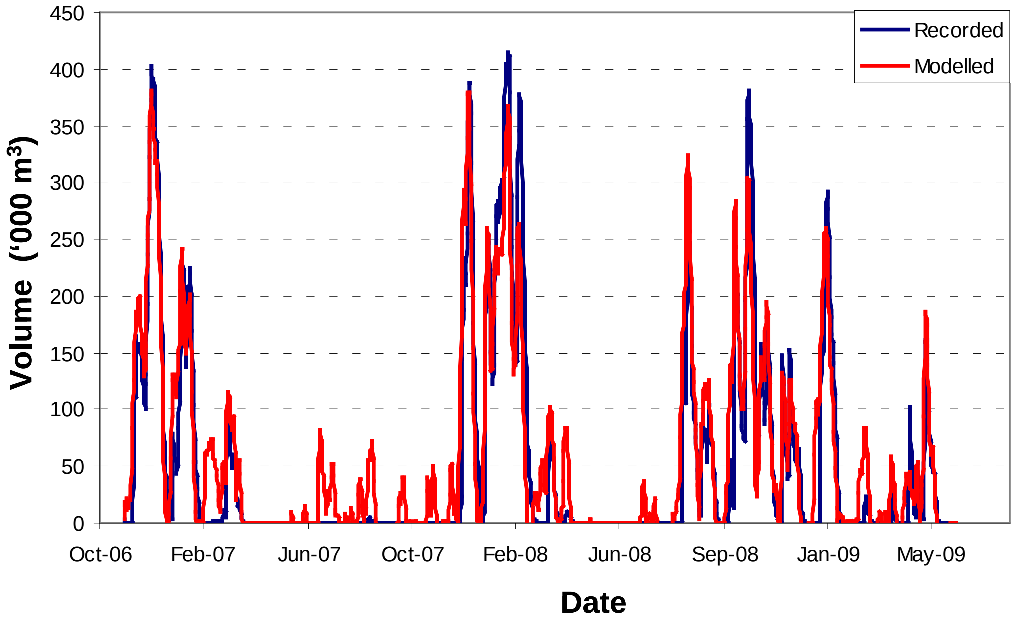


Figure 3.92 Plot of recorded and modelled volume for Turloughmore, Co. Clare

The reservoir model predicted with reasonable accuracy the volume response of Turloughmore, giving an overall efficiency of 83.9% (Fig. 3.92). As has been discussed in previous sections, the hydrological regime of Turloughmore closely resembles that of Lough Aleenaun with a fast response to rainfall events during the winter months. Unlike Lough Aleenaun, however, Turloughmore tends not to flood during the summer months. This difference is the main source of error in this instance. A series of flooding events are predicted during the summer months which do not materialise in the volume record. In order to control the magnitude of these flood events the upper bound of the contributing area was limited, with the area parameter here set at 5.41 km^2. This is a 20% increase over the previous catchment area estimate of 4.5 km^2. Considering the current stage – discharge relation, this would also have to be increased further to over 6 km^2 in order to accurately predict the peak water levels. Given that this model assumes that 100% of effective recharge enters the turlough, the actual catchment area would then have to be factored up further still. This highlights one of the shortcomings of this reservoir model configuration; it does not facilitate the bypass of flow beneath the turlough. This mode of groundwater flow is highly probable in Turloughmore, given the behaviour of the adjoining, lower depression as described earlier.

Lisduff

During the initial model trial for Lisduff, it was found that while the time to peak was fairly well matched across the monitoring period the volume was substantially over predicted in 2006/2007 and 2007/2008, while at the same time substantially under predicting 2008/2009 volumes (Fig. 3.93 a). The annual stability of Lisduff's maximum water level had previously been identified in Section 3.6 where, despite the variability in annual rainfall patterns, Lisduff turlough showed little variation in terms of maximum stage levels reached. One suggested explanation for this was the presence of an unidentified overflow at the upper reaches of the turlough basin. A high level overflow such as this would change the hydrological behaviour by artificially lowering the flow response at the upper end of flooding. In order to test if such an outlet would produce a better modelling result, an outflow with a capacity of 0.5 m^3/s was added at 49.9 mAOD. This allowed the volume in 2008/2009 to be significantly raised relative to the previous two years (Fig. 3.93 b).

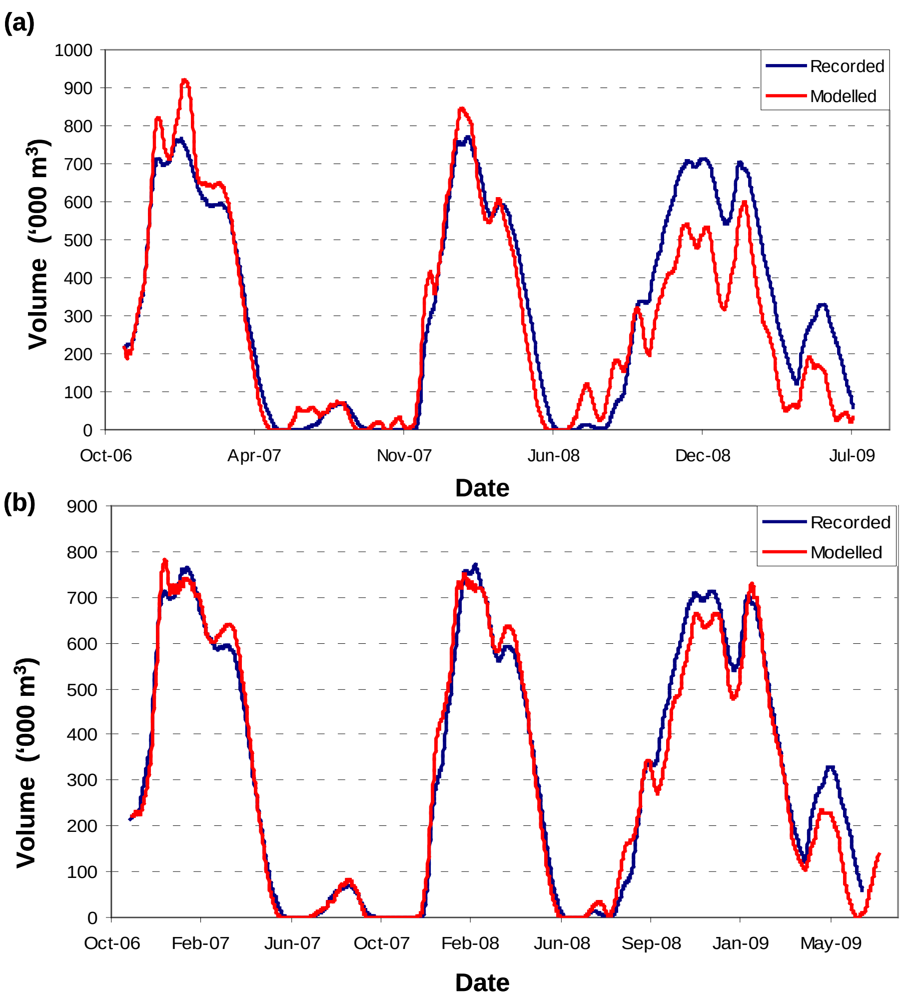


Figure 3.93 Plot of recorded and modelled volume without overflow (a) and with overflow (b) for Lisduff turlough, Co. Roscommon

As can be seen from a comparison of figure 3.93 a and b, the high level overflow resulted in a significant improvement by considerably decreasing the magnitude of inflow at higher flood levels. As with Lough Gealain, the main inaccuracies in the Lisduff model were shown during the 2008/2009 hydrological year. The predicted volume falls short of the first major peak of the flooding season, and also under predicts the final peak following the main recession in May 2009.

Ardkill

The model follows the turlough behaviour extremely well during both recorded recession periods (Fig. 3.94), indicating that the mode of drainage is similar to that of a tank draining through an orifice. The required contributing area, at 2.12 km^2, also tallies well with catchment area of Ardkill, previously estimated at only 3.1 km^2. The maximum level is well matched during the calibration year of 2007/2008 but is underestimated by approximately 60,000 m^3 during the 2006/2007 year. This under prediction translates into difference in level of 0.3 m which, given uncertainties associated with the stage – discharge curve at higher levels, is well within acceptable error bounds.

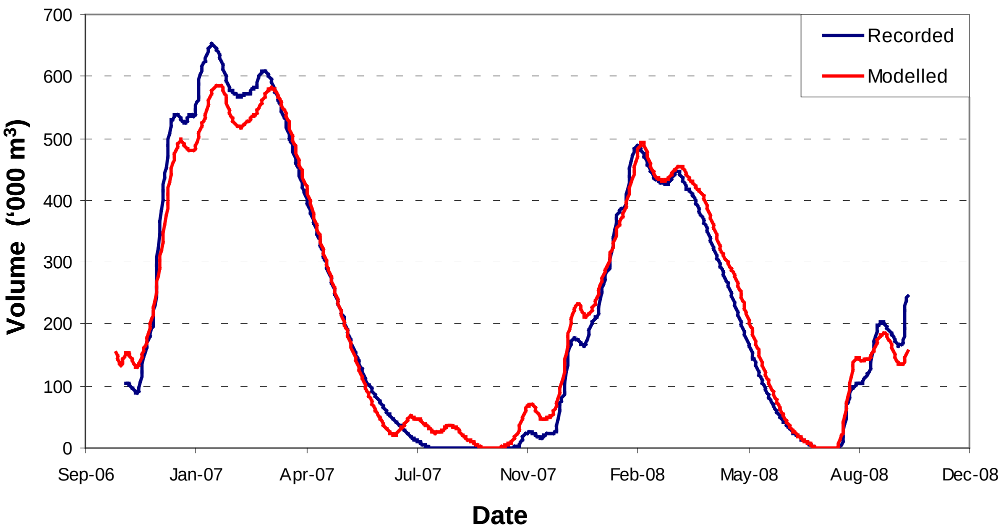


Figure 3.94 Plot of recorded and modelled volume for Ardkill, Co. Mayo

The apparent overfilling which occurs during July at the end of the first main recession event may not be an error associated with the model, but rather due to deficient monitoring data over this period. In the first monitoring year, the Diver was located a little above the base of the turlough and so did not record water level fluctuations at low water levels. Based on records from nearby turloughs, it is likely that Ardkill experienced some renewed flooding in July 2007, and so the renewed flooding predicted during July 2007 may in fact have occurred.

Some over filling was predicted during the initial flooding phase of the 2007/2008 hydrological year. This was shown by some of the other turloughs modelled using this technique (see Coolcam and Croaghill). The presence of additional storage within the karst system could account for this deviation. While the SMD model accounts for some storage which may build up due to evapotranspiration effects, it is very likely that the karst system itself possesses additional storage in the form of matrix and fracture porosity. During periods of heavy rainfall following relatively dry conditions, some of the recharge may be taken into storage. This would have the effect of reducing the recharge entering the turlough. Once this storage reached capacity, it would have little impact upon the mechanisms controlling turlough flooding.

Coolcam

Overall the reservoir model produced a reasonably good fit for Coolcam turlough, showing an overall efficiency of 92.7%, although visually it doesn't appear to give as good a fit as this statistic would suggest (Fig. 3.95). The model gave a good fit for both the peak volumes and the general recession behaviour during 2006/2007 and 2007/2008. However, significant errors arose in the 2008/2009 year, with efficiency falling substantially to 69.6%. As was seen in Ardkill turlough, reservoir volumes were overestimated during the initial phases of flooding. Also, the model showed a greater response to recharge events during recession periods. This is particularly clear in the main 2006/2007 recession, where the calculated inflow caused filling to occur in the model during August 2007. The actual response of the turlough to the same event was far less where a decrease in outflow was shown but the overall volume continued to recede.

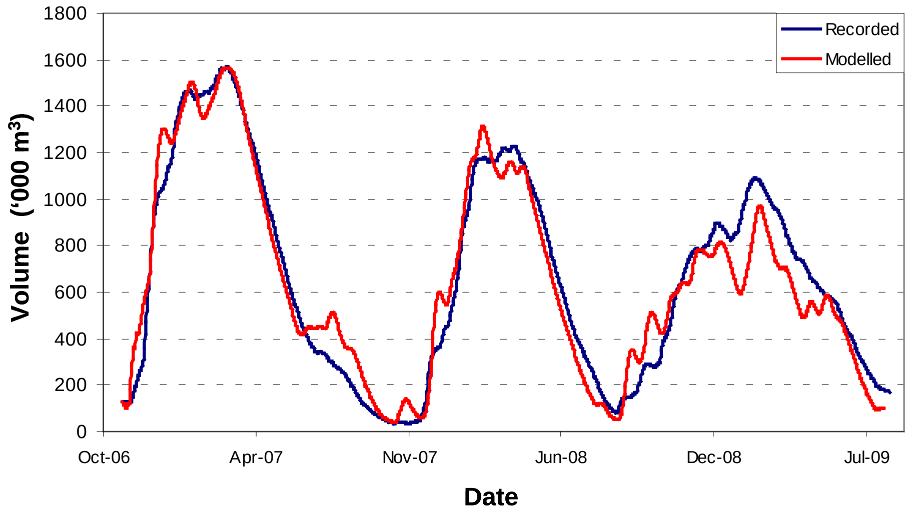


Figure 3.95 Plot of recorded and modelled volume for Coolcam turlough, Co. Galway

Given these discrepancies, it is possible that additional storage plays an important role in the Coolcam flow system. If this storage drained concurrently with the turlough, it could provide the dampening that would be required to remove the tendency towards overfilling in the initial filling and recession phases. It could also go some way to correct the relative magnitude of the annual maxima. The flooding in 2008/2009 occurred over a longer period than either of the previous two years. It also contained more recession events. If turlough recession is taken as an indicator of a more general drainage of storage within the system, then the higher recession frequency in 2008/2009 would represent a greater degree of activity of catchment storage. This activity would serve to decrease the inflow reaching the turlough during such periods. Such a modus operandi would also reduce the impact of rainfall during recession events, as a portion of the generated recharge would be taken up by the catchment storage.

3.7.6 Turlough Conceptual Model

The interpretation of the inflow and outflow time series used in the reservoir modelling procedure is dependent upon the hydrological operation of the turlough. This operation can be described using two conceptual models: the flow–through model and the surcharged tank model. In the first scenario, the flow time series represent the actual flows which occur within the turlough at each time step. In the second scenario, rather than representing actual movement of groundwater through the turlough, the flow time series indirectly represent the relative heads within both the turlough and the underlying and surrounding karst flow system.

3.7.6.1 Flow-Through Model

The simplest interpretation of this reservoir model configuration is that of a flow-through system, with both inflow and outflow occurring simultaneously within the turlough basin (Fig. 3.96). In this case, groundwater inflow and outflow would occur independently at distinct points within the turlough basin. Inflow could be derived from a number of sources: direct rainfall, surface runoff, shallow groundwater as well as deeper conduit driven inflow. Some sources of inflow would act independently of the water level within the turlough, such as direct rainfall and overland flow. Others would be a function of turlough water level, such as shallow groundwater flow entering the turlough in the form of diffuse epikarst flow. At low water levels a gradient would exist into the turlough thus producing inflow. As the turlough water level rises, the epikarst would become inundated and potentially cease its contribution. It is feasible that the gradient could potentially reverse with floodwater entering the storage within the epikarst, similar to bank storage within rivers. Also, the discharge rate from a conduit system terminating within the turlough basin would vary depending upon the head driving it as well as the head within the turlough. In this conceptual model the inflow time series represents the cumulative effect of all systems supplying floodwater to the turlough.

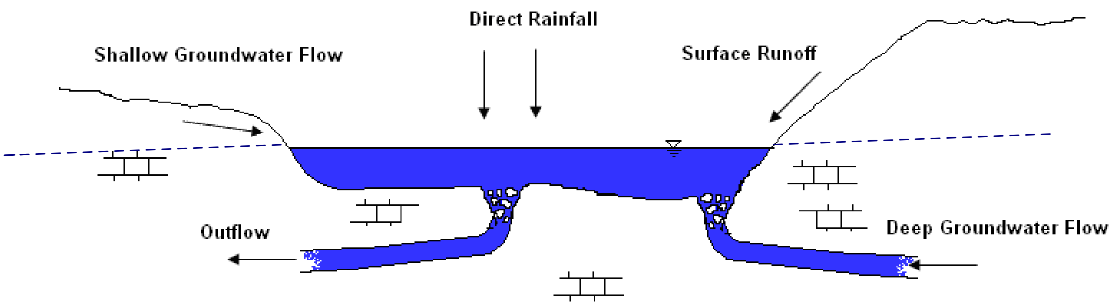


Figure 3.96 Conceptual model for the flow-through turlough system

Turlough discharge occurs in isolation from the inflow points, and may take the form of conduits, fractures or a combination of both. In this case, the outflow time series as defined by the stage - discharge curve, quantifies the cumulative capacity of all modes of outflow. It follows that in such a system there would be a constant flow of groundwater through the turlough, with a far lower residence time than that of the surcharged tank model.

3.7.6.2 Surcharged Tank

The second conceptual model would be that of a surcharged tank, where the volume response in the turlough is dependent upon the relative heads in the turlough and underlying karst flow system (Fig. 3.97). In this model the turlough acts as additional surface storage for the underlying karst flow system, essentially accumulating excess groundwater that cannot be accommodated due to insufficient capacity. The single conduit shown in figure 3.97 may represent an actual conduit, a conduit system or an area of interconnected fractures. Two catchments are defined in the model. The first is the greater catchment area, which drains via the conduit system beneath the turlough. The interaction between this system and the turlough is a function of the relative heads within both. The second is a smaller local catchment which supplies water to the turlough via direct rainfall, surface runoff and shallow groundwater flow independent of the turlough water level. Rainfall on the greater catchment enters the turlough via the conduit flow system, the capacity of which is controlled by the restriction.

During normal recession periods, flow through the conduit system does not enter the turlough. Instead the constriction (and/or friction losses along the conduit) regulates the rate of release of water from the turlough under falling head levels. When head within the system drops sufficiently, the head within the turlough causes the stored groundwater to be discharged back into the system. The rate of the outflow during this phase is dependent upon the flow capacity of the system and the relative difference in heads between turlough and the greater catchment. Assuming the surcharge tank model, there is no outflow from the turlough during filling periods, and little inflow into the turlough during recession periods. Obviously there will still be inflow into the turlough due to direct rainfall, surface runoff and diffuse shallow groundwater flow from the areas immediately surrounding the turlough but in this scenario the net flow approximates actual turlough flow.

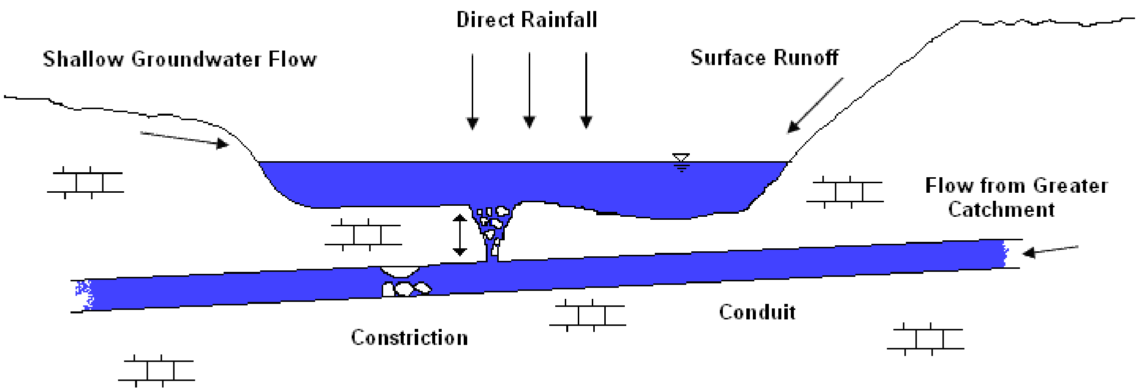


Figure 3.97 Conceptual model for turlough operation as a surcharged tank

Under this model, the proportion of catchment recharge entering the turlough depends upon the flow configuration and capacity of the system. If the catchment is large but has a relatively unrestricted flow system, then only a small fraction of the recharge (equivalent to what is a turlough's potential zone of contribution) actually enters the turlough. Alternatively, if a flow system has a large capacity up gradient but is heavily restricted down gradient of the turlough, then the majority of groundwater flow will be discharged into the turlough. Obviously larger catchments may be able to produce and sustain greater flows than smaller contributing areas, but it is the level of constriction in the system that governs the effect this has upon a turlough. Thus, (outflow) constriction is a determining factor in the hydrological behaviour of turloughs. The constriction itself could be due to a localised narrowing of the pipe or an effective constriction as a result of longer pipe head losses.

With regard to the notional inflow and outflow time series, the outflow is signified by the head within the turlough in terms of the outflow that would occur during full recession given the water level. The inflow time series characterises changes in head within the underlying system as well as the contribution of direct sources of recharge. The balance between hypothetical inflow and outflow controls the rate of filling and emptying. When there is a gradient into the turlough, i.e. inflow is greater than outflow, the volume stored within the turlough basin increases. When the head within the underlying system decreases, this storage is discharged back into the underlying system.

It is feasible that both types of hydrological conceptualization exist as turloughs within the Irish landscape. Results from past investigations into turlough hydrology in the Gort lowlands area (Southern Water Global, 1998; Gill, 2010) supports the surcharged tank model. These studies concluded that the system in this area operated on the basis of a significant conduit system with surcharged tanks, and pipe network modelling based on this idea gave a good simulation of turlough hydrological behaviour. Physical evidence for the surcharged tank model can be seen in turloughs such as Lough Coy, where large estevelles have been witnessed operating in response to the conditions present in the underlying conduit system.

However, the Gort-Kinvarra system consists of exceptionally well-developed conduit systems and vast catchment areas in comparison to the majority of other Irish karst systems. Instead, most turloughs form part of much smaller karst flow systems. Evidence for the flow-through model has been identified during this research. In Lough Aleenaun, groundwater has been observed simultaneously rising and sinking at separate points within the turlough basin, suggesting a flow through system. Another potential flow-through system was identified in Lough Gealain turlough where a large spring flowed into the northeast corner of the turlough basin. The source of this spring lay above the high water level of the turlough and so the turlough stage had no influence over the inflow rate.

These sites may represent the pure, 'type' examples of each system model, but it is equally likely that many turloughs are a complex combination of both modes of functioning.

Irrespective of the conceptual model assumed for individual turloughs, this modelling methodology can be relied upon to link to ecological requirements as it allows the generation of long term hydrological time series from existing daily rainfall and evapotranspiration records. The composition of turlough ecological communities may change in response to both short and long term hydrological behaviour. Hydro-ecological indicators derived from the longer synthesised records will allow the examination of any long term effects, while indicators derived from the hydrological data collected during this research can be used to study any short term effects. The specific indicators developed during this research are described in detail in the next section.

3.8 Turlough Hydroecolgical Indicators

3.8.1 Introduction

The overall objective of this project is to integrate data representing different characteristics of turlough hydrology and ecology with a view to identifying the critical factors that influence biological diversity within and among turloughs. A number of indicators were derived from water level, volume and area time series, while others emerged from the digital terrain and hydrological modelling processes.

3.8.2 Hydrological Indicators

From water level, volume and area time series a number of potential indicators were derived, each tailored to fit with the nature and resolution of the ecological dataset with which it was to be integrated. The hypothesis behind the hydrological indicators used in the interpretation of multiple ecological datasets (namely flood duration, frequency and hydroperiod) will be described here.

3.8.2.1 Elevation

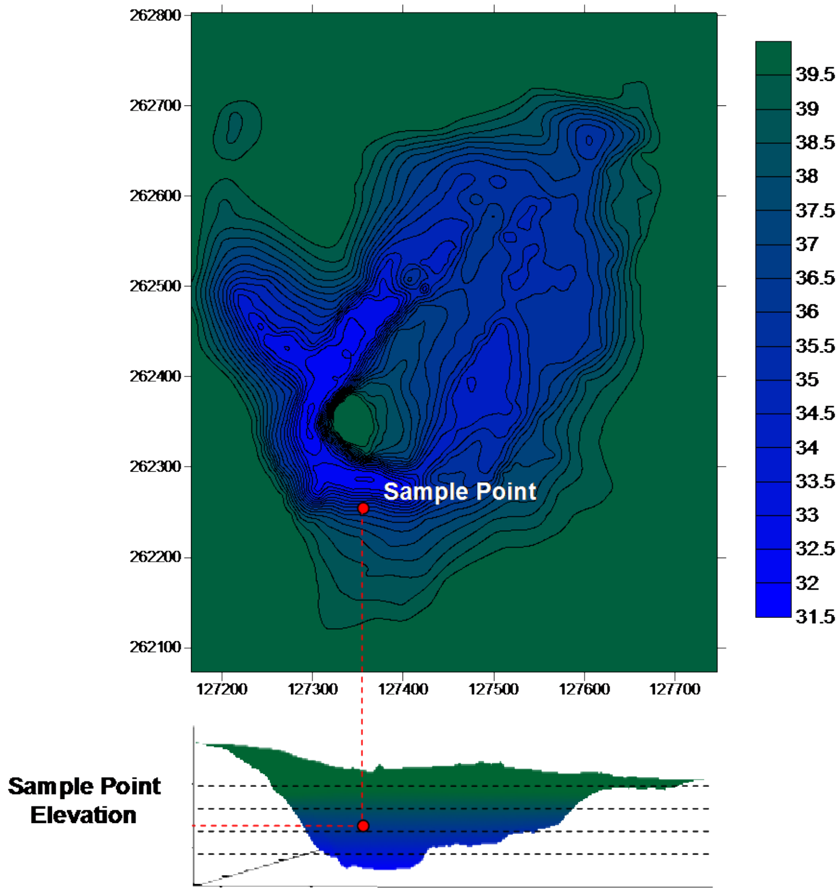


Figure 3.98 Contour map and elevation profile used in the derivation of sample point elevation in Ardkill turlough, Co. Mayo

For the majority of hydrological indicators derived in this research, the critical parameter is the sample elevation. Once the elevation is known, the pattern of inundation for an exact location can be characterised and so relevant hydrological indicators for that point derived.

During ecological fieldwork, carried out as separate tasks within the turlough conservation project, the position of sample points were recorded using a handheld GPS. This logged the (X, Y) coordinates of each point, but not the elevation. Thus the elevation of sample points, such as vegetation relevés and soil samples, had to be derived indirectly using the digital terrain models (DTM) created as part of the hydrological research. The elevation of each sample point was determined by identifying the elevation of the corresponding coordinate on the surface of the DTM. A visual representation of this process is shown for Ardkill turlough in figure 3.98. In practice, this was evaluated by calculating the difference or residual between a plane at zero elevation and the turlough surface at each (X, Y) point using Surfer version 8.6 (Golden Software Inc.).

3.8.2.2. Flood Duration

The duration of inundation strongly influences the distribution and composition of ecological communities within turloughs, with flood duration primarily controlling plant species survival (Casanova & Brock, 2000; Sheehy Skeffington et al., 2006; *Chapter 7: Turlough Vegetation - Description, Mapping and Ecology*). Duration curves provide a way to represent the amount of time a given quantity is equalled or exceeded over a defined interval and have long been used in hydrological analysis for design and regulatory purposes (Fetter, 2001). For example, in river flow it is used to define the 95th percentile flow, which is the flow that is equalled or exceeded 95% of the time, a statistic commonly used to assess the level of dilution available in the water course. In the context of turlough hydrology, duration curves present a means of quantifying the flooding effect or disturbance experienced by ecological communities at any point within a turlough basin. Within any defined period, a flood duration gradient exists whereby elevations at the base of the turlough experience longer flood duration that those higher up the basin. The water level - duration curve quantifies this gradient.

The procedure for generating a duration curve, as outlined in Fetter (2001), is as follows:

- The level data is first sorted in descending order, from highest to lowest
- A rank *m* is assigned to each value from 1 to *n*, *n* being the length of the data set
- The probability *P* of a given level being equalled or exceeded within the period n is given by:

$$P = 100\frac{m}{n+1} \qquad \textbf{(Equation 3.5)}$$

- A plot of probability P against stage (the so-called duration curve) shows the percentage of time each level is equalled or exceeded

Duration curves can be generated over any defined period such as calendar year, hydrological year, inundation period or entire monitoring record, depending upon the application. Invertebrate communities (e.g. population densities) in a given year are highly dependent upon the hydrological regime of that year and so short term duration curves are applicable. In contrast, many vegetation communities respond to long term changes in hydrological regime, and so a particularly wet or dry year may not significantly change the communities present within a turlough. Therefore, longer term duration curves would be more relevant.

An example of duration curves for Rathnalulleagh, Lough Aleenaun and Lisduff for the 2007/2008 hydrological year is shown in figure 3.99. The primary use of flooding depth - duration curves in the context of this research is to quantify the duration of inundation at individual sampling points based upon their respective elevation. So, for example, if a sample point was located at a height of 4 m above the base of the turlough, from figure 3.99 it can be seen that the duration of flooding at that point in Rathnalulleagh is approximately 40% and around 10% in Lough Aleenaun, while in Lisduff the point at this elevation would not have flooded during this period.

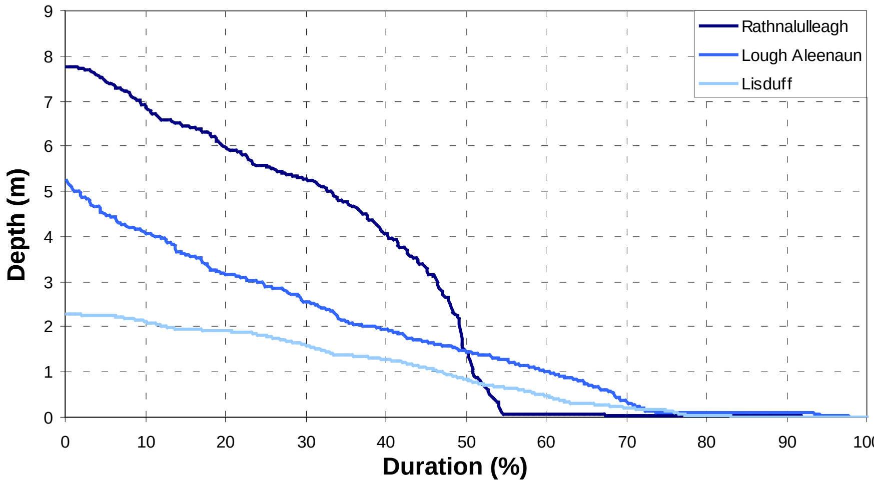


Figure 3.99 Duration curve for Rathnalulleagh, Lough Aleenaun and Lisduff turloughs for the 2007/2008 hydrological year

Flooding depth-duration gives the cumulative time a given elevation is inundated during a defined period. It may not, however, fully quantify the level of disturbance experienced within the turlough basin. This is clearly demonstrated through the comparison of duration curves for Lough Aleenaun and Lisduff in figure 3.99. Lough Aleenaun is the most highly responsive of the study sites, with multiple short-duration flooding events occurring throughout the year. In contrast, the hydrological behaviour of Lisduff is characterised by a single main flood event during the year. Therefore in Lough Aleenaun the total duration, as represented by the duration curve, is split into a number of distinct flooding events whereas in Lisduff it predominantly represents a single flood event. This difference in behaviour is not clear from the duration plots alone, hence there is a need for additional hydrological indicators describing the frequency of flooding.

3.8.2.3 Hydroperiod

A variation on the idea of flood duration is the hydroperiod. This is a widely used variable in ecological studies but can often have vague or very different definitions depending upon the application. The hydroperiod does not differentiate between different elevations within the turlough basin, but instead uses a single variable intended to characterise the flooding duration for each turlough. This variable may take the form of the duration of flooding prior to sampling (Fig. 3.100 [1]), the longest continuous inundation period during which sampling took place (Fig. 3.100 [2]), or the sum of the durations of all flood events over a defined period (Fig. 3.100 [2, 3]), depending upon the application. The specific definitions of hydroperiod used in the interpretation of different ecological datasets are given in the relevant section.

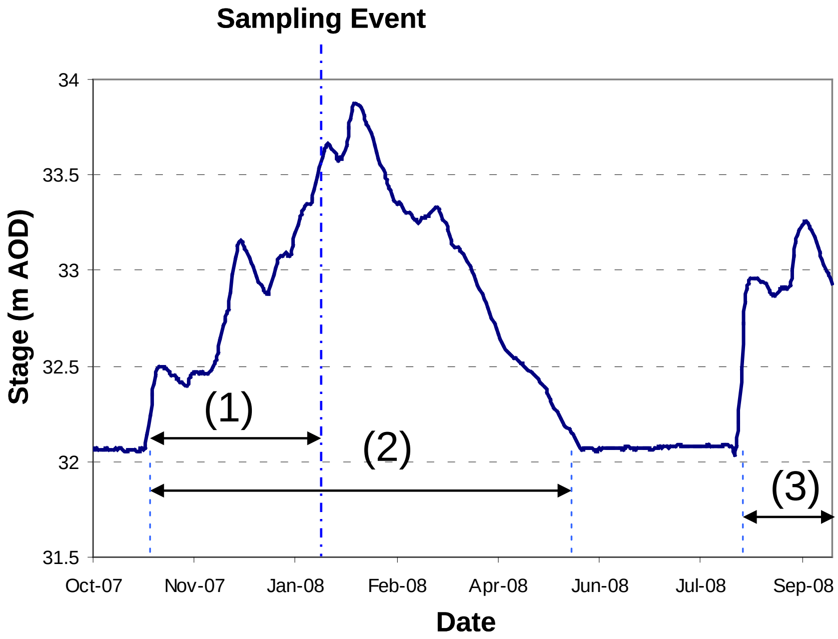


Figure 3.100 Example of different definitions of hydroperiod for Skealoghan turlough, Co. Mayo, during the 2007/2008 hydrological year

The hydroperiod was thus calculated for all 22 turloughs (Table 3.20):

Table 3.20 Hydroperiod for the 2006/2007 flooding season for 22 monitoring sites (*2007/2008 value used due to hydrological data unavailability)

Site Name	*Hydroperiod (days)*	*Site Name*	*Hydroperiod (days)*
Ardkill	293	Kilglassaun	223
Ballinderreen	211	Knockaunroe	213
Blackrock	169	Lisduff	234
Brierfield	267	Lough Aleenaun	158
Caherglassaun	200	Lough Coy	187
Caranavoodaun	205	Rathnalulleagh	175
Carrowreagh	186	Roo West*	213
Coolcam	346	Skealoghan	213
Croaghill	348	Termon	304
Garryland	211	Tullynafrankagh	246
Gealain	212	Turloughmore	135

3.8.2.4 Flood Frequency

Flood frequency is defined as the number of times a given water level is equalled or exceeded over a given interval, and is thus dependent upon the specific flood pattern over the analysis period. Like flood duration, frequency can be generated over any defined period depending upon the application. Unlike flood duration, a frequency gradient does not exhibit a simple pattern from the base of the turlough upwards (Fig. 3.101). Instead, the lowest flood frequencies tend to be shown by zones at the extremes of the flooding range, i.e. the highest and lowest flood levels, with zones in the intermediate range of flooding experience the highest flood frequency.

A flood event represents a disturbance to terrestrial turlough ecological communities as floodwaters change conditions from dry to wet, or aerobic to anaerobic. This transition, and the frequency at which it occurs, plays a major role in determining species composition within such ephemeral water bodies as turloughs. Ecological communities which experience a high frequency of flooding must be able to quickly adapt to this change in environment. This is equally true for communities within different zones of a turlough basin, as these can also experience different flooding frequencies. A flooding season characterised by a single main flood event, such as 2006/2007, will generally show lower flood frequencies and so represent a different level of disturbance than one composed of a series of filling and recession events, such as 2008/2009. Multiple flood events during the winter period may have a lesser impact on the composition of turlough ecological communities than a single event during the summer and so flooding seasonality also has to be considered in the interpretation of flood frequency data.

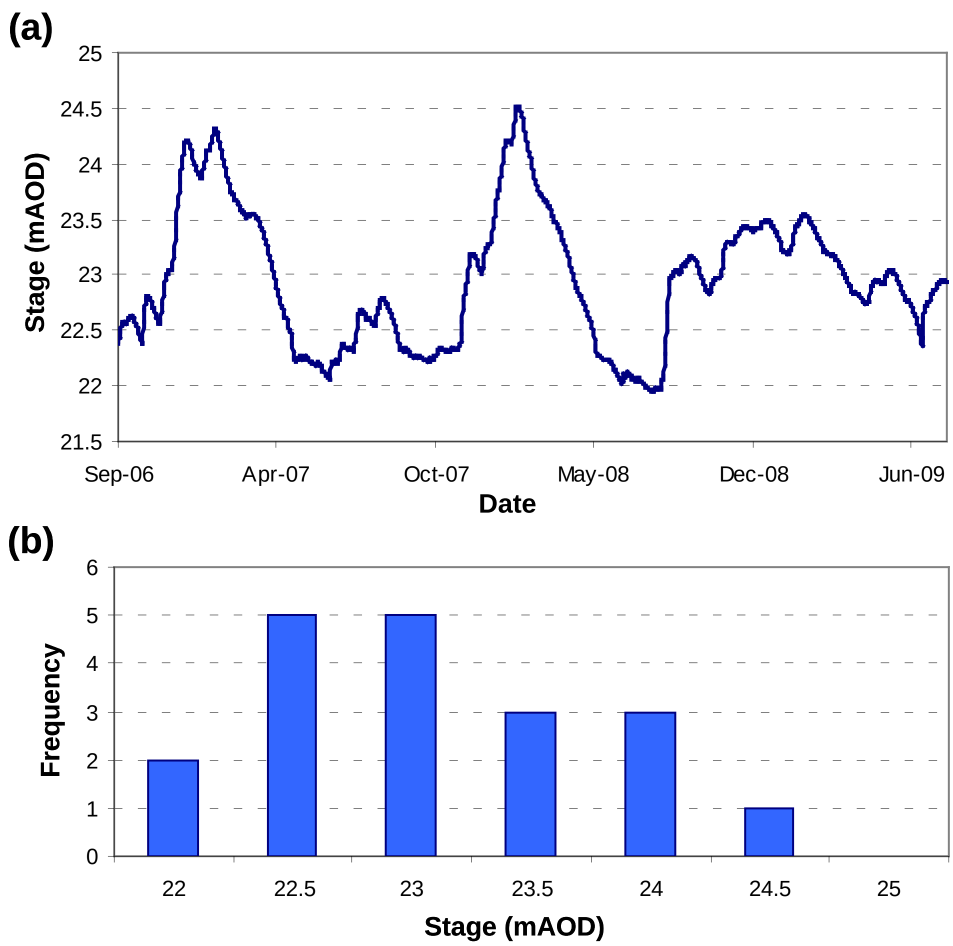


Figure 3.101 Stage hydrograph (a) and associated flood frequencies at 0.5 m intervals (b) for Caranavoodaun turlough, Co. Galway over monitoring period from September 2006 to July 2009

3.8.2.5 Wet/Dry Periods

While flood frequency quantifies the number of flood events experienced by a given elevation, it does not consider the relative lengths of each flood event. When duration is taken into consideration this goes some way to highlight the distinctions in flooding regime. However, to allow more thorough comparison, the longest continuous inundated and dry periods were also calculated for all vegetation relevé points. These periods were calculated using the longest available water level record rather than on a yearly basis, as the longest flooded period tended to cross over years. The wet/dry start date was recorded along with the period length, both in days and as a percentage of the water record length.

3.8.2.6 Areal Reduction Rate

As the dry phase of an ephemeral wetland represents an ecological disturbance for its aquatic fauna, a metric was required to quantify this disturbance and allow differentiation between sites. The idea of the areal reduction rate is to characterize the rate at which flood waters receded across the surface of the turlough. The areal reduction rate (dA/dT), in m^2/day, is defined as the average rate of decrease in surface area between the time of maximum and minimum flooded area and is given by:

$$dA/dT = \frac{A_{max} - A_{min}}{\Delta T} \qquad \textbf{(Equation 3.6)}$$

Where:

A_{max} = maximum flood area (m^2)
A_{min} = minimum flood area (m^2)
T = time between occurrence of maximum and minimum flood area (days)

Table 3.21 Areal reduction rate information used in aquatic invertebrate analysis

Site Name	*Max Date*	*Max Area (m^2)*	*Min Date*	*dT (Days)*	*dA (m^2)*	*dA/dT*
Caranavoodaun	10/02/2008	354866	22/05/2008	102	-354866	-3479
Roo West	08/02/2008	410721	28/05/2008	110	-410721	-3734
Termon	16/03/2008	402128	30/07/2008	136	-141710	-1042
Blackrock	07/02/2008	663368	08/04/2008	61	-663368	-10875
Brierfield	14/02/2008	485275	19/06/2008	126	-485275	-3851
Lisduff	08/02/2008	537626	07/06/2008	120	-537626	-4480

As the flood area reduced at varying rates during the recession depending upon local topography, preliminary collaborative analyses were carried out between aquatic invertebrate data and areal reduction rates calculated over a range of different intervals. Due to the limited invertebrate data available and the range of other factors which affect species populations it was decided to use a general areal reduction rate base upon the maximum and minimum recorded areas during the monitoring periods (Table 3.21). In calculating the areal reduction rate the maximum flood area corresponded to the highest recorded flood level and extent. The minimum flood area was taken as either zero where the turlough fully emptied, or in cases where a permanent water body was present the surface area of the permanent water body.

3.8.2.7 Flood Velocity

As surface gradient can vary substantially in different parts of the turlough, the exact location of sampling points would be required in order to calculate the velocity of flood recession. While sampling locations were not recorded in the field, the general area of sampling within the turlough was known as well as the date and time at which it occurred. From a combination of the hydrological records and the turlough DTM, the flood level and extent at the time of sampling could be ascertained and thus a good estimate of sampling location coordinates be made. The distance between sampling points (δ) was then calculated from these coordinates using:

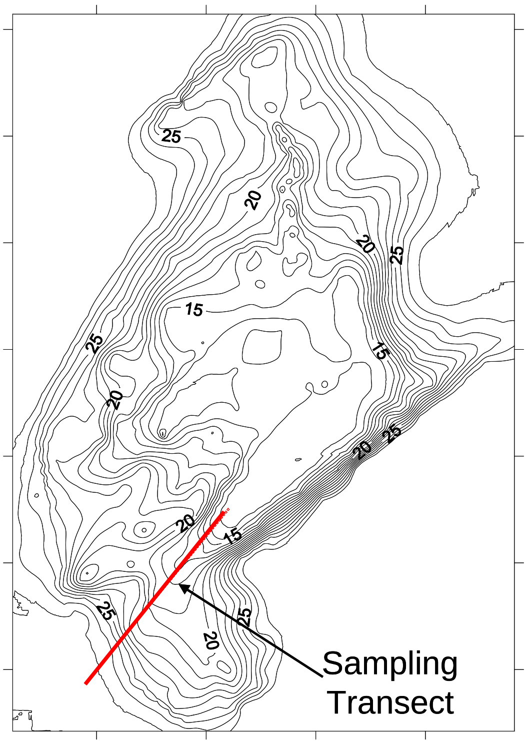
$$\delta = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \qquad \textbf{(Equation 3.7)}$$

By dividing the distance by the time elapsed between sampling events, the mean floodwater velocity along the sampling transect during the intervening period was determined.

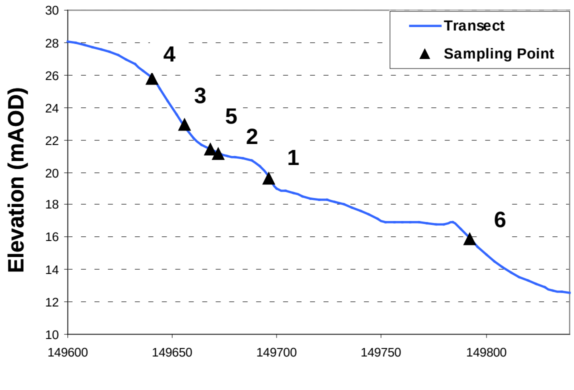
An example of the flood velocity analysis is shown for Blackrock turlough, Co. Galway (Fig. 3.102). Figure 3.102 a shows the sampling transect location within the turlough basin, with the corresponding elevation profile with sample point locations is given in figure 3.102 b. The chronological order that the sampling point occurred within the time series is labelled 1 to 6. The highest flood velocity (-7.092 m/day) over the sampling period occurred during the final phase of recession, between points 5 and 6, which coincided with the flattest section of transect. This pattern is repeated in Roo West and Termon as the highest recession velocities of -5.116 of -0.163 m/day respectively were recorded during the last between the 1/4/2008 and 7/5/2008 (Table 3.22). In Termon, due to the extended duration of flooding the last sampling event took place relatively early in its recession. The average flood velocity further increased in the latter phase of the recession, rising to 0.324 m/day in the month following the 07/05/2008.

Table 3.22 Flood velocities for aquatic sampling intervals on turlough subset

Date	*Flood Velocity (m/day)*			
	Blackrock	*Caranavoodaun*	*Roo West*	*Termon*
19/12/2007	2.563	0.335	4.68	0.77
08/01/2008	1.284	0.091	1.324	0.455
04/02/2008	0.954	0.667	1.889	0.52
04/03/2008	-1.553	-0.414	-1.04	0.071
01/04/2008	-7.092	-0.215	-0.81	-0.074
07/05/2008	-	-0.059	-5.116	-0.163



(a)



(b)

Date	Distance D (m)	dT (days)	V (m/day)
04/12/2007	-	-	-
19/12/2007	38.45	15	2.563
08/01/2008	25.68	20	1.284
04/02/2008	25.76	27	0.954
04/03/2008	45.03	29	-1.553
01/04/2008	198.57	28	-7.092

(c)

Figure 3.102 Contour map of Blackrock turlough including invertebrate sampling transect (a), Elevation profile of transect (b) and calculations of flood velocity between sampling events (c)

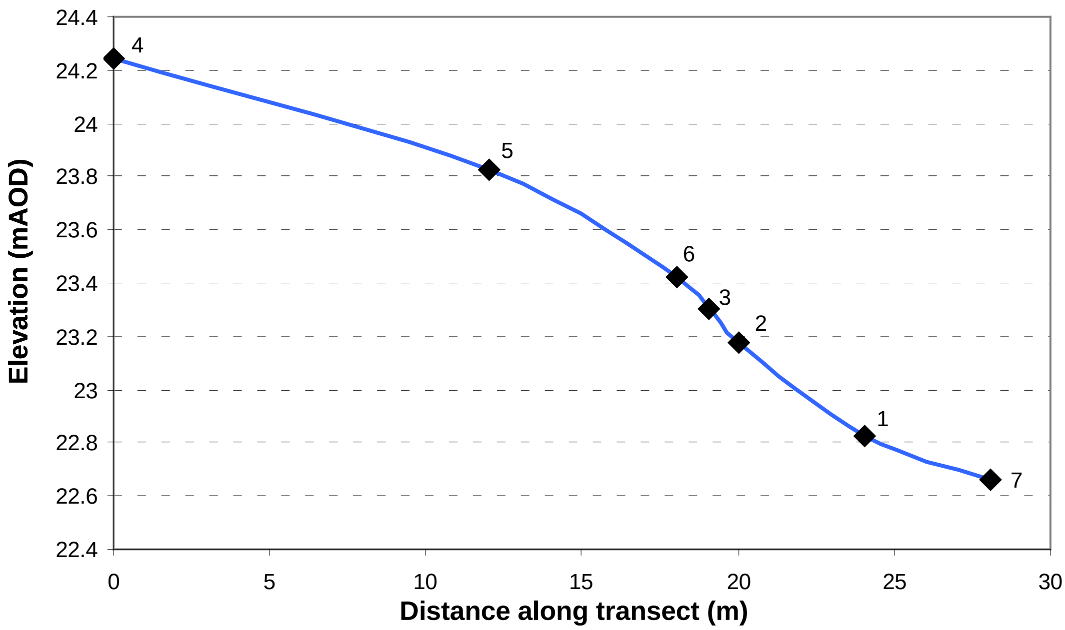


Figure 3.103 Transect elevation profile and aquatic invertebrate sampling locations for Caranavoodaun turlough, Co. Galway

Generally the maximum recession velocity coincides with the final phase of the recession, as turloughs usually have relatively flat bases with steeper sides and so the flattest sections are the last to drain. This is not always the case, however, as shown by the high flood velocity relatively early in the recession of Caranavoodaun. This can be explained by looking at the transect profile (Fig. 3.103). The highest is associated with the recession between sampling points 4 and 5, where the surface gradient is at its least.

3.8.2.8 Aggregation Period

The aggregation period coefficients derived during the aggregated rainfall modelling process in Section 3.7 were used to represent a notional residence time for each turlough (Table 3.23). The aggregation period is an indicator of the memory of the system, or how long water is retained within the turlough, and so provides an indirect measure of flood duration. A large aggregation period implies long flood duration with a lengthy recession, while a smaller value indicates a hydrological regime with rapid filling and emptying.

Table 3.23 Aggregation period for 19 monitored turloughs

Site Name	*Aggregation Period (days)*	*Site Name*	*Aggregation Period (days)*
Ardkill	135	Lisduff	90
Blackrock	38	Lough Aleenaun	10
Brierfield	144	Lough Coy	44
Caherglassaun	66	Lough Gealain	81
Caranavoodaun	80	Rathnalulleagh	85
Carrowreagh	108	Roo West	82
Coolcam	163	Skealoghan	73
Croaghill	120	Termon	176
Garryland	67	Turloughmore	15
Knockaunroe	82		

3.9 Conclusions

The characteristic hydrological diversity of these habitats was quantified through the collection of relevant hydrological and topographic parameters. Three years of water-level data combined with detailed topographic data were used to quantify the temporal variation in water level, volume and area. The form of this groundwater flooding shows significant variation. Turloughs exhibit a range of response and recession characteristics; some have multiple flood events in the course of a year whereas others show a more seasonal response, comprising a single annual flood event. Detailed analysis of turlough flow behaviour provided an insight into the mechanisms controlling turlough filling and emptying. This included investigating the causative relationship of inflow with rainfall, as well as the derivation of stage-discharge relations during the recession phase. Comparison of turlough water-level profiles was also carried out using time-series analysis techniques including correlation, time-lagged correlation and Fourier analysis. This allowed the characterisation of turlough regimes along a disturbance continuum. The dominant effect of outflow capacity on turlough hydrological behaviour was identified. In addition, the clear tidal response displayed by two turloughs was enumerated, using frequency analysis. Thus, through the analysis and interpretation of hydrological datasets, a conceptual understanding of the hydrodynamics of these karst systems has been developed.

Two general models for predicting turlough water level from rainfall and evapotranspiration records have been developed. The multidisciplinary nature of the project dictated that the modelling procedure be capable of representing a wide range of turlough hydrological types. The first model that was developed uses linear regression to predict turlough volume from aggregated rainfall over a defined interval. This technique produced characteristic hydrological parameters and was applied to all monitored turloughs. The second model also predicts volume using rainfall as input, but uses a more refined version of the reservoir modelling technique. The basis of this approach was the identification of characteristic equations governing turlough inflow and outflow, based on rainfall and stage respectively. This method was used for a subset of turlough sites. The models produce satisfactory results, with practicable data requirements, and are readily applicable to new sites, using well-defined field investigation and modelling procedures.

An additional element of this research involved the derivation of critical hydrological factors that influence biological diversity within and among turloughs. From water level, volume and area time series, a number of indicators were derived, each tailored to fit the nature and resolution of the ecological dataset with which it was to be integrated. Hence, for the first time, the role that turloughs occupy within a karst groundwater system has been defined; risks posed to these protected ecosystems may now be evaluated and quantified.

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Chapter 4. Water Chemistry and Algal Biomass

N. Allott, C. Coxon & H. Cunha Pereira

Extensive marl deposition occurs at Lough Gealain, Co. Clare, despite low alkalinity in the floodwater. Lough Gealain also has exceptionally clear water, and very low phosphorus concentrations in the floodwater. *Photo: S. Waldren*

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4.1 Introduction

Previous research on turloughs includes studies on hydrology (Southern Water Global, 1998; Coxon, 1986), vegetation (Goodwillie, 1992), invertebrates (Porst, 2009; Reynolds, 1985; Lansbury, 1965) and land management practices (Ní Bhriain *et al.*, 2002, 2003). Prior to this project there were no published comprehensive data on the chemical characteristics of turlough waters. The chemistry of turlough waters and the extent of development of algal biomass are key aspects in the ecological assessment of any water body, including turloughs. Planktonic algal biomass is routinely quantified as chlorophyll a in standing water bodies.

Phosphorus has long been recognised as the most important limiting nutrient for algal growth in temperate lakes (Reynolds, 2006; Correll, 1998; Hutchinson, 1973). Consequently, many studies of lakes have found P to be positively correlated with algal biomass (Phillips *et al.*, 2008; Dillon & Rigler, 1974; Sakamoto, 1966a, b). However, there are cases where N is an important limiting nutrient, such as in tropical and subtropical lakes (Vincent *et al.*, 1984) or in eutrophic and hypertrophic temperate lakes with high P concentrations (McCauley *et al.*, 1989; Canfield, 1983; Kanninen *et al.*, 1982). Some studies have concluded that both P and N can be co-limiting within the same water body (Morris & Lewis, 1988). Some authors emphasise the influence of the ratio of total nitrogen (TN) to total phosphorus (TP) (TN:TP) on algal biomass (McCauley *et al.*, 1989); N has a more pronounced limiting role only when TN:TP is low, usually below 17 (Sakamoto, 1966a, b; Smith, 1982; Phillips *et al.*, 2008). Although TP and TN are the most important nutrient fractions to measure because they determine the overall fertility of a water body, it can also be informative to measure available fractions of these and other nutrients. Soluble reactive phosphorus (SRP) and total oxidised nitrogen (TON) represent fractions that are readily available for uptake by all algae while silicate is a fraction of silicon that is important for certain algal groups such as diatoms and chrysophytes. N and P in water bodies are strongly influenced by management practices in the catchment, particularly by the spreading of animal slurry and artificial fertilisers. In contrast, alkalinity is produced mainly by dissolution of calcareous minerals in catchment soils and rocks and is therefore largely a natural feature of water bodies. Colour is a measure of the brown colour that is often seen in waters that drain catchments with peat soils. Coloured waters have a lower potential for plant growth because of light attenuation.

Potential sources of nutrients to turloughs include the zone of groundwater contribution (ZOC) and the soils within the basins. Intimate surface water-groundwater relationships and high underground flow rates of karstic hydrological systems render turloughs particularly vulnerable to anthropogenic pressures (Coxon & Drew, 1998; Johnston & Peach, 1998; Tynan *et al*., 2007), particularly to nutrient loading (Kilroy & Coxon, 2005; Kilroy *et al*., 2001). Catchment areas of turloughs are largely dominated by agricultural land, and agricultural activities within ZOCs are expected to be major contributors of nutrients to turlough waters.

Turloughs are located in lowlands dominated by limestone, with soils derived mainly from calcareous till of variable thickness and with catchment landuse dominated by agriculture of variable intensity. Thus turloughs are subject the same pressures, principally nutrient loading from agriculture or other human activities, as are permanent lakes in the same region. However, there are differences between turloughs and permanent lakes that could reasonably be supposed to influence their water chemistry and aquatic biota in ways that are different to those in permanent lakes. The fact that turloughs are mostly dry over much of the growing season and can used as pasture for grazing animals means that there is potential for direct influence from such activities on the subsequent aquatic phase. The existence of terrestrial vegetation on the floor of turloughs, as opposed to the sediment of permanent lakes, may also be expected to influence substrate-water interactions. In addition, the lack of permanent water necessarily has a very fundamental influence on turlough aquatic biota. Fish are absent in many turloughs while invertebrates and algae must either be adapted to survive desiccation or initiate new populations each year from external inocula. The lack of inocula combined with short daylength and low temperatures over much of the flooding season could understandably lead to the assumption that turloughs would have low algal biomass until spring at least.

The aims of this section of the overall project were

- To determine the nutrient status and general chemical characteristics in the set of 22 turloughs over the 2006-2007 flooding season
- To determine the extent to which algal biomass (as chlorophyll a) developed over the 2006-2007 flooding season
- To ascertain the spatial variation in water chemical parameters and algal biomass within a sub-set of four turloughs
- To assess the extent of inter-annual variation in water chemical parameters and algal biomass within a sub-set of four turloughs.

The work presented in this chapter is based on the Ph.D research of Helder Cunha Pereira. Further details of the work presented here can be found in Cunha Pereira *et al*. (2010) and Cunha Pereira (2011).

4.2 Methods

Monthly water samples were collected from October 2006 to June 2007 by throwing a weighted and tethered 5 l plastic bottle from the shore to an area of open water. Locations near springs and swallow holes were avoided. Samples for the study of spatial variation within turloughs were taken every month in four turloughs (Blackrock, Caranavoodaun, Roo West and Termon) from the onset of flooding (beginning of December 2007) until the turloughs had emptied (April-May 2008). An additional December sampling was carried out later in December 2007. Points within the water body were accessed by boat. Points were numbered according to the following criteria: P1 is the edge point in all cases (in the same location as in the first year field season and varying with flood level on each sampling occasion); P2 is the "middle point" (this is considered the deepest and usually most central point of each turlough, close to where the hydrological Divers were located); P3 and P4 are points chosen to coincide with known swallow holes or estavelles or simply away from other points (at a practical distance) to permit a wider spatial sampling. For example, P3 in Caranavoodaun is geographically close to P1, but it is directly above an estavelle and separated from P1 by surrounding vegetation. P3 in Blackrock is also above a large estavelle. P3 in Roo West is close to a small swallow hole, possibly an estavelle.

Samples were analysed for total phosphorus TP, total nitrogen TN, Soluble Reactive phosphorus SRP, total oxidised nitrogen (TON), chlorophyll *a* (Chl *a*), alkalinity, and colour following minor adaptations of "Standard Methods" (Clesceri *et al*., 1989). TP concentration was obtained by acidic persulphate digestion of samples at 120°C and subsequent determination of phosphate by colorimetry (Eisenreich *et al*., 1975; Shimadzu UV-1601 Spectrophotometer). SRP was measured in filtered samples (Whatman GF/C filter) by the colorimetry method used for TP but without digestion. TN was measured after alkaline persulphate digestion of samples at 120°C followed by measuring the resulting nitrate by automated colorimetry (Grasshoff *et al*., 1999; Bran+Luebbe AutoAnalyzer 3). TON was measured on filtered samples using ion chromatography (Dionex Instruments ICS-1500). Chlorophyll *a* was determined by methanol extraction of Whatman GF/C filters, followed by absorbance measurement of the extract at 665 nm (Chl *a* peak) and 750 nm for turbidity correction (Standing Committee of Analysts, 1980; Shimadzu UV-1601 Spectrophotometer). Replicates (at least two from each original 2.5 l sample) were used in the analyses, except in the analyses of alkalinity and Chl *a* for which separate repeatability experiments were carried out.

4.3 Results

4.3.1 General Chemical Characteristics

Table 4.1 shows average values and ranges of all the ecologically important chemical parameters that were measured during the 2006-2007 flooding season. Very low volumes of water in some turloughs at the beginning or end of the flooding season were judged to be non-representative of the flooding season and, therefore, data from these occasions were excluded from the calculation of averages. Turloughs thus affected were Lough Aleenaun, Caherglassan, Lough Coy, Garryland, Lough Gealain, Knockaunroe, Lisduff and Roo West. Data for Lough Coy on December 2006 were also excluded but in this case it was the extremely high water level that prevented the taking of an open-water sample.

Table 4.1 [continues on next page] Mean values, standard deviations and ranges for total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), total oxidised nitrogen (TON), chlorophyll a (Chl a) and silicates, plus mean values for TN:TP ratio, pH, alkalinity, dissolved oxygen, colour and turbidity in the studied flooding season. Also shown are the trophic classifications of the turloughs according to the OECD (1982).

Turlough	*TP (µg l^{-1})*		*SRP (µg l^{-1})*		*TN (mg l^{-1})*		*TON (mg l^{-1})*		*Chl a (µg l^{-1})*	
	Mean±SD	*Range*	*Mean±SD*	*Range*	*Mean±SD*	*Range*	*Mean±SD*	*Range*	*Mean±SD*	*Range*
Ardkill	82±33	32.3-117.1	42±27	1.6-82.6	1.74±1.04	0.6-3.8	1.25±1.04	0-3.1	12.7±16.1	1.8-52.4
Ballinderreen	12±9	4.6-27.8	1±0.4	0.3-1.6	0.73±0.41	0.2-1.5	0.15±0.21	0-0.5	3.0±2.7	1.0-8.8
Blackrock	52±16	27.4-73.5	27±10	15.1-38.0	1.72±0.29	1.3-2.1	1.21±0.37	1.0-2.0	1.3±0.7	0.7-2.5
Brierfield	20±10	12.1-41.2	2±1	0.5-3.3	0.57±0.15	0.4-0.8	0.06±0.11	0-0.3	5.0±3.1	1.1-9.9
Caherglassan	43±12	31.8-66.7	19±7	6.7-29.8	1.22±0.23	0.9-1.6	0.85±0.52	0.3-0.9	3.3±4.3	0.8-13.5
Caranavoodaun	11±4	6.3-18.6	2±1	0.8-3.1	2.30±1.42	0.8-5.1	1.86±1.42	0-4.1	2.8±2.8	0.7-9.2
Carrowreagh	43±8	32.8-55.7	8±8	1.8-21.6	0.91±0.45	0.5-1.6	0.36±0.41	0-1.0	12.1±9.5	2.8-31.3
Coolcam	34±21	8.8-80.8	4±4	0.3-13.9	1.27±0.67	0.5-2.6	0.92±0.59	0-1.7	18.1±11.6	3.0-31.7
Croaghill	25±17	10.5-65.0	4±2	1.9-8.1	1.17±0.68	0.4-2.3	0.71±0.67	0-1.7	7.6±10.3	1.4-32.0
Garryland	25±7	11.7-31.4	11±4	3.5-14.3	1.08±0.42	0.6-1.8	0.57±0.22	0.3-0.8	1.1±0.6	0.4-2.0
Lough Aleenaun	31±14	17.0-59.9	9±6	0.7-16.6	1.25±0.27	0.8-1.5	1.01±0.28	0.7-1.4	9.2±12.8	1.5-36.6
Lough Coy	43±16	24.7-61.9	21±10	4.8-34.4	1.41±0.26	1.1-1.9	1.00±0.25	0.6-1.3	5.2±5.6	0.7-13.5
Lough Gealain	4±1	1.7-5.5	1±0.4	0.2-1.3	0.59±0.20	0.3-0.9	0.35±0.12	0.1-0.5	1.1±0.7	0.3-2.6
Kilglassan	27±12	13.9-44.6	5±4	1.6-12.1	1.45±1.04	0.2-3.3	1.07±1.00	0-2.7	5.0±3.4	1.6-10.6
Knockaunroe	4±2	1.4-7.1	1±0.4	0-1.3	0.55±0.15	0.3-0.8	0.30±0.15	0-0.4	1.2±0.7	0.5-2.2
Lisduff	7±2	4.2-9.6	2±1	0.9-2.4	1.90±0.77	0.7-3.1	1.75±0.84	0-2.5	1.4±0.5	0.8-2.1
Rathnalulleagh	45±22	18.9-83.9	3±2	1.0-6.5	1.25±0.46	0.7-1.9	0.66±0.49	0-1.4	33.5±36.5	6.3-110.5
Roo West	10±4	4.5-17.7	1±1	0.2-1.6	0.59±0.29	0.2-1.0	0.25±0.24	0-0.6	2.1±1.1	0.7-3.7
Skealoghan	20±6	12.7-27.2	6±6	1.2-17.7	0.92±0.69	0.4-2.2	0.50±0.65	0-1.8	6.9±4.2	1.5-11.8
Termon Lough	15±8	4.3-30.2	2±1	1.5-5.1	0.62±0.34	0.4-1.2	0.28±0.32	0-0.8	3.1±2.4	0.6-8.1
Tullynafrankagh	33±18	14.7-58.9	3±2	1.6-7.2	2.14±1.24	0.9-4.6	1.49±1.33	0-3.8	18.4±20.0	3.0-69.4
Turloughmore	19±11	10.2-35.7	3±2	1.6-5.4	0.63±0.43	0.2-1.3	0.33±0.37	0-0.8	4.8±4.6	0.6-11.3

Table 4.1 [continued from previous page]

Turlough	TN:TP ratio	Silicates (mg l^{-1} SiO_2-Si)		pH	Alkalinity (mg l^{-1} $CaCo_3$)	Dissolved O_2 (mg l^{-1})	Colour (mg l^{-1} PtCo)	Turbidity (NTU)	Trophic status (OECD 1982) based on[a]	
		Mean±SD	Range						Mean TP	Mean Chl a
Ardkill	26	1.64±1.95	0.06-5.86	8.10	220	11.0	28	1.9	Eutrophic	Eutrophic
Ballinderreen	73	0.43±0.45	0.01-1.26	8.21	184	11.8	17	1.1	Mesotrophic	Mesotrophic
Blackrock	35	1.27±0.22	1.07-1.66	7.89	167	10.7	72	2.7	Eutrophic	Oligotrophic
Brierfield	32	1.73±1.86	0.03-4.63	8.13	210	11.1	36	2.0	Mesotrophic	Mesotrophic
Caherglassan	30	0.87±0.39	0.16-1.26	7.95	112	11.2	85	3.0	Eutrophic	Mesotrophic
Caranavoodaun	258	1.63±1.68	0.07-4.52	8.16	217	11.0	25	2.2	Mesotrophic	Mesotrophic
Carrowreagh	21	1.23±1.15	0.03-2.97	8.23	219	12.0	48	3.4	Eutrophic	Eutrophic
Coolcam	45	0.90±0.65	0.00-1.75	8.17	214	11.4	23	3.4	Mesotrophic	Eutrophic
Croaghill	57	1.57±1.47	0.06-3.97	8.16	220	11.2	44	2.5	Mesotrophic	Mesotrophic
Garryland	46	1.08±0.29	0.55-1.37	7.71	122	10.0	80	1.9	Mesotrophic	Oligotrophic
Kilglassan	58	1.81±2.59	0.03-6.09	8.22	216	11.6	28	3.5	Mesotrophic	Mesotrophic
Knockaunroe	147	0.43±0.30	0.04-0.87	8.13	139	11.1	10	0.6	Oligotrophic	Oligotrophic
Lough Aleenaun	48	0.32±0.09	0.18-0.42	8.04	160	11.8	14	5.5	Mesotrophic	Eutrophic
Lough Coy	36	1.18±0.39	0.53-1.57	7.86	143	10.6	72	2.5	Eutrophic	Mesotrophic
Lough Gealain	163	0.39±0.25	0.05-0.80	8.17	135	11.2	8	0.7	Oligotrophic	Oligotrophic
Lisduff	282	2.52±2.56	0.04-7.31	8.12	228	11.0	21	4.1	Oligotrophic	Oligotrophic
Rathnalulleagh	34	1.01±0.75	0.00-1.76	8.09	236	11.9	28	5.4	Eutrophic	Hypertrophic
Roo West	65	0.41±0.48	0.01-1.18	8.27	141	11.6	14	1.6	Oligotrophic	Oligotrophic
Skealoghan	37	1.92±2.67	0.04-6.14	8.07	198	9.8	26	1.7	Mesotrophic	Mesotrophic
Termon Lough	49	2.30±2.37	0.04-7.06	8.09	226	10.4	21	1.3	Mesotrophic	Mesotrophic
Tullynafrankagh	93	2.93±3.02	0.14-8.52	7.92	234	11.6	36	2.7	Mesotrophic	Eutrophic
Turloughmore	46	0.36±0.20	0.03-0.54	8.12	168	12.0	11	0.8	Mesotrophic	Mesotrophic

[a] fixed boundary system used.

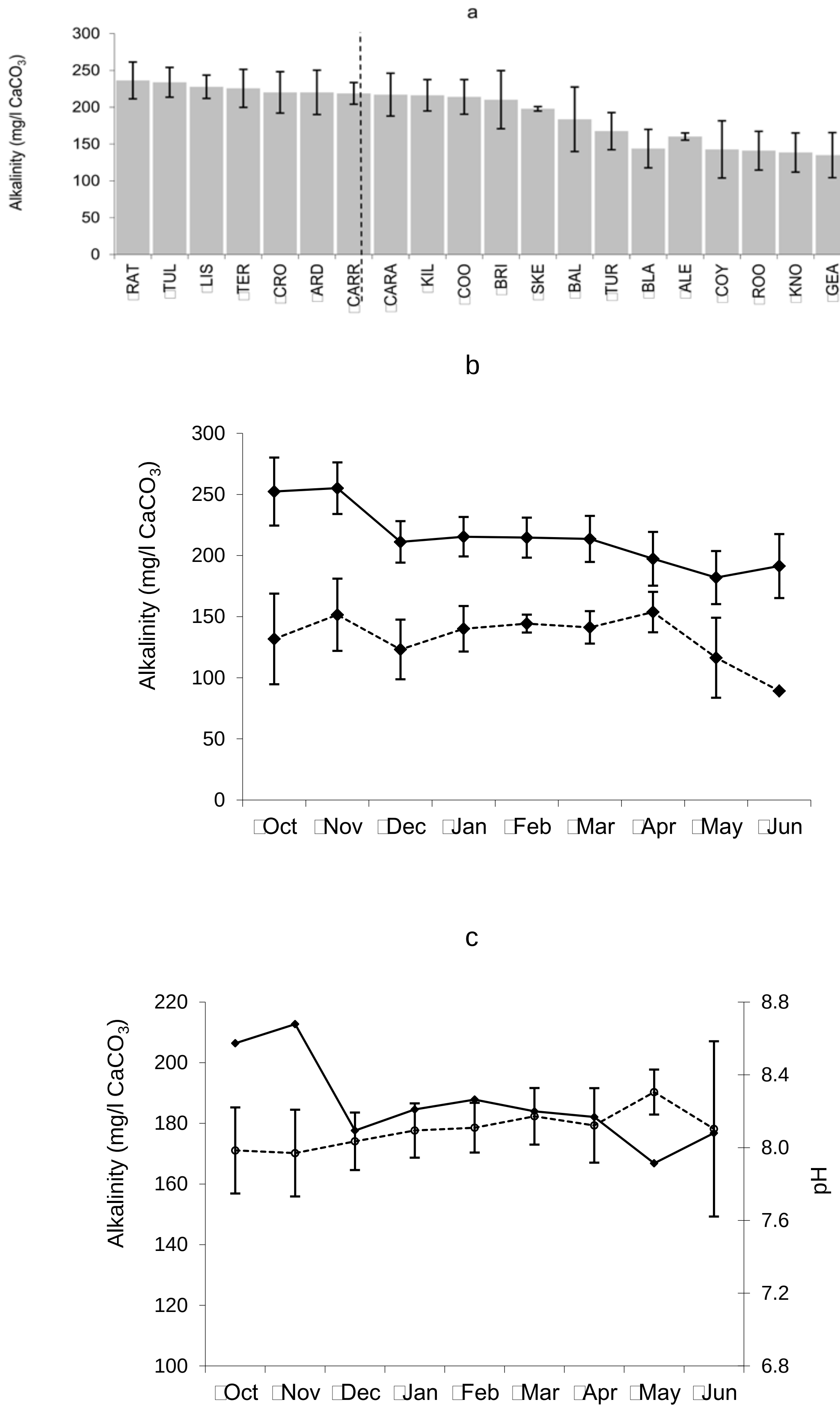

Figure 4.1 (a) average alkalinity (±SD) for the 22 turloughs (vertical line divides the turloughs into two groups, see b); (b) average alkalinity (±SD) over time in the two groups separated in a (solid line - group in the left, broken line - group in the right); (c) average alkalinity (solid line) and pH(broken line, ±SD error bars) over time in the 22 turloughs.

pH ranged between 7.7 and 8.3 and alkalinity between 112 and 236 mg l^{-1} $CaCO_3$. Turloughs in the Burren region (Lough Gealain, Knockaunroe, Lough Aleenaun, Turloughmore and Roo West) and the four coloured and deep turloughs (Blackrock, Coy, Caherglassan and Garryland) that receive drainage from the Sliabh Aughty hills had lower alkalinity than other turloughs (Table 4.1 and Figure 4.1). There was a general trend across turloughs of a slight rise of pH over the flooding season, while in general, alkalinity decreased in all turloughs over the flooding season while pH increased slightly (Figure 4.1). Average colour ranged between 8 and 48 mg l^{-1} PtCo for all turloughs except for the four deep turloughs referred to above where it averaged 72- 85 mg l^{-1} PtCo (Table 4.1). By contrast, turloughs on the region of the Burren (Lough Gealain, Knockaunroe, Roo West, Turloughmore, Aleenaun) had low colour (average ≤14 mg l^{-1} PtCo).

The turloughs varied considerably with respect to the concentration of nutrients and Chl *a* (Table 4.1). Average TP ranged between 4.0 and 82.1 µg l^{-1}, with 16 sites having a mean TP value <35 µg l^{-1} and three sites having <10 µg l^{-1} (SD of averages across turloughs = 18.7 µg l^{-1}); average TN ranged from 0.5 to 2.3 mg l^{-1} (SD = 0.5 mg l^{-1}) and average Chl *a* ranged from 1.1 to 18.4 µg l^{-1} in all turloughs except in Rathnalulleagh, which had a seasonal average of 33.5 µg l^{-1} (SD of averages across turloughs = 7.8 µg l^{-1}). The high Chl *a* average in Rathnalulleagh is due to high values during the season (between 6 and 48 µg l^{-1}) but also to an extreme value in October (110.5 µg l^{-1}). Average TN:TP were above 21 for all turloughs (Table 4.1). Monthly values below 17 occurred in only seven turloughs, usually in only one or two months at the beginning or end of the season, when TN was low.

Average SRP was <5 µg l^{-1} in 14 turloughs, and <10 µg l^{-1} in 17 turloughs. Garryland, Caherglassan, Lough Coy, Blackrock, and Ardkill had SRP seasonal averages >10 µg l^{-1} (Table 4.1). SRP was 17.9% of TP on average for all turloughs (SD=7.3%, n=17) except in the above five, where SRP was 46.7% of TP on average (SD=6.6%, n=5). TON was very low (<0.15 mg l^{-1} on average) in two turloughs (Brierfield and Ballinderreen). Average TON was <0.5 mg l^{-1} in nine turloughs and <1.0 mg l^{-1} in 16 and the highest average was 1.86 mg l^{-1} in Caranavoodaun. The percentage TON of TN for all turloughs (except Ballinderreen and Brierfield, both <15%) was 55.6% (SD=15.9 %, n=20), with the highest value in Lisduff (85.4 %).

4.3.2 Trophic Status

Based on TP, four of the turloughs were oligotrophic, 12 were mesotrophic, six were eutrophic and none were hypertrophic (Table 4.1) according to the OECD (1982) classification scheme. If Chl *a* is used to classify the turloughs instead of TP, six were oligotrophic, 10 were mesotrophic, five were eutrophic and one (Rathnalulleagh) was hypertrophic (Table 4.1). However, the hypertrophic classification for Rathnalulleagh is strongly influenced by one very high value (110.5 µg l^{-1}) in October 2006. If this value is omitted, Rathnalulleagh is classified as eutrophic. Rathnalulleagh remains in the eutrophic category based on TP whether the October TP result is included or not. The relatively high values of TP (October 2006 and June 2007) and Chl *a* (June 2007) in Brierfield have no effect on the classification, which remains in the mesotrophic category if these data are excluded or not.

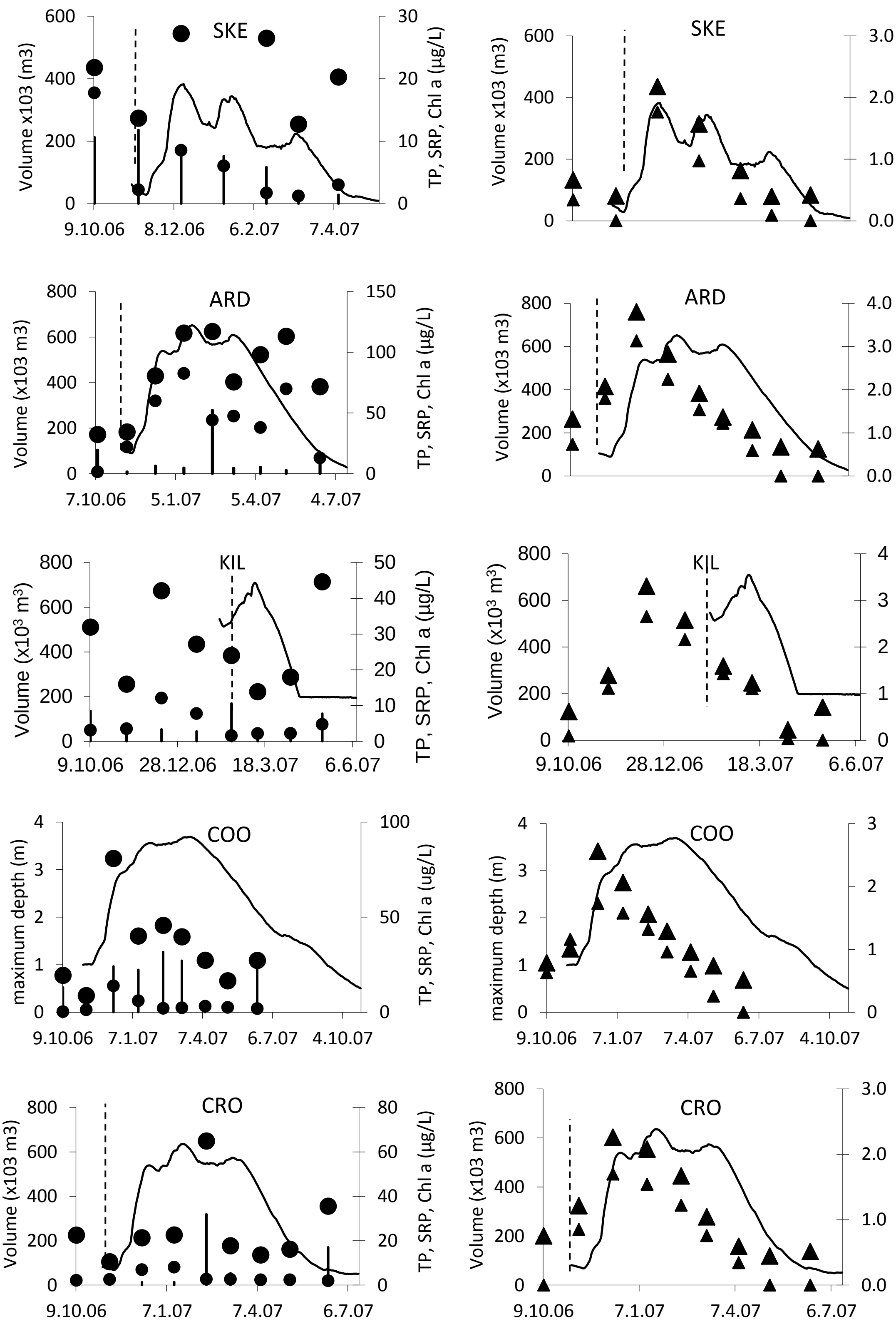

Figure 4.2 Temporal variation of volume (or depth where no topographical data was available) and of TP, SRP and Chl a (left graphs) and of TN and TON (right graphs). TP - large circles, SRP - small circles; Chl a - bars; TN - large triangles; TON - small triangles. Turloughs arranged by geographic position (broadly from north to south and from west to east). Vertical lines indicate the late start of hydrological measurements in some turloughs.

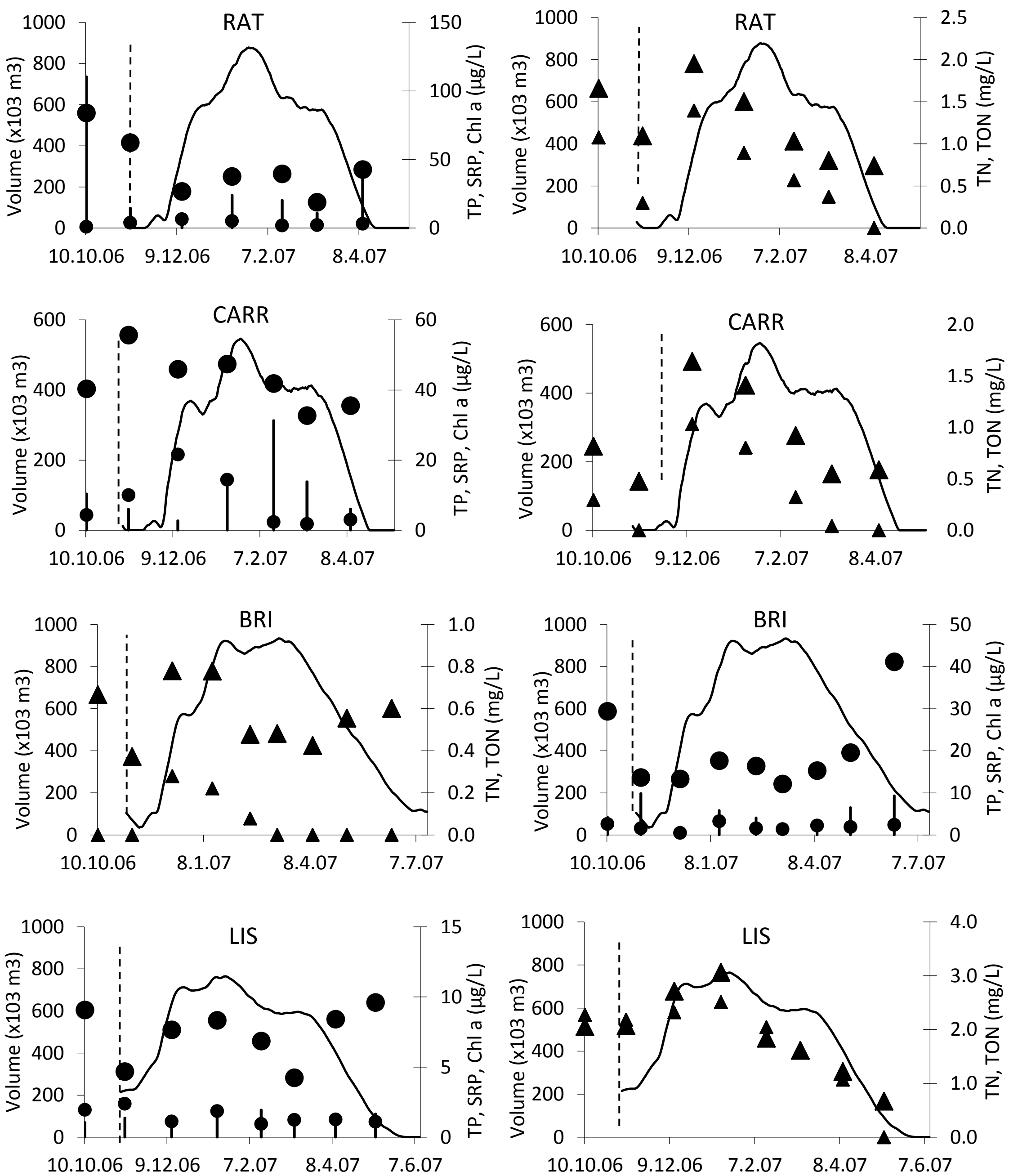

Figure 4.2 Temporal variation of volume (or depth where no topographical data were available) and of TP, SRP and Chl a (left graphs) and of TN and TON (right graphs). TP - large circles, SRP - small circles; Chl a - bars; TN - large triangles; TON - small triangles. Turloughs arranged by geographic position (broadly from north to south and from west to east). Vertical lines indicate the late start of hydrological measurements in some turloughs.

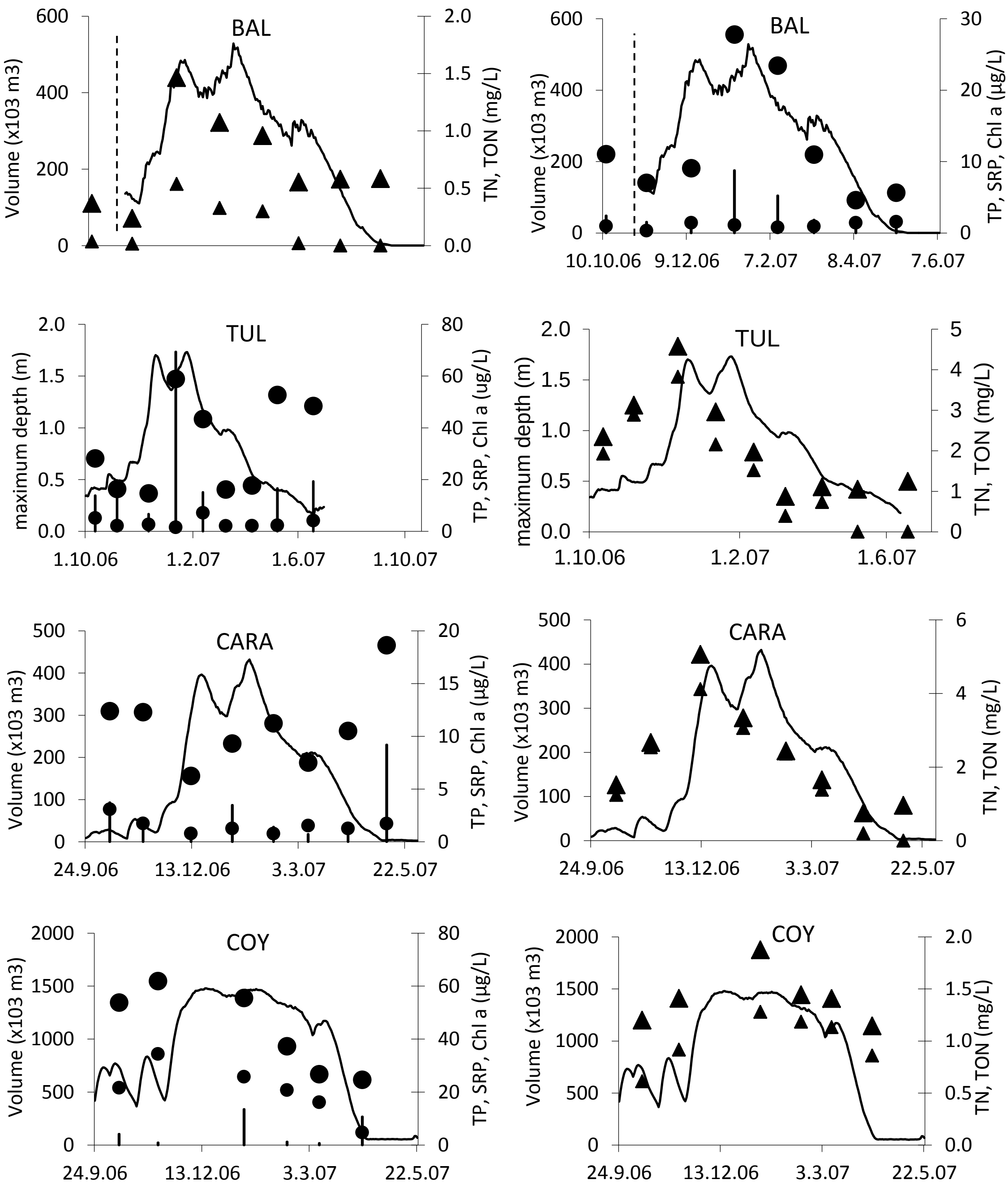

Figure 4.2 Temporal variation of volume (or depth where no topographical data were available) and of TP, SRP and Chl a (left graphs) and of TN and TON (right graphs). TP - large circles, SRP - small circles; Chl a - bars; TN - large triangles; TON - small triangles. Turloughs arranged by geographic position (broadly from north to south and from west to east). Vertical lines indicate the late start of hydrological measurements in some turloughs.

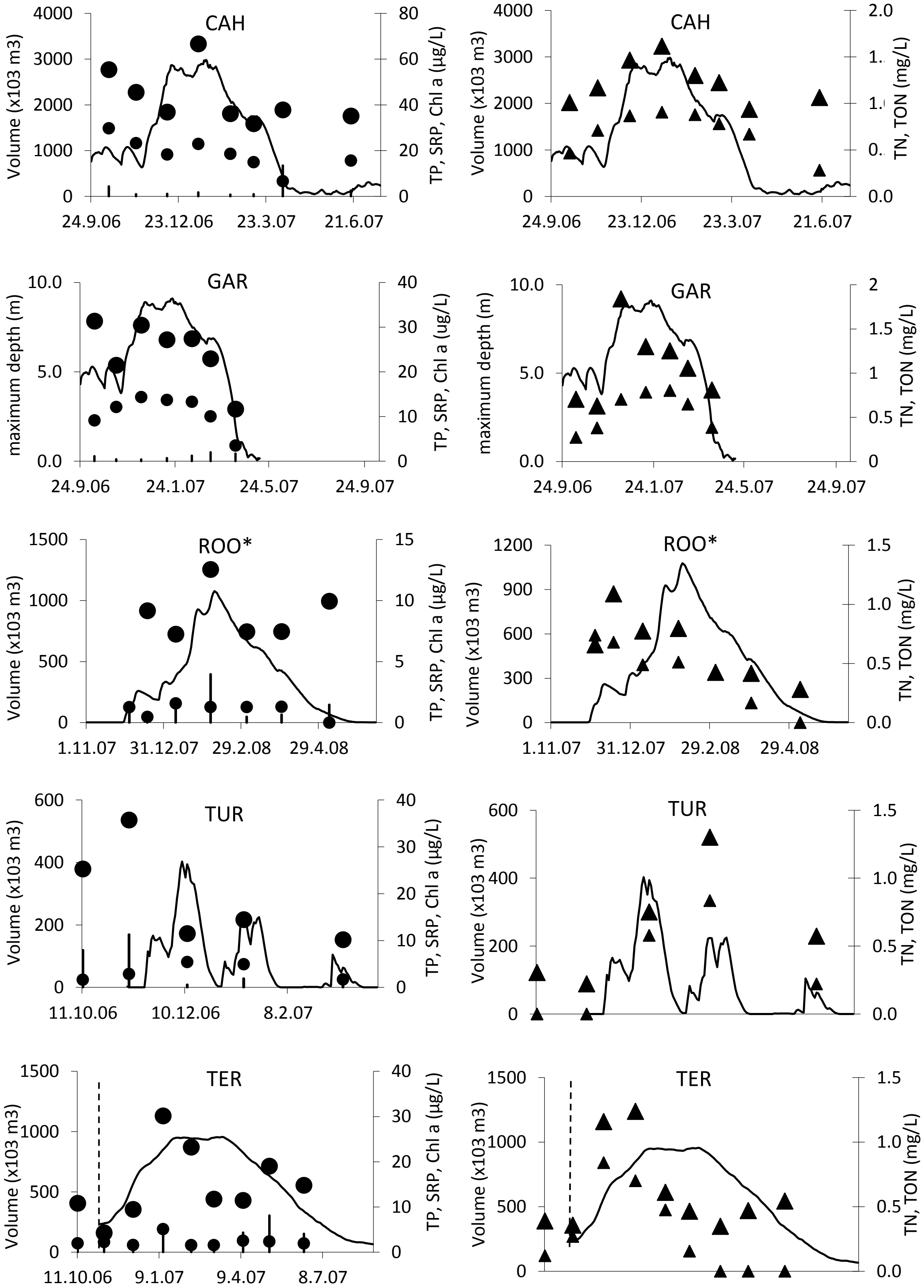

Figure 4.2 Temporal variation of volume (or depth where no topographical data were available) and of TP, SRP and Chl a (left graphs) and of TN and TON (right graphs). TP - large circles, SRP - small circles; Chl a - bars; TN - large triangles; TON - small triangles. Turloughs arranged by geographic position (broadly from north to south and from west to east). Vertical lines indicate the late start of hydrological measurements in some turloughs.

** - the hydrograph for Roo West corresponds to the second year only*

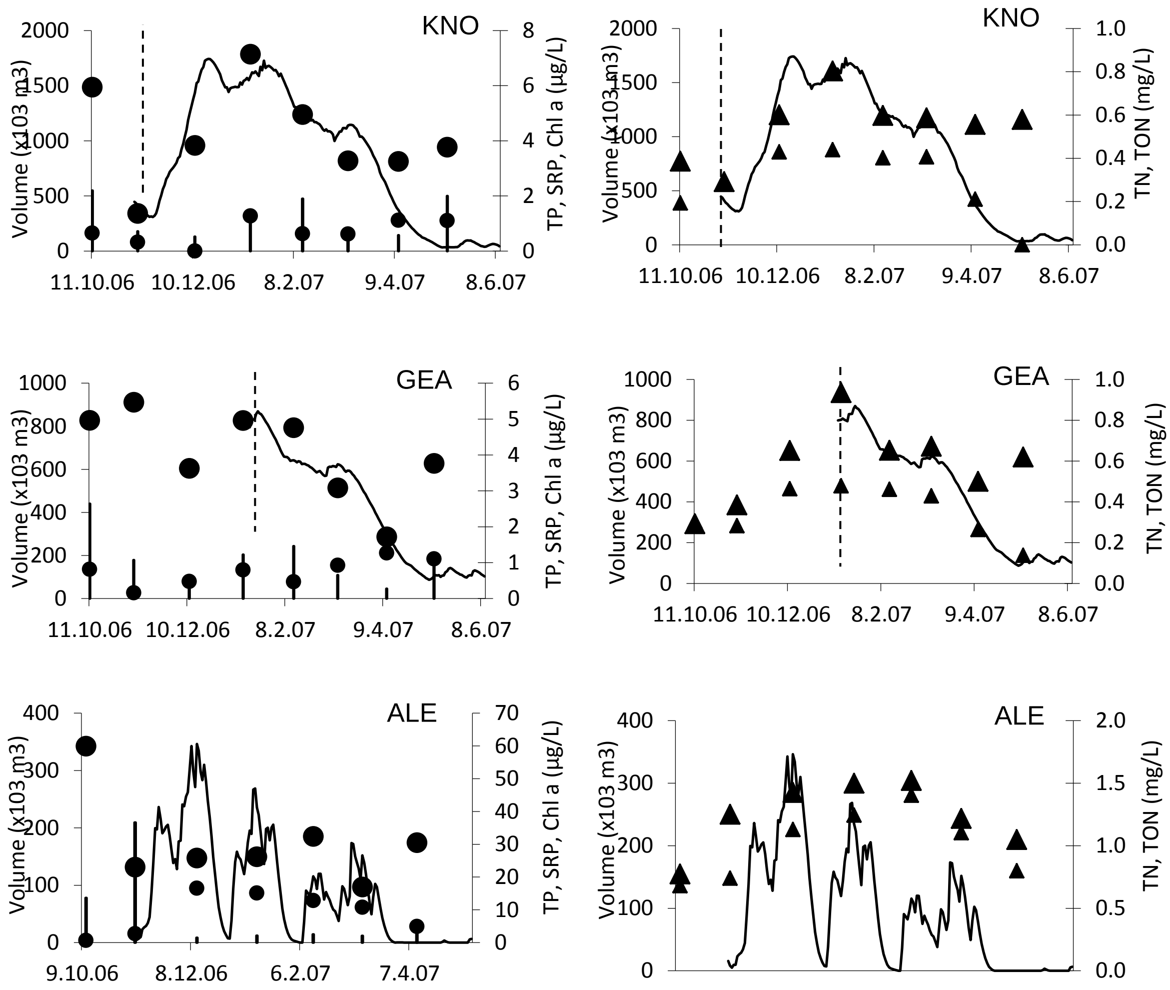

Figure 4.2 Temporal variation of volume (or depth where no topographical data was available) and of TP, SRP and Chl a (left graphs) and of TN and TON (right graphs). TP - large circles, SRP - small circles; Chl a - bars; TN - large triangles; TON - small triangles. Turloughs arranged by geographic position (broadly from north to south and from west to east). Vertical lines indicate the late start of hydrological measurements in some turloughs.

4.3.3 Seasonal Variation in Nutrients

Figure 4.2 shows the concentration of TP, SRP, TN, TON, Chl *a* and turlough volume (or maximum depth in the case of three turloughs for which volumes were not available) for the 2006-2007 flooding season. TN varied systematically over time in most turloughs, increasing to a maximum in mid-winter (December-January) and gradually decreasing thereafter. The maximum TN concentration frequently, though not always, coincided with maximum turlough volume. Sometimes the peak preceded the maximum volume (e.g. Coolcam, Rathnalulleagh, Carrowreagh, Brierfield, Roo West). The decrease in TN after peak concentration often (e.g. in Caranavoodaun, Lisduff) though not always coincided with a decrease in volume. For example, Ardkill, Coolcam, Croaghill, Termon were apparently still filling or remained full while TN declined. Turloughs in the same area often had very similar TN concentrations and similar trends over time (e.g. Caranavoodaun and Tullynafrankagh; Rathnalulleagh and Carrowreagh; Ardkill and Kilglassan). It is also interesting to note that both Turloughmore and Lough Aleenaun, despite draining and re-filling several times in the flooding season, nonetheless showed the same temporal variation in TN as most other turloughs.

TP and Chl *a*, unlike TN, did not show any seasonal pattern that predominated in the turloughs (Figure 4.2). TP was often high in the winter months but not, for example, in Rathnalulleagh, Ardkill and Brierfield. Also, unlike TN, neither TP nor Chl *a* varied systematically with turlough volume. Chlorophyll *a* peak values were usually multiples of those at other times. Chlorophyll *a* was highest in the period November to February in 14 turloughs (five in both November and February, four in January). Three turloughs had peak Chl *a* in October and in May while only one reached peak Chl *a* in March and April. Values as high as 13.5 μg l^{-1} in Lough Coy, 14.5 μg l^{-1} in Carrowreagh, 22.4 μg l^{-1} in Coolcam, 24.0 μg l^{-1} in Rathnalulleagh, and even 69.4 μg l^{-1} in Tullynafrankagh were recorded in the middle of winter (January). Values of Chl *a* ≥10 μg l^{-1} on the first sampling date were found in seven out of the 22 turloughs (Ardkill, Carrowreagh, Coolcam, Lough Aleenaun, Rathnalulleagh, Skealoghan and Tullynafrankagh). A striking example was that of Rathnalulleagh, with a peak of 110.5 μg l^{-1} of Chl *a* in October 2006.

Mean TP and TN were significantly positively correlated in the turloughs ($r=0.50$, $p=0.02$, $N=22$, Spearman), especially once Tullynafrankagh, Caranavoodaun and Lisduff are left out of the analysis ($r=0.88$, $p<0.001$, Spearman), as these three turloughs appear to be outliers with a relatively high TN to low TP concentrations (Figure 4.3).

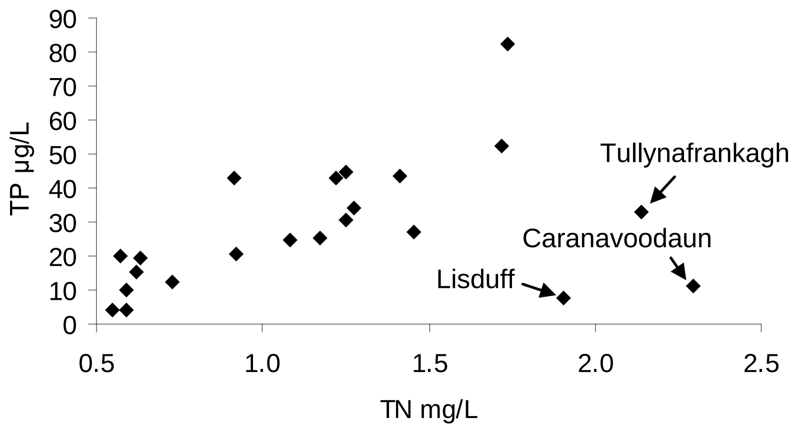

Figure 4.3 Average TP-TN relationship in the 22 turloughs in the first flooding season. The three turloughs with a relatively low TP and high TN are labelled.

4.3.4 Relationships Between Nutrients and Chlorophyll *a*

Chlorophyll *a* (Chl *a*)was not significantly correlated with TN (log of monthly values and seasonal averages, $n=22$, $p>0.30$). However, the linear regression between TP and Chl *a* was significant, using both all monthly values (log Chl a = 0.754 log TP - 0.449, $R^2=0.317$, $p<0.001$; $n=169$) and seasonal averages (log Chl a = 0.663 log TP - 0.345, $R^2=0.342$, $p=0.004$; $n=22$). If the five turloughs with average SRP values >10 μg l^{-1} (Ardkill, Blackrock, Lough Coy, Caherglassan and Garryland) are omitted from this analysis, the regression shows a considerably better fit (log Chl a = 1.147 log TP - 0.802; $R^2 = 0.844$, $R=0.919$, $p<0.001$, $n=17$; Figure 4.4). The plot of average Chl *a* against average TP and the regression line including all turloughs except the five mentioned is depicted (Figure 4.4).

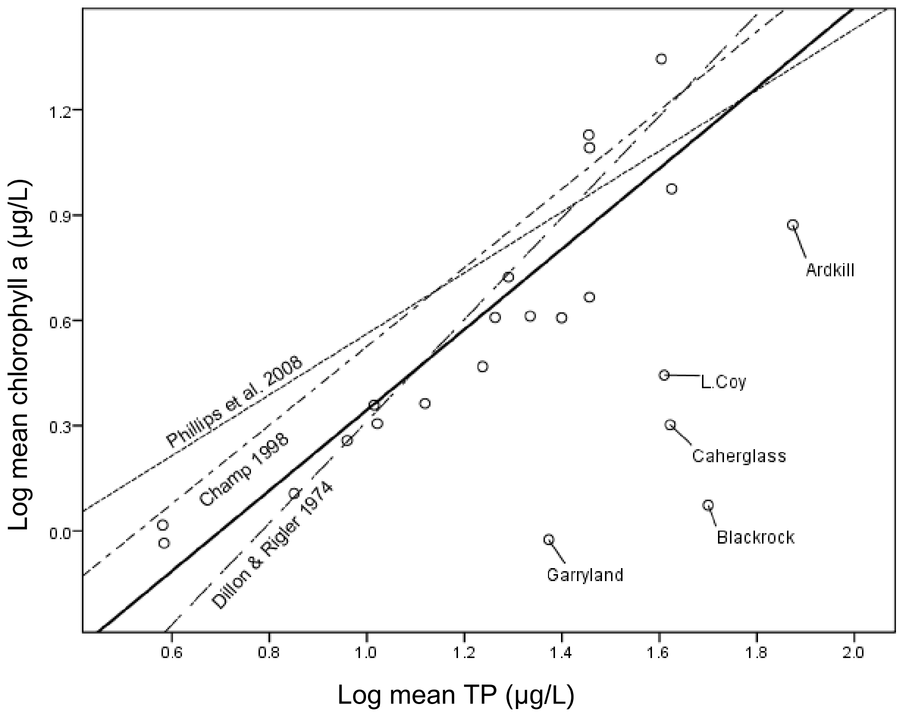

Figure 4.4 Relationship between average log total phosphorus (TP) and average log chlorophyll *a* (Chl *a*) in the 22 turloughs studied. Continuous line represents the linear regression fit (log Chl *a* = 1.147 log TP - 0.802, R^2 = 0.844, N=17) and broken lines represent linear regression lines for lakes in the literature (see text). Labelled turloughs were omitted from the regression because Chl *a* concentration was not considered to be limited by TP in these turloughs.

4.3.5 Spatial Variation Within Turloughs

The four sampling points within turloughs showed very similar absolute values and temporal variation patterns for most chemical variables, including TN, TON, alkalinity, colour and silicates (Table 4.2; Figures 6.3 and 6.4 in Cunha-Pereira 2011). However TP, SRP, Chl *a* and turbidity were found to be more spatially variable within turloughs than the above variables (Table 4.2). It is noteworthy that Chl *a* tended to be higher at the shoreline than at other sampling points (Cunha Periera, 2011). The biggest differences among sampling points were in the first and final months of flooding when water levels were low (Table 4.2).

Blackrock stood out in terms of a number of chemical parameters. It had waters with higher colour, higher TP, higher SRP, lower Chl *a* and higher average turbidity than the other three turloughs (Cunha-Pereira, 2011). These same distinguishing characteristics were also evident in the first year of study, as this turlough was part of the not P-limited coloured-deep turlough cluster (see above). Termon, Caranavoodaun and Roo West also had very similar chemical characteristics as in the first year of the study.

Table 4.2 Coefficients of variation (%) of relevant chemical parameters for all samples collected in the second year. Shaded values highlight values≥25%.

	Dec I	Dec II	Jan	Feb	Mar	Apr	May
TP							
Blackrock	-	2	18	11	2	2	
Caranavoodaun	-	38	19	14	30	36	9
Roo	-	18	15	21	7	32	20
Termon	-	3	7	12	8	41	49
TN							
Blackrock	4	15	4	9	2	4	
Caranavoodaun	31	11	2	2	5	9	8
Roo	11	20	6	22	13	12	9
Termon	34	3	10	17	10	5	17
Chl *a*							
Blackrock	5	17	50	38	18	4	
Caranavoodaun	58	38	7	7	19	77	37
Roo	34	20	8	3	14	46	36
Termon	71	9	5	8	13	17	113
SRP							
Blackrock	5	4	21	13	4	14	
Caranavoodaun	95	39	5	20	7	48	100
Roo	57	46	80	64	15	31	200
Termon	38	15	5	12	9	49	0
TON							
Blackrock	1	4	4	1	1	1	
Caranavoodaun	32	13	2	1	2	2	0
Roo	9	5	4	4	7	11	0
Termon	49	3	7	3	7	25	0
Alkalinity							
Blackrock	2	1	2	1	1	1	
Caranavoodaun	4	3	1	0	1	1	4
Roo	6	2	3	3	1	2	7
Termon	13	2	1	1	1	1	6
Colour							
Blackrock	1	4	2	1	2	2	
Caranavoodaun	6	16	9	12	13	6	12
Roo	9	42	13	8	43	7	9
Termon	30	11	15	36	16	4	25
Silicates							
Blackrock	3	5	4	3	3	67	
Caranavoodaun	4	3	1	1	13	8	22
Roo	15	1	10	7	21	39	18
Termon	3	2	0	5	6	20	15
Turbidity							
Blackrock	7	21	23	6	2	5	
Caranavoodaun	28	47	18	45	11	48	61
Roo	15	33	28	26	28	21	47
Termon	44	45	31	24	41	28	131

4.3.6 Trophic Status of Sites Within Turloughs

The trophic status of both Blackrock and Roo West turloughs remained the same regardless of the sampling point used for its determination, while the trophic status of Caranavoodaun and Termon was either oligotrophic or mesotrophic depending on which site within the turloughs was used to make the assessment (Table 4.3). However, this ambiguity in classification arises largely because the mean values for TP and Chl *a* are quite close to the boundary values of 10 μg l^{-1} for TP and 2.5 μg l^{-1} for Chl *a*) (OECD, 1982).

Table 4.3 Trophic classification (OECD, 1992) of the different sampling points as averages of TP and Chl *a* during the flooding season. Also shown are the classifications for the edge point in the first year of study (in italics).

Sampling Point	Mean TP (μg l^{-1})	Mean Chl a (μg l^{-1})	Trophic classification according to:	
			Mean TP	Mean Chl a
Blackrock				
P1 (1st year)	*52*	*1.3*	*Eutrophic*	*Oligotrophic*
P1 (2nd year)	50	6.6	Eutrophic	Mesotrophic
P2	43	6.4	Eutrophic	Mesotrophic
P3	43	6.1	Eutrophic	Mesotrophic
P4	44	7.0	Eutrophic	Mesotrophic
Caranavoodaun				
P1 (1st year)	*11*	*2.8*	*Mesotrophic*	*Mesotrophic*
P1 (2nd year)	12	3.0	Mesotrophic	Mesotrophic
P2	10	2.2	Oligotrophic	Oligotrophic
P3	8	1.6	Oligotrophic	Oligotrophic
P4	8	1.4	Oligotrophic	Oligotrophic
Roo West				
P1 (1st year)	*10*	*2.1*	*Oligotrophic*	*Oligotrophic*
P1 (2nd year)	9	1.4	Oligotrophic	Oligotrophic
P2	7	1.3	Oligotrophic	Oligotrophic
P3	9	1.3	Oligotrophic	Oligotrophic
P4	9	1.1	Oligotrophic	Oligotrophic
Termon				
P1 (1st year)	*15*	*3.1*	*Mesotrophic*	*Mesotrophic*
P1 (2nd year)	11	2.4	Mesotrophic	Oligotrophic
P2	10	1.5	Oligotrophic	Oligotrophic
P3	9	2.2	Oligotrophic	Oligotrophic
P4	10	1.5	Oligotrophic	Oligotrophic

4.3.7 Inter-annual Variation

Chemical parameters were often strikingly similar between the two years, both in the absolute values and in their trends over time (Cunha-Pereira, 2011). TN and nitrate showed similar trends as in the first year for all turloughs: a peak in winter followed by a steady decline. Trophic status was the same in Caranavoodaun and Roo West in both years. However, Blackcock changed from oligotrophic to mesotrophic because of a sharp increase in Chl *a* in March and April 2008 while Termon went from mesotrophic to oligotrophic owing to lower mean Chl *a* in the second flooding season (Table 4.3). However, as stated above, the ambiguity arises because the measured values are close to the oligotrophic-mesotrophic boundary though in this case only changed when Chl *a* was used and remained the same for TP.

There was one striking difference between years: that of the sharp rise in Chl *a* in March and April 2008 in Blackrock. During this period there were no concomitant visible changes in other parameters (e.g. depth, TP, TN, colour) that could explain this difference between years. These variables were not very different from the same period in 2006-2007 (Cunha-Pereira, 2011), when no rise in Chl *a* occurred.

4.4 Discussion

4.4.1 General Chemical Characteristics

The chemistry of the turloughs waters was typical of the diversity of surface water chemistry that is found in this region of Ireland (see, for example, Flanagan and Toner, 1976; Allott, 1990; Champ, 1998; King & Champ, 2000). Some very clear contrasts in water chemistry among the turloughs relate to differences in the nature of their zones of contribution. The northern group of nine turloughs all had high alkalinity (generally higher than 200 mg l^{-1} $CaCO_3$) reflecting the importance of calcareous tills and limestone bedrock in the zones of contribution. Turloughs in or near the Burren (e.g. Lough Aleenaun, Lough Gealain) where limestone also predominates, but where soils are thin or absent, had notably lower alkalinity compared to the northern group. It seems clear therefore that calcareous soils can make an important contribution to alkalinity in turloughs. Blackrock, Coy, Garryland and Caherglassan had alkalinities in the same range as the Burren turloughs but for a different reason. These four turloughs receive drainage from the Sliabh Aughty hills which are characterised by acid bedrock (mainly Old Red Sandstone) with peat soils and produce waters of low alkalinity. Thus the waters of this group of four turloughs are a mixture of soft water from the Sliabh Aughtys and hard water from the lowland calcareous parts of their catchments, to yield waters of relatively low alkalinity.

In general, turloughs with the highest alkalinity had the highest pH and vica versa, as would be expected in waters where pH is mainly determined by the concentration of the HCO_3^- ion. However, it is interesting to note that some turloughs had a relatively low pH for their level of alkalinity. An extreme case of this was Tullynafrankagh which had the highest average alkalinity but an average pH of only 7.92. Such cases imply a greater degree of supersaturation with CO_2 as a result of soil-water interactions than in turloughs with higher pH for a given level of alkalinity. However, the fact that alkalinity declined and pH increased over the flooding season in all the turloughs implies that they were all initially supersaturated with CO_2 to some extent and that they gradually became less so as $CaCO_3$ was deposited over the flooding season.

Carbonate deposition in turloughs (including three of the 22 sites investigated in this project, Kilglassan, Ardkill and Skealoghan) was studied by Coxon (1994). From this earlier dataset (from sampling in 1982 to 1984), it was noted that calcium concentrations in the turloughs were initially comparable to that of the local groundwater (monitored at Cregduff springs) but decreased during the flooding season while calcium concentration in the groundwater increased or remained constant. Inflowing water at estavelles in the turloughs had a pH close to 7 and comparable to that at Cregduff springs, but the turlough water pH rose rapidly to 8 or more and the waters became supersaturated with calcium carbonate. Thus the trends observed in this earlier dataset are broadly comparable to those of the present investigation.

Further investigation of carbonate depositional processes was beyond the scope of the current research project, but it may be noted that the new information on turlough trophic status is relevant to the discussion of deposition mechanisms. Coxon (1994) concluded that the observed quantity of carbonate deposition could be explained by physico-chemical processes of carbon dioxide loss without invoking biological CO_2 uptake, and it was suggested at that time that the level of algal CO_2 uptake required to explain the deposition occurring in March - April was implausibly high at 750-1500 mg C m^{-2} of water surface per day, as this would imply a naturally highly eutrophic or artificially enriched system. At the time of this earlier research, no data were available on turlough algal productivity. From the levels of TP and chlorophyll *a* observed in the present study, trophic status of the 22 turloughs was seen to vary from oligotrophic to hypertrophic (Table 4.1). Therefore it is possible that algal CO_2 uptake may play a significant role in carbonate precipitation at some sites. However, given that carbonate precipitation is seen to occur in significant quantities at the oligotrophic sites (e.g. Lough Gealain), there is no clear evidence to justify overruling the preliminary findings of Coxon (1994), and further research would be required to quantify the actual role of chemical versus biological factors in precipitation at different sites.

Blackrock, Lough Coy, Garryland and Caherglassan were also a distinct group in ways other than those already mentioned. Hydrologically they are linked (Johnston & Peach, 1998; Drew, 2003; Gill, 2010) and morphometrically they are the deepest of the 22. They had much higher colour than any of the other turloughs as a result of receiving drainage, in part, from peat soils in the Sliabh Aughty hills. The presence of humic and fulvic materials in drainage from peats imparts the characteristic brown colour to such waters. The combination of greater depth and high colour may be expected to lead to reduced light in the water column compared to other turloughs among the 22. The fact that they are linked hydrologically means that they are effectively four sampling points in one large ZOC and are therefore not independent of one another in the statistical sense. All turloughs apart from the above four had much lower colour (8-48 mg l^{-1} PtCo) which reflects the lack of extensive areas of peatland in the catchments.

The low average TP in Gealain and Knockaunroe (both 4.0 μg l^{-1}) indicate a low level of agricultural activity and human habitation in the ZOCs of these turloughs. Similarly low levels of TP have been found in Muckross Lake in Co. Kerry which also receives drainage from a relatively unimpacted catchment. It would appear that an average TP of 4.0 μg l^{-1} may be close to the lower limit of what is found in lowland standing waters in Ireland. The concomitant concentration of TN in these two turloughs was 0.5-0.6 mg l^{-1}.

4.4.2 Algal Biomass in Turloughs

The fact that turloughs exist as water bodies mainly in the winter could be taken to imply that these would be unproductive water bodies. However, the results of this study indicate that phytoplankton biomass as Chl *a* in turloughs was not significantly lower than that found in permanent lakes (Cunha Pereira, *et al*., 2010). Chlorophyll *a* peaks in winter are not unknown in Irish lakes (Irvine *et al*., 2001) and elsewhere (Campos *et al*., 1988) but are not the norm. Although there is not a “typical” universal succession of algal biomass over time in lakes (Hutchinson, 1967; Reynolds, 1984, 2006), it is usual that algal biomass peaks in late spring or summer and is low during winter (Allott 1990; Wetzel 2001; King & Champ, 2000; Irvine *et al*., 2001 for Irish lakes). Accordingly, Irvine *et al*. (2001) found that only two out of 31 Irish lakes in a 2-year study had a maximum concentration of Chl *a* in winter. Allott (1990), in a two year study of six lakes near the Burren, found that Chl *a* peaked in late summer and was low throughout the winter. A factor contributing to high production in winter may be that most turloughs are shallow with relatively clear water and, therefore, have well-illuminated water columns.

Peak Chl *a* occurred at different times across the 22 turloughs but the majority had maxima in November, January and February which is typically the darkest and coldest time of the year.

Garcia and Niell (1993) and Garcia *et al*. (1997) also found that Chl *a* and phytoplankton abundance was highest in winter in a temporary saline lake in Spain, with values similar to those found in turloughs. They found that the decline of phytoplankton biomass in spring was coupled to an increase in zooplankton grazers. The decline of phytoplankton biomass in spring in turloughs could also be due to higher grazing pressures (see also Barone & Naselli-Flores, 2003) and perhaps to a lower availability of nutrients. Alternatively, the phytobenthos may dominate the autotrophic community at this stage (see for example Garcia & Niell,1993; Blindow *et al*., 2002).

Another surprising feature of turloughs is the often high value of Chl *a* found at the early stages of flooding. A striking example in this study was in Rathnalulleagh in October 2006 (110.5 µg l^{-1}), measured only about 19 days after the estimated onset of flooding. This high value raises the question of the origin of algal inocula that initiate phytoplankton populations in turloughs. A recent study (Cleary, 2011) has shown that dry soil from Lough Aleenaun is a substantial source of algal inocula and it may reasonably be assumed that this is the case in other turloughs also. Moreover, some of the algae that are found in turloughs (such as *Tribonema* sp. or *Chlamydomonas* sp.) are known to be able to survive desiccation (Evans, 1958, 1959).

4.4.3 Relationships Between Chlorophyll *a* and Nutrient Levels

The significant linear regression found between TP and Chl *a* suggests that P limits phytoplankton biomass in the majority of the turloughs in this study. TN-to-TP ratios were above 17 as seasonal averages in all turloughs and in the vast majority of the monthly samples, thus emphasising the role of P rather than N, as the main limiting nutrient (Phillips *et al*., 2008). The TP - Chl *a* regression model in turloughs was similar to that for permanent Irish permanent lakes as shown in Champ (1998) but differed slightly from two non-Irish studies (Dillon & Rigler, 1974; Phillips *et al*., 2008). The intercept in the Phillips *et al*. (2008) model was higher than that in this study, but it can be argued that the slope is the most relevant parameter in these comparisons, as it measures the rate of increase of algal biomass per increase in unit TP. In this light, turloughs showed rates of increase in Chl *a* in response to increases in TP similar to those of the Irish and the two non-Irish models. Furthermore, there is considerable variation in the linear relationships between TP and Chl *a* amongst lake studies, and the regression line in the turlough model is within the range of those found for permanent lakes. It can be concluded, therefore, that production of Chl *a* per unit TP in turloughs is within the range of values found in permanent lakes in spring and summer.

The development of algal biomass appears not to have been limited by P in Blackrock, Caherglassan, Lough Coy, Garryland and Ardkill. It is likely that the deeper, more highly coloured waters of the first three of these turloughs were light-limited through the winter instead. Colour, by either suppressing light penetration (Havens, 2003; Havens & Nurnberg, 2004) or sequestering important ions (Jackson & Hecky, 1980), is known to inhibit phytoplankton development and the greater depth of these turloughs would exacerbate the effect. A somewhat different explanation is suggested for Ardkill though it too is relatively deep and therefore more prone to light limitation than most of the other turloughs. However, the most important feature of Ardkill in this regard is probably that it had a much higher average TP than any of the other turloughs, as well as being relatively deep; therefore it is likely that in Ardkill also there was insufficient light to enable the algal community to utilise the available P to the same extent as in the majority of turloughs. While the above comments apply to the majority of the flooding season, there is evidence that Ardkill and, to a lesser extent, other turloughs could have been N limited at the end of the flooding season. At this time (May-June 2007), NO_3-N was undetectable in Ardkill whereas the concentration of MRP was relatively high (70 μg l^{-1} in May and 13 μg l^{-1} in June); these figures are suggestive of N limitation in Ardkill but could not be taken as proof.

4.4.4 Seasonal Variation of Nutrients

There are many studies of permanent lakes that have reported the same pattern of seasonal variation in N as that found in turloughs, both in Ireland (Allott, 1990; King & Champ, 2000; Pybus *et al*., 2003) and elsewhere (Burt *et al*., 1988; Reynolds *et al*., 1992; Petry *et al*., 2002). It is widely accepted that the increasing trend in N during autumn and winter is the result of losses from the catchment at the end of the growing season (Johnsson *et al*., 1987; Kaste *et al*., 2003; EFMA, 2005). N typically increases in surface waters to a maximum in winter and then declines as the catchment supply gradually becomes exhausted. Kaste *et al.* (2003) have shown that the amplitude of this seasonal trend in N is proportional to the flushing rate of the water body, as would be expected. Most of the turloughs showed a seasonal trend in N similar to that described above and it is therefore tempting to conclude that they are in general rapidly flushed water bodies. However, this conclusion would be contrary to the current view on turlough hydology that the rate of flushing in most turloughs is low (see *Chapter 3: Hydrology*) though it is accepted that the rate of flushing in certain turloughs may be rapid. There is certainly good circumstantial evidence that the seasonal trend in N in Lough Aleenaun, Turloughmore and Blackrock is caused by flushing. Lough Aleenaun and Turloughmore filled and drained several times over the flooding season and yet still displayed the same systematic decline in N as in most of the other turloughs; such a trend is suggestive of declining N concentration in inflowing waters rather than any removal process within the turloughs. In the case of Blackrock, the trend in N in the R. Owenshree (just upstream of Blackrock into which it flows) is very similar to that in the turlough (Cunha-Pereira, 2011). If any within-turlough process were responsible for removal of N then one would expect a different N trend in the turlough to that in the stream. (It has not been possible to deduce the relative importance of flushing versus within-turlough processes in the case of the remaining 19 turloughs owing to lack of firm evidence. However, this topic is the subject of ongoing research among the Civil and Environmental Engineering Hydrology Group at Trinity College).

Phosphorus, in contrast to N, fluctuated irregularly across turloughs and over time, suggesting that the mechanisms governing P concentrations in each of the basins are site-specific. It is known that P easily sorbs to particulate matter and forms stable and relatively insoluble compounds with many cations such as iron, magnesium, and calcium (e.g. Otsuki & Wetzel, 1972; McDowell *et al*., 2004). Accordingly, it has been shown that while dissolved N may move conservatively in catchments, dissolved P may be retained in most hydrogeological situations (Weiskel & Howes, 1992). However there is evidence of greater P mobility in karst aquifers with conduit flow, though clearly not in the same systematic manner as N. Kilroy and Coxon (2005) studied temporal variations of P in karst springs in two catchments in western Ireland and found that P generally increased with rainfall but the degree of response varied and the highest peaks occurred at varying times for different springs, even within the same catchment. They also found that the forms of P mainly responsible for the increases were particulate and dissolved organic P, whereas SRP remained dominant and at stable levels in most cases. However, in a few instances, increases of SRP occurred concomitantly with increases in TP. These results suggest that rainfall drives flushing of P through karst catchments (causing an increase in the particulate component), but the timing and the degree of the response may be influenced by local characteristics within each catchment. Such findings help explain the different patterns of P variation across turloughs.

4.4.5 Spatial and Inter-annual Variation Within Turloughs

The study of spatial variation in Caranavoodaun, Roo, Termon and in Blackrock showed that these turloughs were quite homogenous with respect to most chemical variables most of the time. An important exception, because of its importance in water quality monitoring, was Chl *a* which could be higher near the shoreline at the beginning and end of the flooding season. The higher shoreline values of Chl *a* in this study were mostly caused by filamentous algae but in one case (Caranavoodaun in December 2007) it was caused by the diatom *Achnanthidium lanceolatum* (Cunha Pereira, 2011). Minor wind-driven accumulations of algae are a likely explanation because the two variables are correlated and therefore it is not surprising that they might have similar spatial distributions, though higher production of Chl *a* near the shore is an alternative possibility. Wind-driven movements of algae have been recorded previously, for example by George and Heaney (1978) and Stevenson (1996).

Despite the spatial differences found, it is unlikely that large errors in assessment of water quality would be made in these four turloughs if they were to be sampled near the shoreline over a flooding season. The trophic classification does change in two of the four turloughs depending on the sampling point that is used but this arises because all values were close to boundaries in the OECD classification and common sense dictates that differences in trophic classification such as this are largely artefacts of the classification system. The trophic boundaries are quite arbitrary (Carlson, 1977; Carlson & Simpson, 1996). It is important to note that the four turloughs in this part of the study were quite unproductive (all had mean Chl *a* <3.2 µg l^{-1}). Spatial variation in TP and Chl *a* may be considerably higher in turloughs with higher TP concentrations. It is also important to note that the greatest spatial variability occurred at the beginning and end of the flooding season. Therefore, it is clear that samples obtained in the middle of the flooding season are more likely to be representative of the whole turlough than samples taken at other times.

The study of inter-annual variability in the four turloughs showed that, in general, chemical variables behaved similarly in the two years (sometimes strikingly so, such as in the case of TN and silicate for example) but that there were noteworthy exceptions. The most striking exception was the steep increase in Chl *a* in Blackrock in March and April of 2008 which did not occur in the previous season. Water quality in turloughs (as in any water body) is determined by many factors, some of which are natural (such as weather) and some of which are human activities in the ZOC. Such factors are liable to change between years and such changes may affect the quality of surface waters.

4.4.6 Recommendations for Monitoring

Clearly the best way to monitor a range of turloughs is to analyse samples taken thoughout the flooding season from a number of sampling points, as this approach will effectively capture seasonal and spatial variation. However, such an approach would require extensive resources. The results of this study show that a simpler approach could be considered where a sample is taken in the middle of the flooding season (i.e. when water levels are at or near peak) because at this time turloughs were found to be more spatially homogeneous in terms of water chemistry. N is also likely to be near its peak at this time (enabling assessment of its maximum value in a particular turlough) and variable parameters such as TP are more likely to be spatially homogenous. Furthermore, filamentous algal biomass is not important during these periods (see *Chapter 5: Algae*) and the problem of their possible accumulation near the edges should not be an issue. From the values of TP that are obtained, inferences could then be made into the amount of algal biomass that can be produced, though not in the case of deep turloughs or turloughs with highly coloured waters. A disadvantage of this scheme is that TP and Chl *a* (both of which are important in the determination of water quality) have an erratic temporal pattern in turloughs and thus more frequent samples would be required to establish accurate seasonal averages of these two variables.

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Chapter 5. Turlough Algae

N. Allott, C. Coxon & H. Cunha Pereira

Algal mats at Lough Aleenaun, Co. Clare. *Photo: M. Murphy*

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5.1 Introduction

The best known aspect of algae in turloughs is the occasional conspicuous appearance of algal mats when the turloughs empty in early summer (see photo above and Figure 1). Scannell (1972) and Reynolds (1983) refer to such mats as "algal paper" and recorded their occurrence in turloughs in Co. Clare and Co. Galway. It has also been observed by Coxon (1986) during a study of 90 turloughs in nine Counties in western Ireland. She reported that "algal paper" was found occasionally, covering the floor or suspended from vegetation, fences or other features. Scannell (1972) recorded extensive algal mats at a turlough in Co. Clare (located at M2705) in three out of four years in which the turlough was visited, while in the fourth year only fragments of dried algal mats were found. Reynolds (1983) investigated five turloughs on the Aran Islands and found algal mats only in one (Lough an Mhuirbhigh, 500 m south of Kilmurvey). According to local knowledge, algal mats occurred almost annually in L. an Mhuirbhigh but not in other turloughs in the area. Both Scannell (1972) and Reynolds (1983) indicate that the phenomenon of "algal paper" does not appear to be common in turloughs. However when algal mats do occur, they can be extensive. Scannell (1972) refers to mats covering "several acres" while the mats recorded by Reynolds (1983) covered an area of approximately 100 x 50 m.

Little is known of the taxa of filamentous algae that form algal mats in turloughs. Scannell (1972) describes the dominant genus as being *Oedogonium* with some *Spirogyra* present also. However, the identification was made from dried and bleached material which would have made accurate identification difficult. No identifications of algae are provided by Reynolds

(1983). *Tribonema* (Moreland, 1937) and *Cladophora* (Hoek, 1963) have been recorded as constituents of dried algal mats on the margins of receding rivers and shallow pools in continental Europe and in the United States of America. All of the above taxa, and perhaps others, could therefore potentially form algal mats in turloughs.

While the occurrence and nature of algae in algal mats were known to some extent prior to this project, there are no corresponding studies on the phytoplankton communities of turloughs. Indeed, there have been relatively few studies on the phytoplankton of temporary lakes in general (Williams, 2006) which contrasts starkly with the extensive literature on the phytoplankton of permanent lakes. Most turloughs usually become flooded in autumn and drain in early summer though some may fill and empty several times each year. Consequently, algal communities in turloughs must develop, at least initially, when light levels and temperature are declining. Additionally, most turloughs are fed by groundwater which is an unlikely source of algal inocula. In spite of the above constraints on growth of algae, turloughs have been shown to develop phytoplankton biomass concentrations comparable to those of permanent lakes in summer (Cunha Pereira *et al.*, 2010 and Chapter 4). Peaks of chlorophyll a (Chl *a*) occur throughout the flooding season, with high values frequently in the middle of winter (up to 69 μg Chl *a* l^{-1}).

This chapter aims to:

1) describe the occurrence and species composition of algal mats in late spring and early summer of 2007, 2008 and 2009 in the 22 turloughs,

2) describe the species composition and ecological characteristics of the phytoplankton in turloughs,

3) determine the principal environmental factors that influence the algae of turloughs.

5.2 Methods

5.2.1 Algal Mats

The 22 turloughs were inspected for algal mats during the emptying phase in 2007, 2008 and 2009. Turloughs were visited in the first two weeks of March to June 2007 as part of the monthly monitoring of turloughs. Dedicated trips to inspect for algal mats were conducted in 2008 on the 4th of March, the 1st of April, and the 26th, 27th and 28th of May, and in 2009 on the 15th and 16th of June and on the 24th and 25th of July. The optimum timing for visiting turloughs during the dedicated trips was estimated from information provided by local residents. The timing and rate of emptying was found to vary among turloughs and among years. At any given visit, different conditions were often found in turloughs, from turloughs that appeared to have been dry for several days or weeks, to substantially full turloughs, to turloughs at all intermediate stages in between. However, over the three years of observations, all turloughs were inspected at least once at the optimum time for observation of algal mats.

The presence of both living floating mats and dead drying mats was noted, as well as their extent in the turlough basins. Sampling of algae for identification was carried out only in 2008 and 2009. Filamentous algae were collected near the edge of the water body by simply placing them onto a vial with turlough water. Algae from 2008 were preserved in Lugol's solution and analysed with the live material collected in 2009, which was observed up to 48 h after collection (this live material was stored at 4°C until observation). Taxa constituting the mats were identified using an optical compound microscope at 200x and 400x magnification. The relative abundance (in percentage) of the different genera found was estimated. Mean total phosphorus (TP) in the flooding season of 2006/2007 was calculated as the average of monthly total phosphorus values for each turlough. Details of the analytical methods used can be found in *Chapter 4: Water Chemistry and Algal Biomass*.

5.2.2 Phytoplankton Analysis

Sub-samples of samples that were taken for chemical analysis were preserved with Lugol's iodine solution for later phytoplankton analysis. Identification and counting was carried out according to Utermöhl (1958). Samples were observed at 200x or 400x magnification in an inverted microscope (Leica Leitz DM-IL) after at least 24h in a sedimentation column (Uwitec, http://www.uwitec.at). Between 300 and 400 individuals in a number of transects were counted. Cell biovolume for each taxon was calculated by approximation of cell shape to known geometrical forms (Hillebrand *et al.*, 1999; Sun & Liu, 2003). Chl *a* was positively correlated with algal biovolume (R=0.83, N=170, Spearman's rank correlation coeffient), with a slightly better fit than when correlated with cell abundance (R=0.80, N=170, Spearman's correlation coeffient). Biovolume was therefore used as the measure of algal biomass.

Taxa were identified to the species level where possible following John *et al.* (2002), Cox (1996) and Bourrelly (1970, 1981 and 1990). Some taxa were not discriminated beyond general groupings, such as small (d≤10 µm) centric diatoms (considered to be either *Cyclotella* spp. or *Stephanodiscus* spp.), dinoflagellates, unidentified pennate diatoms (i.e. diatoms that were too small for identification, or in ambiguous griddle view; they were generally small with average biovolume of 302 μm^3). *Synedra* sp. was discriminated between small (<70 µm long) and big (>70 µm long); *Synedra nana* was found in one turlough only (Coolcam). Non-identified dinoflagelates were always small (average length=21.4 µm, SD=7.3 µm) and morphologically similar to *Peridinium*, *Peridiniopsis*, *Gymnodinium* or *Katodinium*. The term non-identifiable alone (or n.i.) was reserved for rare cases where specimens were not identifiable. Discrimination between n.i. filament, n.i. flagellate, n.i. colony, n.i. green filament was made when applicable. A common small Cryptophyte with a typical pointy apex was named *Chroomonas/Rhodomonas* (Palsson & Graneli, 2004; Leitao & Leglize, 2000), as it is morphologically similar to *Chroomonas acuta* but also to *Rhodomonas minuta/Plagioselmis nannoplanctonica* (Barone & Naselli-Flores, 2003; Novarino, 2002; Novarino *et al.*, 1994); correct discrimination was therefore not possible. Taxa richness was the number of taxa found in each monthly sample; averages per turlough were calculated as the mean across turlough samples.

Taxa were categorised into "tychoplanktonic" (including metaphytic) or "true planktonic". As most raphid diatoms (Kelly, 2000, Round *et al.*, 1990, Cox, 1996), and most filamentous chlorophytes and *Tribonema* spp. (Irfanullah & Moss, 2005; Berry & Lembi, 2000; John *et al.*, 2002), are usually associated with the benthos (streams, rivers, or shallow lakes and ponds), these were considered tychoplanktonic, while all other algae were considered planktonic. Non-identified algae were ignored and the biovolume of n.i. pennates was considered half planktonic and half tychoplanktonic (as an estimate).

The functional group approach (Reynolds *et al.*, 2002; Reynolds, 2006) was applied to help interpret the data and to put the work in a wider research context. This approach has been found to provide a higher discriminatory power than classical taxonomic groups in ecologically interpreting community data (Kruk *et al.*, 2002) and it has thus been extensively applied in research studies of phytoplankton (Padisák *et al.*, 2009). Functional groups are groups of algae (often cross-phyletic) that have similar adaptive features (e.g. surface area to volume ratios, motility, nutrient use efficiency, sensitivity to grazing). Algae belonging to the same functional group are therefore often found in the same habitat type or similar environmental conditions (Reynolds *et al.*, 2002). Dominant taxa in turloughs were assigned to functional groups based on the classification of Reynolds *et al.* (2002) and the recommendations of Padisák *et al.* (2009).

5.2.3 Hydrological and Environmental Data

The morphometry of the turlough basins and water levels were determined as described in *Chapter 3: Hydrology*. Water temperature was measured using a field mercury thermometer. The sunset-sunrise time period duration of the days sampled ('day length') was calculated according to 'Time and Date AS' (http://www.timeanddate.com) for Dublin, Ireland. 'Number of days flooded' (at a given sampling date) is the number of days a turlough had been flooded until that date; this variable takes into account periods of dryness that could occur in the middle of the flooding season (the case in two turloughs). 'Hydroperiod' was calculated as the total number of days a turlough was flooded during the flooding season. The first sampling date was used for all turloughs as a surrogate for onset of flooding (not known for a number of turloughs) and the last day was when a turlough was found dry at the end of the season or with an estimated volume of less than 10% of its peak volume in the case of turloughs with persisting water throughout the year.

5.2.4 Data Analysis

Predominant taxa were determined after ranking the taxa found by frequency of occurrence, mean biovolume, coefficient of variation of biovolume, and percentage biovolume, across samples and across turloughs. The coefficient of variation was calculated by dividing the standard deviation of biovolume across samples or turloughs by the mean biovolume across samples or turloughs; this was considered to be a measure of evenness of occurrence - the lower the value the more evenly distributed a taxon is across samples or turloughs.

Algal biovolume community data was 4th root transformed and the Bray-Curtis similarity coefficient was applied as recommended by Clarke & Warwick (2001). CLUSTER analysis (Clarke & Gorley, 2006) was used to determine similarity relationships between taxa and between turlough communities (averages of biovolumes within turlough samples were used in order to compare turlough communities). SIMPROF analysis was applied to test statistically significant clustering (at $p<0.05$ level) of turloughs and taxa (Clarke & Gorley, 2006). MDS ordination was used to plot similarity relationships between turloughs. A stress factor <0.20 was considered a reasonable threshold for accurately interpreting the ordinated MDS plots (Clarke & Warwick, 2001). Statistical t-tests (Field, 2005) were used to compare biovolume contribution (log-transformed to assure normal distribution) of algal taxonomical groups between the significant turlough clusters identified with the SIMPROF routine. A SIMPER analysis (Clarke & Gorley, 2006) was additionally undertaken to determine which taxa contributed the most to the dissimilarity found between the significant turlough clusters. Biovolumes were also "standardised": the biovolume of each taxa in each sample was divided by the total biovolume of that sample and averages per turlough (across months) were taken. This eliminates differences in total biovolume across samples and enables the comparison of the relative contribution of each taxon to the total biovolume of each turlough. All multivariate statistical analyses were run with both non-standardised and standardised biovolume data.

The relationships between phytoplankton communities and the environmental variables were assessed using direct gradient analysis. First a detrended correspondence analysis (DCA) of the phytoplankton taxa data was run to determine whether linear or unimodal ordination methods should be applied (Ter Braak & Šmilauer, 2002). Because the length of the first axis resulting from the DCA was less than three, a linear method (Redundancy Analysis or RDA) was used (Ter Braak & Prentice, 1998). Only relevant environmental variables with low covariance ($r<\pm0.60$, $p<0.001$, Spearman rank correlations) were included in the analysis: TP, TN, silicate, alkalinity, colour, water temperature, number of days flooded and mean depth; significant correlations and r values were: TP and TN (0.39), silicate and number of days flooded (-0.53) and silicate and colour (0.59). Significant explanatory variables were determined by automatic forward selection (Ter Braak & Šmilauer, 2002) after Bonferroni correction of the P-value (Abdi, 2007). Only samples without missing values in any of the environmental variables were included (April samples were omitted (no colour measurements), as were some others owing to lack of hydrological data). In total 100 samples (from a total of 171) were included in the initial RDA. Forward selection results showed that colour did not contribute significantly to explain the variance in the phytoplankton data ($p>0.05$). Because colour was discarded, April samples could be included and a final RDA was run with 116 samples (reported herein).

PRIMER 6 and CANOCO for Windows 4.5 were used for multivariate statistical analyses.

5.3 Results

5.3.1 Algal Mats

Algal mats (either dried or floating) were observed in nine of the 22 turloughs in 2007, in 11 of the 22 turloughs in 2008 and in six out of 20 turloughs in 2009 (Table 5.1). Four of the turloughs had algal mats in all three years (Ardkill, Aleenaun, Tullynafrankagh and Roo West). Algal mats in the majority of the turloughs were small, usually less than 1 m^2 in each patch, with very few patches observed in the turlough. More extensive coverage was observed in four of the turloughs (Aleenaun, Ardkill, Garryland and Skealoghan), which had mats ranging from approximately 0.5 ha to 1.6 ha, corresponding to approximately 2 to 8% of the total area of the basins (Figure 5.1). The most extensive coverage was found in Garryland in 2008 with an estimated 1.6 ha, which represents about 8% of the total area of the turlough (Figure 5.1a). In Tullynafrankagh, Roo West and Knockaunroe in 2009 a few floating mats were observed near the shore (see Figure 5.2a); no drying mats were present as the turloughs were still quite full (Table 5.1).

Algal mats were much more extensive in turloughs with high mean total phosphorus (TP>20 $\mu g\ l^{-1}$ see *Chapter 4: Water Chemistry and Algal Biovolume*), which were Aleenaun, Ardkill, Garryland and Skealoghan (Table 5.1). Benthic algal mats were observed in turloughs with low TP such as in Roo West (<10 $\mu g\ l^{-1}$, Table 5.1) but they were small and fragmented (Figure 5.2a). In clearly eutrophic turloughs (e.g. Ardkill, Figure 5.1d), mats were quite thick in places, to the extent of resembling "*parchment in texture and colour*" as described in Scannell (1972).

Table 5.1 Occurrence of visible filamentous algal mats in turloughs in the three years of observation and mean total phosphorus (TP) in the same turloughs over the flooding season of 2006/2007. Y = visible occurrence; * = "extensive" cover (estimated to be 2 to 8% of total area of basin, see text); † = negligible quantity observed; • = turlough was too full to permit full observation.

Turlough	*Mean TP ($\mu g\ l^{-1}$)*	*Occurrence*		
		2007	*2008*	*2009*
Ardkill	82.1	Y	Y	Y*
Ballinderreen	12.4	Y†	Y	
Blackrock	52.4			
Brierfield	19.8		Y†	
Caherglassan	43.2			
Caranavoodaun	11.0		Y†	
Carrowreagh	42.8	Y	Y	
Coolcam	34.0			
Croaghill	25.0	Y		
Garryland	24.6		Y*	•
Kilglassan	27.2			Y
Knockaunroe	4.2			Y†, •
Lisduff	7.4			
Lough Aleenaun	30.7	Y*	Y*	Y*
Lough Coy	43.3			
Lough Gealain	4.0			
Rathnalulleagh	44.6	Y		
Roo West	9.8	Y	Y†	Y†, •
Skealoghan	20.4	Y*	Y	
Termon Lough	15.0		Y	•
Tullynafrankagh	33.0	Y	Y	Y†, •
Turloughmore	19.4			

Figure 5.1 Filamentous algal mats in turloughs: (a) Garryland May 2008, (b) Aleenaun June 2008, (c) Skealoghan April 2007 and (d) drying algal paper hanging from fence in Ardkill July 2009.

Figure 5.2 Filamentous algal mats in Roo West: (a) floating mat July 2009 (the mat was about 0.5 m^2) and (b) drying mats May 2007 (this was the largest patch found, around 5 m^2).

5.3.2 Assemblages of Algae in Algal Mats

Cladophora, *Mougeotia* and *Spirogyra* were the most important genera in algal mats (Table 5.2) with lesser contributions from *Oedogonium*, *Zygnema*, *Tribonema* and others. Some turloughs had very different assemblages of benthic algae from one year to the next (e.g. Ardkill, Skealoghan). Some taxa were more widespread in some years than in others: for example, *Mougeotia* was quite abundant in most turloughs where algal mats were found in 2008 but not in 2009. A total of nine different genera were found in turloughs, with a minimum of one (in Lough Aleenaun) and a maximum of seven (in Skealoghan) (Table 5.2).

5.3.3 Phytoplankton

Cryptophytes and pennate diatoms were the most prominent phytoplankton taxa in turloughs (Table 5.3). Cryptophytes had overall high biovolume ratings (particularly *Cryptomonas* spp.), the highest evenness, and the highest average percentage of biovolume per turlough. Pennate diatoms, such as small *Synedra* sp. (small), *Achnanthidium minutissimum*, *Nitzschia* spp., *Navicula* spp., and other unidentified pennates, were prominent in all turloughs. Less widespread across turloughs, but with high contributions when occurring, were *Gomphonema* spp., *Synedra* sp. (big) and centric diatoms.

Table 5.2 Taxa and approximate relative abundance of filamentous algae found in living floating mats in turloughs in 2008 and 2009 (n.i. = non-identified).

2008		*2009*	
Turlough and date	***Taxa***	***Turlough and date***	***Taxa***
Ardkill (26/5/2008)	*Mougeotia* – 90% *Spirogyra + Zygnema* – 6% *Cladophora +* *Oedogonium* – 4%	Ardkill (16/6/2009)	*Cladophora* – 85% *Spirogyra* – 10% *Oedogonium* – 2.5% n.i. green filament (*Gleotila*?) – 2.5%
Ballinderreen (28/5/2008)	*Spirogyra* – 50% *Mougeotia* – 40% *Zygnema* – 10%	Aleenaun (16/6/2009)	*Spirogyra* – 100%
Brierfield (26/5/2008)	*Mougeotia* – 95% *Zygnema + Spirogyra* – 5%	Kilglassaun (16/6/09)	*Spirogyra* – 85% *Oedogonium* – 10% n.i. green filament – 2.5% *Cladophora* – 2.5%
Caranavoodaun (27/5/2008)	*Mougeotia* – 98% *Spirogyra + Zygnema + Oedogonium + Tribonema* – 2%	Knockanroue (25/7/2009)	*Cladophora* – 99% *Spirogyra* – 1%
Skealoghan (26/5/2008)	*Mougeotia* – 80% *Cladophora* – 7.5% *Spirogyra* – 5% *Zygnema + Tribonema + Ulothrix tenerrima + Oedogonium* – 7.5%	Skealoghan (16/6/2009)	*Cladophora* – 50% *Oedogonium* – 30% n.i. green filament – 15% *Zygnema* – 5%
Tullynafrankagh (28/5/2008)	*Cladophora* – 70% *Oedogonium* – 10% *Spirogyra* – 10% *Zygnema* – 7.5% *Tribonema* – 2.5%	Tullynafrankagh (15/6/2009)	*Cladophora* – 49% *Spirogyra* – 25% *Cladophora* – 25% *Tribonema* – 1%
		Roo West (25/7/2009)	*Mougeotia* – 98% *Cladophora + Spirogyra + Oedogonium* – 2%

Table 5.3 [continues on next page] Summary statistics for phytoplankton taxa in the 22 turloughs: ranking in terms of biovolume (mean or sum of biovolume across samples or turloughs), coefficient of variation of biovolume across samples and turloughs, mean percentage of each taxon's biovolume in total biovolume, occurrence in turloughs and samples (total nr. of samples = 171), each taxon's biovolume as a % total biovolume (i.e. sum of biovolumes of all samples). Taxa are ordered by descending occurrence in samples; showing only taxa with ≥9.9% occurrence. Also shown are the proposed functional group for each taxa and whether a taxa was considered to be tychoplanktonic or true planktonic.

Taxa	*Possible functional group**	*Planktonic (P) or tychoplanktonic (T)*	*Occurrence*		*Mean % of turlough biovolume*	*Ranking by biovolume*	*Coefficient of variation*		*% biovolume of all samples*
			in % of samples	*in nr. of turloughs*			*across samples*	*across turloughs*	
n.i. pennates	MP/T_D or D	P/T**	97.1	22	6.6	7	3.86	1.35	5.3
Cryptomonas	Y	P	94.7	22	22.4	1	2.00	0.88	15.9
Chroomonas/Rhodomonas	X_2	P	91.8	21	10.2	5	1.60	0.79	5.4
n.i.	any	-	87.7	22	0.7	22	2.19	1.14	0.6
Achnanthidium minutissimum	MP/T_D	T	73.7	21	3.3	14	3.47	1.53	2.6
Nitzchia	D	P	71.9	21	1.2	16	5.01	1.80	1.5
Synedra (small)	D	P	68.4	22	6.6	8	4.90	1.89	5.3
Monoraphidium	X_1?	P	62.6	20	0.5	21	3.08	1.53	0.7
Navicula	MP/T_D	T	55.0	21	1.1	20	3.57	1.74	0.7
Mallomonas akrokomos	X_2	P	45.6	19	0.3	36	2.70	0.97	0.2
n.i. centrics	D/B/C	P	37.4	17	3.0	4	9.37	3.31	5.7
Dinobryon	E	P	36.3	17	6.7	2	8.22	3.37	11.3
Gomphonema	MP/T_D	T	35.1	19	0.3	40	3.04	1.35	0.2
Synedra (big)	D	P	32.2	18	3.5	9	5.58	1.97	5.3
Mougeotia	T_D	T	30.4	18	5.6	6	4.15	1.79	5.4
Chlamydomonas	X_2	P	27.5	13	2.3	12	5.00	2.43	2.7
Scenedesmus	J	P	27.5	19	0.1	41	4.35	1.61	0.1
n.i. dinoflagellate	Y	P	24.6	15	0.5	27	3.68	1.37	0.4
n.i. filament	?	T	24.6	19	0.7	19	4.26	1.59	0.7
Eunotia bilunaris	MP/T_D	T	24.0	16	0.6	25	4.35	1.99	0.5
Cymbella/Encyonema	MP/T_D	T	22.8	15	0.3	26	8.16	2.85	0.4
Tribonema	T_D	T	22.2	17	1.9	10	7.86	3.30	4.3
Ochromonas	X_2	P	21.6	16	0.4	29	4.96	1.67	0.3
Fragilaria capucina	D/P	P	21.1	13	0.4	24	5.36	1.91	0.5

Table 5.3 [continuation from previous page] Summary statistics for phytoplankton taxa in the 22 turloughs: ranking in terms of biovolume (mean or sum of biovolume across samples or turloughs), coefficient of variation of biovolume across samples and turloughs, mean percentage of each taxon's biovolume in total biovolume, occurrence in turloughs and samples (total nr. of samples = 171), each taxon's biovolume as a % total biovolume (i.e. sum of biovolumes of all samples). Taxa are ordered by descending occurrence in samples; showing only taxa with ≥9.9% occurrence. Also shown are the proposed functional group for each taxa and whether a taxa was considered to be tychoplanktonic or true planktonic.

Taxa	*Possible functional group**	*Planktonic (P) or tychoplanktonic (T)*	*Occurrence*		*Mean % of turlough biovolume*	*Ranking by biovolume*	*Coefficient of variation*		*% biovolume of all samples*
			in % of samples	*in nr. of turloughs*			*across samples*	*across turloughs*	
Eunotia faba	MP/T_D	T	19.3	14	0.8	18	5.95	2.72	0.7
Nitzchia acicularis	D	P	18.7	13	0.1	35	4.04	1.91	0.2
Closteriopsis acicularis	P	P	17.5	10	0.4	23	5.45	1.94	0.6
Eunotia minor	MP/T_D	T	17.5	13	0.7	34	4.30	1.28	0.3
Spirogyra	T_D	T	17.0	15	7.2	3	6.64	2.30	9.6
Oedogonium	T_D	T	15.2	12	1.9	11	6.07	1.97	3.1
Oscillatoria/Planktothrix	$T_c/S1$	P	14.0	15	0.0	70	6.28	1.83	0.0
n.i. flagellates	any	P	12.9	14	0.4	45	4.63	1.70	0.1
Cosmarium	N	P	11.7	15	0.4	33	4.74	1.33	0.3
n.i. green cells	any	P	11.7	15	0.0	64	4.47	1.81	0.0
Oocystis solitaria	?	P	10.5	9	0.1	52	4.39	1.93	0.1
Aulacoseira	P/B/C	P	9.9	9	0.1	49	6.58	2.10	0.1
Euglena	W_1	P	9.9	11	0.1	46	4.84	1.88	0.1
n.i. green colonies	any	P	9.9	12	0.1	42	8.37	3.17	0.1

* - functional groups were assigned as those that better matched both the habitat description and the known sensitivities and tolerances of each taxon (Padisak *et al.*, 2009; Reynolds *et al.*, 2002)

** can have species of both groups and so 50% was considered true-planktonic and 50% metaphytic/tychoplanktonic.

Chlamydomonas spp. occurred in roughly half of the turloughs and 28% of all samples, and made a considerable contribution to overall biovolume. Other chlorophytes, such as *Monoraphidium* spp. and *Scenedesmus* spp., were common but contributed little to overall biovolume. Some green filamentous algae were common; *Mougeotia* spp., *Spirogyra* spp. and *Oedogonium* spp. in particular were important contributors to overall biovolume and were present in 12 to 18 turloughs and 17% to 30% of all samples. *Tribonema* spp., a non-Chlorophyte filament, also contributed considerably to total biovolume in samples.

Dinoflagellates were present in 15 turloughs and 25% of samples, with considerable evenness across turloughs but in low biovolume. Virtually all were n.i. small dinoflagellates, though *Ceratium hirundinella* was found in low abundance in one sample (in May). Chrysophytes were fairly well represented in turloughs. *Mallomonas akrokomos* was present in 17 turloughs and almost 50% of samples (although in low biovolume), with high evenness. *Dinobryon* spp. was present in slightly fewer samples but in much larger biovolumes. This taxon was the second largest contributor to overall measured biovolume indicating that, when present, it was in great numbers. Cyanophytes, desmids and Euglenophytes were poorly represented in the turloughs and *Oscillatoria/Planktothrix*, *Cosmarium* spp. and *Euglena* spp. were the most noticeable taxa within these groups (Table 5.3).

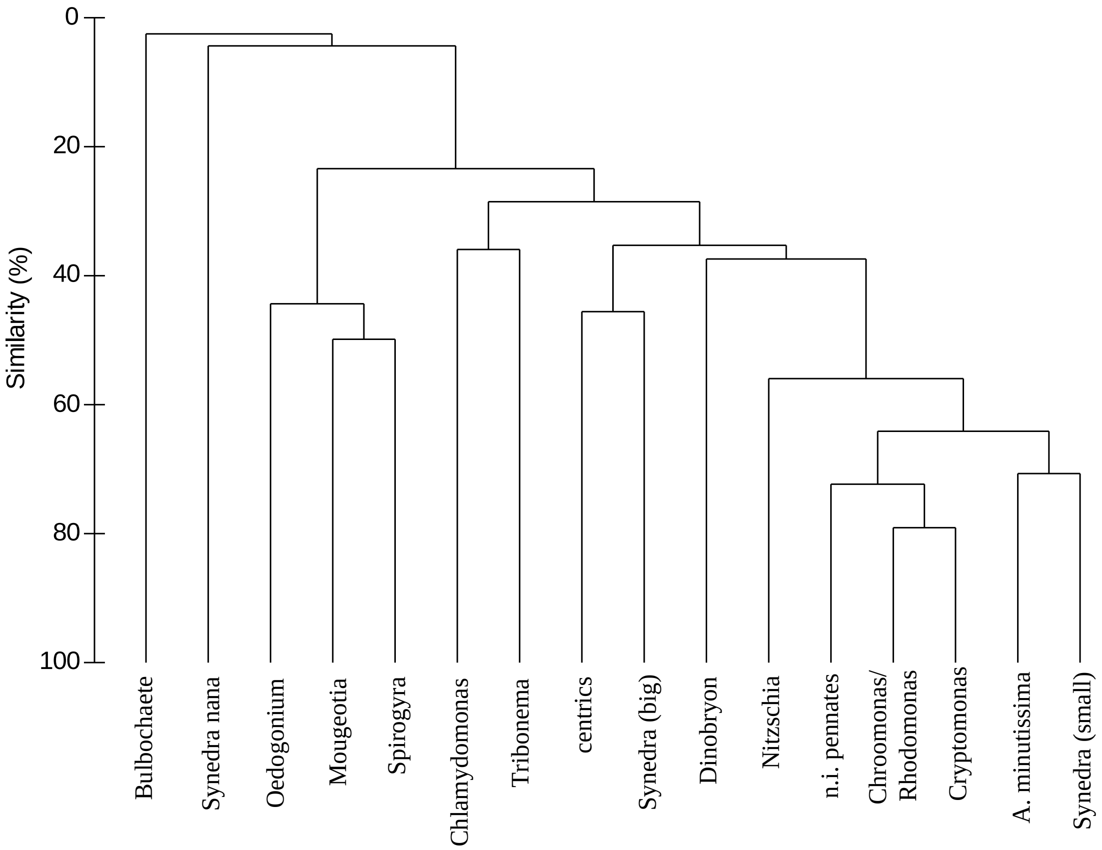

Figure 5.3 CLUSTER/SIMPROF analysis of phytoplankton taxa in the 22 turloughs. Only taxa that contributed to more than 1% of total algal biovolume are shown. All clustering was significant at p<0.05.

The CLUSTER analysis of the taxa contributing more than 1% of total biovolume presented a good overview of the taxa most frequently co-occurring within samples (Figure 5.3):

Cryptomonas spp. and *Chroomonas/Rhodomonas* were the most similarly distributed taxa (about 80% similarity) and the ubiquitous pennate diatoms already mentioned were also largely co-occurring together with these Cryptophyes. Other interesting clustering occurred between centric diatoms and *Synedra* sp. (big) (co-occurring particularly in the winter and first months of flooding), *Tribonema* spp. and *Chlamydomonas* spp. (most abundant in the first two months of flooding), and green filamentous algae (*Oedogonium*, *Spirogyra* and *Mougeotia* species), particularly abundant during spring. This analysis of co-occurrence provides cues for possible functional analogies between linked taxa.

The contribution of tychoplanktonic algae in the 22 turloughs ranged between 5.7% (in Coy) and 81.7% (in Aleenaun) of the total biovolume per turlough, with an average of 31.5% and SD of 19.4%. Figure 5.4 shows the distribution of the biovolume of tychoplanktonic and planktonic algae in each of the turloughs studied.

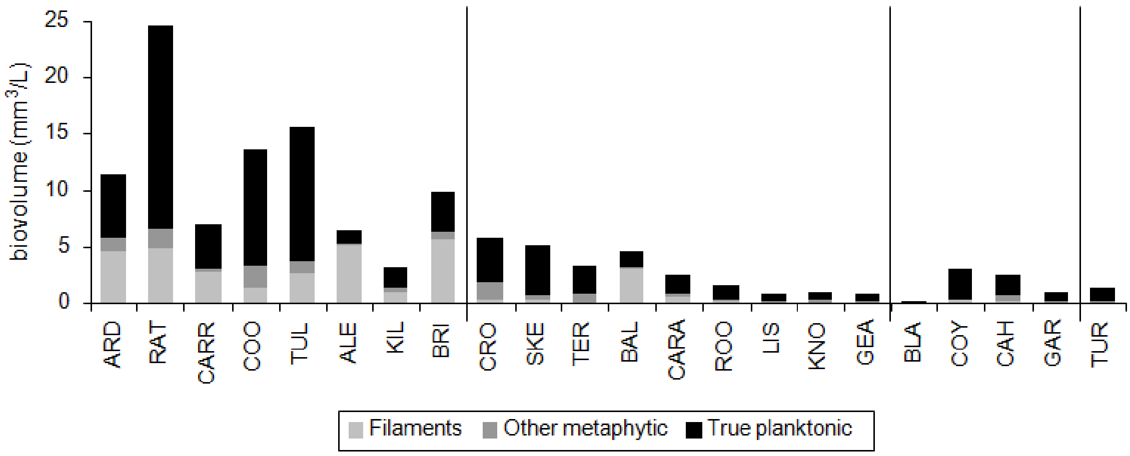

Figure 5.4 Biovolume of tycoplanktonic algae (in light grey - filamentous algae; in dark grey - raphid diatoms) and true phytoplankton (in black). Turloughs are arranged by identified clusters and descending average total phosphorus per cluster (clusters are explained in the text).

5.3.4 Similarity Among Phytoplankton Communities

CLUSTER analysis showed that the phytoplankton communities in the 22 turloughs were almost half (45.2%) overlapping in composition. At similarity levels between 45.2% and 51.4%, four significant turlough clusters were discriminated through CLUSTER/SIMPROF analysis (Figure 5.5a). The clusters were named based on relevant and characteristic chemical and hydrological parameters (Table 5.4): high TP (TP≥20 µg l^{-1}, N=8), low TP (TP≤25 µg l^{-1}, n=9), coloured/deep (turloughs with distinctly high colour waters and greater mean depths, n=4), and Turloughmore (turlough with a distinctly short hydroperiod, n=1). The similarity relationships between turloughs remained the same when using standardised biovolumes (Figure 5.5b) but the SIMPROF routine did not significantly separate the high TP and the low TP clusters in this case (loss of multivariate statistical sensitivity – the standardised biovolume values are more similar amongst themselves than the absolute values). This suggests that there is a gradient of similarity between these 17 turloughs that broadly corresponds to a TP gradient rather than a clear separation into two distinct trophic groups.

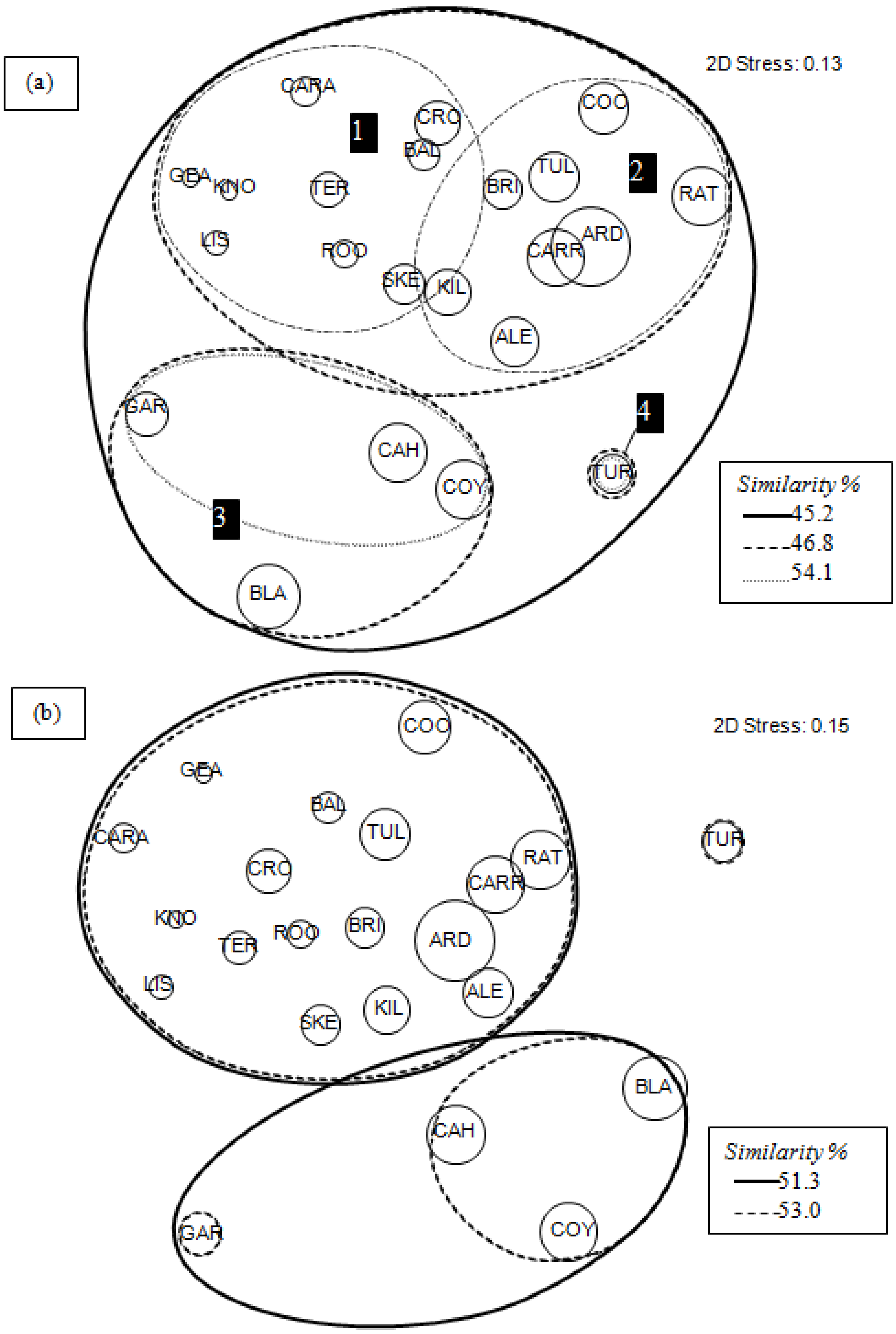

Figure 5.5 MDS plot showing ordination of the 22 turloughs based on similarity of phytoplankton communities using absolute values of averages for turloughs (a) and after standardisation of values by total per sample (b). Areas of circles around the abbreviated names are proportional to the average total phosphorus of the turloughs. The larger enclosed areas represent statistically significant clusters. Clusters are numbered as follows: 1 = low TP; 2 = high TP; 3 = coloured/deep; 4 = Turloughmore.

Table 5.4 Hydrological features, chemical characteristics, phytoplankton biomass and taxa richness in the 22 turloughs, arranged by identified clusters (see text) and by descending average total phosphorus within clusters.

Tur-lough	*Hydro-period (days)*	*Maximum mean depth (m)*	*Maximum Volume ($x10^3$ m^3)*	*Mean TP ($\mu g\ l^{-1}$)*	*Mean colour (mg l^{-1} PtCo)*	*Mean Chl a (µg/L)*	*Mean algal Biovolume (mm^3/m^{-3})*	*Average taxa richness*
High TP								
ARD	293	2.8	653	82	28.3	12.7	75	15.7
RAT	175	3.0	878	45	28.3	33.5	193	16.9
CARR	186	1.9	546	43	47.8	12.1	570	16.4
COO	346	3.7[a]	-	34	22.9	18.1	698	20.4
TUL	246	1.7[a]	-	33	36.4	18.4	80	20.9
ALE	158	2.6	346	31	13.5	9.2	53	16.6
KIL	223	1.5	709	27	27.7	5.0	26	14.9
BRI	267	1.7	933	20	35.6	5.0	64	16.6
Mean	***237***	***2.3*** [b]	***678***	***39.4***	***30.1***	***14.3***	***77***	***17.3***
Low TP								
CRO	348	1.6	636	25	43.8	7.6	48	13.2
SKE	213	1.2	382	20	26.0	6.9	55	13.3
TER	304	2.3	956	15	21.1	3.1	28	13.4
BAL	211	0.8	529	12	17.4	3.0	31	18.6
CARA	205	1.3	432	11	24.9	2.8	21	14.1
ROO	213	2.6	1077	10	13.6	2.1	13	15.0
LIS	234	1.4	765	7	20.6	1.4	8	13.5
KNO	213	2.3	1742	4	10.4	1.2	9	13.4
GEA	212	2.5	870	4	7.9	1.1	7	13.9
Mean	***240***	***1.8***	***821***	***13.0***	***20.6***	***3.2***	***24***	***14.3***
Coloured/deep								
BLA	169	6.8	4008	52	72.2	1.3	3	13.0
COY	187	5.9	1479	43	71.6	5.2	27	16.8
CAH	200	4.8	2985	43	85.1	3.3	21	12.3
GAR	211	9.1[a]	-	25	79.7	1.1	13	10.0
Mean	***192***	***5.8*** [b]	***2824***	***40.8***	***77.2***	***2.7***	***16***	***13.0***
TUR	135	1.3	403	19	11.0	4.8	18	14.8

[a] no topographic measurements available so maximum absolute depth value is given instead
[b] only mean depth values were used (absolute maximum depths were ignored)

5.3.5 Differences in Phytoplankton Communities among Turlough Clusters

Figure 5.6 shows total biovolume and percentage biovolume of algal groups for each turlough, arranged by the identified significant clusters. Turloughs in the coloured/deep cluster had very low total abundances and very few chlorophytes. Their compositions were almost exclusively cryptophytes and diatoms (see also Table 5.5), and at times had taxa virtually absent from other turloughs (e.g. *Asterionella formosa* or *Melosira varians*). The percentage contribution of the different algal groups in Turloughmore was similar to those in the high TP and low TP turloughs, but the actual taxonomic composition differed sufficiently to form a separate cluster (Table 5.5).

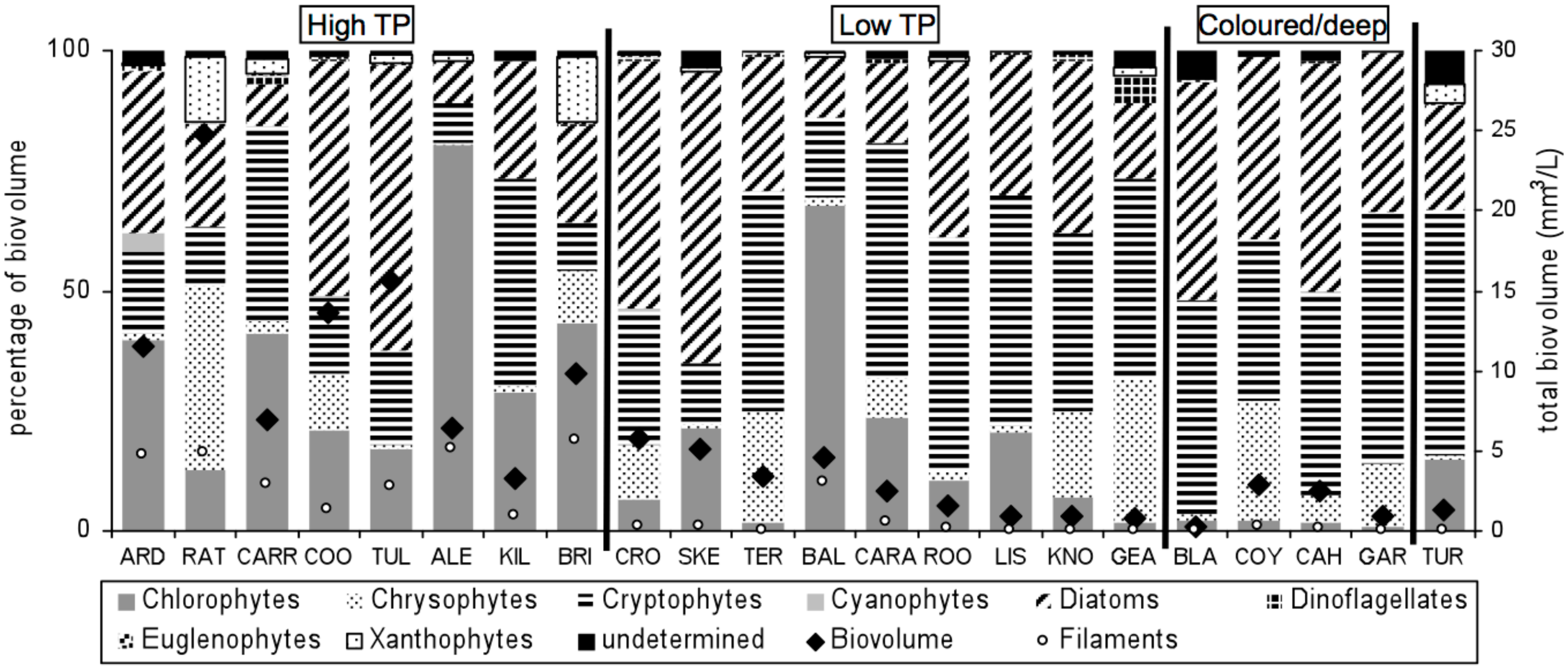

Figure 5.6 Percentage biovolume of algal groups (separated by vertical bars), total biovolume (large black symbol) and biovolume of filamentous algae (small white circle) for the 22 turloughs (arranged by identified clusters and ordered by descending TP within each cluster).

Table 5.5 [continues on next page] Percentage biovolume of algae in each month's samples for each identified cluster (only showing taxa contributing to the upmost 75% of cumulative total month's biovolume). Note: Chroo/Rhodomonas = Chroomonas/Rhodomonas

October		***November***		***December***		***January***		***February***	
High TP									
Tribonema	27.1	Spirogyra	41.6	n.i. pennates	23.7	n.i. centrics	49.0	Cryptomonas	42.0
Synedra	18.4	Tribonema	14.4	Synedra	18.5	Cryptomonas	17.4	Synedra	14.0
Cryptomonas	11.8	n.i. pennates	5.5	Fragilaria/Synedra	14.1	Synedra	7.2	Synedra nana	7.8
Chlamydomonas	9.0	n.i. centrics	5.2	Spirogyra	6.4	Synedra nana	5.1	n.i. pennates	6.7
A. minutissimum	6.5	Cryptomonas	5.1	Cryptomonas	5.7			Chroo/Rhodomonas	6.1
Chroomonas acuta	3.2	Synedra	4.4	A. minutissimum	5.0				
				Monoraphidium	4.5				
Low TP									
Chlamydomonas	34.3	Chroo/Rhodomonas	23.9	Fragilaria/Synedra	71.9	Cryptomonas	40.0	n.i. pennates	36.0
Cryptomonas	19.0	Cryptomonas	22.9	Chroo/Rhodomonas	10.1	Chroo/Rhodomonas	19.6	Mougeotia	14.0
Mougeotia	17.8	n.i. filament	12.0			Fragilaria/Synedra	13.3	Fragilaria/Synedra	11.6
Dinobryon	7.6	A. minutissimum	7.4			Synedra	6.7	Achnanthidium minutissimum	10.7
		n.i. pennates	5.9					Cryptomonas	7.1
		Fragilaria/Synedra	5.7						
Coloured/deep									
Cryptomonas	46.5	Cryptomonas	53.5	n.i. pennates	38.9	Synedra	39.3	Melosira varians	26.3
Chroo/Rhodomonas	17.1	Chroo/Rhodomonas	20.7	Eunotia bilunaris	20.9	n.i. centrics	25.1	Synedra	19.8
Synedra	11.0	n.i. flagellates	5.2	Cryptomonas	14.1	Cryptomonas	13.9	Fragilaria/Synedra	16.3
Closterium	3.5			Synedra	13.0			Eunotia faba	15.4
Turloughmore									
Cryptomonas	46.4	Cryptomonas	49.1	Navicula	50.4	Navicula	23.3		
Chlamydomonas	9.7	Chlamydomonas	11.7	n.i. pennates	26.0	n.i. filament	17.4		
Chroo/Rhodomonas	7.4	n.i. pennates	10.0			Nitzchia	17.3		
Nitzchia	7.2	Chroo/Rhodomonas	7.8			Fragilaria/Synedra	15.0		
n.i. pennates	5.8					n.i. pennates (colonial)	10.4		

Table 5.5 [continuation from previous page] Percentage biovolume of algae in each month's samples for each identified cluster (only showing taxa contributing to the upmost 75% of cumulative total month's biovolume). Note: Chroo/Rhodomonas = Chroomonas/Rhodomonas

March		*April*		*May*		*June*	
High TP							
Synedra nana	24.8	Dinobryon	44.1	Dinobryon	21.1	Bulbochaete	18.4
Cryptomonas	21.4	Spirogyra	23.5	Mougeotia	15.1	Dinobryon	14.0
Dinobryon	9.9	Mougeotia	11.2	Spirogyra	14.9	Cryptomonas	12.9
Fragilaria/Synedra	9.7			Oedogonium	9.6	Oedogonium	12.0
Spirogyra	6.0			Chroo/Rhodomonas	7.7	Fragilaria/Synedra	9.0
Closteriopsis acicularis	5.2			Cryptomonas	6.3	Spirogyra	7.0
						Mougeotia	4.6
Low TP							
Spirogyra	23.1	Mougeotia	36.6	Dinobryon	28.4	Dinobryon	32.4
Mougeotia	17.0	Chroo/Rhodomonas	18.9	Cryptomonas	14.3	Cryptomonas	26.7
Chroo/Rhodomonas	15.4	Oedogonium	13.2	Chroomonas/Rhodomonas	11.7	Chroo/Rhodomonas	20.5
Cryptomonas	10.0	Cryptomonas	13.0	A. minutissimum	11.0		
A. minutissimum	8.5			Mougeotia	5.2		
n.i. pennates	6.0			n.i. pennates	4.7		
Coloured							
Cryptomonas	40.1	Cryptomonas	41.7	n.i. pennates	29.3	Chroo/Rhodomonas	21.3
Chroo/Rhodomonas	39.3	Mallomonas	31.6	Navicula	23.8	Cryptomonas	15.3
		Chroo/Rhodomonas	8.3	Cryptomonas	15.8	n.i. flagellates	14.0
				Melosira varians	10.3	n.i. filament	10.4
						Chlamydomonas	9.9
						Navicula	6.2
Turloughmore							
n.i. centrics	26.8						
Navicula	22.5						
n.i. pennates	12.4						
Chlamydomonas	8.9						
Cryptomonas	6.8						

Table 5.6 SIMPER results of differences between high and low TP turlough clusters (absolute biovolumes and standardised biovolumes). All biovolume values are 4th root transformed µm^3/mL. Only taxa contributing to the top 25% of dissimilarity are shown.

Absolute Biovolumes *Average dissimilarity=48.62%*					
Species	**High TP Average Biovolume**	**Low TP Average Biovolume**	**Average dissimilarity**	**Dissimilarity contribution (%)**	**Cumulative contribution to dissimilarity (%)**
Spirogyra	16.78	6.46	2.00	4.12	4.12
Chlamydomonas	11.55	3.35	1.62	3.32	7.45
Centric diatoms	11.98	3.43	1.50	3.09	10.54
Oedogonium	12.84	4.55	1.48	3.03	13.57
Dinobryon	14.25	9.53	1.36	2.80	16.37
Synedra (big)	12.86	5.99	1.35	2.77	19.15
Mougeotia	13.40	9.25	1.33	2.73	21.87
Tribonema	11.70	5.26	1.30	2.67	24.54
Standardised Biovolumes *Average dissimilarity=41.78%*					
Species	**High TP Average Biovolume**	**Low TP Average Biovolume**	**Average dissimilarity**	**Dissimilarity contribution (%)**	**Cumulative contribution to dissimilarity (%)**
Chlamydomonas	1.14	0.37	1.38	3.29	3.29
Centric diatoms	1.10	0.59	1.09	2.62	5.91
Spirogyra	1.39	0.89	1.06	2.53	8.44
Chroomonas/ Rhodomonas	1.41	2.13	1.03	2.46	10.91
Synedra (big)	1.32	0.78	1.03	2.45	13.36
Oedogonium	0.98	0.62	1.01	2.43	15.79
Eunotia minor	0.39	0.96	0.98	2.35	18.14
Dinobryon	1.15	1.21	0.94	2.25	20.38
Mougeotia	1.25	1.16	0.89	2.14	22.52
Tribonema	1.06	0.77	0.86	2.05	24.57

A t-test of the differences in relative abundance of algal groups between the high TP and low TP turlough clusters revealed that only two groups were significantly different: Chlorophytes were more abundant in the high TP cluster and cryptophytes were more abundant in the low TP cluster (log percentage of biovolume of algal groups, $p<0.04$). The majority of the biovolume of chlorophytes was of filamentous forms (79%) so it was not surprising to find that both sums and percentage biovolume of filamentous algae were also significantly higher in the high TP cluster than in the other clusters (log sum and percentage biovolume t-test, $p\leq0.01$), even though a few turloughs in the high TP group had relatively low filamentous algae abundance and some turloughs in the low TP cluster had relatively high filamentous algae biovolume (Figure 5.6). SIMPER analysis revealed that the taxa differing the most in abundance between the high TP and low TP groups were *Chlamydomonas* spp., centric diatoms and *Spirogyra* spp. (all more abundant in the high TP group) with a number of other filamentous algae (*Oedogonium* spp., *Mougeotia* spp. and *Tribonema* spp., also more abundant in the high TP cluster) being important contributors to dissimilarity between these two groups as well (Table 5.6). This confirms that filamentous algae are more abundant in high TP turloughs, as stated above. High TP turloughs also tended to have the highest taxa richness (Table 5.5), with a number of chlorophytes absent from other groups of turloughs, including green filaments (*Binuclearia* spp., *Bulbochaete* spp. and *Chaetonema* spp.) and Chlorococcales (*Actinastrum* sp., *Coelastrum* spp., *Micractinium* sp. and *Tetrastrum* sp.).

5.3.6 Seasonal Succession of Phytoplankton

Figure 5.7 shows the temporal variation in abundance of the algal groups summarised for all turloughs and Table 5.5 shows the most abundant taxa in each month within each turlough cluster. Diatoms and cryptophytes were present in considerable amounts throughout the season and clearly dominated over the winter months (December to February). The most abundant taxa during winter were *Cryptomonas* spp., *Chroomonas/Rhodomonas*, *Synedra* sp. (small and big), and other pennates, including the small pennate diatom *Achnanthidium minutissimum* at times. Centric diatoms also made large contributions predominantly in winter, appearing in blooms in specific turloughs and months. Xanthophytes (which are almost exclusively represented by the filamentous alga *Tribonema* spp. (99.95% of this group's biovolume) represented a sizable fraction of the phytoplankton only during the first two months, particularly in the high TP group (Table 5.5). Chlorophytes made higher contributions during the first two months of flooding and during spring (March to June); in the high and low TP turloughs the biovolume of chlorophytes was clearly dominated by filamentous forms (Table 5.5). In October the green flagellate *Chlamydomonas* spp. was a substantial contributor to the high TP and low TP clusters and in Turloughmore (Table 5.5); this taxon was also significant in Turloughmore in November and in March, after the turlough had been dry for a month. Chrysophytes made a particularly noticeable contribution during later months, especially between April and June, and *Dinobryon* spp. was the taxa mainly responsible for this, although other taxa appeared occasionally in great numbers (*Mallomonas* sp. in Coy in April or *Uroglena* sp. in Caranavoodaun in May). *Dinobryon* spp. and filamentous green algae comprised a large proportion of the biovolume during spring in both the high and low TP turloughs (Table 5.5).

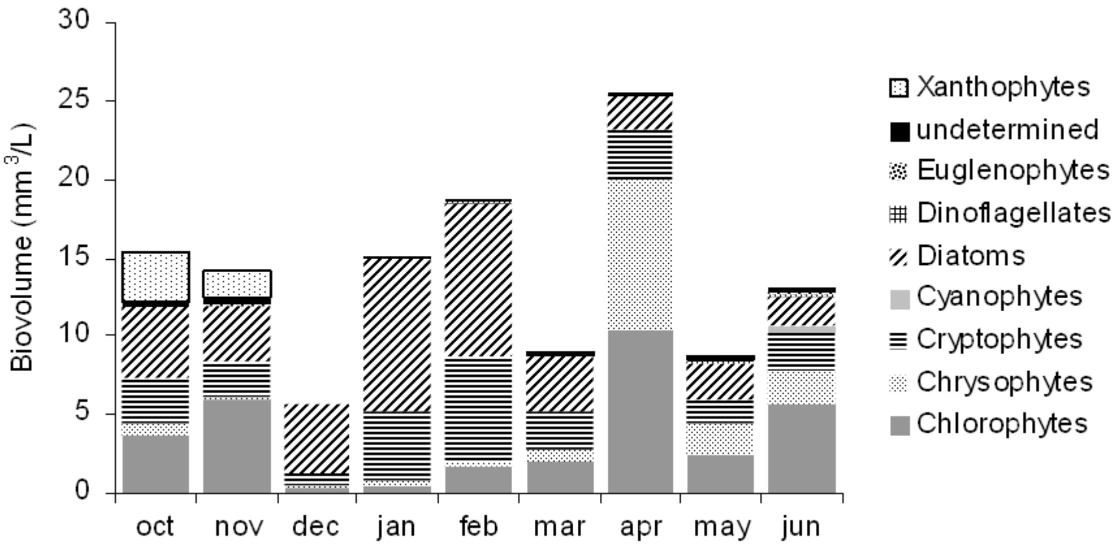

Figure 5.7 Biovolume of algal groups by month in all 22 turloughs.

All other algal groups constituted a small proportion of the total monthly biovolume and, together with the Xanthophytes, were not present in all 22 turloughs, unlike the aforementioned four groups. Cyanophytes constituted a sizeable proportion of the phytoplankton only in June (although they were present in a few turloughs in October and November also) and Euglenophytes in October and June only (Figure 5.7). Dinoflagellates were found from October to June with varying temporal distribution depending on the turlough, but always as a small percentage of the total biovolume.

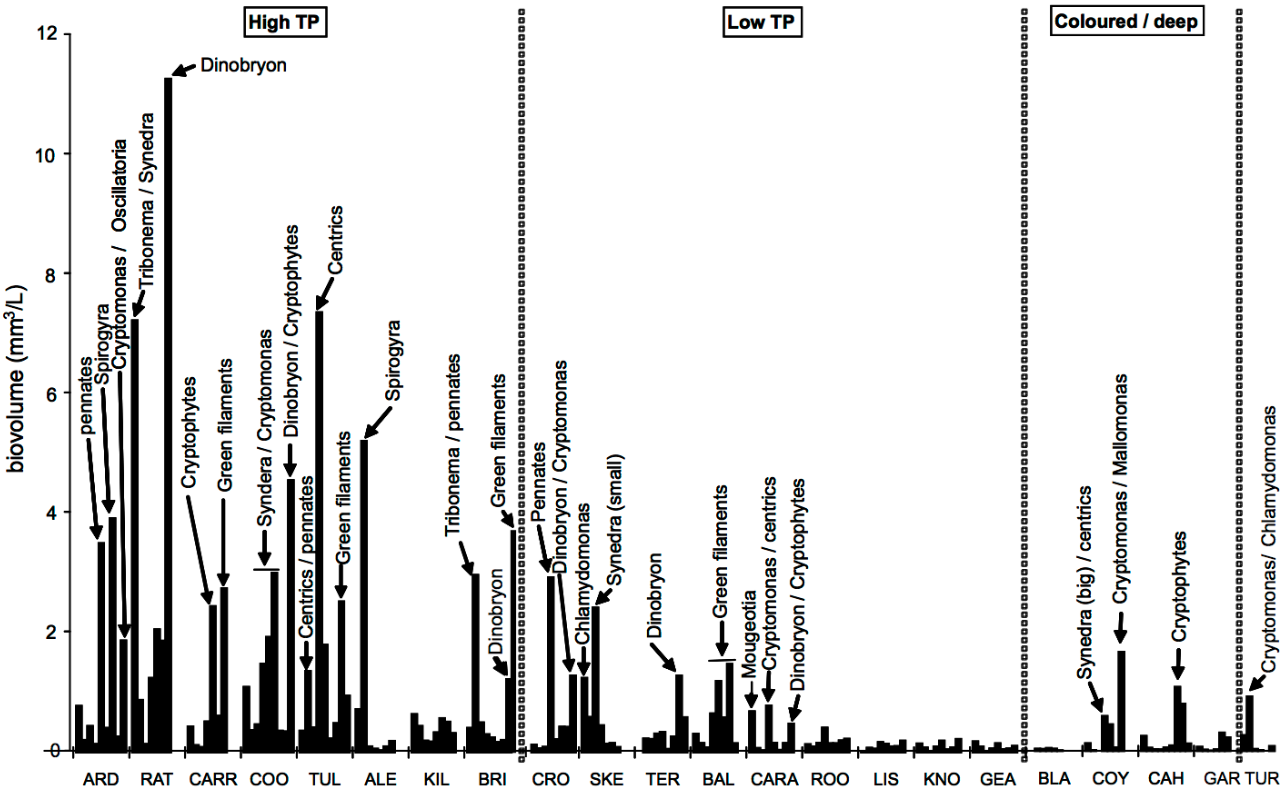

Figure 5.8 Monthly total phytoplankton biovolume of each of the 22 turloughs showing the taxa that dominated the biovolume peaks (>60% of total biovolume); turloughs arranged by identified clusters and in order of descending mean TP within clusters.

As shown elsewhere (Cunha Pereira *et al.*, 2010 and *Chapter 4: Water Chemistry and Algal Biomass*) algal abundance (as Chl *a*) over time varied erratically across turloughs, with peaks occurring at varying times in different turloughs. Figure 5.8 depicts the taxa dominating the total biovolume in the most important of the peaks. Not surprisingly, some of the peaks are dominated by cryptophytes or pennate diatoms, but of particular interest are the several peaks of filamentous algae and Chrysophytes (particularly *Dinobryon* spp.) when these taxa were often absent or present in low abundance in months preceding or proceeding these peaks. There are also a few examples of sudden blooms of *Chlamydomonas* spp., *Oscillatoria/Planktothrix*, and centric diatoms.

5.5.7 Influence of Environmental Variables on Phytoplankton Distribution

Figure 5.9 presents the variation over time of relevant environmental factors (mean depth, water temperature, day length and silicates). RDA analysis showed that season (represented by number of days flooded and temperature, the latter significantly correlated with day length), TP and mean depth were the main explanatory variables of phytoplankton composition (Table 5.7a). When standardised biovolumes were used, TP and season were still the main explanatory variables ($p<0.007$). These results confirm the indications above that TP is an important explanatory variable of phytoplankton composition. The first two axis of the RDA explained 78% and 71% of the species-environment relationship using absolute and standardised biovolumes respectively, and 11% of the species variance in both cases. The samples of the coloured/deep turloughs seem to drive the explanatory value of the mean depth variable, as these samples plot towards the highest end of the mean depth gradient (Figure 5.10). When the analysis was rerun without the samples from these turloughs it is seen that mean depth ceases to be a significant explanatory variable for the remainder of the turloughs (Table 5.7b). It should be borne in mind that the four coloured/deep turloughs are both much deeper but also more coloured than the other 18; thus both mean depth and colour can be responsible for the separation of this group.

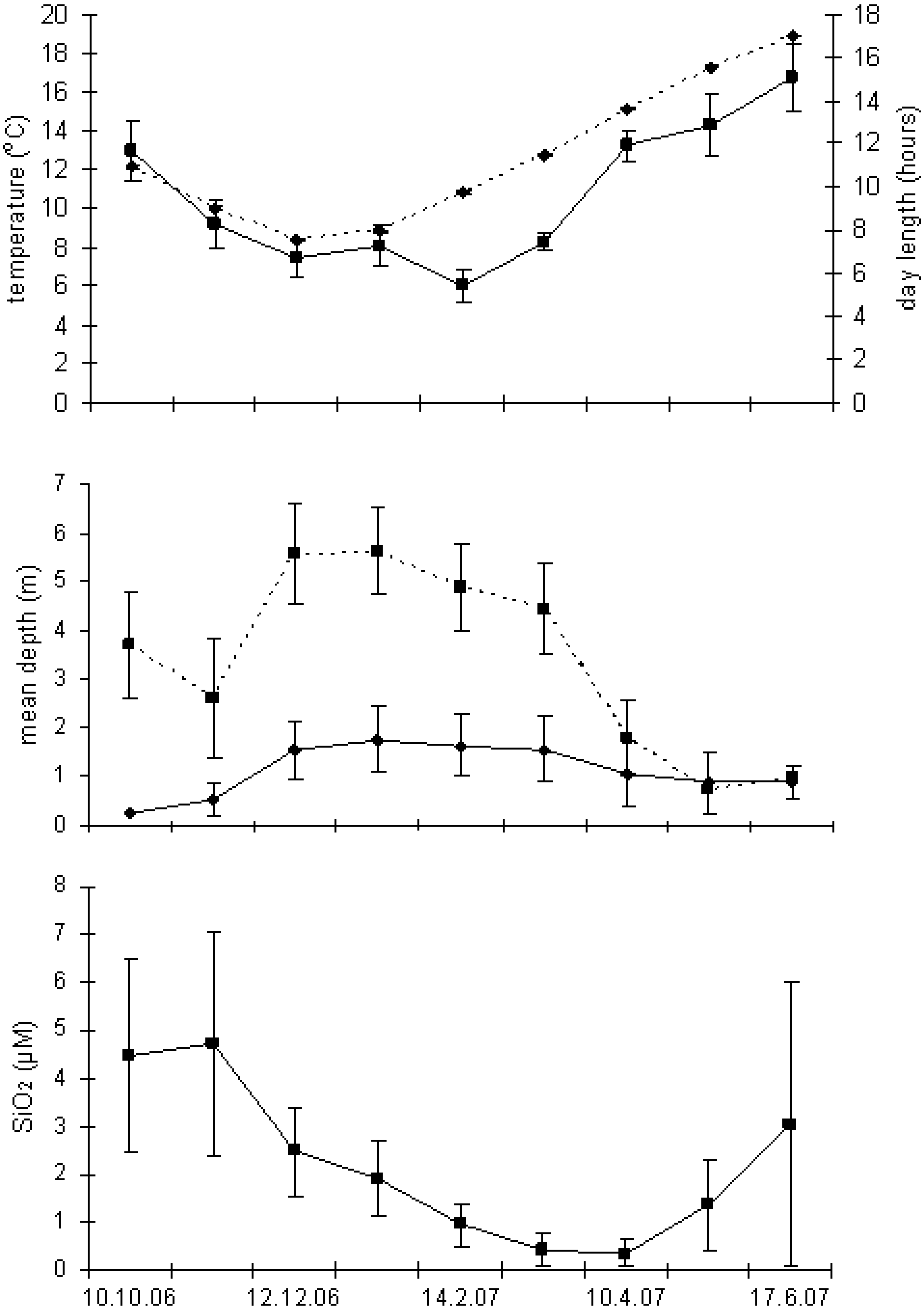

Figure 5.9 Mean temperature (solid line) and day length (dashed line) (a), mean depth of coloured/deep (dashed line) and rest (solid line) of turloughs (b), and mean silicate concentration over time in the 22 turloughs (c). Error bars are ± standard deviations.

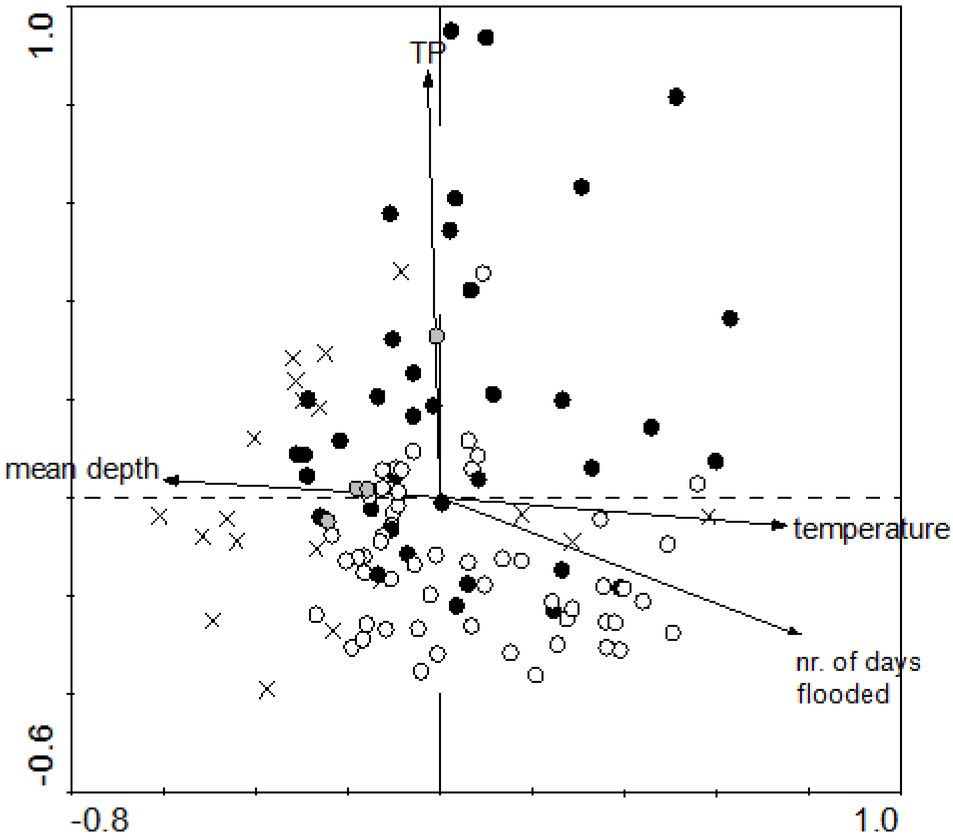

Figure 5.10 First two axis of the RDA analysis including all 22 turloughs showing significant explanatory variables (arrows). Symbols correspond to identified turlough clusters: black circles - high TP, open circles - low TP, grey circles – Turloughmore; x - coloured/deep turloughs.

Table 5.7 Automatic forward selection results of environmental variables including all turloughs (a) variables that were significant at p<0.0071 after Bonferroni correction, n=116 samples, and (b) the same analysis excluding coloured/deep turloughs (only the first three variables were significant; p<0.0071, n=97 samples).

(a)

Marginal Effects		*Conditional Effects*			
Variable	Lambda1	Variable	Lambda A	P	F
nr days flooded	0.05	nr days flooded	0.05	0.001	6.0
temperature	0.05	TP	0.03	0.001	4.1
TP	0.03	mean depth	0.04	0.001	4.6
mean depth	0.03	temperature	0.02	0.001	2.7

(b)

Marginal Effects		*Conditional Effects*			
Variable	Lambda1	Variable	Lambda A	P	F
nr days flooded	0.06	nr days flooded	0.06	0.001	5.89
temperature	0.06	TP	0.05	0.001	5.13
TP	0.05	temperature	0.03	0.001	3.38
mean depth	0.03	mean depth	0.01	0.116	1.41

5.4 Discussion

5.4.1 Algal mats

Visible algal mats were a common occurrence in the turloughs towards the end of the flooding season but in most cases such mats consisted of small patches only. The results confirm previous reports that extensive algal mats (*'algal paper'*) are not a widespread occurrence in turloughs. The closest to the description to "an apparent snowfield" (as described by Scannell, 1972) observed in this study was in Garryland in 2008 (Figure 5.1a). The taxonomic diversity of algae in the algal mats that were found in this study was much higher than that reported by Scannell (1972). The main taxa found are known to grow in shallow ponds or slow-flowing rivers or streams (e.g. Padisák *et al.*, 2009, John *et al.* 2002). They also occur typically at the time of year when they were found in turloughs (i.e. spring and early summer, see Graham *et al.*, 1995, Hillebrand, 1983). *Tribonema*, which was common in the autumn phytoplankton communities of the turloughs (Table 5.5), was at times a component of the algal mats in this study but it was never abundant.

It is known that benthic algae require specific conditions to develop. In particular, a suitable substratum, relatively calm (but not stagnant) waters, and reasonably shallow depths (allowing light penetration) are needed for abundant development of benthic algal communities (Stevenson, 1996). Relatively warm weather and a period of stable shallow conditions may be important for the development of benthic algae in turloughs, followed by a period of relatively slow and gradual recession of the water table to allow for an extensive deposition of the material. Furthermore, trophic status of the water seems also to be an important factor (see below). The results of the present study indicate that suitable conditions for the development of algal mats probably do not exist every year, nor in all turloughs.

Water level at the time of observation is important when recording the occurrence of algal mats. For example, Garryland had extensive algal mats in 2008 but in 2009 it was too full (at the time of visit) to assess whether mats would be found. At other sites (e.g. Kilglassaun in 2008) the turlough appeared to have been dry for quite some time and, if any algal mats had developed, they may have already disappeared. Some observations in fact showed that drying mats can completely disappear within three weeks.

Topographically turloughs are usually shallow (<3 m deep) and have gentle slopes and fairly flat floors, conditions which appear to be ideal for filamentous algal growth (see Lowe, 1996; Wetzel, 1964). Indeed, among the five turloughs observed by Reynolds (1983), the turlough that developed extensive mats had a wide shallow basin. Most of the turloughs in our study fit this description but some do not. Ardkill for example has pronounced slopes in some sections, and despite this, drying algal mats were extensively observed here (Figure 5.1d). Therefore, other factors seem to play a more important role.

An important factor for filamentous algal development appears to be the trophic status of the water body. It is clear (Cunha Pereira *et al.* 2011, and this chapter) that biomass of filamentous green algae in the phytoplankton was generally higher in turloughs with high total phosphorus concentrations (i.e. ≥20 μg l^{-1}) and clear shallow waters. Higher yields of filamentous greens in enriched waters have also been found in other wetlands (e.g. McCormick & O'Dell, 1996). Therefore it is not surprising that more extensive algal mats were found mainly in high TP turloughs. However, some turloughs with relatively high TP such as Blackrock, Coy, Caherglassan, and Coolcam did not develop extensive algal mats. Blackrock, Coy and Caherglassan are the deepest of the 22 turloughs and had highly coloured waters; both factors would militate against the growth of benthic algae because of their negative impact on the underwater light regime. However, it should be noted that Garryland, which did develop extensive algal mats, is almost as deep and was as coloured as the above three turloughs. Coolcam on the other hand is neither deep nor highly coloured but had the longest hydroperiod of any of the turloughs, a feature which has been shown to be associated with high abundances of macroinvertebrates in turloughs (Porst & Irvine, 2009). Thus it is possible that the lack of algal mats in Coolcam could be due to grazing by invertebrates though this cannot be confirmed because the invertebrates of Coolcam were not studied in detail (Chapter 8). This study has shown that patches of filamentous algae are a common occurrence in turloughs, irrespective of nutrient status, but extensive algal mats are only found in turloughs with high average TP. However, turloughs with high TP did not necessarily develop extensive algal mats, most likely for the reasons given above.

Algal mats decompose quickly and are therefore a potential source of nutrients for turlough soils and the terrestrial communites of turloughs. In this way the algal mats represent a transfer of nutrients from the aquatic phase of turloughs to the terrestrial phase albeit only in localised areas of the more nutrient-rich turloughs. There are insufficient data at the present time on the biomass and nutrient content of algal mats to permit quantification of nutrient transfers by this mechanism.

5.4.2 Ecological Characteristics of Turlough Phytoplankton

Cryptophytes, together with small pennates, were the most widespread groups of algae in turloughs. *Cryptomonas* has been assigned to the **Y** functional group, including taxa known to be able to live in virtually all lentic ecosystems where grazing pressure is low (Padisák *et al.*, 2009; Barone & Naselli-Flores, 2003; Reynolds *et al.*, 2002). Although there are no data on zooplankton abundance in turloughs, it is plausible to assume, given this group's temperature sensitivity and ecology (Gyllström & Hansson, 2004), that their abundance during the first months of flooding and during winter (when cryptophytes are particularly prominent) would be low. Studies of European lakes and temporary water bodies, for example, have shown that grazing pressure from zooplankton only becomes important at the onset of spring (Garcia & Niell, 1993; Sommer *et al.*, 1986). *Cryptomonas* is also known to be tolerant of low light and temperature and is assumed to prefer enriched waters (Reynolds *et al.*, 2002). However, some studies suggest that the occurrence of *Cryptomonas* spp. is quite independent of trophic status (Barone & Naselli-Flores, 2003; Ojala, 1993), and we also found that this taxon was abundant in all turloughs, irrespective of trophic status.

The small Cryptophyte *Chroomonas/Rhodomonas* is part of the $\mathbf{X_2}$ functional group, typical of shallow meso-eutrophic waters. Although most turloughs are meso-eutrophic, this taxon was also common (and relatively more abundant) in oligotrophic turloughs. There are numerous examples of the abundance of this taxon in oligotrophic environments in the literature (Dokulil & Teubner, 2003; Pybus *et al.*, 2003; Salmaso, 2002). By contrast, studies of meso-eutrophic systems also found *Rhodomonas/Plagioselmis/Chroomonas* to be present in relative abundance (Kruk *et al.*, 2002, Aktan *et al.*, 2009). Reynolds *et al.* (2002) indeed note that there is uncertainty on the sensitivity of the $\mathbf{X_2}$ functional group to nutrient status.

Cryptomonas spp. and *Chroomonas/Rhodomonas* co-occurred in virtually all turlough samples (only in one turlough, Rathnalulleagh, was the latter not present) and this co-occurrence is often found in lakes also (Aktan *et al.*, 2009; Salmaso, 2002). This is evidence, therefore, that these cryptophytes may be largely functionally related. These taxa are often prevalent in turbid waters (Tavernini *et al.*, 2009) or after extreme climatic or hydrological events (Devercelli, 2010), denoting their adaptability to dynamic hydrological environments such as that found in turloughs. They are also found to dominate winter communities in particular.

Barone & Naselli-Flores (2003), for example, found *Cryptomonas* and *Plagioselmis nannoplanctonica* to be the most common cryptophytes occurring in Sicilian lakes, with particular prevalence during winter, when the lowest values of water temperature, illumination and grazing pressure were recorded. In western Ireland, Allott (1990) found that *Cryptomonas* spp. and *Rhodomonas minuta* were the most frequently occurring taxa in six lakes geographically close to the turloughs in this study; these taxa were co-occurring in the majority of samples and were also especially dominant during winter (see also Pybus *et al.*, 2003).

The diatoms predominant in turloughs were usually small-celled and fast growing types, thus able to take swift advantage of the available nutrient resources in turbulent conditions. Most are part of functional group **D** (i.e. *Synedra* spp., *Nitzschia* spp.), known to be tolerant to low light and shallow mixed depths (Reynolds *et al.*, 2002). This functional group has been described as typical of shallow, well-mixed waters, liable to be turbid (including rivers) which again matches well with the environment in turloughs. *Achnanthidium minutissimum*, a characteristically benthic diatom also abundant in the turloughs, is known to colonise periphytic communities and be tolerant of low light (Johnson *et al.*, 1997); it is also known to be able to live in a wide range of habitats, even those characterised by physical disturbance (Peterson, 1996a, b).

Centric diatoms, depending on the species, have different ecological affinities, particularly for nutrient levels and depth of mixed layer. Centrics in turloughs were found abundantly in oligotrophic turloughs (Knockaunroe and Gealain) as well as in more eutrophic ones (such as Tullynafrankagh and Carrowreagh). Therefore, they could belong to functional groups **D**, **B** or **C**, depending on the environmental characteristics present where they are found. They were mostly small and occurring in conspicuous blooms, particularly during the winter. This shows a marked colonising r-selected character (see also Kasten, 2003). Similar co-dominance by centrics and cryptophytes during the winter period (when recorded temperatures were at a minimum, turbulence was high, and nutrients were abundant) has been found in permanent lakes (e.g. Moustaka-Gouni, 1993).

A notable proportion of the algae found in turloughs can be considered tychoplanktonic, such as the filamentous algae and certain diatoms. These algae are probably associated with the vegetation on the turlough floor and can be suspended in the water column owing to the shallow depth of the sampling points and wind-driven mixing (see also Moustaka-Gouni, 1993). It is interesting to note that these algae can be assigned to the **MP** functional group (including metaphytic, periphytic and epilithic diatoms drifted in the plankton, such as *Achnanthidium minutissimum*) and to $\mathbf{T_D}$ (including metaphytic filamentous green algae and diatoms). The **MP** group is characteristic of frequently stirred turbid shallow lakes (Padisák *et al.*, 2009) and $\mathbf{T_D}$ was developed specifically to describe algal assemblages found in the plankton of mesotrophic rivers (Borics *et al.*, 2007). Interestingly, the descriptions of these habitats fit well with the environmental conditions found in turloughs: turloughs can even be likened to “slow-flowing rivers”, because of their highly dynamic hydrological nature.

Table 5.8 Overall phytoplankton succession in turloughs with the respective functional associations (Reynolds *et al*., 2002; Padisák *et al*., 2009), adaptive strategies (Reynolds, 2006), and habitats where each group is typically found (as described by Reynolds *et al*., 2002 and Padisák *et al*., 2009).

Taxa	*Functional groups*	*Strategies*	*Typical habitat*
Autumn (October and November)			
Tribonema/Spirogyra/Mougeotia	T_D (possibly)	R	Mesotrophic standing waters, or slow-flowing rivers with emergent macrophytes
Cryptomonas	Y	C	All habitats where grazing pressure is low
Chlamydomonas/Chroomonas/Rhodomonas	X_2	C	Shallow, meso-eutrophic environments
Planktonic diatoms (*Synedra* (big and small), *Nitzchia* spp., *Nitzchia acicularis*, n.i. pennates, and centrics)	D (centrics: D, B or C)	CR	Shallow turbid waters including rivers (D) and species sensitive to stratification (B/C)
Tychoplanktonic pennates (*A. minutissimum, Navicula,* n.i. pennates)	MP/T_D	CR	Frequently stirred up, inorganically turbid shallow lakes or slow-flowing rivers with emergent macrophytes
Winter (December to February)			
Planktonic and tychoplanktonic pennates (*Synedra* (big and small), *A. minutissimum*, n.i. pennates, *Nitzchia*) and centrics	D and MP/T_D (centrics: D, B or C)	CR	Shallow turbid waters including rivers (D), frequently stirred up, inorganically turbid shallow lakes or slow-flowing rivers with emergent macrophytes (MP/T_D) and species sensitive to stratification (B/C)
Cryptomonas / Chroomonas/Rhodomonas	Y/X_2	C	All habitats where grazing pressure is low and shallow, meso-eutrophic environments
Spring (March to June)			
Metaphytic green filaments (*Spirogyra*, *Mougeotia* and others)	T_D	R	Mesotrophic standing waters, or slow-flowing rivers with emergent macrophytes
Dinobryon	E	S	Usually small, shallow, base poor lakes or heterotrophic ponds
Cryptomonas/Chroomonas/Rhodomonas	Y/X_2	C	All habitats where grazing pressure is low and shallow, meso-eutrophic environments
Small pennates (*Synedra* (small), *A. minutissimum*)	D and MP/T_D	C	Shallow turbid waters including rivers (D) and frequently stirred up, inorganically turbid shallow lakes or slow-flowing rivers with emergent macrophytes (MP/T_D)

5.4.3 Environmental Factors Affecting Phytoplankton Community Structure and Temporal Succession in Turloughs

The coloured/deep turloughs had very low algal biomass throughout the season and lacked a clear succession, with cryptophytes and diatoms dominating throughout. In contrast to most of the turloughs, these turloughs were not found to be P-limited, and high colour (Havens & Nurnberg, 2004; Jackson & Hecky, 1980) and mean depth (Nõges & Nõges, 1999; Garcia *et al.*, 1997) are probable factors limiting the growth of algae in these turloughs (Cunha Pereira *et al.*, 2010). Turloughmore had a distinctly short hydroperiod and probably owing to this fact it showed a truncated succession among the 22 turloughs. In this turlough we find prevalence of r-selected, fast growing and small-celled organisms, such as cryptophytes, pennate diatoms (*Navicula*, *Nitzschia*), and, at times, centric diatoms, but it did not develop further. Interestingly *Chlamydomonas*, an r-selected, colonising taxa, was particularly notable in this turlough, and was abundant after periods of prolonged dryness (as in March). *Chlamydomonas* was also abundant in many turloughs following the onset of flooding (i.e. October), confirming its rapid colonising character.

Turloughs in the low and the high TP clusters (n=17) showed a clear and similar temporal succession of phytoplankton communities (summarised in Table 5.8) which can be considered the "norm" among the 22 turloughs in this study. Such typical turloughs were, in general, shallow (mean depth 0.8-3.0 m), continuously flooded during the sampling period, and nutrient limited (Cunha Pereira *et al.*, 2010).

The most noticeable shifts in community structure occurred at the onset of winter (December) and at the onset of spring (March). There are obvious differences in day length and temperature between these periods (Figure 5.9), which contributed to the changes in community structure (as indicated in the RDA analysis). Besides these factors, changes in nutrient levels, hydrological regime and grazing pressure over time may have also contributed to changes in community structure. In permanent lakes these are known to be important factors in shaping community structure - see Jeppesen *et al.* (2005) and Leitao & Leglize (2000) for the influence of nutrient availability, Na & Park (2006), Nõges & Nõges (1999) and Reynolds & Lund (1988) for the influence of hydrological factors, and Garcia & Niell (1993) and Sommer (1986) for the influence of grazing pressure; reviews in Reynolds (1984, 2006).

Besides the ubiquitous cryptophytes and pennate diatoms, the first two months of flooding were characterised by the abundance of fast growing C-strategists such as *Chlamydomonas,* and of low light tolerant filamentous species such as *Mougeotia* and *Tribonema*. Mean depths are low during this period and fresh nutrients are available for uptake. These conditions suit rapid resource-utilising, fast-growing r-selected species, which can take advantage of the resources under mixed conditions. Temperature and light levels are still sufficient for the growth of green algae (both for the flagellate *Chlamydomonas* and the filamentous forms), which are sensitive to these factors. *Mougeotia* and other green filaments, for example, are found abundantly in the autumn plankton of deep European lakes (Sommer, 1985, 1986). *Tribonema* is known to tolerate lower temperatures and irradiances than green filamentous algae (De Vries & Hillebrand, 1986), and coincidentally it was found most prominently during the autumn in turloughs, while in spring the green forms dominated.

In winter, when water temperatures and day lengths are at the minimum (Figure 5.9), the turlough communities were almost exclusively dominated by small pennates and cryptophytes. These algae often dominate winter plankton in lakes, even under ice when lakes freeze in winter (Pasztaleniec & Lenard, 2008). In spring there is a rise in temperature and light availability and a decline in silicate concentration (Figure 5.9). These conditions, in addition to a probable increase in zooplankton abundance, probably account for the decline in the abundance of diatoms and cryptophytes (both sensitive to grazing) and for the increase in the abundances of filamentous green algae (*Mougeotia* spp., *Spirogyra* spp., *Oedogonium* spp. and *Bulbochaete* spp. in particular, but *Ulothrix tenerrima*, *Binuclearia* spp. and *Klebsormidium* sp. also in lower abundance), and of Chrysophytes (particularly *Dinobryon* spp.), which are taxa known to be tolerant to grazing pressure and typical of this time of the year in many water bodies. Green filaments are well adapted to spring temperatures and light intensities (see Graham *et al.*, 1995 and Berry & Lembi, 2000 for *Spirogyra*; Graham *et al.*, 1996 and Hillebrand, 1983 for *Mougeotia*) and *Dinobryon* is also common in the spring plankton in lakes (Olrik, 1998; Sandgren *et al.*, 1995). This taxon, as in turloughs, often appears in "sudden" pulses, thought to be benefiting from declining diatom populations and the availability of trace metals (Kangro & Olli, 2005; Dokulil & Skolaut, 1991). Blooms of Chrysophytes in turloughs also coincide with the decline in diatom abundance, and so these explanations could apply to the case of turloughs as well. Green filamentous algae were more abundant in nutrient rich turloughs, which is in accordance with other studies. McCormick & O'Dell (1996) found that periphyton dominated by cyanobacteria and epiphytic diatoms in oligotrophic waters in the Florida everglades was replaced by green filamentous algae including *Spirogyra* and *Mougeotia* in stations with elevated TP concentrations or after experimental enrichment. Also, Hainz *et al.* (2009) studied 133 sites in Central Europe and found that *Spirogyra* grew optimally in meso-eutrophic conditions. Total phosphorus, which was found to influence total algal biomass in turloughs (Cunha Pereira *et al.*, 2010 and *Chapter 4: Water chemistry and Algal Biomass*), appear to drive phytoplankton composition towards higher abundances of green algae in general (e.g. *Chlamydomonas*), not only filamentous forms. Overall, green algae have relatively high half P saturation constants (Padisak, 2004), and so it is not surprising that they were found to be more abundant in turloughs with higher phosphorus concentrations.

5.4.4 Conservation Value of Turlough Algae

The algae that are found in turloughs are ubiquitous in various water bodies of temperate latitudes (e.g. ponds, lakes and slow flowing rivers) and as such they do not warrant a high conservation value being placed on them. However, the assemblages and succession of algae in turloughs are nonetheless unusual and are of ecological interest. It is also worth noting that small areas of algal mats are probably a natural feature of turloughs in the late Spring but the occasional extensive algal mats that have been recorded in the past are likely to be the result of artificial enrichment. The unusual hydrological regime of turloughs is an important influence on turlough algae. Therefore, the assemblages, biomass and succession of algae in turloughs will be relatively natural if the hydrological regime of turloughs is not altered (for example by artificial drainage) and if nutrient losses from the catchment are kept to reasonably natural levels.

5.5 Conclusions

The first algae to colonise turloughs in autumn were typically fast-growing flagellates, such as *Chlamydomonas,* and filamentous forms, such as *Tribonema*. Such algae, together with the ubiquitous cryptophytes, pennates and small dinoflagellates, are often typical of small ponds (Reynolds, 2006; Alam *et al.*, 2001; Evans, 1958). The algal communities in winter, dominated by cryptophytes and diatoms, were similar to those of many permanent lakes in winter (Pasztaleniec & Lenard, 2008), and the algae found in spring (dominated by filamentous greens, particularly in nutrient-rich turloughs), were again characteristic of ponds, but also of slow-flowing rivers. In general, and as expected, K selected species (typical of stable water columns, see de Hoyos & Comin, 1999; Jacobsen & Simonsen, 1993; Allott, 1990) did not occur in turloughs. Algal mats were not found to be a widespread feature in turloughs. All the turloughs that developed extensive algal mats had high TP but all turloughs with high TP did not develop algal mats. It is thought that lack of light may have inhibited the development of algal mats in coloured and deep turloughs whereas grazing by invertebrates may be responsible in others. Algal mats are a potential source of nutrients to the terrestrial system where they occur in turloughs but their importance in this regard cannot be quantified at the present time.

5.6 References

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Glossary of terms

Epilithic: Growing on rock.

Epiphytic: Growing on plants.

Metaphytic: Loosely associated with plants but not directly attached to them.

Tychoplanktonic: Algae or other organisms that are circumstantially carried into the plankton, for example, by turbulence. They can also be referred to as accidental plankton or pseudo-plankton.

Chapter 6. Turlough Soils and Landuse

S. Kimberley

Land parcel boundaries restrict the movement of livestock and increase the ecological diversity in turloughs. Croaghill, Co. Galway. *Photo: M. Murphy*

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6.1 General Introduction to Turlough Soils and Landuse

Soils are both the medium in which ecologically influential biogeochemical transformations take place (Kolka & Thompson, 2006) and the primary storage of available nutrients for most wetland plants (Mitsch & Gosselink, 2000). Wetland soil properties are highly variable (Reddy, 1993) and it is important to evaluate the spatial variability of soil physical and chemical properties when assessing the ecological functions of any wetland (Stolt *et al.*, 2001) and when developing soil sampling programmes for monitoring purposes. An improved understanding of the drivers of turlough soil type and soil property spatial variation, and links with landuse, is also necessary for adequately describing turlough structures and functions. Turloughs are inherently temporally variable and the periodic drying up of wetlands has a marked effect on system function as the aquatic component disappears and soil microbial processes become terrestrial (Howard-Williams, 1985). Both spatial and temporal variability have implications for making meaningful soil nutrient comparisons among turloughs.

Eutrophication currently presents a significant threat to turloughs. The origin of P in turlough floodwaters is unknown with debate divided on whether the principal source is internal (i.e.

directly from grazing livestock and indirectly from livestock/nutrient additions via turlough soils) or whether it originates in the catchment and is transported into the turlough via groundwater. Transport processes between soil and the overlying water column affect the availability of phosphorus for assimilation by biota and an evaluation of soils as a potential contributor of P to turlough floodwaters is a research priority. Turlough soils and landuse are under-researched and an improved ecological understanding of turloughs requires comprehensive knowledge of associated soil types, soil property variation, landuse practices and the links between the soils and the water column.

The overall aims of this aspect of the project were:

- To elucidate drivers of turlough soil type and soil property spatial variation (Sections 6.1, 6.2 and 6.3).
- To evaluate the effect of sampling period on turlough soil nutrient comparisons (Section 6.4).
- To investigate phosphorus release from soils to turlough floodwaters as part of an overall review of turlough nutrient cycling (Sections 6.5 and 6.6).

6.2 An Examination of Soil Type, Soil Property and Grazing Regime Variation Among Turloughs

6.2.1 Introduction

Qualitative evidence suggests that the range of turloughs have a broad range of soil types in comparison to other wetlands (Goodwillie 2001). Quantitative evidence shows that turlough soils are complex and highly variable in their origin and distribution as a consequence of geomorphological and hydrological variations (MacGowran, 1985; Coxon, 1986). Field observations indicate that different soil types encourage the establishment of different vegetation types, with different requirements and tolerances for nutrient availability, drainage properties and toxic substances (Goodwillie, 1992). The establishment of different vegetation communities is likely to influence the distribution of aquatic invertebrate communities and consequently the ecology of turlough floodwaters. Describing, classifying and mapping turlough soil types are therefore important components of turlough ecological assessment. Understanding the similarity or dissimilarity of turloughs in terms of their soil types and soil properties is important for aiding interpretation of the distribution of biological communities among turloughs and for further informing the debate relating to the merits of turlough typology. Soil types also influence the nutrient retention capacity and grazing potential of turlough land, yet soil-related research in turloughs is currently very sparse. We aim to address this substantial research gap by providing an examination of soil type and soil property variation across a broad range of turloughs.

In general terms, turlough soils are hydric soils, defined as "soils that formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part" (Mitsch & Gosselink, 2000). Turlough soils are generally poorly developed, shallow soils with simple profiles (MacGowran 1985). The soils can be classified according to the Irish Soil Survey as organic rendzinas and rendzina-like soils (loamy and sandy), which generally occur at the upper parts of these basins exceptionally exposed to flooding, grading to gleys (peaty and sandy), river silts and raw marl and peats (MacGowran 1985).

Coxon (1986) described turlough surface deposits into five broader groups which can be related to both duration and depth of inundation, including Marl (or marl plus peat-marl), Peat (or peat plus peat-marl), Silt/clay, Sand/silt or diamicton (poorly sorted deposits) and Variable (mixture of deposits: peat or marl, peat-marl in parts, diamicton in parts). Soil type distribution among turloughs is likely to depend heavily on variation of subsoil type, hydrology and floodwater hydrochemistry. Variation in subsoil type can influence, in particular, the nature of the sand/silt/clay fraction and the related properties of soil texture and structure. Soil development is also likely to depend on the drainage characteristics of the underlying bedrock (Coxon, 1986). Turloughs are generally fed with alkaline floodwaters which influence the deposition of marl and shell marl accumulation. Characterising the relative importance of subsoil type, hydrology and hydrochemistry in determining the distribution of turlough soil types is a critical aspect of the evaluation of turlough structure and function. Describing the hydrological characteristics of turlough soil types is also important for evaluating the potential for using soil types as indicators of hydrological regime. Wetlands are characterised by high degrees of soil property spatial variation. Individual soil properties are likely to be highly spatially variable both within and among turloughs and an examination of this variation is important for informing the development of soil sampling strategies for conservation assessment purposes. An improved understanding of turlough soil property variation will ultimately inform the potential use of different soil properties for characterising turlough soil conditions.

Turloughs are marginal grazing land and conservation and land management are intimately linked (Sheehy Skeffington *et al.*, 2006). Grazing exerts a profound influence on turlough ecology, particularly on the distribution of vegetation communities. In addition to hydrology, soil type is potentially an important driver of turlough grazing intensity. Soils with good drainage characteristics and structure are likely to be more intensively grazed than poorly drained soils with weak structure. Turlough soil types under relatively more intense grazing regimes are consequently likely to be relatively more nutrient enriched than less intensively grazed soil types; conversely, sites with more nutrient enrichment are likely to support more intensive grazing. Evaluating turlough grazing regimes is extremely challenging given the dynamic, undocumented nature of turlough landownership. Turlough land tenure can be commonage, private ownership or a combination of both (Visser *et al.*, 2007; Aughney & Gormally, 1999).

The characteristic patchwork arrangement of land holdings is a consequence of a past reliance on turloughs as a water source, particularly before the advent of rural water schemes in Ireland in the 1950s (Moran, 2005). During the 1880s, the Land Commission (the government agency charged with transferring land from landlords to tenants) allocated small areas of turloughs to local farmers to provide access to water (Sammon, 1997).Turloughs continue to be an important water source and the pattern of landuse is therefore primarily a function of hydroperiod, which also influences the grazing potential of the different land holdings (Sheehy Skeffington & Gormally, 2007). The central basin is often managed as commonage with landowners adjacent to or near the turlough having grazing rights. These rights can either relate to exact amount of stock or alternatively it is agreed informally amongst shareholders who generally know the relative amount of stock their particular turlough can support (Sheehy Skeffington & Gormally, 2007). Fields often radiate from the central commonage area or where there is no commonage, individual fields stretch right across the basin (Moran *et al.*, 2008). Turloughs are grazed by domestic livestock in the summer months and they support relatively low-intensity farming owing to their inaccessibility for much of the year (Sheehy Skeffington & Gormally, 2007). Most land-owners graze cattle (dairy and beef animals; Aughney & Gormally, 1999) but sheep are also found as are horses and donkeys and geese (Feehan, 1998; Aughney & Gormally, 1999). It is well recognised that grazing regimes and stocking rates vary widely both within and among turloughs (Ní Bhriain *et al*., 2002; 2003; Moran, 2005; Sheehy Skeffington & Gormally, 2007). Current management practices on turloughs are poorly documented with only two studies addressing this in detail (Ní Bhriain *et al*., 2003; Moran, 2005). A broad-scale, baseline assessment of turlough grazing regimes is important for providing a current assessment of grazing activities on turloughs and for providing comparable information across a range of turloughs.

The overall objective of this work was to improve understanding of the factors affecting turlough soil types, ecologically important soil properties and grazing regimes. The specific objectives of this aspect of the project were i) to examine soil type and soil property variation among turloughs and to elucidate environmental drivers of this variation; ii) described the properties and hydrological characteristics of turlough soil types and iii) to examine associations between grazing regime, soil types and soil properties.

6.2.2 Methods

6.2.2.1 Qualitative Soil Type Descriptions, Classification and Mapping

Soils were described at an average of 30 point locations within each of 22 turloughs between May and August 2006, 2007 and 2008. Soils were described within the upper, middle and lower elevations within each land-parcel, however in some cases lower areas were inaccessible owing to persistent flooding. The field recording sheet used during the survey is presented in Figure 6.1. A gouge auger and screw auger were used to sample the soil horizons to a minimum of 50 cm depth. Soil pits were beyond the scope of this study given the limited resources, however the gouge auger and screw auger provided sufficient information to determine the depth and physical characteristics of the O, A and B horizons. Horizon nomenclature was applied to mineral soil types identified as 'Well drained mineral' and 'Poorly drained mineral'. Peat soils are not traditionally described using such nomenclature and different layers are identified simply by their individual depth ranges. Fen peats and Peat-marl soil types were described in this way. Marls with peaty topsoils (AlluvMRLPT) were described using traditional horizon nomenclature owing to the presence of a mineral marl layer. The depth colour, mottling, nature of organic matter, marl deposits and shell marl, texture, structure and stoniness of each horizon was described. Soil depth was measured using a 1 m soil depth probe. Soil colour (matrix and mottling) was described using Munsell Soil Colour Charts 2006. The abundance, size and contrast of mottles and the sharpness of mottle boundaries were described according to criteria in Hodgson (1978). The nature of organic matter content was described as either semi-fibrous (partly decomposed fibres which are largely destroyed by rubbing) or fibrous (containing large amounts readily identifiable plant remains; Finch, 1971). The proportion of marl deposits and shell marl flecks were also estimated (None, Few [<2% of matrix], Common [2-20% of matrix], Many [20-40% of matrix] Abundant [>40% matrix]. Soil texture was determined in the field using hand textural analyses (Ball, 1986; Finch, 1971). Soil structure was described as weak, moderate or strong and stone abundance was also estimated.

Soils at each sampling point were classified using a modified version of soil categories generated by the Teagasc/EPA Soils and Subsoils Mapping project (Fealy *et al*., 2009). This classification scheme allows for the broad grouping of soils in the absence of detailed chemical analyses of each horizon in the soil profile.

The classification scheme principally uses parent material (calcareous/non-calcareous), depth class (shallow/deep) and drainage class (well drained/poorly drained) to assign soils to one of nine broad categories. This scheme was expanded to capture the full range of turlough soil types. These modifications included i) a distinction between organic and mineral soils; ii) two additional alluvial marl soil types (marl soils with peaty topsoil: AlluvMRLPT; and peat-marl: PtMRL, a continuum from marl to peat common in turloughs; Coxon, 1986) and iii) a 'Very Shallow' category as many turlough soils are extremely thin. A summary of the soil classification criteria used during the study is presented in Table 6.1. Diagnostic characteristics of each soil type are presented in Table 6.2.

Soils within the 22 turloughs were mapped by combining the EPA Subsoils base map with the point soil descriptions. The subsoil map was first clipped using the turlough boundary shapefile. The boundary represents the Goodwillie (1992) vegetation boundary in most cases. The boundaries for Lough Coy and Roo West were determined by digitising vegetation maps presented in Tynan *et al.* (2006) and van Ravensberg and van der Wijngaart (2000) respectively. The maximum recorded flood level was used as the boundary for Lough Gealain (Owen Naughton, pers. comm.) in the absence of a vegetation map at the time of sampling. The sampling points were then spatially joined with the subsoil map. The next step identified the dominant soil type associated with each subsoil type within each turlough. In addition, a summary of the various classes used for soil classification was compiled for each subsoil type within each turlough. This method provides a broad summary description of dominant soil characteristics occurring in relation to each subsoil type within each turlough. The Teagasc/EPA soil type is mapped as a default in the limited number of cases where a subsoil type lacks coinciding sampling points (Table 6.3).

Turlough Soil Classification

Date: County/Turlough:

Sample No.: Elevation: GR (Location on map):

Sample Site Description

Dominant plant species:

Slope: 0-5, 6-10, 11-30, >30 Poaching: N S M S Rock Outcrops: N, R, VR, ER, RO

Dung: N S M S Grazing: N S M S

Soil Depth:

Parent material:

Comments:

Horizon			
Depth (cm)			
Matrix Colour			
Nature of OM			
Mottling	P / A	P / A	P /A
Colour			
Abundance	0 None 1 Few <2% 2 Common 2-20% 3 Many 20-40% 4 Very many > 40%		
Size	1 < 1 mm 2 1-2 mm 3 2-5 mm		
Contrast	1 Sharp 2 Clear 3 Diffuse		
Marl	P / A	P / A	P / A
Shell marl	0 None 1 Few <2% 2 Common 2-20% 3 Many 20-40% 4 Very many > 40%		
Roots	P / A	P / A	P / A
Texture			
Soil Structure	1 Weak 2 Moderate 3 Strong		
Stoniness	0 None 1 Few <2% 2 Common 2-20% 3 Many 20-40% 4 Very many > 40%		

Figure 6.1 Field recording sheet used for soil descriptions.

Table 6.1 Criteria used for turlough soil type classification

Classes	*Descriptions*		
Parent material	The parent material or C horizon was identified using the EPA Subsoil Map 2006. The vast majority of turlough soils are derived from calcareous parent materials (B).		
Depth class	Soil depth classes were determined using ranges presented in USDA (2003). The depth classes included three categories: Very shallow (< 25cm); Shallow (25-76cm); Deep (> 76 cm).		
Drainage class	Well drained	Excessively drained	Mostly coarse textured (sandy), skeletal soils on porous materials in upland positions.
		Well drained	No obvious sign of impeded drainage (mottling etc.) throughout the solum. Exception where under pasture, sparse mottling may occur in topsoil.
		Moderately well drained	Background colour of entire profile as for 'Well drained' with limited feint mottling allowable above 45cm; more distinct common mottling below 45cm.
	Poorly drained	Imperfectly drained	General background colour below 30cm partly reduced (grey colour with some grey-brown and brown), with mottling. Above 30cm natural colours (grey-brown and brown) with or without mottling.
		Poorly drained	General background colour throughout profile a reduced grey with many prominent mottles to the surface or a definite reduced layer at any depth below 30cm and mottling to the surface.
		Very poorly drained	Background colour of entire profile a reduced grey or grey-blue throughout with few mottles allowable; with or without organic surface layer.
Organic/Mineral	Organic soils were identified by the absence of mottling, the presence of fibrous organic matter, dark colouration (10 YR 3/1, 3/2, 3/3, 2/1or 2/2) and often an organic texture as defined by Ball (1986). Mineral soil characteristics included semi-fibrous organic material, brown (10 YR 4/3, 5/3) colouration and/or the presence of gleying and mottling. Poorly drained mineral soils with peaty top soil were assigned to the mineral class. Silty and silty clay textures were key indicators of alluvial soils. Less that 20% OM content.		
Marl and/or shell marl abundance	Estimated proportions of marl and shell marl were used to identify horizons with significant amounts of marl and/or shell marl. Horizons with 20-40% or > 40% marl and/or shell marl were used as a diagnostic characteristic of peat-marls, marls with peaty topsoil and shallow marl alluvium.		

Table 6.2 Diagnostic characteristics of turlough soil types

Soil type	*Code*	*Characteristics*
Well drained mineral		
Very shallow well drained mineral	BminVSW	Soil depth <25cm; well drained mineral soils derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Shallow well drained mineral	BminSW	Soil depth 25-76cm well drained mineral soils; derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Deep well drained mineral	BminDW	Soil depth >76cm; well drained; mineral soils; derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Poorly drained mineral		
Very shallow poorly drained mineral	BminVSP	Soil depth < 25 cm; poorly drained mineral soils derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Shallow poorly drained mineral	BminSP	Soil depth 25-76cm; poorly drained mineral soils derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Deep poorly drained mineral	BminDP	Soil depth >76cm; poorly drained mineral soils derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Shallow poorly drained mineral soils with peaty topsoil	BminSPPT	Soil depth 25-76cm; poorly drained mineral soils derived principally from calcareous parent materials. Distinct peaty topsoil present with organic texture and dark (10 YR 3/1, 3/2, 3/3, 2/1or 2/2) colouration. Lower horizons generally have silty clay, clay loam textures with semi-fibrous organic material.
Deep poorly drained mineral soils with peaty topsoil	BminDPPT	Soil depth >76cm; poorly drained mineral soils derived principally from calcareous parent materials. Distinct peaty topsoil present with organic texture and dark (10 YR 3/1, 3/2, 3/3, 2/1or 2/2) colouration. Lower horizons generally have silty clay, clay loam textures with semi-fibrous organic material.

Soil type	*Code*	*Characteristics*
Well drained organic		
Very shallow well drained organic	BorgVSW	Soil depth <25cm; well drained organic soils derived principally from calcareous parent materials. Generally have organic or loamy textures with fibrous organic material.
Shallow well drained organic	BorgSW	Soil depth 25-76cm; well drained organic soils derived principally from calcareous parent materials. Generally have organic or loamy textures with fibrous organic material.
Poorly drained organic		
Very shallow poorly drained organic	BorgVSP	Soil depth <25cm; poorly drained organic soils derived principally from calcareous parent materials. Generally have organic or loamy textures with fibrous organic material. M/SM not significant.
Fen Peat	FenPt	Soil depth >30cm; poorly drained organic soils derived principally from calcareous parent materials. Generally have organic or organic silty clay textures with fibrous organic material. Dark (10 YR 3/1, 3/2, 3/3, 2/1or 2/2) or Dusky red (10 R 3/2, 3/3or 3/4) colouration. 0-20% marl or shell marl may or may not be present.
Alluviums		
Peat-marl	PtMRL	Mid-point of the continuum from marl to peat and has a characteristic calcium carbonate content of 55-70% and an organic matter content of 10-25% (Coxon, 1986). Dark (10 YR 3/1, 3/2, 3/3, 2/1, 2/2) or greyish brown (10 YR 5/2) soil matrix with abundant flecks of snail shell marl and/or marl deposition. Profile generally undifferentiated into horizons. Depths range from very shallow to deep.
Marl with peaty topsoil	AlluvMRLPT	Profile generally has two distinct horizons consisting of peaty topsoil with organic texture and dark colouration (10 YR 3/1, 3/2, 3/3, 2/1, 2/2) and a grey (10 YR 5/1, 6/1, 7/1 or 8/1) marl horizon with a clay, silty clay or silty clay loam texture. Distinct mottling is often present.
Marl alluvium	AlluvMRL	Generally grey (10 YR 5/1) or greyish brown (10 YR 5/2), very shallow or shallow, often stony soils. Abundant marl and/or shell marl evident. Semi-fibrous organic matter. Deeper lacustrine type soils
Mineral alluvium	AlluvMIN	Generally dark, very shallow, often stony soils with silty textures and semi-fibrous organic material. Marl and/or shell marl often common but not abundant.

Table 6.3 EPA/Teagasc soil types used in the absence of turlough soil descriptions

Soil Type	*Code*
Predominantly shallow soils derived from calcareous rock or gravels with/without peaty surface horizon.	BminSRPT
Lacustrine-type soils	Lac
Cutaway/cutover peat	Cut
Water	Water

6.2.2.2 Quantitative Soil Property Assessments

Six surface soil samples spanning the upper, middle and lower elevation zones were collected from 22 turloughs to a maximum depth of 20 cm. Vegetation maps (Goodwillie, 1992) and topography were used to delimit upper, middle and lower elevation zones. Samples were analysed for pH, organic matter content (OM), calcium carbonate content ($CaCO_3$), non-calcareous sand/silt/clay fraction (INORG), total nitrogen (TN), total phosphorus (TP). Estimations of pH were made on an approximately 1:2 (v:v) suspension of moist soil and double-distilled water (DDW) (Allen, 1989) using a Jenway 3030 calomel electrode. Prior to remaining analyses, samples were air-dried and passed through a 2mm sieve. OM was measured as a percentage weight loss following ignition at 550^oC (Allen, 1989). $CaCO_3$ was estimated as a percentage weight loss following loss on ignition by further ignition at 1000^oC (Dean, 1974). INORG was calculated as the initial sample weight less OM and $CaCO_3$ fractions. TN was measured according to Verado *et al.* (1990) using an ELEMENTAR analyser. TP was measured by nitric acid (69%) digestion (Kuo, 1996) using an MDS 2000 microwave digestor followed by ICP (inductively-coupled plasma) analysis. Reference soil material was included during the TP digestion procedure which indicated an 85% P recovery; TP results were subsequently increased by 15%.

6.2.2.3 Landuse Assessments

Turlough land parcels were mapped onto OSI 1:5000 base maps using GIS-software (ArcGIS 9.3) employing the same turlough boundary used to generate the soil type maps. Many walls and fences in turloughs are in poor repair and only land parcel boundaries which restrict livestock movement were mapped. GPS coordinates were used to map land parcel boundaries not evident on the OSI 1:5000 base maps. Each land parcel was described as either grazed or ungrazed. A ‘grazed’ land parcel is used by the landowner as part of an overall grazing regime, where cattle are moved on a rotational basis between different paddocks on the farm. An ‘ungrazed’ land parcel is not rotationally grazed but may be sporadically grazed by horses and/or wildlife. The majority of land parcels were grazed to some extent and a land parcel was designated as ungrazed following confirmation from a landowner or NPWS ranger. The proportion of grazed area was calculated for each turlough.

For a subset of land parcels, landowners were interviewed to obtain detailed information on livestock type and number, length of the grazing period and relevant land parcel location. There are no available records of turlough land-parcel ownership and consequently the collation of grazing intensity data was driven by our ability to contact landowners on an *ad* *hoc* basis. When calculating livestock units per hectare (LU/ha) the total area that the animals had access to was used even though some land parcels are only partially flooded. Grazing Intensity (LU/ha grazing days year) was calculated as the product of LU/ha (Department of Agriculture Fisheries and Food, 2007) and the number of days the land parcel was grazed per year. Grazing intensity information was generated for 79 land parcels.

6.2.2.4 Hydrological and Hydrochemical Variables

Hydrochemical information for each site was provided by Helder Cunha Pereira. Monthly floodwater samples were collected from the onset of flooding (October 2006) until they were dry or had very low water levels (April-June 2007). Hydrochemical variables included mean seasonal pH, colour, alkalinity, total P, molybdate reactive P, total N and Nitrate-N. Further details on hydrochemical methods used can be found in Cunha Pereira *et al*. (2010) and *Chapter 4: Water Chemistry and Algal Biomass*.

Hydrological descriptors for each site were provided by Owen Naughton. Hydrological variables included maximum depth of flooding (m), hydroperiod (days) and recession duration (days). Hydroperiod constitutes the sum of the durations of all flood events between October 2006 and June 2007. In this case, recession duration represents a notional minimum time that it would take for the turlough to drain from full (i.e. maximum drainage capacity/maximum recorded volume). Flood duration and flood frequency was also determined for each soil sample collected for quantitative analyses. Further details on hydrological methods used can be found in *Chapter 3: Hydrology*.

6.2.2.5 Data Analyses

Proportions of area occupied by different soil types within each turlough were generated from the soil type maps using ArcGIS 9.3. Box plots were used to examine the variation of soil pH, OM, $CaCO_3$, INORG, TN and TP within and among turloughs. We used multivariate analysis of variance (MANOVA) to compare soil TN and TP among turloughs. Data were log transformed prior to MANOVA to achieve normality and constancy of error terms. We used univariate ANOVA to further examine soil TN and soil TP variation among turloughs. Values were only considered significant after Bonferroni correction for multiple comparisons. Homogeneity of variance was checked with the Levene statistic before choosing post hoc tests. Soil TP comparisons used the Tukey post hoc test as homogeneity of variance was verified. Soil TN comparisons used the Games Howell post hoc test in the absence of homogeneity of variance among groups. In this case the Welch and Brown-Forsythe tests were used to verify significant differences among turloughs. For both soil TN and soil TP the variance percentage attributed to each component was estimated by dividing the component variance by total variance.

Site-specific data on subsoils (EPA subsoil type map), grazing, hydroperiod, recession duration and floodwater pH and alkalinity were collated to elucidate the drivers of soil type and soil property variation among turloughs. We also used non-metric multidimensional scaling (NMS) ordination to detect environmental gradients underlying variation of mean pH, OM, INORG and $CaCO_3$ across turloughs. We also used NMS to investigate associations between axis scores and environmental variables. Environmental variables included karstic rock (%), limestone till (%), water (%), grazed area (%) hydroperiod (days), max floodwater depth (m), recession duration (days), mean floodwater pH, alkalinity (mg l^{-1} $CaCO_3$), colour (mg l^{-1} PtCo units), MRP (µg l^{-1}), TP (µg l^{-1}), Chl*a* (µg l^{-1}), TN (mg l^{-1}) and Nitrate-N (mg l^{-1}) .

NMS avoids assumptions of linearity among variables and has the capacity to deal with a variety of variables with a minimum of distortions (McCune & Grace, 2002). Soil properties were standardised using the Z transformation prior to ordination to remove arbitrariness in the units of measurement (Odeh *et al*., 1991). The NMS ordination was performed using the Euclidean distance measure and autopilot in the PC-ORD package version 5 (McCune & Mefford, 1999). Joint plots and correlation coefficients were used to examine the relationships between the environmental variables and the ordination axes. We specified a combination of Pearson $r^2 > 0.1$ and Kendall`s *tau* > 0.25 to identify important associations with ordination axes. Associations between grazing intensities and mean soil TN mg $kg^{-1}$ and soil TP mg $kg^{-1}$ were examined across land parcels for which three soil sub-samples were available using Spearman`s Rank correlation and scatterplots.

6.2.3 Results

6.2.3.1 Associations Between Dominant Soil Types, Subsoil Types, Grazing Regime and Hydrology Across 22 Turloughs

Soil type maps with elevation contours for each turlough are presented in Appendix 6.1. A summary of the proportions of area occupied by different soil types within each turlough is presented in Table 6.4. For descriptive purposes, turloughs are grouped in Table 6.4 according to dominance of mineral, organic and marl soil types. Subsoil type, grazing regime and hydrological information for each turlough is presented in Table 6.5.

Mineral soil types frequently occur in association with alluvial soils but rarely in conjunction with organic soil types. Turloughs with high proportions of mineral soil types include Blackrock, Carrowreagh, Garryland, Rathnalluleagh, Caherglassan, Lough Coy, Turloughmore and Coolcam. Blackrock and Rathnalulleagh have high proportions of well drained mineral soils on the upper elevations whereas the majority of mineral soils across the remaining turloughs have impeded drainage. Caherglassan and L. Coy have high proportions of mineral alluvium on the basin floor. Turloughmore has an unusual combination of shallow poorly drained mineral soils and well drained organic soils, which are associated with limestone till and karstic rock respectively. A high proportion of alluvial mineral soil distinguishes Coolcam from the rest of this group. Turloughs characterised by mineral soil types generally have high proportions of till.

The tills in this case are generally limestone tills with the exception of Rathnalluleagh which has a relatively high proportion of sandstone till. The majority of the turloughs in this mineral group are completely grazed and generally have hydroperiods and recession durations less than 200 days and 50 days respectively. Coolcam is also distinguished from the group by a low proportion of grazed area, a high proportion of standing water and a relatively longer hydroperiod and recession duration, as noted in *Chapter 3: Hydrology*. Exposed karstified limestone bedrock (KaRck) and carboniferous limestone till (TLs) are the dominant subsoil types across sites. Coolcam and Croaghill are the only two turloughs that lack either of these subsoil type, both of which also exclusively contain sand and gravel subsoil types. Surprisingly, high proportions of the subsoil type 'cutover peat' are mapped within three turloughs dominated by mineral soil types. This is likely to be a subsoil type mapping error in the Teagasc/EPA database as no evidence of cutover peat was recorded in Blackrock, Carrowreagh or Rathnalluleagh.

Fen Peats are the most extensively occurring organic soil type and generally occur in association with very shallow, well drained or poorly drained organic soils. Ardkill, Ballindereen, Caranavoodaun, Croaghill, Kilglassan, Lisduff and Skealoghan and L. Aleenaun are dominated by organic soil types. Ardkill and Ballindereen have high proportions of very shallow poorly drained soils whereas Caranavoodaun, Croaghill, Kilglassan, Lisduff and Skealoghan are dominated by Fen Peats. L. Aleenaun is the only turlough in this group with a substantial proportion of marl with peaty topsoil. Turloughs in this group have a diverse mix of subsoil types, however they generally have lower proportions of limestone till and higher proportions of marl and lacustrine subsoils than turloughs dominated by mineral soil types. The majority of these turloughs also have substantial proportions of ungrazed area and have relatively longer hydroperiods and recession durations than turloughs in the mineral group. L. Aleenaun is distinguished from the group by a relatively short hydroperiod and recession duration.

Turloughs have a diverse range of alluvial soil types including alluvial marls, marls with peaty topsoil, peat-marls and mineral, non-calcareous alluviums. Brierfield, Tullynafrankagh, Knockaunroe, L. Gealain, Roo and Termon are dominated by a diverse range of marl/alluvial type soils. High proportions of marl with peaty topsoil distinguish Brierfield from the rest of the group. Knockaunroe and Tullynafrankagh are the only turloughs with significant proportions of peat-marl. L. Gealain, Roo and Termon are dominated by alluvial marls.

Low proportions of limestone till are associated with this group of sites. Over 50% of the areas of Termon, Tullynafrankagh and Lough Gealain have permanent water according to the subsoil type map. Brierfield and Roo are dominated by Fen Peat and Lacustrine deposits respectively. Marly turloughs are generally under relatively leas grazing pressure than mineral and organic turloughs. L. Gealain is the only turlough that is completely ungrazed and Termon, Tullynafrankagh and Knockaunroe have less that 20% grazed area. Hydroperiods and recession durations are relatively longer than those associated with the group of 'mineral' turloughs, however the ranges are similar to that associated with the group of 'organic' turloughs. Floodwater pH and alkalinity are not distinctly higher within the 'marl' group relative to the 'organic' group.

Table 6.4 Proportions (%) of turlough area occupied by different soil types. Explanations of soil type codes are presented in Tables 6.5 and 6.6

	Turlough Soil Types														***EPA/Teagasc Soil Types***			
Site	*BminVSW*	*BminSW*	*BminDW*	*BminVSP*	*BminSP*	*BminDP*	*BorgVSW*	*BorgSW*	*BorgVSP*	*FenPt*	*PtMRL*	*AlluvMRLPT*	*AlluvMRL*	*AlluvMIN*	*BminSRPT*	*Lac*	*Cut*	*Water*
BLA	50.3	15.6			33.2									0.8				
CARR				47.0	53.0													
GAR				50.6	44.3	5.1												
RAT	2.0	35.6			62.4													
CAH				50.5	21.9									27.6				
COY	12.2			46.1										41.7				
TUR					85.3		11.0									3.8		
COO					1.9								0.7	94.8	0.6	2.0		
ARD									70.8	29.2								
BAL			1.7				25.6		66.1	6.6								
CARA							33.4			64.1		2.5						
CRO		1.4							7.6	90.8							0.2	0.2
KIL							34.4			65.6								
LIS									14.3	85.7								
SKE							35.1			64.9								
ALE							35.5		47.0			17.5						
BRI		0.4				4.6						95.0						
TUL		8.1								36.9	55.1							
KNO									9.0		74.6							16.4
GEA									48.7				50.5					0.8
ROO			0.6				23.8						75.6					
TER		0.1							7.0				92.9					

Table 6.5 Proportions of turlough area occupied by different subsoil types and rotationally grazed. KaRck=Karstified limestone bedrock at surface; TLs=Limestone till (Carboniferous); TDSs=Sandstone till (Devonian); FenPt=Fen peat; Cut=Cutover peat; BasEsk=Esker sands and gravels; GLs=Limestone sands and gravels (Carboniferous); A=Alluvium undifferentiated; Mrl=Marl(Shell); L=Lake sediments undifferentiated; Water = Water.

Turlough	***Subsoils (% area)***											*Grazing (% area)*	*Hydroperiod*	*Recession duration*	*Floodwater pH*	*Floodwater alkalinity*
	KaRck	*TLs*	*TDSs*	*FenPt*	*Cut*	*BasEsk*	*GLs*	*A*	*Mrl*	*L*	*Water*					
BLA	15.6	50.3			33.2			0.8				100	169	40.1	7.9	166.9
CARR	0.8	46.2			53.0							100	186	41.6	8.2	218.8
GAR	26.9	50.6								17.3	5.1	100	211	54.4	7.7	122.1
RAT	2.0		35.6		62.4							100	175	42.4	8.1	236.4
CAH	25.3	50.5									27.5	100	200	49.5	7.9	112.4
COY	12.2	38.9								7.2	41.7	100	187	32.0	7.9	142.7
TUR	11.0	85.3								3.8		100	135	12.4	8.1	167.5
COO						0.6	1.9		0.7	2.0	94.8	45	346	140.9	8.2	214.0
ARD	17.7	23.2							29.2		29.8	60	293	100.6	8.1	220.2
BAL	66.1	1.7								25.6	6.6	84	211	78.3	8.2	183.6
CARA	33.4	2.5								19.9	41.4	100	205	80.7	8.2	217.1
CRO			7.6		0.2		1.4			44.6	46.2	76	348	71.8	8.2	220.2
KIL		34.4		4.9					60.7			100	223	50.7	8.2	216.2
LIS		14.3		85.7								53	234	67.5	8.1	227.8
SKE	13.4	35.1			43.6						7.9	87	213	64.1	8.1	197.8
ALE	35.5	47.0		17.5								100	158	11.0	8.0	160.2
BRI	0.4	4.6			95.0							54	267	99.4	8.1	210.2
TUL	8.1	24.4								12.4	55.1	19	246	N/A	7.9	233.8
KNO	30.1	9.0		44.5							16.4	1	213	53.8	8.1	138.5
GEA	48.7									0.8	50.5	0	212	69.1	8.2	134.9
ROO	23.8	0.6								61.1		100	213	57.3	8.3	141.0
TER	0.1	5.8									92.9	12	304	142.5	8.1	225.6

6.2.3.2 Associations Between Mean Soil pH, OM, INORG and $CaCO_3$ and Environmental Variables Across 22 Turloughs

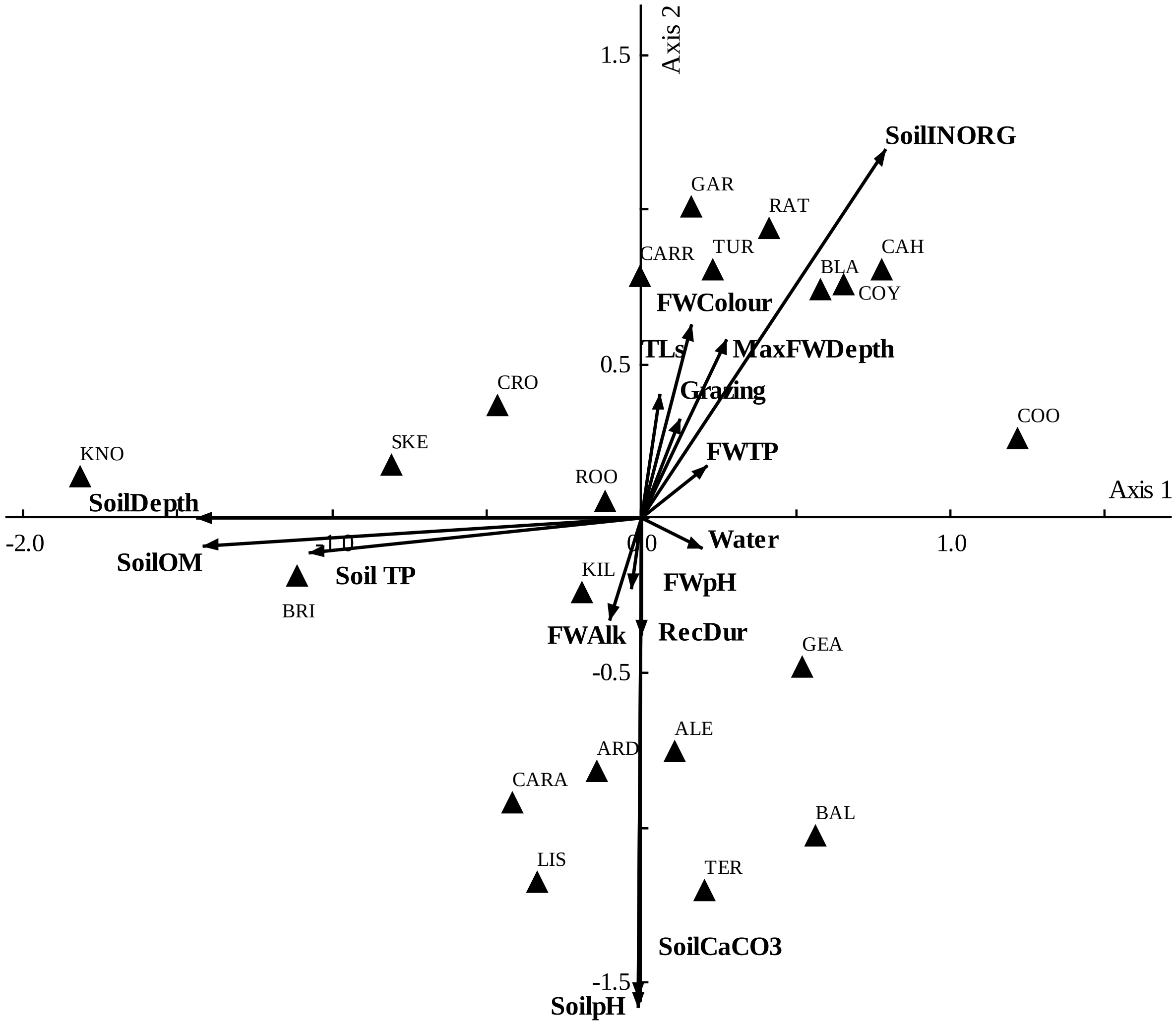


Figure 6.2 NMS ordination of 22 turloughs in variable space with soil properties and environmental variables overlaid

The NMS ordination of mean soil pH, OM, INORG and $CaCO_3$ lead to a two dimensional solution with an acceptable final stress (5.3%) and low instability after 250 iterations were run. The ordination extracted a high proportion (97.3%) of total variation in the dataset, with 35.7% loaded of Axis 1 and 61.6% loaded on Axis 2. The NMS therefore revealed two major gradients of variation and are presented in Figure 6.2. Associations between soil properties, environmental variables and NMS ordination scores are presented in Table 6.6. Turloughs with high sand/silt/clay proportions form a relatively distinct cluster towards the top of Axis 2 which represents an INORG/$CaCO_3$ gradient (Figure 6.2). This cluster includes the same turloughs identified as having predominantly mineral soil types, namely Blackrock, L. Coy, Garryland, Caherglassan, Turloughmore, Rathnalulleagh and Carrowreagh. Caranavoodaun, Ardkill, L. Aleenaun, L. Gealain, Lisduff, Termon and Ballindereen form a relatively distinct cluster at the opposite end of Axis 2. The mean soil pH of these turloughs ranges between 7.6 and 8.3 and the majority have mean $CaCO_3$ contents between 20 and 42.5%. Axis 2 has a positive correlation with TLs, grazing, floodwater colour, max floodwater depth and a negative correlation with floodwater alkalinity, floodwater pH and recession duration. The remaining sites are distributed as a continuum along Axis 1, which represents an OM/INORG/soil depth gradient. The extremes of the continuum are represented by Coolcam and Knockaunroe. Coolcam has shallow, mineral, alluvial soils whereas Knockaunroe has deep, peaty soils. Coolcam has an alkaline soil pH, which distinguishes this turlough from the group of 'mineral' turloughs. Axis 1 has a positive correlation with max floodwater depth and floodwater TP and negative correlation with mean soil TP.

Table 6.6 Pearson's *r* and Kendall`s *tau* correlation coefficients between soil properties, environmental variables and the NMS ordination axes (Fig. 2). Environmental variables with r^2 values > 0.1 and *tau* values > 0.2 are highlighted. Strongest correlations between soil properties and ordination axes are also highlighted (n = 104).

Variable	*Axis 1*		*Axis 2*	
	r^2	*tau*	r^2	*tau*
Mean soil pH	0.005	-0.087	**0.884**	**-0.889**
Mean soil $CaCO_3$ (%)	0.006	-0.164	**0.903**	**-0.780**
Mean soil INORG (%)	**0.45**	0.602	**0.680**	**0.554**
Mean soil OM (%)	**0.809**	**-0.802**	0.052	**-0.203**
Mean soil depth (cm)	**0.821**	**-0.731**	0.001	-0.019
Mean soil TN mg kg^{-1}	0.064	-0.135	0.070	**0.202**
Mean soil TP mg kg^{-1}	**0.612**	**-0.725**	0.064	-0.155
Karstic Rock (%)	0.010	0.116	0.082	-0.096
Limestone Till (%)	0.033	0.123	**0.227**	**0.280**
Water (%)	**0.110**	0.142	0.055	-0.142
Grazing (%)	0.069	0.195	**0.179**	**0.396**
Hydroperiod (days)	0.006	-0.222	0.094	-0.301
Turlough max depth (m)	**0.155**	**0.326**	0.329	**0.365**
Recession duration (days)	0.001	-0.154	0.214	**-0.376**
Mean floodwater pH	0.057	-0.15	0.186	**-0.218**
Mean floodwater alkalinity (mg l^{-1} $CaCO_3$)	0.020	-0.155	0.128	**-0.232**
Mean floodwater colour (mg l^{-1} PtCo units)	0.091	0.106	0.355	**0.386**
Mean floodwater MRP (µg l^{-1})	0.060	0.197	0.029	**0.276**
Mean floodwater TP (µg l^{-1})	**0.119**	**0.277**	0.096	**0.346**
Mean floodwater Chl*a* (µg l^{-1})	0.062	0.050	0.076	0.129
Mean floodwater TN (mg l^{-1})	0.029	0.112	0.021	-0.063
Mean floodwater Nitrate-N (mg l^{-1})	0.013	0.029	0.063	-0.067

6.2.3.3 Soil Property Variation Among 22 Turloughs

Figure 6.3 (a-f) presents boxplots of soil properties for 22 turloughs which are ordered along the x axis according to groupings presented in Table 6.4. pH, OM, INORG and $CaCO_3$ varied significantly among turloughs ($H(21)$ = 87.08, p < 0.001, $H(21)$ = 68.74, p < 0.001, $H(21)$ = 80.76, p < 0.001, $H(21)$ = 86.53, p < 0.001 respectively). Turloughs with high proportions of mineral soil types were characterized by a combination of high INORG contents, low $CaCO_3$ contents and generally an acidic-neutral soil pH range (Figure 6.3 a-d). There was no clear distinction between 'organic' and 'marl' turlough groupings in terms of pH, OM, INORG and $CaCO_3$. The median organic matter contents of Ardkill, Caranavoodaun, Croaghill, Kilglassan and Skealoghan are indicative of peaty substrates. The soils of Ballindereen, Lisduff and L. Aleenaun are less organic with relatively higher calcium carbonate contents (Figure 6.3c).

Soils within this ‘organic’ group of turloughs are generally alkaline with the exception of Croaghill, Kilglassan and Skealoghan which contain both moderately acidic and moderately alkaline soils (Figure 6.3a). Turloughs within both the ‘organic’ and ‘marl’ groupings exhibited very broad soil $CaCO_3$ ranges with the exception of Croaghill and Skealoghan. Mean $CaCO_3$ was lower than expected in L. Gealain and Roo as persistent flooding at lower elevations prevented sample collection within the extensive areas of alluvial marl. Using Pillai’s trace, there was a significant difference between soil TN and soil TP among turloughs, V=0.1.14, F (42, 220) = 6.9, p < 0.001. Subsequent separate univariate ANOVAs revealed that both soil TN and soil TP varied significantly among turloughs, F (21) = 5.64, p < 0.001 and F (21) = 6.32, p < 0.001 respectively. The majority of soil TN and TP variation was explained by turlough (Table 6.7). Median TN ranged between 4650 and 25850 mg kg^{-1} across turloughs (Fig. 6.3e). Coolcam has significantly lower soil TN than Ardkill, Kilglassan, Roo and Caherglassan. Caherglassan also has significantly lower soil TN that Kilglassan, Roo and Ardkill. Turloughs with high proportions of mineral soil types generally had relatively lower median TN than more organic turloughs, which were characterized by high degrees of spatial variation in TN. Median TP ranged between 241 and 1498 mg kg^{-1} across turloughs (Fig. 6.3f).

Coolcam had significantly lower TP than most turloughs. Lisduff had significantly lower soil TP than Kilglassan, L. Aleenaun and L. Coy. L. Aleenaun had significantly higher soil TP than L. Gealain, Termon and Turloughmore. There was no clear distinction between mineral and organic turloughs regarding TP concentrations and TP is highly spatially variable within the majority of sites. The majority of turloughs with low TP concentrations (< 500 mg kg^{-1}) have extensive areas of alluvial soils.

Table 6.7 Analysis of variance was used to determine the proportion (%) of total soil property variability explained by Turlough and Error (component variance/total variance).

Variable	*Turlough*	*Error*
TN (mg kg^{-1})	52	48
TP (mg kg^{-1})	55	45

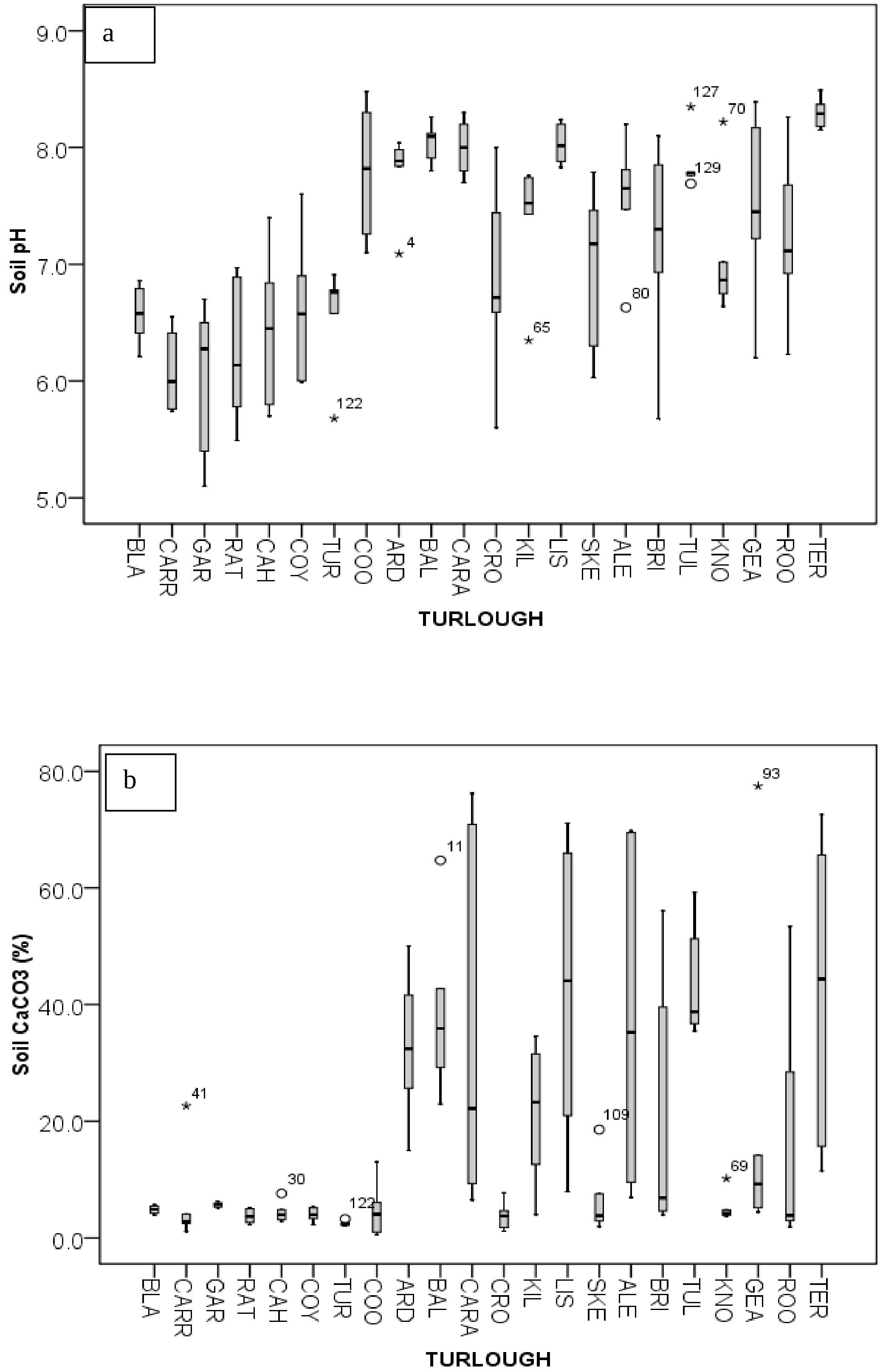
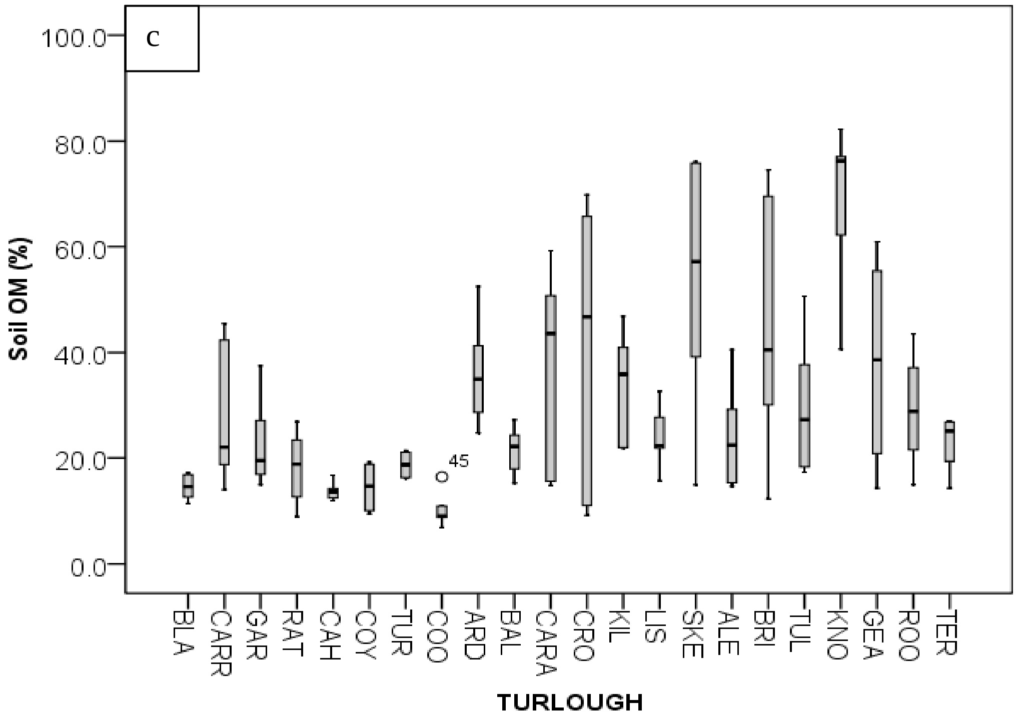


Figure 6.3 Variation of a) soil pH and b) soil $CaCO_3$ among 22 turlough sites



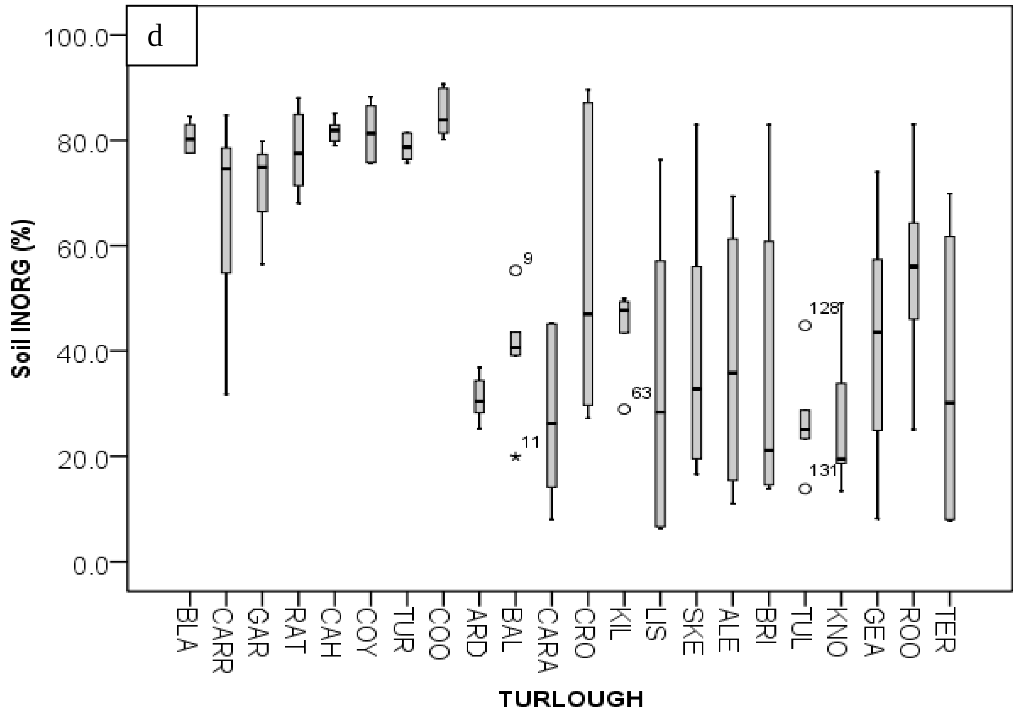


Figure 6.3 Variation of c) soil OM and d) soil INORG among 22 turlough sites.

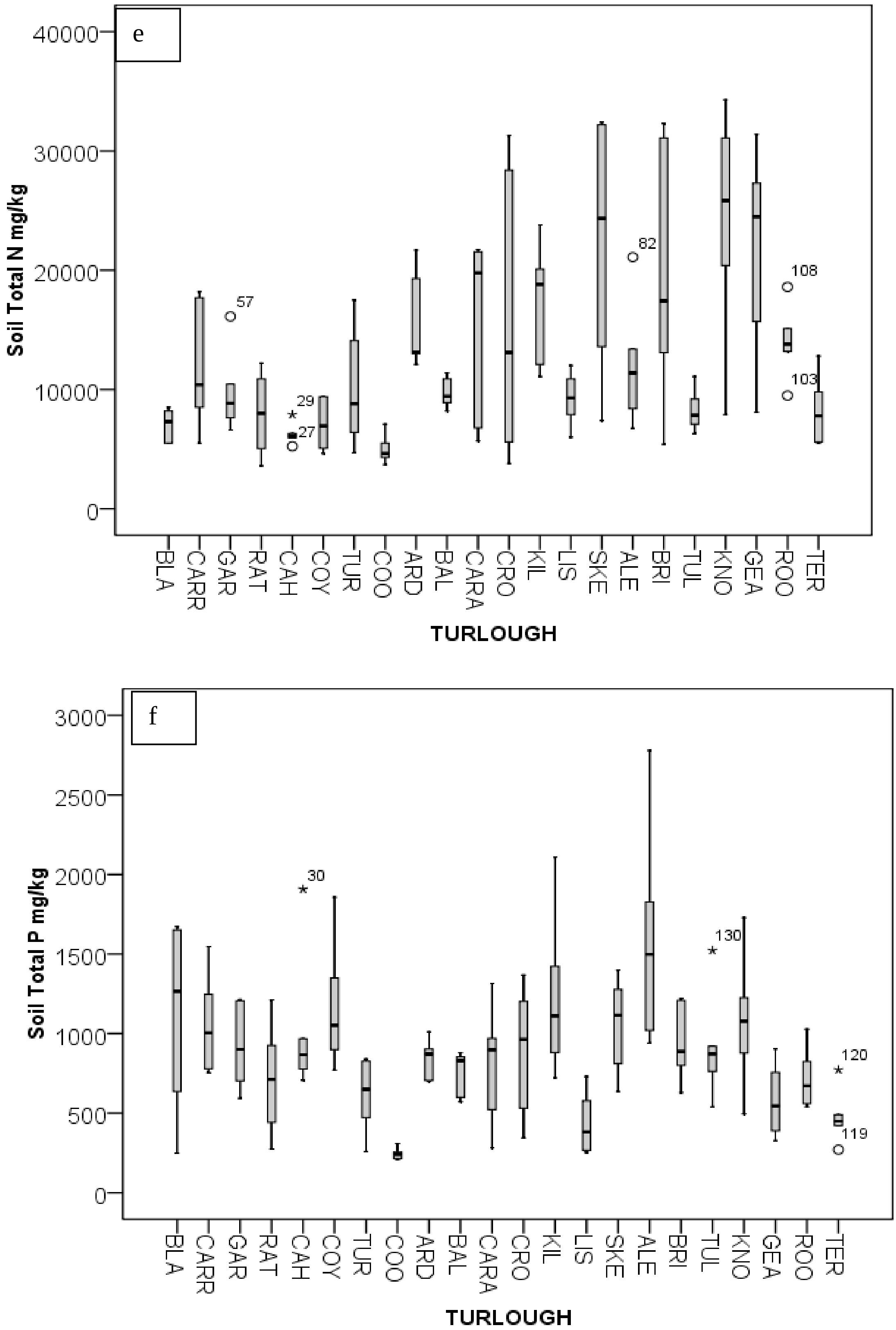
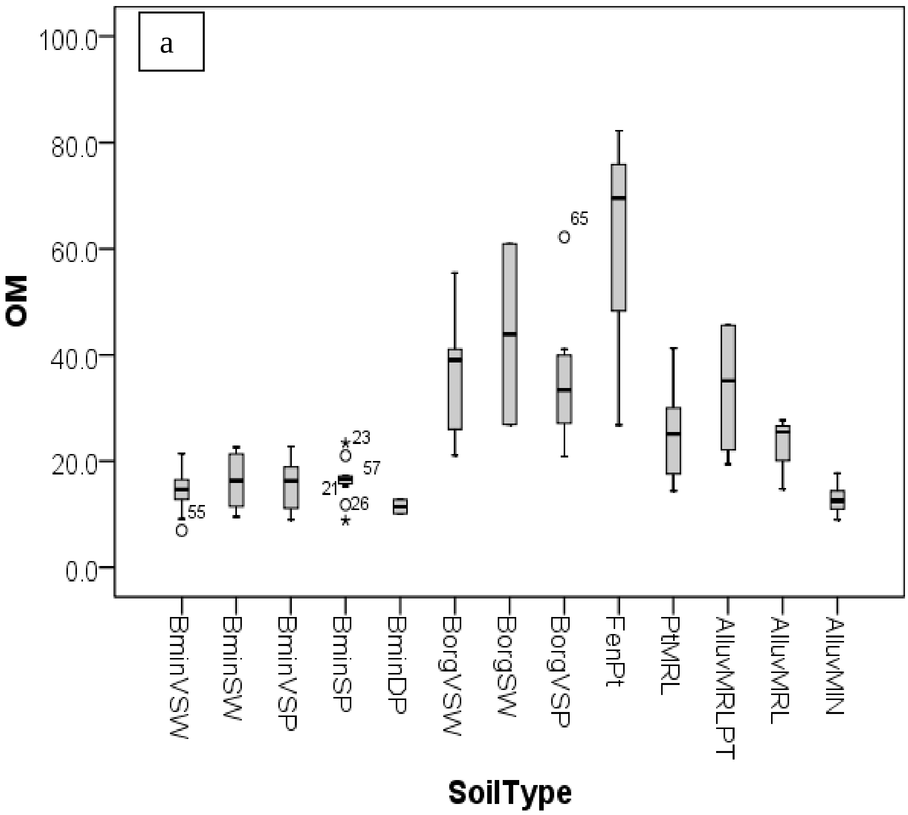


Fig. 6.3 Variation of e) soil TN and f) soil TP among 22 turlough sites.

6.2.3.4 Soil Property, Hydrological and Grazing Characteristics of Turlough Soil Types

Samples collected for soil quantitative analyses, as outlined in Section 6.1.2, were grouped into soil types for the purposes of comparing soil nutrient properties, hydrological variables and grazing regimes among soil types. Figure 6.4 (a-h) presents boxplots of soil properties, flood duration and flood frequency for 14 soil types. BminDPPT and BminSPPT were not sampled. Soil type maps were intersected with land parcel maps to provide a summary of grazing activity associated with each soil type (Table 6.8). BminVSW, BminSW, BminVSP, BminSP, BminDP, and AlluvMIN are characterised by elevated proportions of sand/silt/clay and low $CaCO_3$ contents (Fig 6.4b,c). BorgVSW, BorgSW, BorgVSP and FenPt are dominated by the OM fraction (Fig 6.4a). Alluvial marl and peat-marl are characterised by high $CaCO_3$ contents (Fig 6.4c). Alluvial marl with peaty topsoil had a broad range of $CaCO_3$ contents owing to variation in the depth of the peaty topsoil. The majority of soil types have a wide pH range and consequently this soil property is not a useful indicator of soil type (Fig 6.4 d). BorgVSW, BorgSW, BorgVSP and FenPt all have a very broad range of TN concentrations (Fig 6.4e). The mineral soil types can also however have high TN concentrations. These concentrations are likely the result of fertiliser addition rather than organic matter accumulation. Most soil types also have broad ranges of soil TP (Fig 6.4f).

The majority of turlough soil types were associated with broad ranges of flood duration and flood frequency (Fig 6.4g,h). Contrary to expectation, mineral soil types were not associated with relatively shorter flood durations than organic soil types. BorgSW, AlluvMRL and AlluvMIN have a narrow flood duration range relative to other soil types and are characterised by long flood durations. Most soil types are associated with a very broad range of flood frequencies with the exception of BorgSW and BminDP. Very high proportions (89-100%) of BminVSW, BminSW, BminVSP, BminSP, BminDP and BorgVSW are grazed (Table 6.8). Significant proportions (26-45.8%) of BorgVSP, FenPt and AlluvMRLPT are ungrazed, whilst the majority of the areas of AlluvMRL, AlluvMIN and PtMRL are ungrazed.



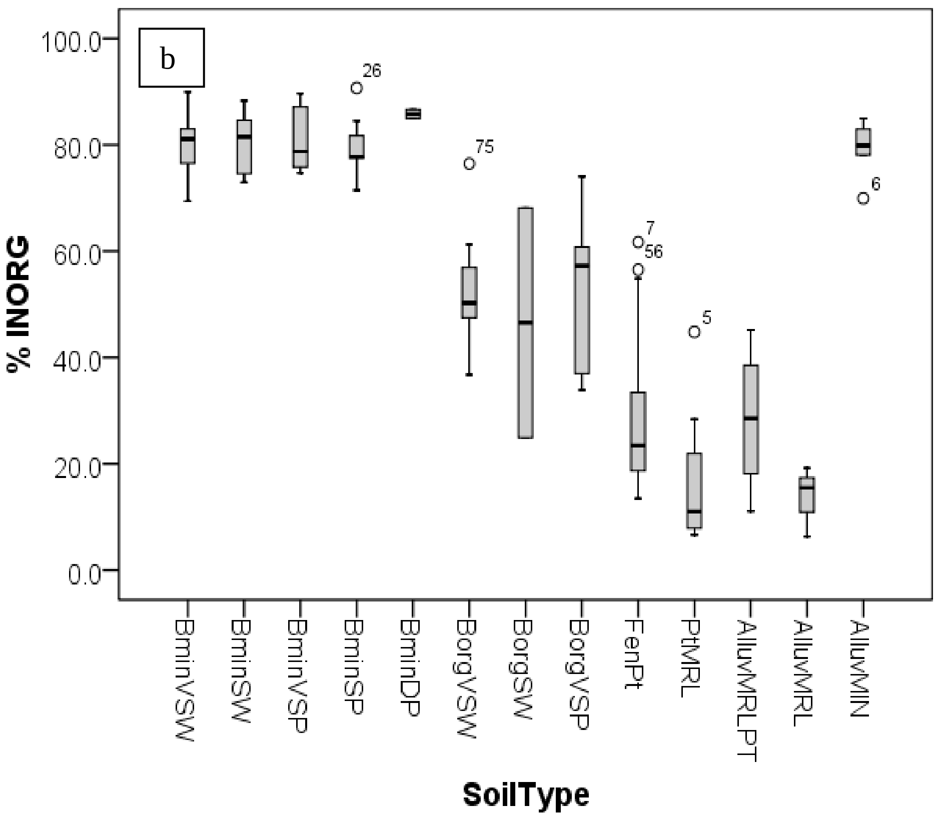


Figure 6.4 Variation of a) soil OM and b) soil INORG among turlough soil types.

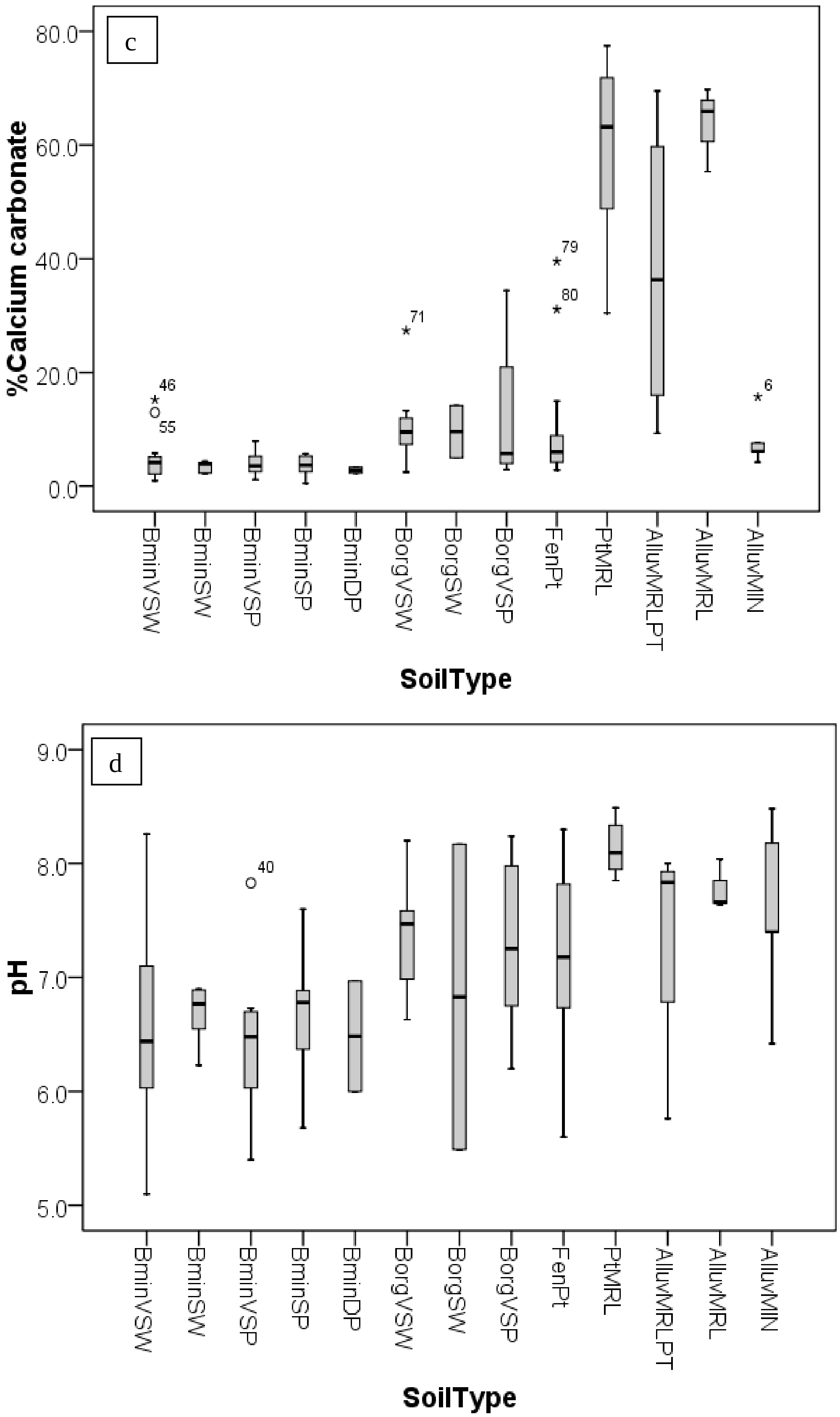
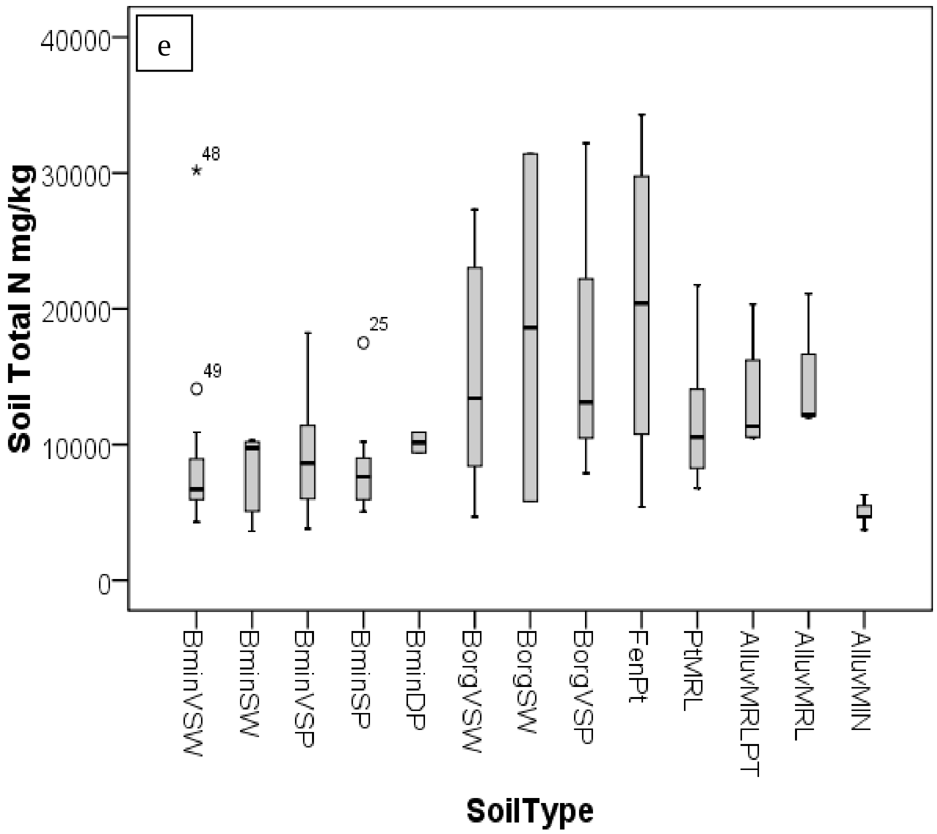


Figure 6.4 Variation of c) soil $CaCO_3$ and d) soil pH among turlough soil types.



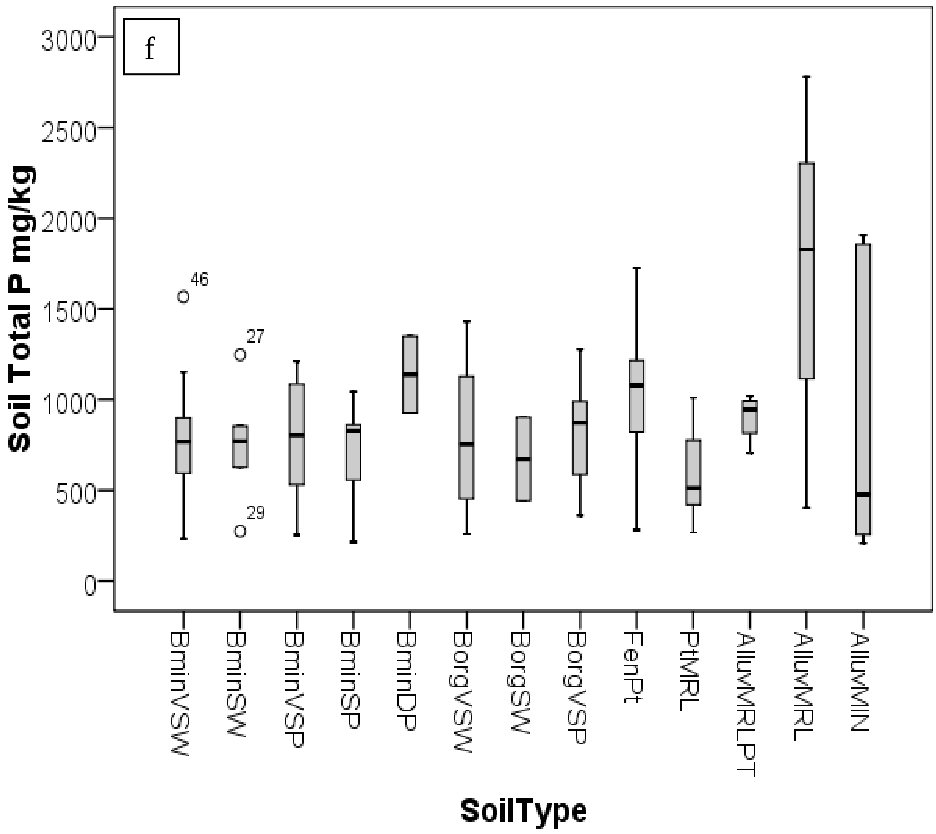


Figure 6.4 Variation of e) soil TN and f) soil TP among turlough soil types.

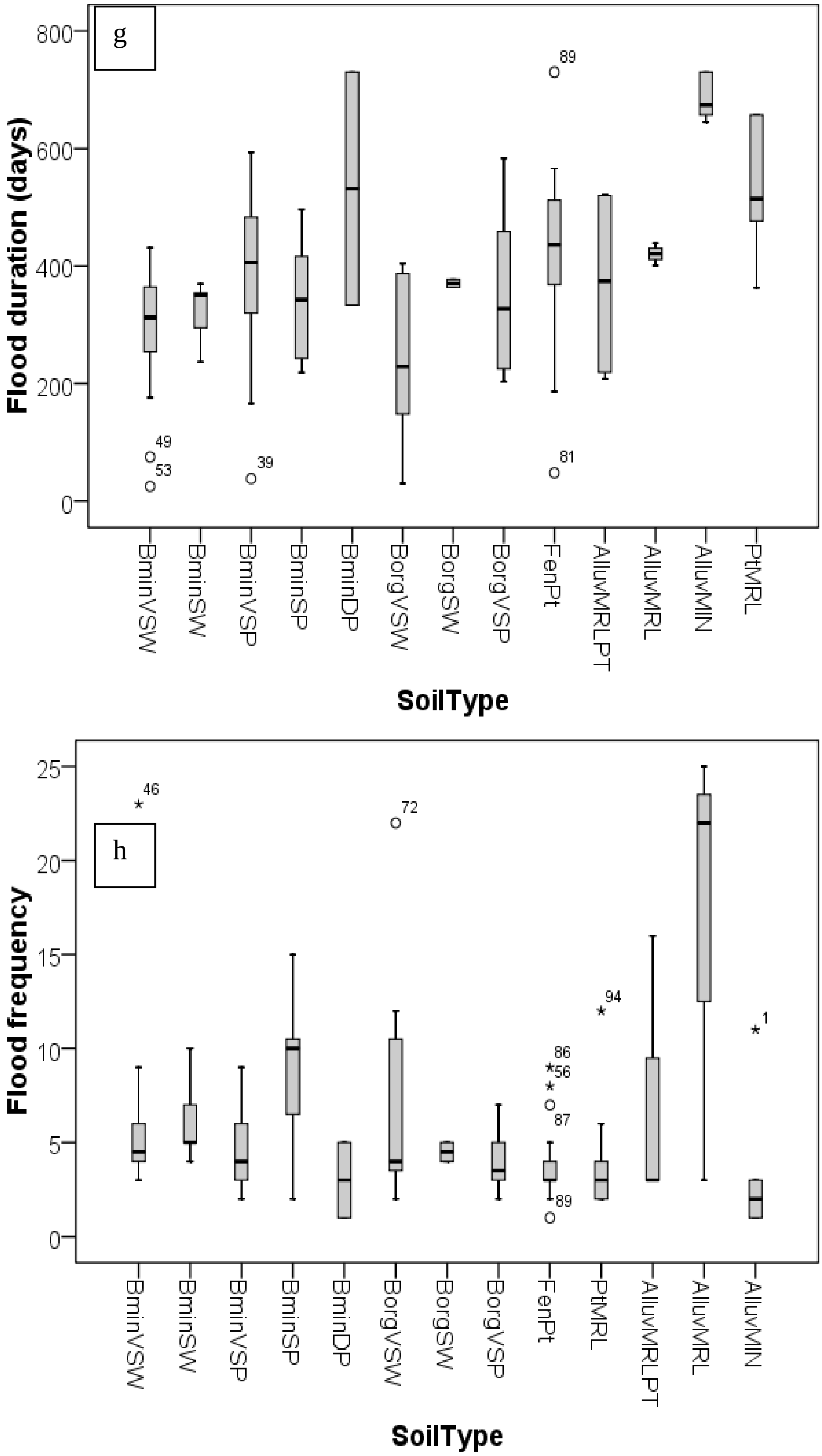


Figure 6.4 Variation of g) flood duration and h) flood frequency among turlough soil types.

Table 6.8 Proportions of grazed and ungrazed area for each soil type.

Soil Type	*% Area Grazed*	*% Area Ungrazed*
BminVSW	100.0	0.0
BminSW	98.5	1.5
BminVSP	99.7	0.3
BminSP	99.5	0.5
BminDP	89.7	10.3
BorgVSW	99.5	0.5
BorgVSP	57.1	42.9
FenPt	73.5	26.5
Pt-MRL	0.2	99.8
AlluvMRLPT	54.2	45.8
AlluvMRL	22.6	77.4
AlluvMIN	43.3	56.7

6.2.3.5 Relationships Between Grazing Intensity and Soil TN and TP

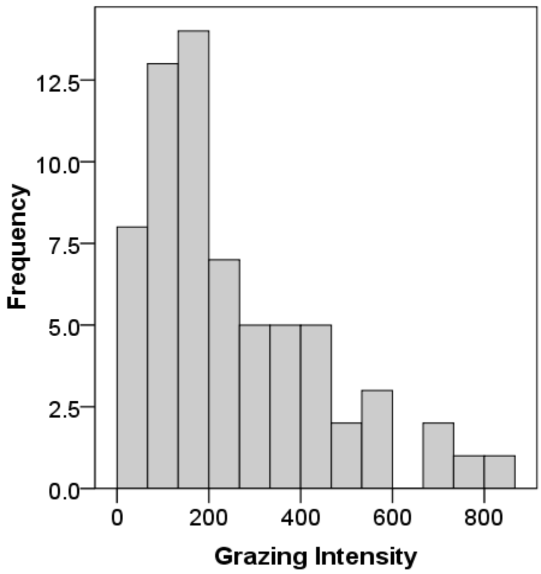


Figure 6.5 A histogram of grazing intensities across turloughs (*N* = 66).

Land parcel maps and associated grazing intensities (LU/ha grazing days year) are presented in Appendix 6.1. A frequency distribution of grazing intensities is presented in Figure 6.5. An estimate of grazing intensity was determined for 79 turlough land parcels. Grazing intensities for 13 land parcels were in excess of 900 LU/Ha grazing days. Grazing intensities of this magnitude would be considered suitable on an improved agricultural grassland field (with high fertiliser application) on an intensive dairy farm, and are unrealistic for turloughs without supplementary feeding (James Moran, pers. comm.). Boschi and Baur (2007) state that low to moderate grazing intensities range between 10-434 LU/ha grazing days. In order to contextualise the grazing intensities, this range was doubled and divide into Low (10-283 LU/ha grazing days), Moderate (284-566 LU/ha grazing days) and High (567-850 LU/ha grazing days) categories. This range supports the assertion that grazing intensities in excess of 900 LU/Ha grazing days are erroneous and consequently thirteen land parcels were excluded from the dataset. The histogram is skewed to the right and low level grazing intensities occurred most frequently across turloughs (Figure 6.5). The five land parcels with high level grazing intensities were within Turloughmore, L. Coy, Caherglassan, Brierfield and Ballindereen.

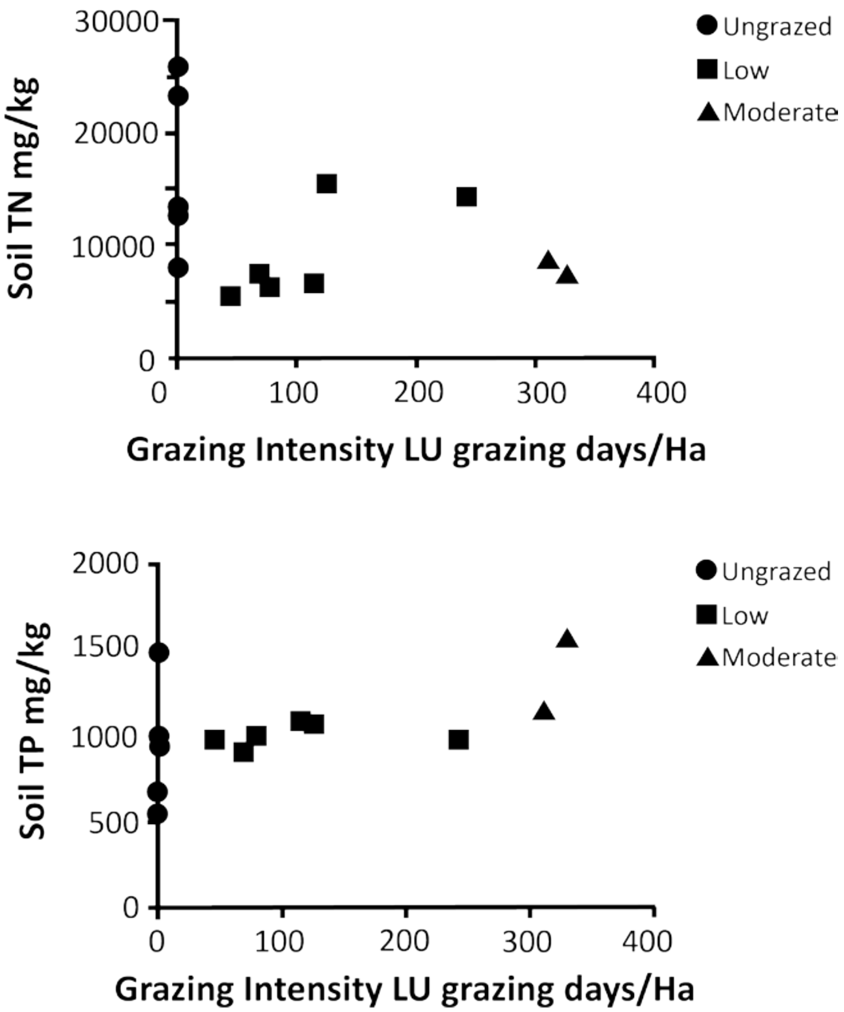


Figure 6.6 Associations between grazing intensity (LU/Ha grazing days) and a) mean soil TN mg kg^{-1} and b) mean soil TP mg kg^{-1}.

Associations between grazing intensities and mean soil TN mg kg^{-1} and soil TP mg kg^{-1} were examined across land parcels for which three soil sub-samples were available (Fig. 6.6 a and b). Ungrazed land parcels have broad ranges of both soil TN and TP. There was no clear association between soil TN or TP and grazing intensity (Fig. 6.6 a and b).

6.2.4 Discussion

Results from the present study support the assertion that turloughs contain a broad range of soil types. Mineral and organic soil types generally do not occur in conjunction with each other, whereas alluvial soils can occur in association with either mineral or organic soils. Blackrock, Garryland, Caherglassan, L. Coy, Turloughmore, Carrowreagh and Rathnalluleagh support non-alluvial mineral soil types, are characterised by high INORG contents and low OM and $CaCO_3$ contents and form a relatively distinct grouping. This group of turloughs is associated with both high proportions of till subsoil types and relatively short hydroperiods and recession durations. This cluster of turloughs is also positively associated with floodwater colour and floodwater depth. Coolcam is the only turlough which has a vast expanse of mineral alluvial soil. Anecdotal evidence from local landowners notes that the hydrological regime of Coolcam changed about ten years ago and that extensive areas of this turlough now remain flooded all year. The fact that 94.8% of the area is covered by water rather than a specific subsoil type highlights the very wet nature of this turlough.

In a broader study of 60 turloughs, Coxon (1987) suggested a relationship between deposits and duration of flooding. Diamicton, sand/silt and silt/clay deposits appeared to be associated with relatively shorter flooding durations than both peat and marl. The present study presents quantitative evidence supporting this hypothesis. Debate persists as to whether different deposits are the result, rather than the cause, of the different durations of flooding. It is suggested that the occurrence of non-alluvial mineral subsoil types is co-dependent on till subsoils and relatively shorter flood durations. Blackrock, Garryland, Caherglassan and L. Coy are a chain of turloughs in the Gort lowlands which have been the subject of much research. They are associated with deep karst groundwater flow and it has been suggested that collectively they are a distinct type of turlough. Turloughmore, Carrowreagh and Rathnalluleagh present a similar combination of soil types and there may be some merit in typing turloughs based on soil type if the biological communities of ‘mineral’ turloughs are also distinct. The soil type proportions and ordination of sites based on soil properties present some conflicting information in terms of the distinction between ‘organic’ and ‘marly’ turloughs. Turloughs with high proportions of organic and marl soil types respectively did not form distinct clusters on the ordination diagram. Many sites identified as representative of the $CaCO_3$ end of the INORG/$CaCO_3$ gradient were dominated by organic soil types. Kilglassan, Skealoghan and Croaghill are identified by both the ordination and soil type maps as having organic/peaty soils. Flooding conditions at Roo and Knockaunroe during 2007 and 2008 prevented soil sampling within the lower turlough areas and therefore the mean soil properties do not reflect the general marly nature of these turloughs. Ardkill has a high proportion of shell marl subsoil and also L. Aleenaun has a significant area of alluvial marl with peaty topsoil. Organic soils in Caranavoodaun, Lisduff and Ballindereen often had shell marl fragments just below the peat-marl range. Brierfield is excluded from the marl grouping as soil samples were taken from the peaty topsoil layer and don`t reflect the dominant soil type which is alluvial marl with peaty topsoil. The lack of clear distinction between ‘organic’ and ‘marly’ turloughs in terms of subsoil types and hydrological and hydrochemical variables suggests that categorising turloughs into organic and marly types is arbitrary and ill advised. The majority of turloughs with non-mineral soil types have very broad ranges of $CaCO_3$ probably owing to the patchy nature of marl deposition and shell marl accumulation. Turloughs with marl soil types and/or high mean $CaCO_3$ contents do not have distinctly higher floodwater alkalinities. This indicates that longer flood durations are the key driver of marl accumulation, which is in agreement with previous studies (Coxon, 1987).

Soil properties exhibited a high degree of spatial variation both within and among turloughs. Different soil properties varied to different extents across sites, which demands that soil sampling strategies are developed on a site specific basis and should include a preliminary assessment of soil types and soil property variation. The highly variable nature of both TN and TP has major implications for trophic assessments of the terrestrial phase of the turlough habitat. The relatively lower TN concentrations of mineral turloughs can be accounted for by the accumulation of TN with OM. This also accounts for the broader ranges of TN associated with the four organic soil types, namely BorgVSW, BorgSW, BorgVSP and FenPt. P is considered the primary driver of turlough floodwater primary productivity and trophic assessments are currently focused on P. TP has a strong, positive association with P sorption capacity and inorganic P (Daly *et al.,* 2001) and available forms of P are also likely to be highly spatially variable. Broad ranges of TP, flood duration and flood frequency were also associated with soil types and consequently no soil types were identified as a potential indicator of TN or TP status.

Trophic assessments of the terrestrial phase of the habitat should use vegetation as trophic indicators rather than soil nutrient assessment. Longer-term datasets are required to adequately identify useful soil indicators of hydrological regime.

The investigation of grazing regimes across sites and soil types both revealed that mineral soil types are under relatively more grazing pressure than organic/marly soil types. Large proportions of PtMRL, AlluvMRL and AlluvMIN are ungrazed, reflecting the poor grazing potential of these soil types and associated vegetation communities. Soil conditions are an important driver of turlough grazing activities. If flood durations in 'mineral' turloughs become longer, areas of alluvial mineral soils are likely to increase and negatively impact on the grazing potential of the site. The turlough study sites present a broad range of grazing regimes and grazing intensities including completely grazed turloughs, largely ungrazed turloughs and turloughs with a mosaic of grazed and ungrazed land parcels. Results presented here provide quantitative evidence that turlough grazing intensities are generally low, and only 5% of land parcels were identified as potentially over grazed. However, sheep grazing, as at Garryland, results in an extremely short sward that may well have negative impacts on plant species diversity. The fact that eleven of the turlough sites contain ungrazed land parcels supports the assertion that turlough land abandonment is widespread (Sheehy Skeffington, *et al*. 2006; Visser *et al*., 2007). Shrub encroachment in the absence of grazing has been highlighted as a potential conservation issue. Shrub encroachment is unlikely however in the wetter turloughs given than long flood durations will eliminate woody species from the basin area. Grazing absence is likely to be a more significant conservation issue in turloughs with shorter hydroperiods, however these turloughs are associated with mineral soil types and better grazing potentials and are consequently less likely to be abandoned. The lack of association between soil TN and TP and grazing intensity may have numerous explanations. Currently ungrazed land parcels may have been grazed in the past or the levels of grazing are not sufficiently high to influence soil TN and TP. Indeed soil samples were not collected from land parcels with high level grazing intensity. A detailed study of the effects of grazing intensity on soil nutrient status was beyond the scope of this work yet the collated information form the basis for future studies on this topic.

6.2.5 Conclusions – Turlough Soil Types, Soil Properties and Grazing Regime Variation

- A broad range of soil types occur across turloughs, however, at the within-turlough scale turloughs present either a limited combination of mineral soil types or organic and marly soils.
- Turloughs with non-alluvial mineral soil types are associated with till subsoils and relatively short flood durations. These turloughs are also relatively deep and have coloured floodwater.
- Non-mineral sites contain complex associations of organic and marly soil types and are generally associated with long hydroperiods and recession durations and less extensive till subsoils.
- Soil properties are highly variable both within and among turloughs and future soil sampling strategies should include a preliminary assessment of soil type and soil property variation. In light of the observed variation in soil TN and TP, trophic assessments of the terrestrial phase should focus on using plant species as nutrient indicators.
- Turlough soil types could not be characterised in terms of soil TN, TP, flood duration or flood frequency. Further attempts to evaluate the use of soil types as indicators of nutrient status should focus on assessing the P dynamics of the most extensively occurring soil types. Longterm hydrological datasets are a pre-requisite for evaluating soil types as hydrological indicators.
- Turlough grazing regimes are generally low and over grazing is apparently not a major concern for turlough conservation. Land abandonment is widespread across sites but is unlikely to adversely affect turlough vegetation given the negative influence of flooding on woody species. Soil type exerts an important effect on turlough grazing activities, and mineral soil types are under more intense grazing pressure than organic and marl soil types. Vegetation communities associated with mineral soil types are likely to be heavily influenced by grazing.
- The soil description and classification methods used here provide a cost-effective approach to soil description, although limited, detailed horizon description using soil pits would improve understanding of soil development in turloughs.

6.3 Relationships Between Flooding, Landuse and Surface Soil Properties of Turloughs

6.3.1 Introduction

A substantial research gap exists with respect to soils as a critical structural and functional component of the turlough habitat. An understanding of turlough soil property variation is important for informing the development of terrestrial phase assessment, monitoring strategies and soil-related ecological research. A more comprehensive knowledge of the distribution of nutrient-related soil properties as influenced by flooding and landuse factors is critical for assessing the potential effects of future flooding regime or landuse change on ecologically important turlough soil properties. Elucidating the drivers of soil property distribution in wetlands is challenging given the number of factors that affect soil properties. Wetland soil property heterogeneity is linked with differences in parent material, elevation, topography, erosional or depositional environment, vegetation, pedogenic effects and hydrology (Stolt *et al*., 2001). Turloughs are likely to exhibit a high degree of soil property heterogeneity as the turlough landform is recognised as highly variable with regards to size (< 0.1 km^2 to > 3 km^2), depth, topography, groundwater connections and inundation patterns (Sheehy Skeffington *et al.*, 2006). Flooding frequency and flood duration have been identified as critical factors influencing soil property distribution in groundwater dependent wetlands (Day et al., 1998). More frequently flooded wetlands have been shown to have higher soil organic matter contents than less frequently flooded wetlands owing to reduced decomposition rates linked to prolonged anaerobic conditions (Bai *et al*., 2005). Organic matter content influences the porosity, nutrient availability and cation exchange capacity of soils (Mitsch & Gosselink, 2000) and understanding the influences on soil organic matter is critical for understanding the productivity of turlough ecosystems. Carbonate accumulation is also common within turloughs. After draining, the vegetation of turloughs is often covered with calcite crystals and in some turloughs tufaceous crusts cover bedrock outcrops (Coxon, 1994). Carbonate accumulation in turlough surface soils is likely to influence the soil pH. Soil pH is a critical functional component of soils as pH-controlled reactions alter the solubility, and therefore the availability, of nutrients (Plaster, 2003).

Understanding the association between flooding factors, soil carbonate content and pH are important for understanding drivers of nutrient availability in turlough soils. Nitrogen (N) and phosphorus (P) are key productivity drivers in wetlands. Nitrogen is often the most limiting nutrient in flooded soils (Mitsch & Gosselink, 2000), making nitrogen dynamics in turloughs highly significant. P is also an important limiting chemical in wetlands and has been identified as a major limiting nutrient in bogs and freshwater marshes (Mitsch & Gosselink, 2000) and turlough floodwaters (Cunha Pereira *et al.*, 2010). A positive association between flood frequency and soil total P, total N and organic matter has been reported for wetlands (Bai *et al*., 2005). Biogeochemical cycling in turloughs is therefore potentially highly sensitive to changes in flooding regime resulting from climate change related increases in winter precipitation (McElwain & Sweeney, 2006) and potential new drainage schemes established in response to local community pressure.

Landuse is potentially another important factor affecting turlough soil nutrients. The ephemeral nature of turlough flooding facilitates the use of turloughs as marginal grazing land (Visser *et al*., 2007). Fields often radiate from a central commonage area, resulting in a mosaic of land parcels under different grazing regimes (Sheehy Skeffington & Gormally, 2007). The grazing practices within any turlough land parcel are influenced by the quality of grazing conditions, which are linked to soil conditions, and by the individual circumstances of the landowner. In relation to the latter point, turlough land abandonment is becoming increasingly common and many turlough land parcels are now ungrazed owing to an increased focus on high-intensity agriculture (Visser *et al*., 2007). Variation in grazing activities is likely to affect a range of soil properties such as organic matter and nutrients. An improved understanding of the relationships between soil properties and grazing presence and absence is important for evaluating the implications of turlough landuse changes on soil properties. Turlough soils are an important structural and functional element of turlough ecology yet they have rarely been the focus of research. Understanding the interrelationships of nutrient-related soil properties and flooding and landuse factors is critical for developing an improved understanding of turlough ecological functioning. Our objective was to examine the influences of flooding and landuse factors on the variation and distribution of turlough surface soil properties.

6.3.2 Materials and Methods

6.3.2.1 Site Selection

Eighteen turloughs representing the geo-hydrological spectrum were chosen using best available hydrological criteria (Fig. 6.7). Four of the 22 turloughs were excluded owing to lack of hydrological information. The geographical coordinates are provided for each turlough (Table 6.9). Fifteen of the sites are designated as candidate Special Areas of Conservation (cSAC) under the Habitats Directive (92/43/EEC). Brierfield, Carrowreagh and Rathnalulleagh are solely designated as Natural Heritage Areas (NHA) under national legislation.

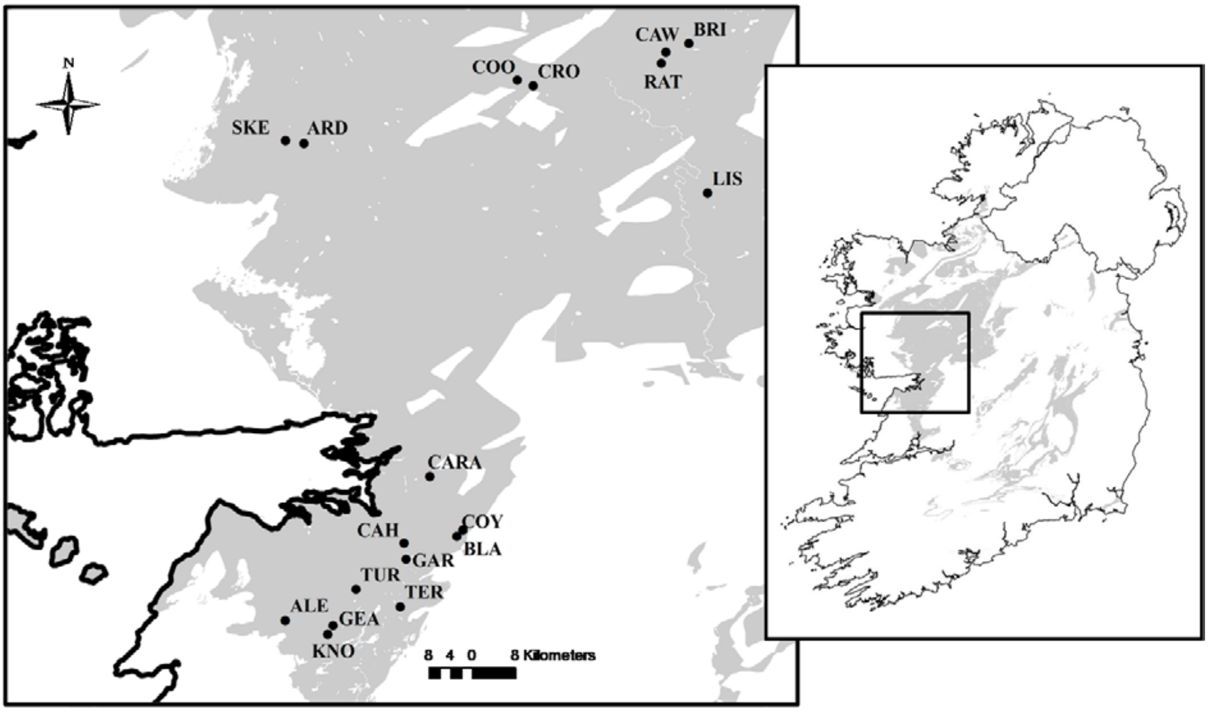


Fig. 6.7 Geographical distribution of the 18 turloughs studied (abbreviations are explained in Table 1). Shaded areas correspond to areas of pure bedded limestone (geological data from the Geological Survey of Ireland Database: http://www.gsi.ie/Mapping.html).

Table 6.9 Turlough names, site codes and locations (See Fig. 6.7).

Turlough	*Site code*	*Irish National Grid*
Ardkill	ARD	127360 262500
Blackrock	BLA	149780 208130
Brierfield	BRI	181600 276560
Caherglassan	CAH	141235 206225
Caranavoodaun	CARA	145314 215421
Carrowreagh	CARR	178420 275080
Coolcam	COO	157420 271390
Croaghill	CRO	159631 270711
Garryland	GAR	141750 204050
Knockaunroe	KNO	131317 193982
Lisduff	LIS	184250 255500
L. Aleenaun	ALE	127740 195440
L. Coy	COY	149000 207500
L. Gealain	GEA	131502 194828
Rathnalulleagh	RAT	177710 273760
Skealoghan	SKE	124737 262878
Termon	TER	140941 197346
Turloughmore	TUR	134950 199480

6.3.2.2 Soil Sampling and Analyses

Two surface soil samples were collected from the upper, middle and lower elevation zones of each turlough (*n*=6) to a maximum depth of 20 cm. Vegetation communities are generally distributed in concentric zones within a turlough (Goodwillie, 2003) and were used to delimit the sampling zones. Samples were analysed for pH, organic matter content (OM), calcium carbonate content ($CaCO_3$), non-calcareous sand/silt/clay fraction (INORG), total nitrogen (TN), total phosphorus (TP) as described above in section 6.2.2.2.

6.3.2.3 Environmental Variables

The elevation of each soil sampling point was determined by applying the GPS-positions to digital elevation maps using GIS-software (ArcView, ESRI Inc., USA). The topographic GPS surveys were carried out using a Trimble R6 GPS system with a horizontal and vertical accuracy of 10 mm and 15 mm respectively. Contour maps and depth-area relationships were computed for each turlough using Surfer® version 8.6. The water depth in each turlough was continuously measured using Mini-Diver® DI501 and DI502 monitors (Schlumberger Water Services) placed in the bottom of each turlough. For each soil sampling point the duration and frequency of inundation was determined for the two year period from 1st January 2007 to 31st December 2008. The duration of the inundation is here characterized by the total number of flooded days or flood duration (FD). The inundation frequency (FF) is the number of inundation events over the two year period. For further details, see *Chapter 3: Hydology*, section 3.8.

Landuse was described as either grazed or ungrazed. Grazed land parcels are currently rotationally grazed whereas ungrazed land parcels are not rotationally grazed but may be sporadically grazed by horses, geese or wild goats. Vegetation at each sampling point was broadly classified into one of three vegetation categories, comprising grassland, sedge dominated and aquatic community types (Sheehy Skeffington *et al*., 2006).

6.3.2.4 Data Analyses

Turlough boundaries are undefined and one sample from each of four turloughs lay just outside the maximum recorded flood level for 2007 and 2008. These samples were excluded from the data analysis as hydrological information could not be generated for these sampling points. The final data set therefore consisted of 104 samples. Descriptive data analyses were carried out using SPSS 16.0 (Norusis, 2008). Outlying values were checked and validated.

Multivariate analysis

We used non-metric multidimensional scaling (NMS) ordination to detect environmental gradients underlying variation of soil properties across turloughs, as described in section 6.2.2.5. Normality of soil property data (pH, OM, INORG, $CaCO_3$, TN, TP) was checked using the Kolmogorov-Smirnov (n > 50) prior to analyses. TN and TP were log-transformed and OM, INORG and $CaCO_3$ were arcsine-root transformed prior to NMS ordination.

Soil properties were standardised using the Z transform prior to ordination to remove arbitrariness in the units of measurement (Odeh *et al*., 1991). The NMS ordination was performed using the Euclidean distance measure and autopilot in the PC-ORD package version 5 (McCune & Mefford, 1999). Joint plots were used to illustrate the gradients of soil property variation across sites. Kendall *tau* rank correlation coefficients were used to examine the relationships between the environmental variables (soil depth, flood duration, flood frequency, grazing and vegetation type) and the ordination axes. Vegetation categories were converted to binary variables prior to correlation with the ordination axes. The significance of Kendall *tau* correlation coefficients was tested using the asymptotic approximation for $n > 40$ (Rohlf & Sokal, 1995).

Univariate analyses

Univariate analyses were used to further investigate the associations between soil properties and environmental variables. As data were non-normally distributed, Spearman rank-order correlation was used to examine associations between flood duration, flood frequency and soil properties. Relationships between variables with highly significant ($P \leq 0.001$) associations (Zar, 1972) were investigated further using scatterplots. Univariate analyses were also used to investigate the effect of grazing regime (grazed/ungrazed) and vegetation type on soil TN and TP. Data normality was checked using either the Kolmogorov-Smirnov (n > 50) or Shapiro Wilks (n < 50) test prior to analyses and post transformation. The Mann-Whitney *U* test was used to compare TN and TP among grazing regimes as transformation did not yield even an approximately normal distribution. One-way analysis of variance (ANOVA) was used to compare TN and TP among vegetation types. Data were log transformed prior to analysis. The Games Howell post hoc test and the Welch and Brown-Forsythe tests (Field, 2009) were used in the absence of homogeneity of variance among vegetation types to verify significant differences. These analyses were conducted using SPSS 16.0.

6.3.3 Results

Table 6.10 Soil nutrient properties used in the study and their statistical characteristics (*n*=104). Q_1 = Lower quartile; Q_2 = Upper quartile.

Variable	*Abbreviation*	*Unit*	*Min*	Q_1	*Median*	Q_3	*Max*
Total Nitrogen	TN	mg kg^{-1}	3600	6350	9070	16019	34300
Total Phosphorus	TP	mg kg^{-1}	244	628	1019	1373	3270
pH	pH		5.1	6.4	6.9	7.9	8.5
Calcium carbonate	$CaCO_3$	%	0.5	3.7	5.6	15.1	77.5
Organic Matter	OM	%	6.9	15.2	21.6	40.4	82.3
Non-calcareous inorganic content	INORG	%	6.3	25.7	61.5	79.7	90.7

Summary statistics of the results (*n* =104) are presented in Table 6.10. The TN concentrations of samples ranged from 3600 to 34300 mg kg^{-1}, with a median value of 9070 mg kg^{-1}. TP concentrations ranged from 244 to 3270 mg kg^{-1} (median = 1019 mg kg^{-1}). The pH status of turlough surface soils ranged from acidic (<5.5) to alkaline (> 7.4). The majority of soils were circumneutral (5.5 to 7.4) and alkaline soils were more common than acidic soils. The two acidic soils were mineral in nature, rather than acidified peats, with INORG contents in excess of 70%. $CaCO_3$ was the most positively skewed variable, with thirteen samples with greater than 50% calcium carbonate content. $CaCO_3$ in the main body of data ranged between 3.7 and 15.1%. The dataset was approximately equally divided (median = 21.6%) between mineral (< 20% OM) and organic soils (>20%). A wide range of INORG was also recorded (6.3 – 90.7%, median 61.5%).

The NMS ordination of soil properties lead to a three dimensional solution with an acceptable final stress (6.6%) and instability (0.00778) after 200 iterations were run. The ordination extracted a high proportion (97.2%) of total variation in the dataset, with 36.9% loaded on Axis 1, 9.7% loaded on Axis 2 and 50.6% loaded on Axis 3. The NMS therefore revealed two major gradients of variation. The two main axes (Axis 1 and 3) account for 87.5% of the variation and are presented in Figure 6.8. Associations between environmental variables and NMS axis scores are presented in Table 6.11. The NMS ordination illustrates that soils are distributed as a continuum along the main axes.

Axis 3 shows a pH/INORG gradient, the extremes of which are acidic mineral soils and calcareous alkaline soils. The biplot shows that INORG increases with increasing axis scores and both pH and $CaCO_3$ increase with decreasing axis scores. Most samples from Caherglassan, Blackrock, Garryland, Coy, Rathnalluleagh, Carrowreagh and Turloughmore form a relatively distinct cluster towards the top of Axis 3. These turloughs have acidic soils with high proportions of sand/silt/clay. Distinctly alkaline samples from Termon, Ardkill, Lisduff and Lough Aleenaun are located towards the extreme lower end of Axis 3. Along Axis 3, there is a significant positive association between Grass and Grazing and axis scores and a significant negative correlation between flood duration and sedge communities and axis scores (Table 6.11). Non-calcareous mineral soils are positively associated with grazed grassland and relatively shorter flood durations whereas calcareous soils are associated with sedge dominated vegetation and relatively longer flood durations. Axis 1 represents an OM/nutrient gradient. TN, TP, OM and soil depth are positively associated with each other and negatively associated with axis scores along Axis 1 (Table 6.11). Deep, peaty soils from

Knockaunroe, Skealoghan and Croaghill are located at the extreme left of Axis 1 whereas very shallow alluvial mineral samples from Coolcam are located to the extreme right of the same axis.

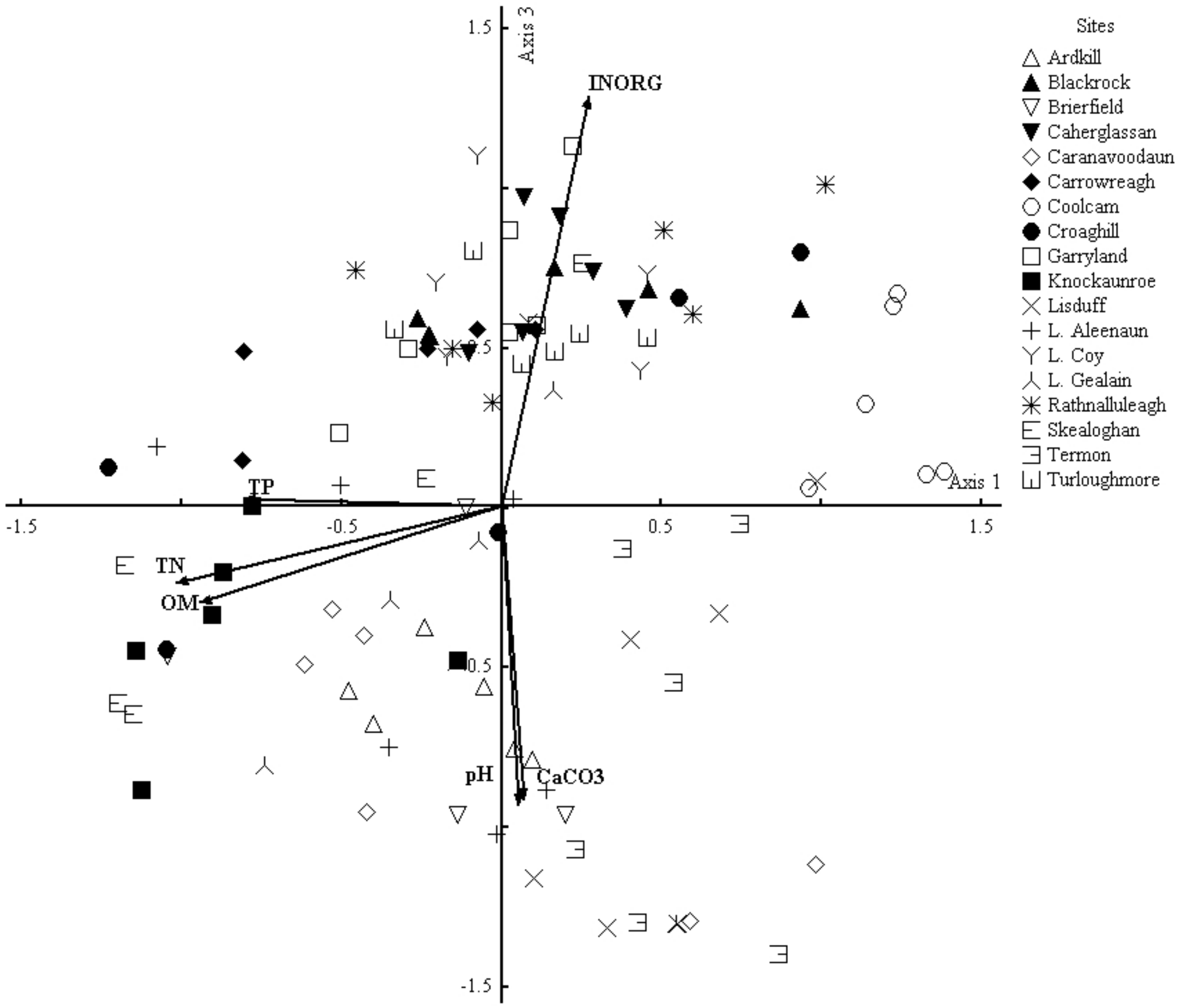


Figure 6.8 NMS ordination of 104 samples in variable space with soil properties overlaid. Symbols indicate turlough site. 36.9% of the variation is loaded on Axis 1 and 50.6% of variation is loaded on Axis 3. Biplot vector cut-off is 0.6. The length of each biplot line is proportional to the r^2 of the indicated variable with the axis; the direction indicates the direction of increasing values in the graph. TN: Total Nitrogen (mg kg^{-1}). TP: Total Phosphorus (mg kg^{-1}). INORG: percentage non-calcareous inorganic content. OM: Organic Matter. $CaCO_3$: Calcium carbonate.

Table 6.11 Kendall`s *tau* correlation coefficients between environmental variables and the NMS ordination axes (*n* = 104) (Fig. 2). *** = *P* ≤ 0.001

Variable	*Axis 1*	*Axis 3*
	tau	*tau*
Flood Duration	0.068	-0.257***
Flood Frequency	-0.073	0.143
Grazing	0.017	0.342***
Grass	0.164	0.460***
Sedge	-0.147	-0.326***
Aquatic	0.019	-0.138
Soil Depth (cm)	-0.280***	-0.109

A correlation matrix of Spearman Rank coefficients is presented in Table 6.12, with highlighted values significant at the $P \leq 0.001$ level. $CaCO_3$ and FD exhibited significant positive association ($R = 0.445$; $P \leq 0.001$), with samples comprised of more than 50% $CaCO_3$ associated with flood durations in excess of 350 days over the two year period (Fig. 6.9a). pH and $CaCO_3$ were positively correlated with each other ($R = 0.635$; $P \leq 0.001$) and both were negatively associated with INORG ($R = -0.484$ and $R = -0.723$ respectively; $P \leq 0.001$ in both cases). The full range of turlough pH conditions were associated with soils comprised of less than 30% $CaCO_3$, whereas soils with greater than 30% $CaCO_3$ were all strongly alkaline (Fig. 3b). INORG steadily decreased as $CaCO_3$ increased beyond 20% (Fig. 6.9c). OM and INORG exhibited a strong negative association ($R = -0.744$; $P \leq 0.001$), as expected. There was a strong negative linear association between INORG and OM for soils with less than 20% $CaCO_3$ (Fig. 6.9d). The relationships between $CaCO_3$, OM and INORG in turloughs suggest that both the sand/silt/clay fraction and organic content steadily decrease as $CaCO_3$ accumulates beyond 20% dry weight. INORG decreases with increasing OM content in turlough soils with less than 20% $CaCO_3$. Mineral turlough soils can be dominated by $CaCO_3$ or the sand/silt/clay fraction.

Table 6.12 Spearman Rank correlation matrix of associations between soil properties and hydrological variables (n = 104). *** = $P \leq 0.001$

	Flood Duration	Flood Frequency	TN mg kg $^{-1}$	TP mg kg $^{-1}$	pH	$CaCO_3$	OM	INORG	Soil Depth
Flood Duration	1								
Flood Frequency	-0.134	1							
TN mg kg $^{-1}$	-0.061	-0.045	1						
TP mg kg $^{-1}$	-0.084	0.351***	0.489***	1					
pH	0.350***	-0.237	0.041	-0.260	1				
$CaCO_3$	0.445***	-0.078	0.267	-0.018	0.635***	1			
OM	0.010	-0.190	0.896***	0.428***	0.145	0.290	1		
INORG	-0.309	0.141	-0.673***	-0.017	-0.484***	-0.723***	-0.744***	1	
Soil Depth	0.037	0.093	0.254	0.353***	-0.040	-0.015	0.352***	-0.253***	1

TN: Total Nitrogen (mg kg $^{-1}$). TP: Total Phosphorus (mg kg $^{-1}$). OM: percentage organic matter by loss on ignition. $CaCO_3$: percentage calcium carbonate estimate by ignition. INORG: percentage non-calcareous inorganic content. Flood Duration: Total number of days flooded (Jan 2007-Dec 2008). Flood Frequency: Number of inundation events (Jan 2007-Dec 2008). Soil Depth (cm)

Both TN and TP exhibited significant positive correlation with OM ($R = 0.896$ and $R = 0.428$ respectively; $P \leq 0.001$ in both cases). 25% of soils in this study had TN concentrations greater than 16019 mg kg^{-1}, the majority of which had OM contents in excess of 40%. OM had a strong positive association with soil depth ($R = 0.352$). TN and OM had a strong linear association, with OM explaining 79% of variation of TN (Fig. 6.10a). TN also showed a significant negative association with INORG ($R = -0.673$; $P \leq 0.001$) which follows from the strong negative correlation between OM and INORG. All samples with greater than 50% $CaCO_3$ were present within the cluster of outlying samples and a moderate linear association was observed between TN and INORG within the main body of data (Fig. 4b). TP had a weak association with OM (Fig. 6.10c). There was a significant positive association between TP and

FF (R = 0.351; $P \leq 0.001$). A general increasing trend was observed between TP and FF (Fig. 4d), with low TP concentrations (< 500 mg kg^{-1}) associated with less than seven flood events

The median TN concentration was significantly higher (Fig. 6.11a) under the un-grazed regime than under the grazed regime (Mann-Whitney U = 716, P < 0.05). Conversely, the median TP concentration was significantly higher (Fig. 6.11b) under the grazed regime than the un-grazed regime (Mann-Whitney U = 753, P < 0.05). TN varied highly significantly among the three vegetation types (one-way ANOVA: log transformed data, $F_{2, 101}$ = 10.065, P < 0.001), with Sedge having a higher mean TN concentration (13693 mg kg^{-1}) than Grass (8008 mg kg^{-1}) (Fig. 6.12a). There was no significant difference in TP among the three vegetation types (Fig. 6.12b).

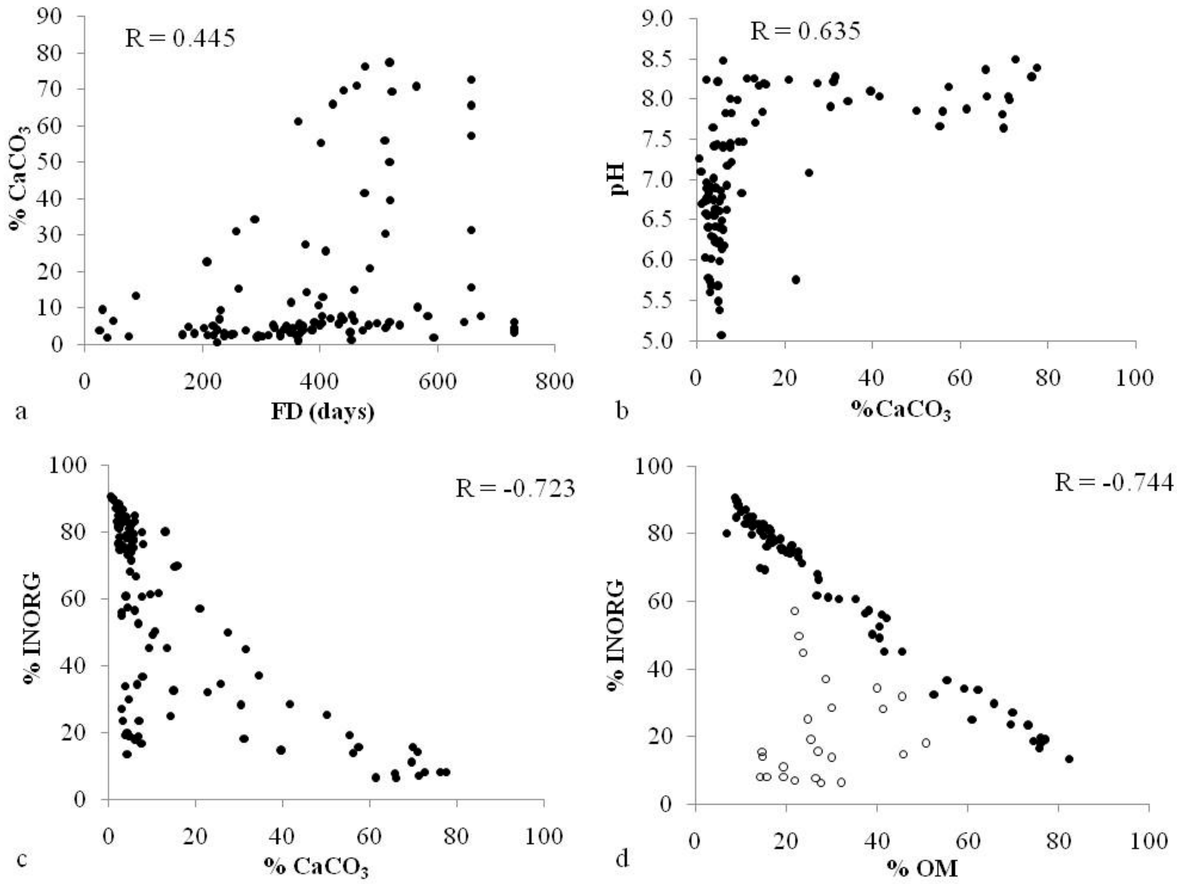


Figure 6.9 Scatterplots of associations between (a) calcium carbonate ($CaCO_3$) and flood duration (FD); (b) pH and calcium carbonate content ($CaCO_3$); (c) inorganic content (INORG) and calcium carbonate ($CaCO_3$) and (d) inorganic content (INORG) and organic matter (OM) (Open circles = >20% $CaCO_3$; Closed circles = <20% $CaCO_3$).

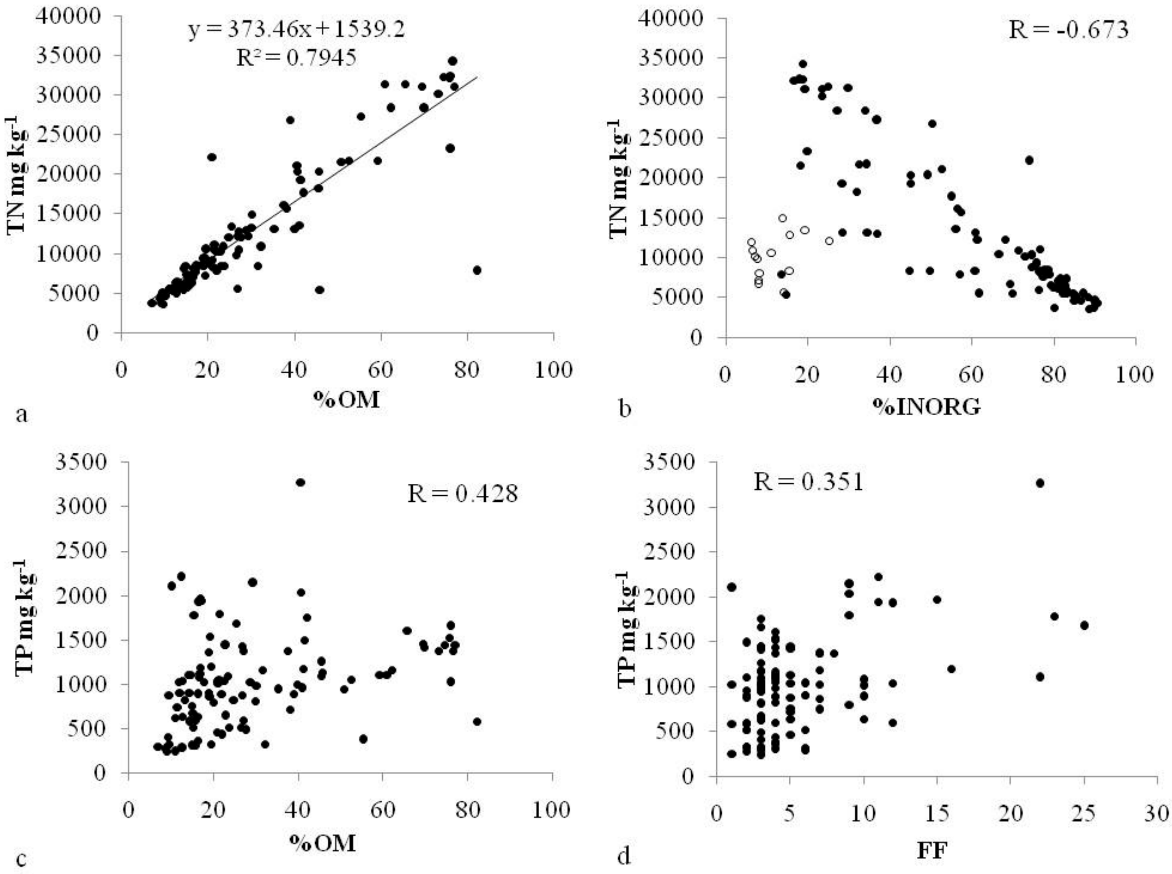


Figure 6.10 Scatterplots of associations between (a) total nitrogen (TN) and organic matter (OM) and (b) total nitrogen (TN) and inorganic content (INORG) (Open circles = <50% calcium carbonate (Closed circles = >50% calcium carbonate); (c) total phosphorus (TP) and organic matter (OM) and (d) total phosphorus (TP) and flooding frequency (FF).

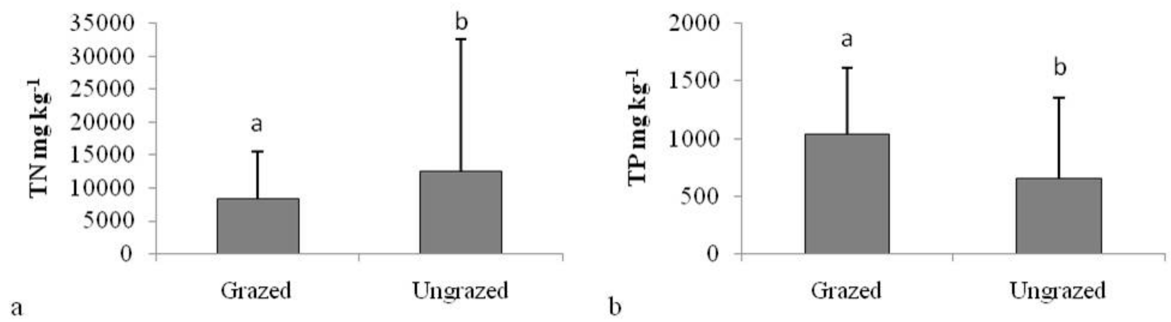


Figure 6.11 Variation in (a) median total nitrogen (TN) and (b) median total phosphorus (TP) among Grazed (n = 76) and Ungrazed (n = 28) regimes. Bars not sharing letters represent significant differences at p < 0.05. Error bars represent the interquartile range.

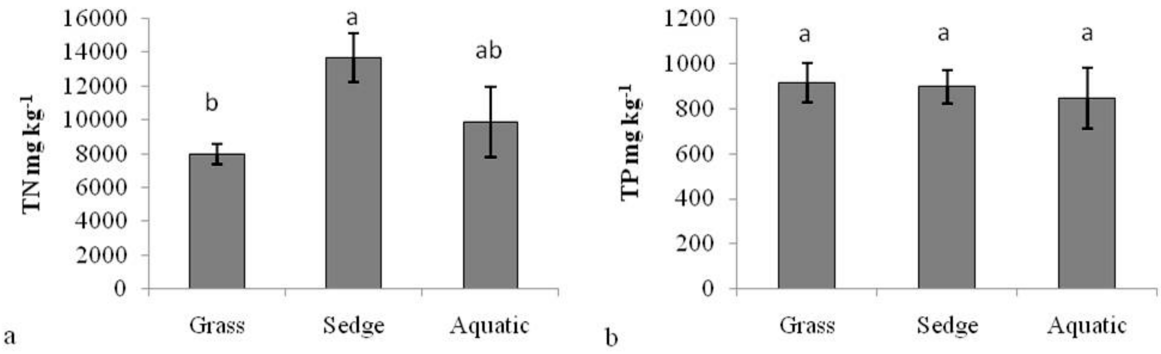


Figure 6.12 Variation in mean (a) total nitrogen (TN) and (b) total phosphorus (TP) among grass dominated (n = 42), sedge dominated (n = 43) and aquatic (n = 19) vegetation types. Data shown are back transformed from log10 transformations. Error bars are ± 1 standard error.

6.3.4 Discussion

The positive association between grazing, grassland and non-calcareous mineral soils identified by the present study suggests that turloughs with mineral soils are relatively more intensively grazed than turloughs with calcareous soils. Turlough mineral soils are associated with relatively shorter flood durations than calcareous turlough soils. Management practices are influenced by the inherent grazing potential of a turlough and soil properties, which in turn are shaped by hydrological regime (Moran *et al.*, 2008). Soil drainage is a major determinant of the grazing potential of land, with a relatively lower production capacity associated with wet soils (Lee, 1974). Turloughs may or may not contain free draining till subsoils (Coxon, 1987), the presence of which is likely to exert a positive influence on the sand/silt/clay content of turlough soils and consequently the grazing capacity of land. Debate persists as to whether till subsoils are the 'cause' rather than the 'result' of relatively shorter turlough flood durations (Coxon, 1987). Less palatable sedge-dominated vegetation communities are associated with soils with higher soil moisture contents than grass/forb dominated communities (Regan *et al.*, 2007). Flood duration also directly influences the timing and duration of grazing activities at any site. The present study found that flood duration also exerts a positive influence on the $CaCO_3$ content of turlough soil. Similarly, Coxon (1987) found that that marl (calcite deposition) accumulation in the sedimentary record was associated with a longer duration of flooding than sand/silt and silt/clay deposits. $CaCO_3$ accumulation is likely to influence the vegetation communities and consequently the grazing potential of turlough land. $CaCO_3$ in turloughs is also composed of shell marl in addition to calcite deposits from incoming floodwaters. Shell marl accumulation is also patchy, being restricted to residual pools, and turloughs which empty completely have a poor snail fauna (Donaldson *et al.*, 1979). In the present study, long durations of flooding did not necessarily result in $CaCO_3$ accumulation however, and floodwater alkalinity is a likely key determinant of turlough soil $CaCO_3$ contents. Cunha Pereira *et al.* (2010) reported that mean seasonal turlough alkalinities range between 112 and 236 mg l^{-1} and such variation is likely to influence the spatial distribution of $CaCO_3$ deposition. $CaCO_3$ accumulation is also linked to flooding depth. Physical agitation of shallow alkaline turlough waters by wind action can speed the release of carbon dioxide to the atmosphere (Coxon, 1994) and patchy $CaCO_3$ deposition may result.

The pH status of soils was positively related to the accumulation of $CaCO_3$ although the relationship was non-linear. The pH range identified in the present study was broader than the range determined by Regan et al. (2007) across thirty turloughs (6.6-8.6), however more acidic soils have been previously reported for turloughs (Moran *et al.*, 2008; Kimberley & Waldren, 2005). An increase in soil pH related to the input of calcium cations from a mineral source is typical, however organic content can influence this relationship, resulting in the occurrence of lower than expected pH, owing to the complexing of calcium cations to organic compounds or the release of organic anions (Glaser, 1987). pH conditions in turloughs are also potentially influenced by highly fluctuating moisture conditions as soil saturation can make the pH of both acidic and alkaline soils converge to 7 (Ponnamperuma, 1972). Evidently, alkaline (pH > 7.4) turlough soils can have a wide range of $CaCO_3$ contents and the pH status of turlough soils should not be used as an indicator of $CaCO_3$ content. $CaCO_3$ contents in excess of 30% reliably indicate alkaline pH conditions, however. Regional climate model predictions for Ireland (McGrath *et al.*, 2005) predict increases in rainfall quantities and in the frequency of extreme precipitation events during winter months. These conditions would result in extended flood durations in turloughs which may increase the extent and degree of calcium carbonate deposition and accumulation in turlough soils, potentially reducing the grazing potential of turlough land.

Univariate analyses revealed that grazing regime and flooding frequency influence soil TP in turlough soils. TP presented a broad range of concentrations (400 to 1600 mg kg^{-1}) which is in accordance to other studies on wetlands (Xu *et al.*, 2009). Many samples from the present study lie within the agricultural range, reflecting the use of turloughs as marginal agricultural land. The higher TP of grazed areas may be attributed to nutrient inputs from grazing animals or historical fertiliser application. TP concentrations beyond the natural range (> 1200 mg kg^{-1}) (Zaimes *et al.*, 2008) were generally associated with grazed areas. Extensive data on inorganic and organic P fractions and stocking densities are required to adequately establish the effect of grazing on turlough soil P enrichment. High TP concentrations were associated with a wide number of inundation events whereas low TP concentrations (< 500 mg kg^{-1}) were associated with less than seven inundation events. Wetting and drying cycles are known influence soil P dynamics (Sah & Mikkelsen, 1986). Research integrating data on current and historical stocking densities and hydrological regimes is required to characterise the relative importance of grazing and flood frequency on turlough soil TP content.

pH or $CaCO_3$ did not exert a significant effect on soil TP concentrations but they are likely to influence the spatial distribution of available P in turlough soils. P forms complexes with calcium at high pH and P availability diminishes as pH increases beyond 7.0 (Plaster, 2003). Research related to P availability in turlough soils should be a priority. Such research should be cognisant of the fact that the mineral fraction of turlough soils can be dominated by either INORG or $CaCO_3$ derived from different sources.

Turloughs soils were found to exhibit a wide range of TN concentrations. The TN content of soils is generally very diverse ranging from less than 0.1% to over 2% in highly organic soils (Haynes, 1986). OM was identified as an efficient predictor of TN in turlough soils. This supports the assertion than organic matter dynamics are tightly coupled to biogeochemical cycles of nitrogen in wetland soils. The higher TN of sedge dominated vegetation communities and ungrazed areas was likely owing to organic accumulation driven by higher lignin contents of *Carex* spp. and lack of herbage removal respectively. The botanical origin of organic material is an important characteristic of organic soil (Wen, 1984) and sedge dominated communities produce litter that is more difficult to decompose owing to higher concentrations of decay resistant compounds (Berendse et al., 1989). Intensive investigations of the effect of hydrological and grazing regime on plant communities in Skealoghan Turlough, Co. Mayo in western Ireland found that litter accumulation in soils decreased with increasing stocking rate owing to herbage removal by grazing animals (Moran *et al*., 2008). Turlough land abandonment is likely to result in an increase in both soil organic matter and soil TN concentrations. Results from the present study indicate that landuse, vegetation and soil depth are more important drivers of turlough soil TN than flooding factors. Highly organic turlough soils tend to be deep, reflecting the potential for peat accumulation in turloughs, and alluvial mineral soils are very shallow. The distribution of these soils is not apparently linked to flooding or landuse factors, and is more likely linked to differences in parent materials. Highly alkaline turlough soils with $CaCO_3$ contents in excess of 50% tend to have a narrow low range of TN concentrations, possibly owing to sparse vegetation cover and reduced organic matter accumulation.

6.3.5 Conclusions - Relationships Between Flooding, Landuse and Surface Soil Properties

- Turlough surface soil properties are highly variable and soil sampling for ecological research or conservation assessment should be cognisant of this variation.
- The results highlight the importance of determining the nature of the mineral fraction of turlough soils for soil classification purposes.
- Flooding, landuse, vegetation, $CaCO_3$, pH and INORG are significantly interrelated.
- Increases in turlough flood duration linked with climate change may result in increased $CaCO_3$ contents in turlough soils, which may influence P availability and vegetation community composition.
- More intensive turlough soil research should focus on the effects of parent material on turlough soil inorganic content, on elucidating the influence of different forms of $CaCO_3$ on P availability. Another research priority should be long-term turlough hydrological monitoring which is essential for further evaluating the influences of flooding parameters on turlough soil property variation.
- Shifts in turlough landuse arising from extended flood durations, changes in agricultural policy or land abandonment are likely to influence the pools of nutrients available for vegetation.
- Soil nutrient assessments should not be incorporated into an EU Habitats Directive monitoring programme for turloughs until the variability and environmental drivers of available forms of soil N and P are investigated.

6.4 Examinations of Turlough Soil Property Spatial Variation in a Conservation Assessment Context

6.4.1 Introduction

Eutrophication presents a significant threat to the quality of water bodies (Solimini *et al.,* 2006) and also potentially to turloughs as recent evidence identifies some turloughs as having eutrophic, highly productive floodwaters (Cunha Pereira *et al.,* 2010). Understanding the link between turlough nutrient status and geo-hydrological settings is critical for understanding nutrient pressures and impacts in turloughs. Visser *et al.* (2006) challenge the validity of typing turloughs based on combinations of hydrology, geomorphology and elements of ecology and promote an alternative dry-wet continuum concept, the extremes of which are determined by the degree of limestone karstification. Most wet turloughs are associated with shallow epikarst groundwater flow, high alkalinities, assumed nutrient-poor floodwaters and long hydroperiods. Turloughs representative of the dry end of the spectrum are associated with deep conduit groundwater flow, less alkaline floodwaters and relatively shorter hydroperiods (Visser *et al.,* 2006). It should be noted that the hydroperiod information reported by these authors is deduced from response to rainfall and date of draining. A holistic assessment of turlough trophic conditions should encompass the terrestrial phase, particularly as turloughs are used as marginal grazing land (Visser *et al.,* 2007) and are subject to nutrient loading from livestock and, in some turloughs, low level fertiliser application. Wetland soils are characteristically highly variable (Reddy, 1993) and this present study is primarily concerned with evaluating the potential for using soil nutrient assessments as a method for assessing the impacts of nutrient pressures on turloughs.

Hydrological regime is thought to exert the greatest influence on turlough biogeochemical processes. Soil moisture contents in turloughs at any given time are determined by the timing and duration of flood recession and soil drainage characteristics. Within the turlough environment soil moisture would be expected to exert a profound influence on microbial activity and spatial patterns of decomposition and nutrient supply (Ettema & Wardle, 2002). Flood duration exerts a major influence on the organic content of wetland substrates owing to reduced decomposition rates resulting from prolonged anaerobic conditions (Bai *et al.,* 2005). Diamicton, sand/silt and silt/clay turlough deposits appear to be associated with a short duration of flooding, while peat and marl are associated with a long duration of flooding.

It remains unclear however whether the different deposits are the result, rather that the cause, of the different durations of flooding (Coxon, 1987). The patchy deposition of marl within turlough basins due to irregular topography, depth of flooding and duration of flooding (Coxon, 1994) would also be expected to influence nutrient availability by altering the pH status of soils.

Whilst heterogeneity in nutrient related soil properties is well recognised, the scale or extent to which this spatial variation occurs in turloughs during the terrestrial phase and the implications for conservation oriented sampling strategies are poorly understood. The current study is also concerned with developing an improved understanding of the drivers of nutrient availability in turlough soils. This work was carried out as part of Sarah Kimberley`s PhD research, which predates the project *Assessing the Conservation Status of Turloughs*. Our objectives were (i) to examine differences in soil nutrient properties among turloughs under contrasting nutrient pressures and (ii) to examine variation of available N and P along turlough flooding gradients.

6.4.2 Methods

6.4.2.1 Site Selection and Sampling Strategy

Three turloughs representative of two types of karst flow systems were selected for study namely a deep karst flow system associated with the Coole-Garryland SAC Complex, Co. Galway (henceforth, Coole Garryland) and a shallow karst flow system corresponding with the East Burren SAC Complex, Co. Clare (henceforth, East Burren; Fig. 6.13). Coole Garryland includes Garryland, Caherglassan and Hawkhill turloughs and East Burren includes Knockaunroe, Gortlecka and Cooloorta turloughs. Coole Garryland and East Burren respectively represent the 'dry' and 'wet' extremes of the dry-wet continuum proposed by

Visser *et al.* (2006). Soils within Coole Garryland turloughs are potentially more nutrient rich than East Burren turloughs owing the larger zones of groundwater contribution, greater levels of disturbance and more intense grazing pressures.

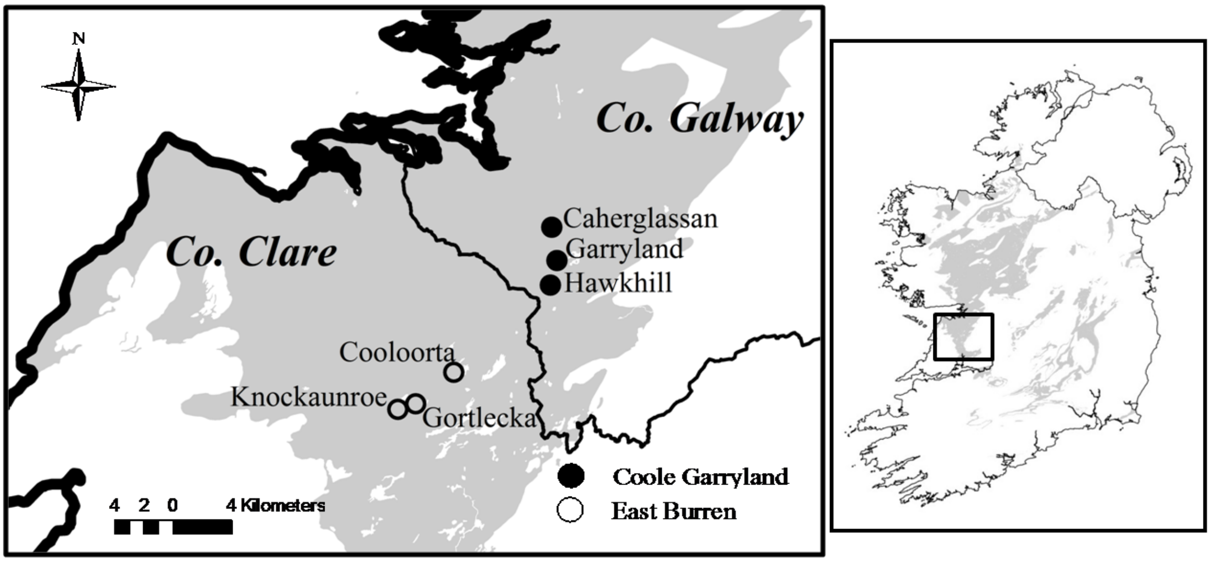


Figure 6.13 Distribution of the six study sites in Counties Clare and Galway. Shaded areas correspond to areas of pure bedded limestone (geological data from the Geological Survey of Ireland Database:http://www.gsi.ie/Mapping.html).

Six surface soil samples spanning the hydrological gradient of each turlough were collected to a maximum depth of 10 cm during July 2003. Vegetation communities are generally distributed in concentric zones within a turlough (Goodwillie, 2003) and were used to delimit the sampling zones. Vegetation grades from the surrounding grassland or woodland through various sedge and grass communities to either exposed mud or marl to wet grassland interspersed with aquatic species. Flooding is acknowledged as the main factor determining vegetation zonation within turloughs and hydroperiod appears to be particularly relevant at the turlough base where it is longest. Goodwillie (2003) presents a list of the main plant communities occurring in turloughs. The communities are not strict phytosociologial ones but their separation shares the same approach of using diagnostic or distinctive species. These communities have been amalgamated into three vegetation types, comprising grass, sedge and aquatic community types generally associated with increasing wetness (Tynan *et al.,* 2006). Upper elevation zones were identified by grass dominated vegetation communities, middle zones by sedge dominated communities and lower zones by the occurrence of aquatic species. At each sampling point, approximately 15 cores were taken using a soil corer to a depth of 10 cm within a 1m^{2}quadrat and bulked to provide a composite sample.

Figure 6.14 Garryland turlough (left) and Cooloorta turlough (right) at the time of sampling (June 2005).

Table 6.13 Vegetation communities (after Goodwillie 2003) and soil moisture ranges occurring within the upper, middle and lower elevation zones along the flooding gradients of Garryland turlough, Co. Galway and Cooloorta turlough, Co. Clare. Dominant plant species are noted in brackets

	Garryland			***Coolorta***		
Elevation Zone	*n*	Vegetation community	% Soil moisture range	*n*	Vegetation community	% Soil moisture range
Upper	7	***Lolium* grassland** *(Lolium perenne, Bellis perennis, Leontodon autumnale)*	40-44	5	**Sedge Heath** *(Potentialla erecta, Carex panicea, Molinia caerulea)*	40-47
Middle	4	**Dry *Carex nigra*** *(Carex nigra, Phalaris rundinacea, Ranunculus repens)*	44-54	2	***Schoenus* Fen** *(Schoenus nigricans, Cirsium dissectum)*	46-49
Lower	5	***Eleocharis acicularis*** *(Eleocharis acicularis, Polygonum spp.)*	62-83	4	**Magno-caricion** *(Carex elata, Scirpus lacustris)*	71-80

Spatial variation of available N and P was investigated along the flooding gradients of Garryland turlough in Coole Garryland and Cooloorta turlough in East Burren (Fig. 6.14). One transect of 4 m^2 quadrats at 3m intervals was oriented along the flooding gradient in each turlough. A 77 m transect and a 52 m transect were laid out in Garryland and Cooloorta turloughs respectively. 4 m^2 quadrats were selected as transects passed through a range of vegetation types from grazed grassland to tall sedge communities and this quadrat size included a representative area of all vegetation types. Fifteen cores were collected to a depth of 10 cm from both transects over a three day period in June 2005. Hydrological information for both turloughs was not available for the sampling period. Hydrological data presented in Cunha Pereira *et al.* (2010) and Naughton (2011) state that Garryland was flooded for 7 months between October 2006 and October 2007. Equivalent information is not available for Cooloorta turlough however two turloughs (Knockaunroe and L. Gealain) occurring in close proximity to Cooloorta were flooded for 8 months during 2006-2007. This information suggests that Cooloorta has a longer hydroperiod than Garryland. In the absence of detailed hydrological information, vegetation communities (Goodwillie 2003) were used as a surrogate to delimit zones with different hydroperiods. The vegetation communities occurring along each transect and the soil moisture ranges within each zone are presented in Table 6.13. The soil moisture contents increased with decreasing elevation, supporting the assertion that vegetation communities reflect different hydroperiods. The soil moisture contents of the lower zones in both turloughs indicate potential soil saturation.

6.4.2.2 Laboratory Analyses

Samples collected for the comparison of soil properties among Coole Garryland and East Burren were analysed for pH, organic matter content (OM), calcium carbonate content ($CaCO_3$), non-calcareous sand/silt/clay fraction (INORG), total nitrogen (TN), total phosphorus (TP) as described in section 6.2.2.2. In additon, Pfeo was determined by the iron-oxide strip test (Menon *et al.,* 1988).

Samples collected along the flooding gradients of Garryland turlough and Cooloorta turlough were analysed for pH, OM and TN using methods outlined above. Moist samples were analysed for available forms of N (Nitrate-N and Ammonium-N), water extractable P (Pw), oxalate extractable P (Pox) and oxalate extractable iron (Feox). Soil moisture (SM) was measured according to (Allen, 1989). Pw represents P in the soil solution and was determined by the method of van der Paaw (1971) using a solution-soil ratio of 40:1 with distilled water and shaken for 1 hour. Pox represents labile P which can replenish the soil solution P concentration (Uusitalo & Tuhkanen, 2000). Acid oxalate extracts were analysed for amorphous forms of Fe (Feox) which represents the readily reducible form of Fe. Nitrate-N and Ammonium-N were measured by potassium chloride extraction (Mulvaney, 1996) followed by spectrophotometric analysis using a Bran+Luebbe AutoAnalyzer 3. Nitrate-N and Ammonium-N concentrations were summed to give an estimate of total inorganic N (Nin). Soil depth (SD) was measured at the centre of each quadrat using a 1m soil depth probe.

6.4.2.3 Statistical Analyses

We used nested multivariate analysis of variance (MANOVA) to compare soil nutrient properties between Coole Garryland and East Burren. Data were rank transformed prior to MANOVA (Conover & Iman, 1981) as transformation did not correct for non-normality and constancy of error terms. We subsequently used nested univariate analysis of variance on ranks to determine which properties differ between karst flow types. The total variance percentage attributed to each component was estimated by dividing the component variance by total variance for each soil property.

Trends in nutrient availability along each transect within each turlough were investigated using linear graphs. Coefficients of variation (CV) were calculated for each soil property to provide a relative assessment of variation along each transect. Data from both turlough flooding gradients were pooled for examination of the relationships between the available fractions of N and P and soil physico-chemical properties. Relationships between soil physico-chemical characteristics and Pw, Nitrate-N, Ammonium-N, Nin were investigated using scatterplots and Spearman Rank correlation as the data were non-normal. Linear stepwise multiple regressions were performed to assess the relative and/or unique contributions of soil properties (Pox, Feox, OM, SM, pH and SD) in the prediction of Nin and Pw in turlough soils. Pw, Pox, Feox and SD were log transformed prior to multiple regression analysis to achieve approximately linear relationships between independent variables and

Pw. Multiple regression analyses were not performed on Nitrate-N as transformation did not achieve an approximately linear relationship with soil predictors. Data analyses were carried out using SPSS 16.0 (Norusis, 2008).

6.4.3 Results

6.4.3.1 Soil Property Comparisons Between Turlough Types

Figure 6.15 shows the boxplots of the soil properties for Coole Garryland and East Burren. Using Pillai's trace, there was a significant difference between the soil properties of the two turlough types, V=0.92, F (7, 24) = 38.3, $p < 0.001$. Subsequent separate univariate ANOVAs revealed highly significant effects of hydrogeological setting on pH, F (1, 30) = 28.14, $p < 0.001$, OM, F (1, 30) = 33.5, $p < 0.001$, and INORG, F (1, 30) = 59.39, $p < 0.001$. Turloughs in Coole Garryland exhibited a broad soil pH range, ranging from moderately acidic to moderately alkaline whereas East Burren turlough soils were predominantly highly alkaline (Fig. 6.15a). Coole Garryland turlough soils are mineral, characterised by low proportions of OM and $CaCO_3$ relative to INORG. East Burren turloughs have distinctly more organic, often peaty, soils (Fig. 6.15b). A high proportion of variability in $CaCO_3$ was not explained by type or turlough (Table 6.14). The $CaCO_3$ content of soils in the East Burren was highly skewed ranging from 3.3% to 69.6%, whereas in Coole Garryland the contents ranged between 3.3% and 16.9% (Fig. 6.15b). There was no significant difference in TN, TP or Pfeo between Coole Garryland and East Burren. The majority of TN and Pfeo variation was not explained by type or turlough and the majority of TP variation was attributed to variation among turloughs within type (Table 6.14). Contrary to expectations, highest concentrations of TN, TP and Pfeo occurred within East Burren (Fig. 6.15 c, d and e respectively).

Table 6.14 Analysis of variance was used to determine which soil properties differ between karst flow types and to determine the proportion (%) of total soil property variability explained by each of Type, Turlough and Error (component variance/total variance).

Variable	*Type*	*Turlough*	*Error*
pH	34	29	37
%$CaCO_3$	2	16	82
%OM	45	14	41
%INORG	57	14	29
TN (mg kg^{-1})	11	31	58
TP (mg kg^{-1})	6	56	38
Pfeo (mg kg^{-1})	1	15	84

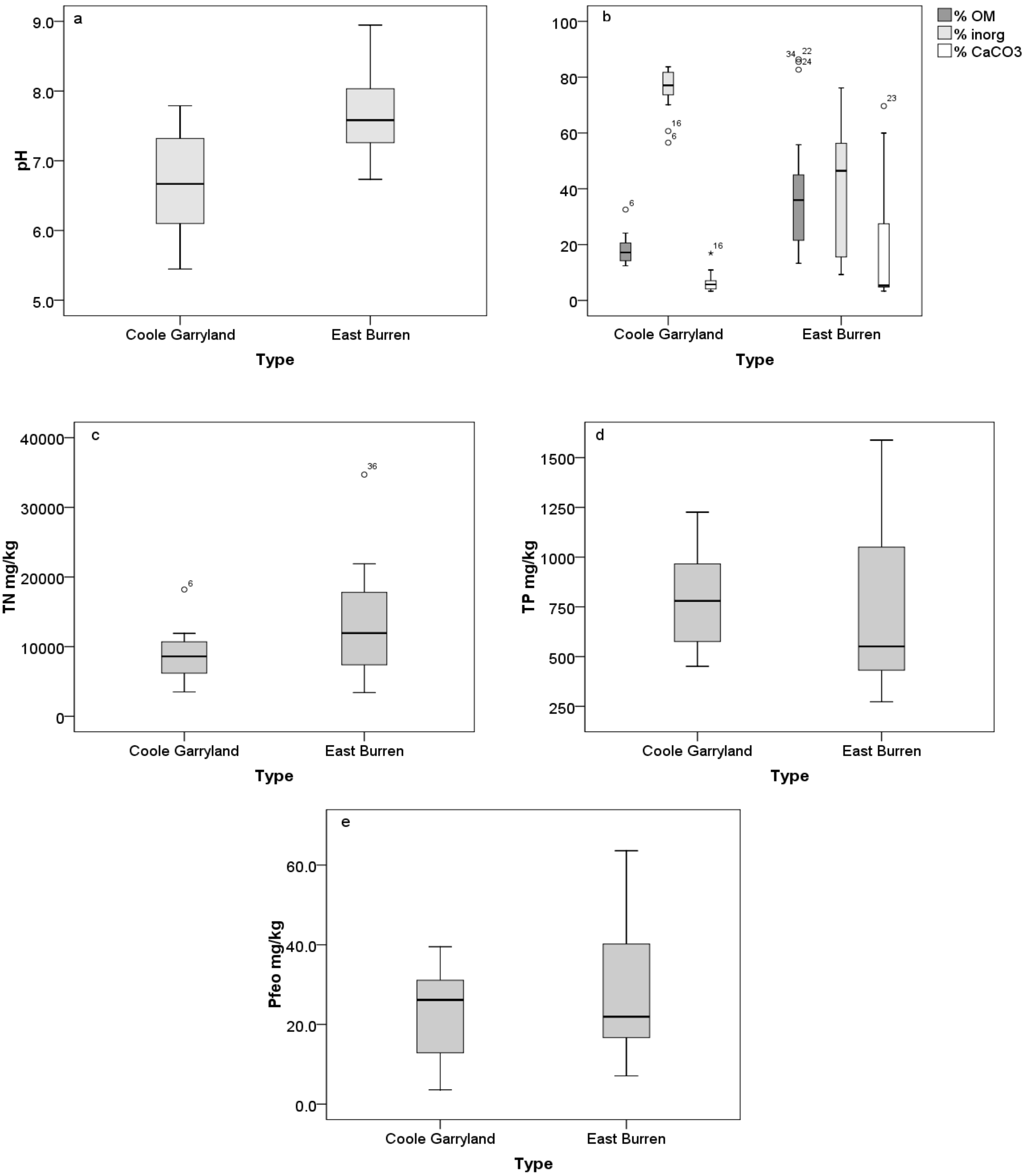


Figure 6.15 Boxplots of a) pH; b) organic matter content (OM), calcium carbonate content ($CaCO_3$) and non-calcareous inorganic content (INORG), c) total nitrogen (TN); d) total phosphorus (TP) and e) desorbable phosphorus (Pfeo) for Coole Garryland and East Burren turloughs.

6.4.3.2 Spatial Variation of Available Nitrogen and Phosphorus Along Turlough Flooding Gradients

Spatial trends in available N and P along the flooding gradients of Garryland and Cooloorta turloughs are presented in Fig. 6.16a-h. Scales were standardised across turloughs for each variable and zonation (upper, middle and lower) was indicated to facilitate a visual comparison of trends along the flooding gradients of both turloughs. In Garryland, TN ranged between 5657 and 16125 mg kg^{-1} and exhibited a general linear increase with decreasing elevation along the majority of the transect length. Deviations from this trend occurred with the lower zones, where TN exhibited marked fluctuations (Fig. 6.16a). Ammonium-N remained consistently higher than Nitrate-N along the Garryland flooding gradient, with the exception of samples from the middle zone where the concentrations converged at a very low level. The majority of soils had Ammonium-N concentrations below 30 mg kg^{-1} with the exception of sample 16 which had an elevated concentration approaching 70 mg kg^{-1} (Fig. 6.16b). Nitrate-N remained below 10 mg kg^{-1} along the flooding gradient with very low concentrations recorded in the middle and lower zones. TN concentrations ranged from 7900 to 23,390 mg kg^{-1} in Cooloorta. The majority of concentrations were below 15,000 mg kg^{-1} with elevated concentrations in samples 8 and 9 in the lower zone (Fig. 6.16e). Ammonium-N was consistently higher than Nitrate-N in the upper and middle zones. A shift in this trend occurred within the lower zone where concentrations of both forms of available N decreased to a similarly low magnitude (Fig. 6.16f). A sharp increase in Ammonium-N occurred between samples 9 and 10, where concentrations increased from 5.47 to 26.12 mg kg^{-1}.

Coefficients of variation for TN were similar along the Garryland and Cooloorta flooding gradients (Fig. 6.16 a; e). Ammonium-N varied to a greater degree than Nitrate-N in Garryland whereas Nitrate-N varied to a greater degree than Ammonium-N in Cooloorta (Fig. 6.16 b; f). Along the Garryland flooding gradient Pw ranged between 0.41 and 2.93 mg kg^{-1} and exhibited an erratic trend along the flooding gradient (Figure 6.16c). The majority of Pox concentrations remained below 200 mg kg^{-1} with the exception of sample 16 which had concentrations approaching 600 mg kg^{-1} (Figure 6.16d). In Cooloorta, Pw ranged between 0.16 and 0.58 mg kg^{-1} and exhibited a stable trend along the flooding gradient (Fig. 6.16g). Pox concentrations were consistently very low within the upper and middle zones. Highest Pox concentrations occurred within the lower zone in Cooloorta where concentrations reached a maximum of 240 mg kg^{-1} (Fig. 6.16h).

Coefficients of variation indicated that Pw varied to a greater degree in Garryland than Cooloorta (Fig. 6.16c; g) whereas Pox varied to similarly high degree within both turloughs (Fig. 6.16d; h).

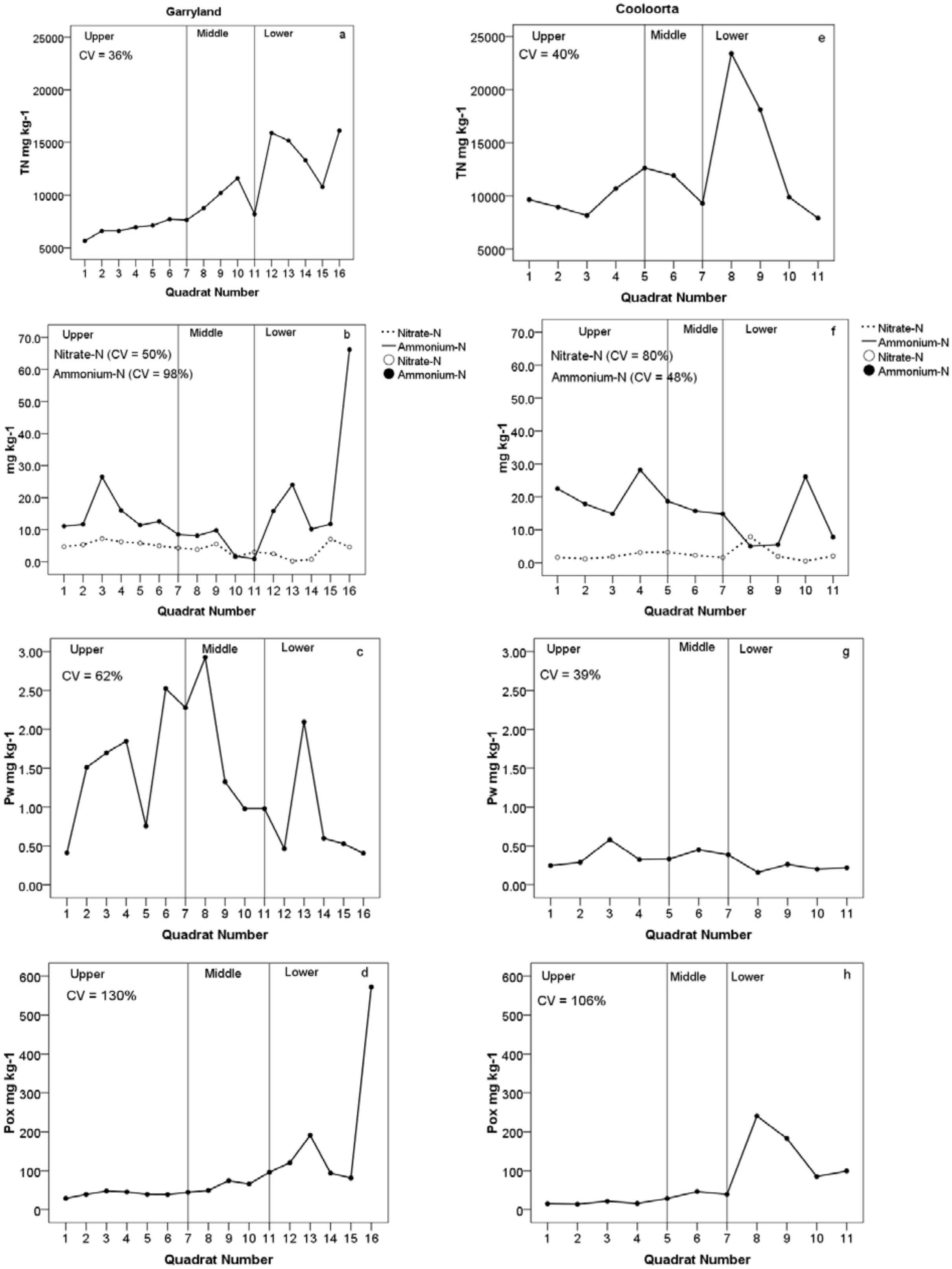


Figure 6.16 Spatial variation of total nitrogen (TN), nitrate-nitrogen (Nitrate-N), ammonium-nitrogen (Ammonium-N), water extractable Phosphorus (Pw) and oxalate extractable phosphorus (Pox) along the flooding gradients of Garryland and Cooloorta turloughs. Upper = Upper elevation zone; Middle = Middle elevation zone and Lower = Lower elevation zone. CV=Coefficient of variation.

6.4.3.3 Relationships Between Available Forms of Nitrogen and Phosphorus and Soil Properties

Results of correlations between Nitrate-N, Ammonium-N and Nin and TN, OM, pH, SM and SD are presented in Table 6.15. Results of correlations between Pw and Pox and Feox, OM, pH, SM and SD are presented in Table 6.16. Significant negative correlations ($p < 0.01$) were detected between Nitrate-N and pH, Pw and OM and Pw and pH. A significant positive association was found between Pw and Feox. The relationship between Nitrate-N and pH has a low Spearman r value (< 0.6) as indicated by the wide spread of points (Fig. 6.17a). A wide spread of points also characterises the relationship between Pw and Feox (Fig. 6.17b). Samples with Feox concentrations ranging between 7000-9000 mg kg^{-1} have a wide range of Pw concentrations. Pw has a curvilinear association with pH and OM (Fig. 6.17c). A wide range of Pw concentrations are associated with acidic soils whereas soils in the alkaline range all have Pw concentrations less than 0.05 mg kg^{-1}. Soils with less than 20% OM have a wide range of Pw concentrations whilst the majority of soils with OM contents in excess of 20% OM have Pw concentrations less than 1 mg kg^{-1} (Fig. 6.17d).

Table 6.15 Spearman Rank coefficients and p values of correlations between Nitrate-N, Ammonium-N and total inorganic N (Nin) and selected soil property variables (N=27). Highlighted values** are significant at the p < 0.01 level.

Variable		*Nitrate-N*	*Ammonium-N*	*Nin*
TN (mg kg^{-1})	Coefficient	-0.324	0.053	0.030
	p	0.099	0.794	0.881
%Organic Matter	Coefficient	-0.380	0.194	0.155
	p	0.051	0.332	0.440
pH	Coefficient	-0.578	0.143	0.037
	p	0.002**	0.475	0.854
%Soil Moisture	Coefficient	-0.212	0.058	0.074
	p	0.289	0.774	0.714
Soil Depth (cm)	Coefficient	-0.321	-0.091	0.092
	p	0.102	0.653	0.646

Multiple regression did not identify any soil property variable as a significant predictor of Nin. pH was identified as a significant negative predictor of Pw ($F_{1,25}$ = 32.551, $ß$ = -0.75, $p < 0.001$), readily available P decreases as pH increases. pH accounts for 56.6% of variation in Pw (R^2= 0.57). A generalised model would account for approximately 1.8% less variance in the outcome (R^2_{adj} = 0.55). No other variables were identified as significant predictors of Pw in this model. Examination of standardised residuals did not identify any outlying cases. The residuals were approximately normally distributed and the tolerance statistic indicated that there was no multicollinearity between predictors. Evidence of mild heteroscedasticity was identified. The assumption of independent errors is tenable (Durbin-Watson = 1.765).

Table 6.16 Spearman Rank coefficients and p values of correlations between water extractable P (Pw) and oxalate extractable P (Pox) and selected soil property variables (N=27). Highlighted values** are significant at the p < 0.01 level.

Variable		*Pw*
Pox (mg kg^{-1})	Coefficient	-0.082
	p	0.875
Feox **(**mg kg^{-1})	Coefficient	0.619
	p	0.001**
%Organic Matter	Coefficient	-0.553
	p	0.003**
pH	Coefficient	-0.694
	p	0.000**
%Soil Moisture	Coefficient	-0.356
	p	0.068
Soil Depth (cm)	Coefficient	-0.355
	p	0.069

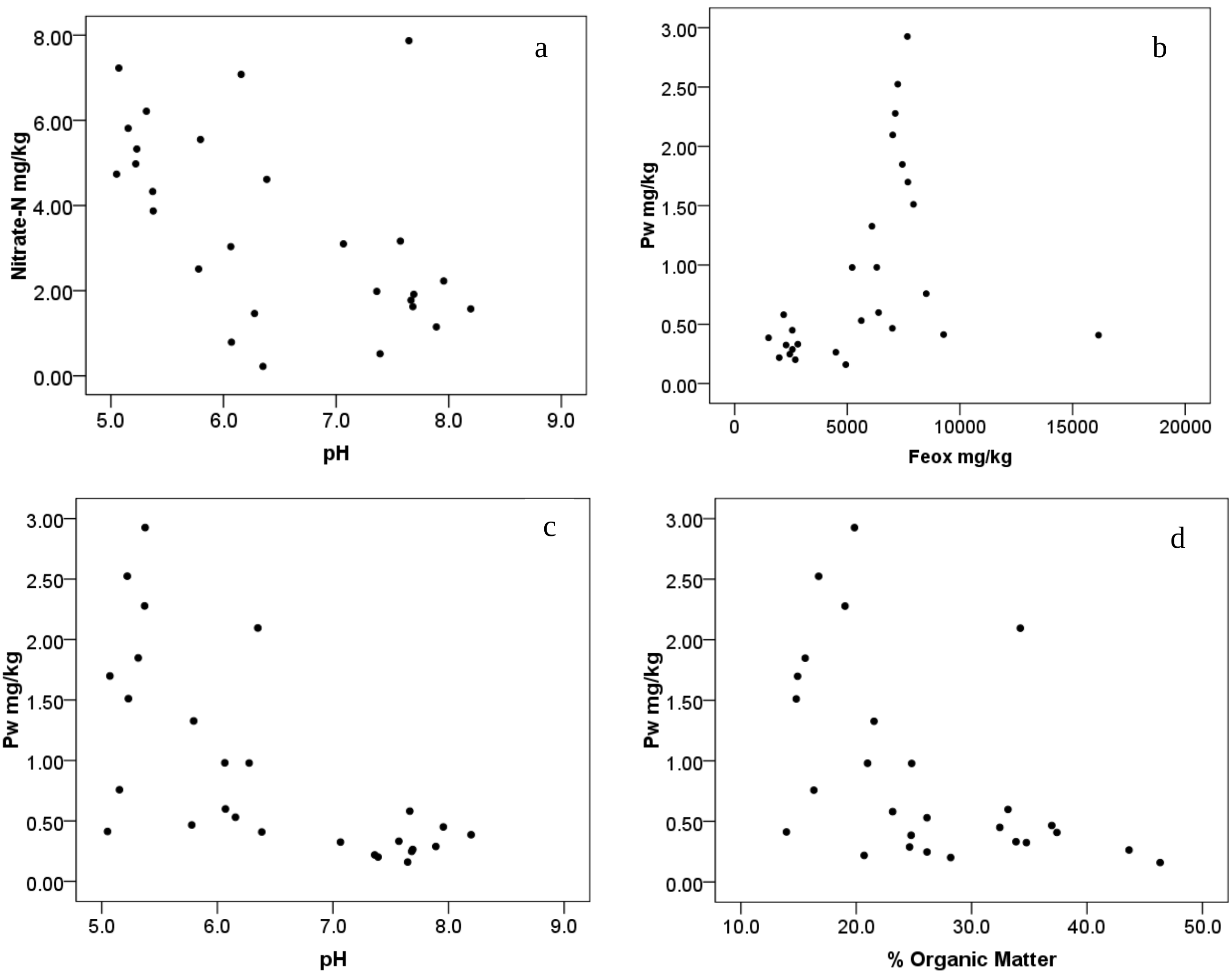


Figure 6.17 Scatter plots of a) Nitrate-N and pH; b) water extractable P (Pw) and reducible Fe (Feox); C) water extractable P (Pw) and pH and d) water extractable P (Pw) and % Organic Matter.

6.4.4 Discussion

6.4.4.1 Spatial Variation of Nutrient-Related Turlough Soil Properties

The more alkaline and peaty soils of East Burren turloughs reflect the longer flood durations associated with these shallow epikarst turloughs. Visser *et al.* (2006) identified floodwater alkalinity as a critically important variable in the dry-wet turlough gradient. Mean seasonal alkalinities of Garryland (217 mg l^{-1} $CaCO_3$), Caherglassan (216 mg l^{-1} $CaCO_3$) and Knockaunroe (228 mg l^{-1} $CaCO_3$) (Cunha Pereira *et al.,* 2010) indicate a similar alkalinity status for Coole Garryland and East Burren, however, and the more calcareous nature of the East Burren turlough soils is likely the result of longer hydroperiods and consequent greater duration of calcium carbonate deposition. Coxon (1994) found that marl (calcite deposition) accumulation in the sedimentary record was associated with a longer duration of flooding than sand/silt and silt/clay deposits. Longer hydroperiods are also likely to exert a positive influence on present day marl deposition. $CaCO_3$ in turlough soils is also derived from the accumulation of snail shell marl. The wider range of $CaCO_3$ associated with East Burren may also be the result of shell marl accumulation in these turloughs. Large numbers of fresh-water snails are associated with a more permanent water body (Coxon, 1994). Turloughs representative of the dry end of the hydrological continuum, which generally empty completely, have a poor snail fauna, with numerous snails occurring only in small permanent pools (Donaldson *et al.* 1979). Marl accumulation in soils is likely to influence turlough ecological functioning by, *inter alia*, promoting calciphilic flora (Bartgis & Lang, 1984). Attempts to evaluate the influence of marl accumulation on turlough ecological functioning should be cognisant of spatial variability in $CaCO_3$ and its origin.

The peaty nature of the East Burren turloughs suggests that the hydrological conditions induce organic matter accumulation in these turloughs. Retarded organic matter oxidation and mineralization are characteristic of wetlands largely owing to factors such as inhibited microbial activity, and the absence of electron acceptors such as iron oxides and hydroxides (Sahrawat, 2004). The dominance of sedge and reed dominated plant communities with high lignin contents in the East Burren would also negatively influence the organic matter decomposition rates and promote accumulation. The distinctly higher mineral content of Coole Garryland turlough soils may also be attributed to the presence of limestone till which is largely absent from East Burren turloughs.

Limestone till is associated with mostly mineral soil types (Gardiner & Radford, 1980) and promotes the development of more coarsely textured soils.

There was no distinction in soil nutrient status between Coole Garryland and East Burren despite the clear differences in background soil physico-chemical properties. Recent research indicates that turloughs in Coole Garryland have a mesotrophic/eutrophic status whereas turloughs in East Burren have an oligotrophic status (Cunha Pereira *et al.,* 2010). This distinction in floodwater quality is apparently not reflected in the soil nutrient status. The broader range of TN and TP concentrations in East Burren reflects the characteristic N and P accumulation associated with organic soils (Roswall, 1976; Al Abbabas & Barber, 1964). Wetlands exhibit a wide range of TP concentrations (400 to 1600 mg kg^{-1}; Fisher & Reddy, 2001; Xu *et al.,* 2009) and the results from this study indicate an even broader TP range for turlough soils. Site-specific factors such as grazing practices may be an important driver of TP variation among turloughs.

Distinctly lower Pfeo concentrations were expected in East Burren owing to the negative effect of OM on P sorption in agricultural soils (Daly *et al.,* 2001). Highest Pfeo concentrations were actually recorded in East Burren but concentrations within both karst flow systems do not reflect a nutrient enriched condition. The high proportions of residual variances for some nutrient properties observed in the present study suggests that attempts to relate soil trophic conditions to turlough types defined by hydrogeology are compromised by high degrees of spatial variation.

The spatial patterns of available N and P along the flooding gradients of Garryland and Cooloorta reveal the highly variable nature of available nutrients in turlough soils. Lower zone soil moisture contents are indicative of soil saturation and soils may be reduced in these areas. The elevated peak of ammonium-N in the lower zone of Garryland indicates ammonium accumulation. Nitrification is an aerobic process and soil saturation can result in nitrification inhibition and the accumulation of ammonium-N in soils (Ponamperuma, 1972). Anaerobic conditions in soils can also result in the release of iron and aluminium bound P (Verhoeven *et al.,* 1993). Such release processes may account for the elevated Pox concentrations observed within the lower zones of both turloughs.

The relatively higher TN concentrations within the lower zones are the likely result of OM accumulation resulting from longer hydroperiods. Lower zones of turloughs may also accumulate nutrients from surface run-off during the terrestrial phase.

The high degrees of N and P variation observed along the flooding gradients of both turloughs highlight potential difficulties for making meaningful site assessments of turlough soil nutrient status. Beckett and Webster (1971) conducted a useful review of soil variability and compiled available information, from a wide range of sources, on the coefficients of variation associated with a range of soil properties. Comparisons of CVs recorded along the turlough flooding gradients with the median CV for available N (25-30%) and available P (45%) suggests that turlough soils are highly variable and future soils sampling strategies for ecological assessments should conduct preliminary spatial studies prior to sampling. The observed variation of nutrients highlights the importance of replicate sampling within the upper, middle and lower zones to capture the extent of variation in turloughs.

6.4.4.2 Interrelationships of Turlough Soil Properties

Concentrations of Nitrate-N and Ammonium-N are of a similar magnitude along both flooding gradients and generally reflect a low nitrogen environment (< 30 mg kg^{-1}). No soil properties were identified as potential indicators of total inorganic N (Nin) in turlough soils although a decreasing trend in Nitrate-N availability with increasing pH was observed. N availability is not positively associated with TN in turloughs and soils with elevated TN concentrations may present extremely low levels of available forms of N.

Pw concentrations within Garryland and Cooloorta reflect an oligotrophic and ultra-oligotrophic condition respectively. The positive association between Pw and pH and OM and negative association between Pw and Feox indicate that P availability in turloughs is driven by combination of factors. pH was identified as the most significant soil predictor of P. P can be retained by the formation of insoluble Ca-P and Mg-P compounds in alkaline wetland soils (Novak, 2004) and alkaline turlough soils indicate low P availability along turlough flooding gradients. The negative associations between nutrient availability and pH highlight the potentially significant influence of marl accumulation on turlough ecological functioning. Flooding regime and soil moisture conditions also influence the pH status of soils. A decrease in redox potential can increase the pH of acid soils and decrease the pH of alkaline soils (Ponanmperuma, 1972).

Such changes in pH can result in P release to the soil solution (Verhoeven *et al*., 1993) and would be expected to influence P availability in turlough soils.

6.4.5 Conclusions - Soil Property Comparisons Between Turlough Types

- Results from the present study suggest that soils in 'dry' turloughs are not substantially more nutrient rich than 'wet' turloughs. Turloughs representative of both extremes have low levels of available soil nutrients and the nutrient pressures associated with Coole Garryland do not appear to be causing excessive nutrient enrichment of the associated turlough soils.
- Turloughs are characterised by high degrees of variation at different spatial scales and assessments of the trophic status of the terrestrial phase are a challenging exercise, particularly as turloughs contain both dried and saturated turlough soils during the terrestrial phase.
- Elevated concentrations of available forms of N and P were associated with the saturated lower zones. These elevated concentrations may be the result of nutrient accumulation in the lower zones or the product of anaerobic conditions. Field assessments of soil redox potential are advisable during turlough soil sampling to enable adequate interpretation of nutrient data.
- The occurrence and distribution of vegetation communities and plant species indicative of different trophic conditions (Ellenberg, 1988) are likely to be more useful than soil nutrient assessments for assessing the impacts of nutrient pressures on the terrestrial phase of turloughs.
- Future turlough research should focus on evaluating nutrient pressures on turloughs associated with a range of hydrogeological settings reflecting a floodwater P gradient.
- Soil nutrient assessments should not be used for conservation assessment until more detailed research on turlough soil N and P dynamics is conducted. Such research should focus on N mineralisation rates, nitrification rates, P mineralisation and P retention capacities of mineral, organic and calcareous soils in a range of turloughs representative of a P gradient.
- Soil properties vary to different extents within different turloughs and future soil research should conduct preliminary spatial assessments prior to establishing experimental designs.

6.5 Temporal Variation of Soil Nutrient Properties in Turloughs

6.5.1 Introduction

Turlough description according to substrate trophy, in addition to hydrochemistry, is required to adequately understand ecological factors such as turlough vegetation community dynamics (Tynan *et al*., 2006) and to provide a holistic assessment of turlough trophic conditions. It is well recognised that spatial and temporal variation in soil properties present a major challenge to ecologists attempting to assess either the present status or changes in ecosystems, as soil variation can affect both the precision of estimates and the ability to detect true underlying relationships (Mader, 1963; Grigal *et al*., 1991; Robertson & Gross, 1994).

The periodic drying up of wetlands has a marked effect on system function as the aquatic component disappears and soil microbial processes become terrestrial (Howard-Williams, 1985). There is plentiful evidence of seasonal variation in the availability of N and P in agricultural soils (Pote *et al.*, 1999) but information on the temporal variation of these key nutrients in wetland soils is limited, and absent for turloughs. During the period from April to October the lower elevations of many turloughs often remain saturated and nutrient cycling would be expected to follow that of a wetland soil that never dries out, in contrast to shallow soils on the middle and upper slopes of basins which generally dry out completely. Turlough soil nutrient availability would be expected to vary markedly with time at any given location as soils dry out and processes shift from anaerobic to aerobic. We aimed to evaluate the effect of sampling period on soil nutrient status comparisons among two turloughs representative of contrasting trophic conditions. This work was carried out as part of Sarah Kimberley`s PhD research, which predates the project *Assessing the Conservation Status of Turloughs*.

6.5.2 Methods

6.5.2.1 Site Selection and Sampling

Two permanent 3m x 3m plots were located within the upper, middle and lower zones within two turloughs: Garryland turlough, Co. Galway and Knockaunroe turlough, Co. Clare (See Section 6.2.2 for location of sites). Garryland has mesotrophic floodwaters whereas Knockaunroe has oligotrophic floodwaters (Cunha Pereira *et al.*, 2010). Sampling commenced in mid June 2004, when floodwaters had receded, and finished in mid August 2004, immediately prior to inundation.

Samples were collected on five sampling occasions, including mid June, early July, mid July, early August and mid August. Ten cores were collected from each plot to a depth of 10 cm depth and were combined to form a composite sample.

6.5.2.2 Laboratory Analyses

Samples were analysed in duplicate for water extractable P (Pw) (van der Paaw, 1971) and available forms of nitrogen (NO_3-N and NH_4-N) (Mulvaney, 1996). NO_3-N and NH_4-N were summed to give an estimate of total available N (Nin). Soil moisture was determined on a single representative sub-sample collected from each plot on each sampling occasion (Allen, 1989). Analyses of available nutrients were conducted on moist samples within one week of collection. Soils were stored in polythene bags placed in cool boxes and subsequently sieved through a 4mm sieve and thoroughly homogenised. Samples collected during mid June were analysed for pH (Allen, 1989), OM (Allen, 1989) and $CaCO_3$ (Dean, 1974), TP (Kuo, 1996) and TN (Verado *et al.*, 1990), as described in section 6.2.2.2. These analyses were conducted on soils oven dried for 48 hrs at 35^oC and passed through a 2 mm sieve.

6.5.2.3 Data Analyses

One-way ANOVA was used compare TN and TP between Garryland and Knockaunroe. Repeated measures ANOVA as a nested model was used to compare Pw, NO_3-N and NH_4-N Nin among turloughs over time. Factors in the nested form of the repeated measures design included Turlough, Zone and Replicate Plot and Sampling Period. A Turlough*Sampling period interaction was added to facilitate the comparison between turloughs at each sampling period.

6.5.3 Results

Soils in Garryland turlough are moderately acidic and mineral in nature with mean TN and TP concentrations of 9137 and 824 mg kg^{-1} respectively. Knockaunroe soils are distinctly alkaline and peaty with highly variable $CaCO_3$ contents. Knockaunroe had a mean TN and TP of 19246 and 585 mg kg^{-1} respectively (Table 6.17). There was no significant difference in TP between turloughs. Knockaunroe had significantly high TN than Garryland, F (1, 12) = 7.34, p < 0.05.

Knockaunroe soils had mean soil moisture contents in excess of 50% throughout the terrestrial phase whereas soil moisture contents in Garryland were less than 50% (Figure 6.18e).

During the terrestrial phase mean Nin concentrations ranged between 16.5 and 43.6 mg kg^{-1} in Garryland and 30.9 and 67.5 mg kg^{-1} in Knockaunroe (Figure 6.18a). NH_4-N accounted for the majority of available N in Knockaunroe and consequently temporal patterns closely follow that of Nin with NH_4-N concentrations ranging between 14.0 and 56.0 mg/kg (Figure 6.18c). Extremely high amounts of NH_4-N variation were recorded at Knockaunroe during Early July and at both Garryland and Knockaunroe during Mid July. NO_3-N concentrations generally remained higher than NH_4-N in Garryland during the terrestrial phase and remained below 25 mg/kg in both turloughs throughout the terrestrial phase (Figure 6.18b). Mauchly`s test indicated that the assumption of sphericity had been violated for Nin, X^2 (9) = 40.29, $p < 0.001$, NH_4-N, X^2 (9) = 40.29, $p < 0.001$, and NO_3-N, X^2 (9) = 21.50, $p < 0.05$, therefore multivariate tests are reported. There was no significant interaction effect between turlough and sampling period for Nin or NO_3-N indicating that these variables did not differ significantly between turloughs at any sampling period. There was a weakly significant interaction effect between turlough and sampling period for NH_4-N, V =0.723, F (4, 7) = 4.57, $p < 0.05$ indicating that differences of NH_4-N between turloughs are dependent on sampling period (Figure 6.18c).

Table 6.17 Background soil properties within Garryland turlough and Knockaunroe turlough. Data shown are mean ± 1SD. N=6

Soil Property	*Garryland*	*Knockaunroe*
pH	6.4±0.3	7.9±0.2
%OM	22.6±5.2	40.0±16.9
%$CaCO_3$	11.4±7.9	33.0±28.0
%INORG	65.9±4.6	26.9±17.9
TN mg kg^{-1}	9137±2031	19246±8911
TP mg kg^{-1}	824±185	585±306

Mean Pw concentrations ranged between 1.10 and 2.40 mg kg^{-1} at Garryland and 0.36 and 1.62 mg kg^{-1} at Knockaunroe during the terrestrial phase. Mauchly`s test indicated that the assumption of sphericity had been met, X^2 (9) = 15.96. There was a weakly significant interaction effect between turlough and sampling period for Pw, F (4, 40) = 3.234, $p < 0.05$ indicating that differences between turloughs are dependent on sampling period (Figure 6.18d). Garryland had higher Pw concentrations than Knockaunroe during Mid July and Early August. Differences between sites were obscured by high degrees of spatial variation within Garryland during Mid June, Early August and Mid August.

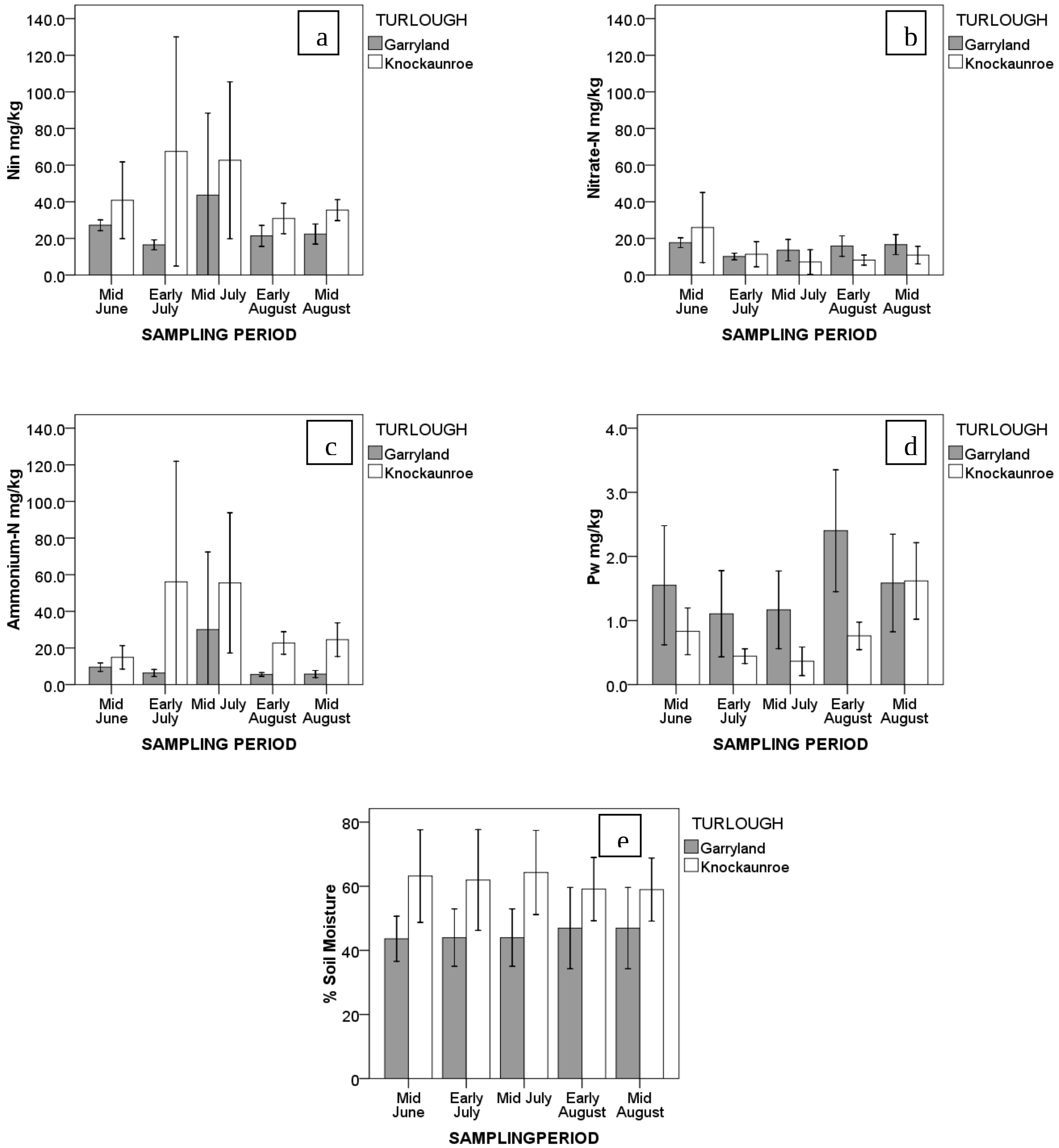


Figure 6.18 Comparisons of a) mean total inorganic N (Nin); b) mean Nitrate-N; c) mean Ammonium-N; d) mean water-extractable P (P_w) and e) Soil Moisture between Garryland and Knockaunroe at different sampling periods.

6.5.4 Discussion

The results from this study show that nutrient availability in turlough soils is highly temporally variable and that the degree of spatial variation varies at different times during the terrestrial phase. Clear differences in mean NH_4-N concentrations between turloughs were evident at some sampling periods during the terrestrial phase but not at others. There were no clear differences in Nin and NO_3-N between the two turloughs at any point during the terrestrial phase. The higher TN concentrations at Knockaunroe may account for the elevated NH_4-N concentrations at this site. The TN content of soils is generally very diverse ranging from less than 0.1% (1000 mg kg^{-1}) to over 2% (20,000 mg kg^{-1}) in highly organic soils (Haynes, 1986) and TN concentrations at Knockaunroe are at the high end of this range. The elevated NH_4-N concentrations at Knockaunroe may also be attributed to soil wetness. Knockaunroe soils had high soil moisture contents during the terrestrial phase and such conditions may inhibit nitrification, resulting in NH_4-N accumulation. The high degrees of within-turlough spatial variation of NH_4-N during the Early July and Mid July are likely owing to the patchy drying of soils. Soil N dynamics are sensitive to shifts in moisture content and present major challenges for comparing soil N fertility among turloughs. Turlough soil N assessments should include only unsaturated soils, as sampling both saturated and unsaturated soils is likely to result in a highly skewed data set.

Cunha Pereira *et al*. (2010) report a mesotrophic and oligotrophic status for Garryland based on mean floodwater TP and Chl*a* respectively. Knockaunroe floodwater TP and Chl*a* both reflect an oligotrophic status. A wide range of TP concentrations (400 to 1600 mg kg^{-1}) have been reported for wetlands (Fisher & Reddy, 2001; Xu *et al.*, 2009). Relating the mean TP concentrations for Garryland and Knockaunroe to this range indicates a mesotrophic (800-1200 mg kg^{-1}) and oligotrophic (400-800 mg kg^{-1}) status respectively. There is some agreement therefore between the soil TP and floodwater TP conditions within both turloughs. Mean Pw consistently reflected an oligotrophic condition, however, within both turloughs throughout the terrestrial phase. Attempts to assess the link between turlough floodwater quality and soil nutrient status should analyse for a range of soil P fractions, including the P retention capacity of the soils, in order to achieve a full assessment of soil P status.

6.5.5 Conclusions - Temporal Variation of Turlough Soil Nutrient Properties

N availability in turloughs is highly spatially and temporally variable. Comparisons of soil N status among turloughs using sub-samples analysed for NO_3-N and NH_4-N are unlikely to yield meaningful results. Investigations of N mineralisation and nitrification rates would more adequately inform turlough N cycling and the processes driving soil N availability.

- The present study indicates that sampling period is important for detecting differences in P status among turloughs and soil sampling strategies should therefore be cognisant of temporal variability.
- Future studies on the temporal variation of nutrients in turlough soils should involve moist sample analysis, which provides a better reflection of actual conditions. Dried sample analysis may be better for comparing nutrient status among turloughs as they reflect differences in potential nutrient availability.
- Future soil sampling strategies for nutrient assessment purposes in turloughs should take soil moisture and redox conditions into account to enable meaningful data interpretation.
- Holistic trophic assessments of turloughs should combine spatial and temporal nutrient information on both the aquatic and terrestrial phases of the habitat, integrated with biological community composition data.

6.6 An Assessment of the Potential for Phosphorus Release from Turlough Soils to Floodwaters

6.6.1 Introduction

Eutrophication presents a significant threat to turloughs. Turloughs can be as productive as permanent lakes and algal biomass is P limited in the majority of turloughs *(Cunha Pereira et al.*, 2010). In addition, trophic status classification of the twenty-two study sites (OECD, 1982) indicates that six turloughs have eutrophic floodwaters. The origin of P in turlough floodwaters is unknown with debate divided on whether the principal source is internal (i.e. directly from grazing livestock and indirectly from turlough soils) or whether it originates in the catchment and is transported into the turlough via groundwater. Nutrient inputs during the dry phase from grazing cattle are considered the primary P input to turlough soils. Hooda *et al*. (1999) suggest that through-soil transport of P from grazing can lead to P loading of surface waters. This occurs via an increase in nutrient loading and P storage in soils, along with increases in soluble forms that can be released to the water column (Fisher & Reddy, 2001). The dynamic hydrology of turloughs and resulting flood-drain conditions of soils increases the potential for P release from soils. The desiccation and re-wetting of wetland soils with high organic content often results in a release of P into the water column (McDowell & Sharpley, 2003). The processes of P release are controlled by environmental factors such as pH, temperature, redox potential, available soil phosphorus and microbial activities (Christophoridis & Fytianos, 2006). Transport processes between soil and the overlying water column affect the availability of phosphorus for assimilation by biota and retention by soils (Reddy & DeLaune, 2008). The transport processes involved in mobilisation of phosphorus between sediment or soil and overlying water column are advection, dispersion, diffusion, seepage, resuspension, sedimentation and bioturbation (Fig. 6.19). Dissolved inorganic and organic P concentrations in soils are typically much higher than the overlying water column; thus the flux of these dissolved components is generally from soil to overlying water column. Particulate P (PP) generated in the water column by detrital tissue or precipitation reactions results in settling on soil surface. The flux of particulate matter is generally from water column to soil. Settling of PP provides long-term retention by wetlands, whereas flux of dissolved components into water column provides bioavailable P to biotic communities.

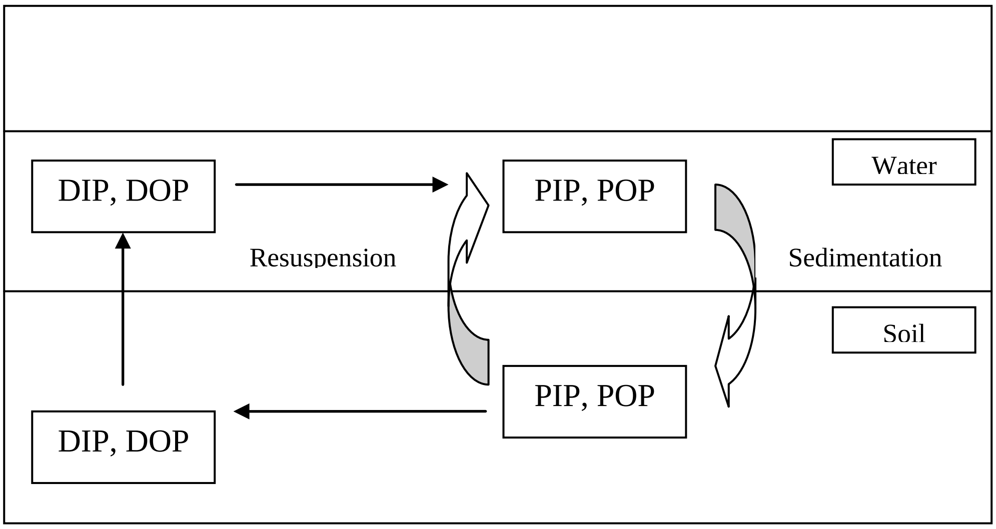


Figure 6.19 A schematic showing exchange processes between water column and soil of turlough when flooded (adapted from Reddy & DeLaune 2008). DIP: Dissolved Inorganic P. DOP: Dissolved Organic P. PIP: Particulate Inorganic P. POP: Particulate Organic P.

Overall net P flux is generally from the water column to the soils or sediments. Continuous accretion of P in soils, however, increases the dissolved P concentrations of soil pore waters which results in flux from sediments to the water column. Although flux of dissolved P is small, it is critical in regulating water quality (Reddy & DeLaune 2008).

In early summer as turlough water recedes, the partial drying of the wet soils would be expected to result in increased sorption of P, thereby reducing its availability. P sorption decreases and P bioavailability increases for up to four months after drying out (Sah & Mikkelsen, 1986). This would make turlough waters vulnerable to P enrichment during flooding in early autumn owing to a reduction in P sorption rates by soils. The case is strong therefore for evaluating contributions of P from soils to floodwaters in turloughs as part of overall investigation of turlough floodwater eutrophication processes. The potential for P release from turlough soils to the water column was assessed via an MSc project conducted by Angela Keane and co-supervised by N. Allott and S. Kimberley. The project aimed to i) compare P release from turlough soils under different management regimes and ii) to assess the eutrophication threat to turlough floodwaters from P released from turlough soils.

6.6.2 Methods

6.6.2.1 P Release From Turlough Soils

P release from Knockaunroe soils (ungrazed/oligotrophic floodwaters) and Lough Aleenaun soils (grazed/eutrophic floodwaters) was compared using a controlled experiment. Five replicate sods were collected from the centre of $1m^2$ quadrats from each turlough and placed into small tanks for transport to TCD Botanic Gardens. Vegetation and soil type were described for each sample (Table 6.18). Soils were classified according to criteria outlined in Section 6.3.2. Sods were artificially flooded for 10 days with turlough floodwater from Lough Gealain (which has very low water TP, see *Chapter 4: Water Chemistry and Algal Biomass*). Water samples were collected from the tanks at hours 0, 3, 5, 7, 23, 27, 50, 123, 170 and 218 after flooding and analysed for TP, SRP and turbidity.

15 soil cores were collected to a depth of 10 cm from the area surrounding the extracted experimental sod within each quadrat. Soil samples were analysed for pH, soil moisture and organic matter content. An inorganic P fractionation scheme determined inorganic P forms representing the readily exchangeable, Fe/Al bound and Ca/Mg bound P extractable pools (Reddy *et al.* 1998). Soil chemistry of the experimental sods is presented in Table 6.9. Soils from both turloughs were moderately alkaline. Knockaunroe soils were wetter and more organic than L. Aleenaun soils. Mean P inorganic and organic fractions were higher in L. Aleenaun compared with Knockaunroe. Organic P accounts for the majority of soil TP in both turloughs (Table 6.19).

Table 6.18 Soil characteristics, parent material and vegetation type of experimental sods.

Turlough	*Sample Code*	*Grid Reference*	*Soil Depth*	*pH*	*Organic matter content %*	*Parent Material*	*Soil Type*	*Vegetation Community (TCD Vegetation Map)*	*Dominant plant species*
Knockaunroe	KNO1	E 131311 N 194151	53 (Shallow)	8.2 Moderately alkaline	69.4 (Peaty)	Karstic Rock	Pt-MRL	*Flooded Pavement*	*Carex nigra, Ranunculus flammula, Baldellia ranunculoides, Juncus spp., Mentha aquatica*
Knockaunroe	KNO2	E 131388 N 194132	49 (Shallow)	7.1 Slightly alkaline	70.7 (Peaty)	Fen Peat	Fen Pt	*Eleocharis palustris-Ranunculus flammula*	*Carex nigra, Mentha aquatic, Juncus spp., Ranunculus flammula, Agrostis stolonifera,*
Knockaunroe	KNO3	E 131441 N 194229	>100 (Deep)	8.2 Moderately alkaline	26.5 (Organic)	Karstic Rock	AlluvMRLPT	*Eleocharis palustris-Ranunculus flammula*	*Carex nigra, Juncus spp., Ranunculus flammula*
Knockaunroe	KNO4	E 131470 N 194243	>100 (Deep)	8.2 Moderately alkaline	29.1 (Organic)	Karstic Rock	AlluvMRLPT	*Flooded Pavement*	*Carex nigra, Juncus spp., Ranunculus flammula*
Knockaunroe	KNO5	E 131421 N 194233	79 (Deep)	7.1 Slightly alkaline	73.8 (Peaty)	Fen Peat	FenPt	*Eleocharis palustris-Ranunculus flammula*	*Carex nigra, Juncus spp., Eleocharis palustris, Mentha aquatica*
L. Aleenaun	ALE1	E 124789 N 195358	17 (Very shallow)	8.0 Moderately alkaline	13.8 (Mineral)	Limestone Till	BminVSW	*Agrostis stolonifera-Glyceria fluitans*	*Agrostis stolonifera, Rumex crispus, Myosotis scorpioides, Plantago lanceolata, Potentilla anserina, Ranunculus repens*
L. Aleenaun	ALE2	E 124694 N 195401	14 (Very shallow)	7.4 Slightly alkaline	27.5 (Organic)	Limestone Till	BorgVSW	*Agrostis stolonifera-Glyceria fluitans*	*Agrostis stolonifera, Rumex acetosa, Plantago lanceolata, Ranunculus repens, Bellis perennis*
L. Aleenaun	ALE3	E 124841 N 195357	13 (Very shallow)	8.3 Moderately alkaline	14.6 (Mineral)	Limestone Till	BminVSW	*Agrostis stolonifera-Glyceria fluitans*	*Agrostis stolonifera, Potentilla anserina, Trifolium repens, Rumex crispus, Myosotis scorpiodes, Ranunculus repens, Plantago lanceolata*
L. Aleenaun	ALE4	E 124942 N 195352	11(Very shallow)	8.1 Moderately alkaline	17.1 (Mineral)	Limestone Till	BminVSW	*Agrostis stolonifera-Glyceria fluitans*	*Agrostis stolonifera, Plantago lanceolata, Ranunculus repens, Galium palustre, Myosotis scorpiodes, Rumex crispus, Potentilla anserina*
L. Aleenaun	ALE5	E 124892 N 195418	>100 (Deep)	8.0 Moderately alkaline	18.2 (Mineral)	Fen Peat	AlluvMRLPT	*Agrostis stolonifera-Glyceria fluitans*	*Agrostis stolonifera, Plantago lanceolata, Ranunculus repens, Galium palustre, Myosotis scorpiodes, Rumex crispus, Potentilla anserina*

Table 6.19 Soil chemistry of sods from Knockaunroe and Lough Aleenaun turloughs. Values shown are the mean ± SD

Variable	*Turlough*	
	Knockaunroe	*L. Aleenaun*
pH	7.8±0.6	8.0± 0.3
%OM	53.9±23.9	18.2±5.5
%SM	71.2±11.7	39.8±5.9
Total P (mg kg^{-1})	1210±318	1536±318
Readily exchangeable P (mg kg^{-1})	0.3±0.2	1.8±1.0
Ca/Mg P(mg kg^{-1})	2.5±1.0	5.9±1.1
Fe/AL P(mg kg^{-1})	263±215	401±124
Total Inorganic P (mg kg^{-1})	363±215	504±125
Organic P (mg kg^{-1})	847±328	1031 493

6.6.2.2 Comparison of Catchment and Within-Turlough Scale Nutrient Pressures on Turlough Floodwater Quality

P contributions from soils to floodwaters were compared with catchment-scale pressure information in order to isolate sources of P to turlough floodwaters. P contributions from soils to L. Aleenaun floodwaters were estimated between 07/11/2006 and 17/11/2006 using the average net increase in SRP, TP and PP between 0 hours and 218 hours. The 07/11/2006 was chosen as this is the first date for which concomitant water quality and hydrological data are available. During this ten day period the floodwater volume and flooded basin surface area at L. Aleenaun increased by 126252 m^2 and 80201 m^2 respectively. On the 07/11/2006 SRP, TP and PP concentrations were 3, 23 and 20 µg l^{-1} respectively.

The Impact Potentials and Risk Categories of the zones of groundwater contribution (ZoC) to Knockaunroe and Lough Aleenaun were compared with a view to evaluating the catchment-scale nutrient pressures on both turloughs. Impact Potentials and Risk Categories for each ZoC were determined via Risk Assessment protocols outlined in Chapter 11.

6.6.2.3 Data Analyses

Trends in P release were displayed using linear graphs. Repeated measures analysis of variance (ANOVA) was used to compare P release among turloughs.

6.6.3 Results

6.6.3.1 P Release From Turlough Soils

There was no significant difference in mean SRP release between Knockaunroe and L. Aleenaun (Fig. 6.20). Mean TP release was significantly higher in L. Aleenaun than Knockaunroe ($F_{1, 4}$ = 8.8084, p = 0.0179) (Fig. 6.21).

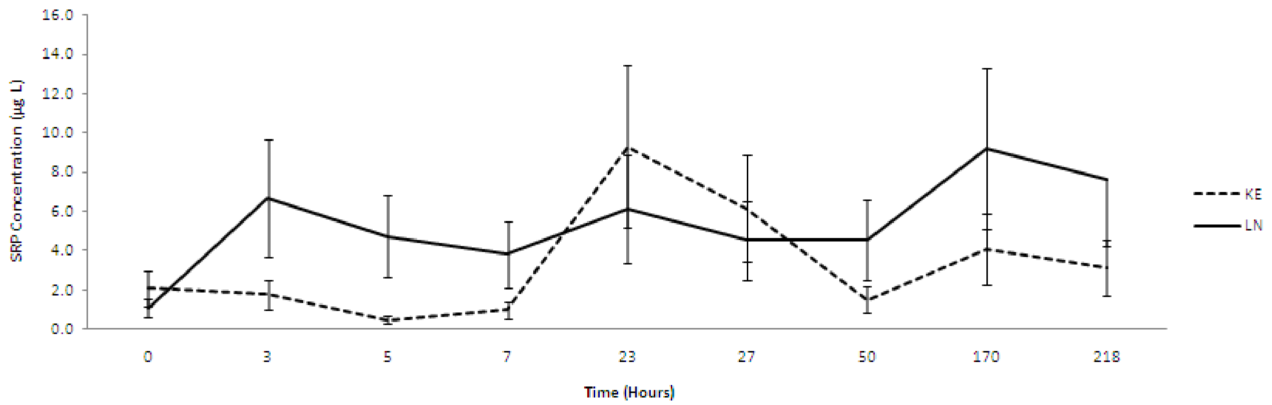


Figure 6.20 SRP release (µg l^{-1}) measured over time for Knockaunroe turlough (KE) and Lough Aleenaun (LN) turlough.

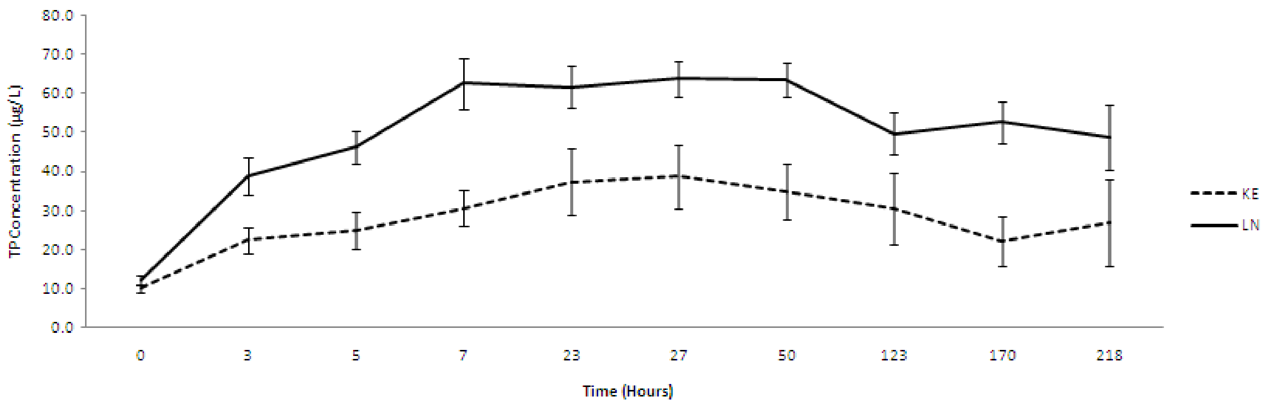


Figure 6.21 TP release (µg l^{-1}) measured over time for Knockaunroe turlough (KR) and Lough Aleenaun (LN) turlough.

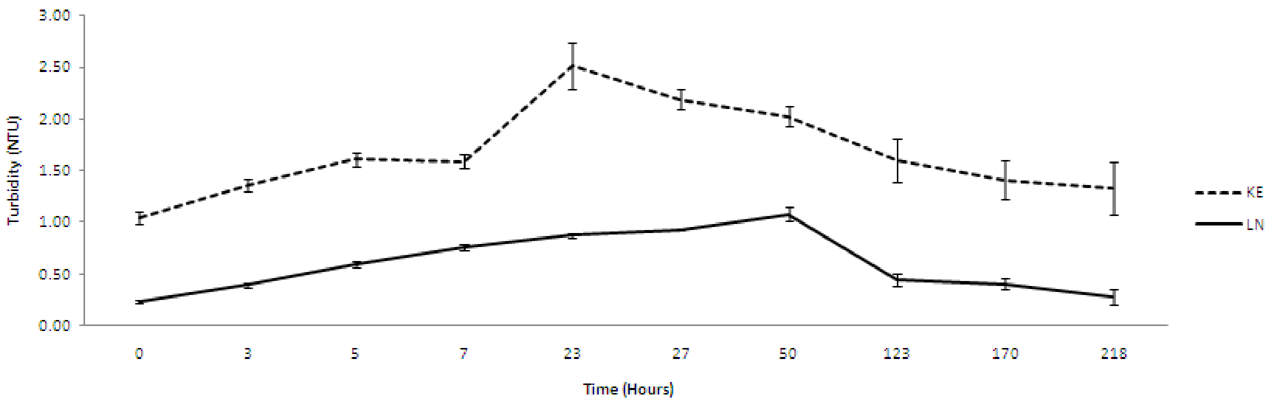


Figure 6.22 Turbidity (NTU) measured over time for Knockaunroe turlough (KE) and Lough Aleenaun (LN) turlough.

Turbidity was consistently higher in Knockaunroe than L. Aleenaun. In Knockaunroe, the level of turbidity increased until 23 hrs before decreasing. Turbidity generally increased until 50 hours in L. Aleenaun before steadily decreasing (Fig. 6.22) indicating a continuous release of suspended matter into the water column over two days. Gas bubbles were observed in both experimental scenarios and the release of particulate matter to the water column is probably owing to gas being released from the soils as they become reduced. Particulate P was the largest fraction of P released to the water column which also indicates a resuspension of soil particles from soil to the water column.

Estimates of SRP, TP and PP inputs from soils between 07/11/2006 and 17/11/2006 are presented in Table 6.20. These results indicate negligible P contributions from soils to floodwaters during this period.

Table 6.20 Estimated P loading from soils between 07/11/2006 and 17/11/2006 at L. Aleenaun.

Increase in Vol.m^3	*Increase in SA m^2*	*Estimated SRP contribution from soils ($\mu g\ l^{-1}$)*	*Estimated TP contribution from soils ($\mu g\ l^{-1}$)*	*Estimated PP contribution from soils ($\mu g\ l^{-1}$)*
126252	80201	0.2	0.9	0.7

6.6.3.2 Comparison of catchment-scale and within-turlough scale influences on turlough floodwater quality

The pressures within the zones of groundwater (ZoC) contributing to each turlough were compared with a view to isolating sources of P to Lough Aleenaun (Table 6.21). Zones of groundwater contributing to both turloughs are assigned to TCD Risk Category 1B which identifies the turloughs as probably at significant risk. No areas of Extreme or High Impact Potential occurred in either ZoC. Lough Aleenaun ZoC has a 17% more Moderate Impact Potential area compared with Knockaunroe. Both ZoCs have equal livestock densities and the number of septic tanks is five times higher in Knockaunroe ZoC than Lough Aleenaun ZoC. The proportion of ZoC occupied by Improved Pasture is similar for both turloughs.

Table 6.21 Landuse pressures within the zone of groundwater contributing to Knockaunroe and L. Aleenaun turloughs.

Turlough	*TCD RA Category Predicted/ Adjusted*	*% Extreme Impact Potential*	*% High Impact Potential*	*% Moderate Impact Potential*	*% Low Impact Potential*	*Livestock density (LU ha^{-1})*	*Septic tank density km^{-2} Extreme Pathway Susceptibility*	*% Improved Pasture (CORINE)*
Knockaunroe	1B/1B	0	0	79	21	0.4	24	26
L. Aleenaun	1B/1A	0	0	96	2	0.4	5	16

6.6.4 Discussion

The low levels of SRP release observed for Knockaunroe and L. Aleenaun may be accounted for by a combination of factors such as low concentrations of inorganic P, soil alkalinity, high soil moisture contents and the presence of vegetation. Results from the present study show that turlough soils have a high proportion (> 90%) of organic P relative to other wetland surface soils (30-70%) (Reddy *et al.*, 1998). Inorganic P fractions release P more readily under flooded conditions than organic fractions (Reddy *et al.*, 1998; Dunne *et al.*, 2007) as anaerobic P mineralisation is a relatively slower process. Loosely adsorbed P is important for controlling the P concentration of the overlying water column (Reddy *et al*., 1998) and this fraction would be expected to contribute P to floodwaters immediately after inundation.

The pools of readily available soil P were less than 1% of soil TP however in both turloughs and this fraction of soil P does not contribute significant amounts of SRP to floodwaters. The soils of both turloughs are moderately alkaline yet concentrations of Ca/Mg bound P were low in both turloughs. Ca/Mg bound P is highly insoluble under alkaline soil conditions and this fraction is unlikely to have released P to the water column during the experiment.

Fe/Al P was the highest inorganic P fraction in both turloughs. P associated with Fe and Al oxides is only desorbable into solution under extended waterlogging conditions (Patrick & Mahaptra, 1968). Release of P from this fraction to the water column would be expected after soil reduction however the degree and timing of soil reduction during the experiment is unknown. The P release between 50 and 170 hours may be accounted for by release from Fe and Al oxides as soils were likely to be sufficiently reduced by that stage.

Soil moisture contents of experimental soils from Knockaunroe were substantially higher than L. Aleenaun. Flushes of mineral P have been reported for re-wetted substrates as a consequence of drying-induced microbial-cell lysis (Baldwin & Mitchell, 2000) which may account for the initial SRP release in L. Aleenaun. Littoral sediments exposed to wetting/drying cycles have a reduced P affinity compared to sediments which rarely dry out (Watts, 2000). Shallow, coarse textured turlough soils which experience extended dry periods may release flushes of P immediately after inundation and future research on P release should focus on turlough soils which are prone to dessication.

The presence of vegetation may also negatively influence P release to the water column. Bostic and White (2006) investigated the influence of vegetation on wetland P release after flooding and found that vegetated, P-unenriched soil released insignificant amounts of SRP. It has been shown however that plant colonisation during dry periods in P enriched soils is a significant mechanism for P release from the soil (Bostic & White, 2006) and this process could result in the redistribution of soil P under natural conditions in turloughs.

The fact that higher TP concentrations were associated with the less turbid floodwaters of L. Aleenaun suggests that L. Aleenaun soils release relatively more P-enriched particles than Knockaunroe. In shallow lakes during windy periods, resuspension of sediments may be an important mode of P transfer to the water column. P flux by this process may occur at shorter time scales but at more rapid rates compares to diffusive flux (Reddy & DeLaune 2008).

TP release from L. Aleenaun soils increased the trophic status of the experimental floodwaters from oligotrophic to eutrophic. The impact of P release from soils on floodwaters is dependent on the P status of incoming floodwaters, however and oligotrophic floodwaters from L. Gealain were used in this experiment.

Attempts to isolate sources of P to L. Aleenaun floodwaters proved inconclusive. Catchment-scale pressures described here do not account for the difference in floodwater trophic status between L. Aleenaun and Knockaunroe. L. Aleenaun soils exerted a significant positive effect on the TP concentrations of the experimental floodwaters, however when results from the experiment were scaled-up to reflect a more natural scenario, P contributions to floodwaters were negligible.

6.6.5 Conclusion – P Release From Turlough Soils

- Turlough soils with relatively higher inorganic P fractions do not release significant amounts of SRP to the water column.
- Particulate P contributions from relatively p-enriched soils can potentially influence floodwater TP concentrations although further research is necessary to adequately quantify such contributions.
- Identifying key nutrient pressures on turloughs is an extremely challenging task requiring a focussed case study research approach. Such an approach would allow for the collection of detailed information on nutrient pressures at various scales.
- Evaluating the specific influence of soils on turlough floodwaters demands an improved understanding of the hydrochemistry of incoming floodwaters and soil P dynamics. Further laboratory based studies on P release rates should use flow-through experimental systems that simulate field conditions by maintaining a higher soil to water column gradient.

6.7 Nutrient Cycling in Turloughs (adapted from Reddy & DeLaune 2008)

6.7.1 Nitrogen Cycling in Turloughs

Wetlands contain a complex assemblage of inorganic and organic nitrogen compounds. The relative proportion of organic and inorganic forms depends on the sources of nitrogen entering the system, and the relative rates and turnover times of these compounds. Organic nitrogen forms are present in dissolved and particulate forms, whereas inorganic nitrogen is present in dissolved forms. Particulate forms are removed through settling and burial, whereas the removal of dissolved forms is regulated by various biogeochemical reactions functioning in soil and the overlying water column. The relative rates of these processes are affected by physicochemical and biological characteristics of the soil and water column and the organic substrates present. The shifts from aquatic to terrestrial phases in turloughs result in oscillation between aerobic and anaerobic soil conditions, which adds a further layer of complexity to describing N cycling within these wetland systems.

6.7.1.1 Nitrogen Inputs

The inputs of N to turloughs include biological N fixation and point and non-point loads from external sources. Dinitrogen (N_2), the most common form of N and making up to 78% of the atmosphere, is biologically broken down by organisms capable of fixing N. Measurable quantities of N also enter via dry and wet deposition. Nitrate N is readily soluble in water and highly mobile in soils and is the predominant form of N entering via springs, estavelles and epikarst flow from point and/or non-point sources. Surface waters, where present, can also contribute N to turloughs. Nitrate N is also the predominant form of N in overland run-off and soil/subsoil throughflow. N inputs from both sources may occur at sites which are surrounded by sloping, agricultural land. N inputs also include livestock deposition of urea, ammonium and nitrate additions from fertilisers and slurry. Generally, half of the nitrogen in cattle slurry is in organic form and the other half is as ammonium. It is noteworthy that fertiliser application to turloughs has never been widespread and the majority of farmers applying fertilisers do so at low rates < 25 N, P or K kg ha^{-1}. Ammonium salt fertilisers applied to aerobic soils are rapidly oxidised to nitrate. Intensive use of these fertilisers coupled with excessive rainfall or irrigation have resulted in elevated levels of nitrate in groundwaters.

Turlough flooding is unpredictable, however, and flooding shortly after fertiliser or slurry application would likely result in a flush of nutrient input to floodwaters which may trigger an algal bloom. European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2010 (S.I. No. 610 of 2010) prohibits the application of inorganic and organic fertilisers to karst features and land liable to flood and this legislation should be enforced in relation to turloughs.

6.7.1.2 Intrasystem N Reservoirs and Transformations

The nitrogen cycle in wetlands can be depicted as the storage of nitrogen in major reservoirs, which serve as a source or a sink, and a flux between those reservoirs. The main storages or reservoirs of N are plant, algal and microbial biomass, particulate and dissolved organic N, inorganic forms of N and gaseous end products. Nitrogen is an essential nutrient for macrophytes and algae and, next to carbon, nitrogen is the largest component of the plant biomass. Some plants and algae can assimilate both ammonium and nitrate nitrogen, and in some cases some soluble organic compounds. Sources of nitrogen to plants include external sources, mineralisation of organic nitrogen in water and soil, and flux of ammonium from the soil to the water column. In addition, algae may obtain nitrogen through biological fixation. N limitation can affect photosynthetic activity, thus controlling overall productivity. Tissue nitrogen is directly related to the amount of available nitrogen in water and soil. Plant biomass is returned to the detrital pool, where it undergoes decomposition and mineralisation of organic N. The largest storage of nitrogen is in organic forms present in soil organic matter. Soil organic N is comprised of humic compounds and complex proteins with a small percentage of amino acids and amines. Soil organic nitrogen is not readily bioavailable and numerous factors influence the bioavailability of N in wetlands e.g. hydrologic fluctuations, water depth and microbial activity. Microbial biomass usually represents 0.5-3.0% of total N and is a key component of the N cycle. Microbial consortia use detrital matter as an energy source and in the process breakdown organic nitrogen to ammonium N. Dissolved organic N can be very important in oligotrophic wetlands, where most of the N is is in the dissolved organic form. A significant portion may be remineralised depending on factors such as microbial activity and nutrient status. Inorganic forms of N stored in wetlands include ammonium, nitrite and nitrate, which occur in various oxidation states. Inorganic forms are not typically stable, comprising < 1% of the total N within wetlands.

Organic N is converted to ammonium N via mineralisation under aerobic or anaerobic conditions and subsequently to nitrate N via aerobic nitrification. Ammonium N is present under acidic soil conditions, whereas ammonia is present under alkaline conditions. Ammonia is absorbed on soil cation exchange complex or fixed in the crystal lattice of clay minerals. Nitrite, a product of nitrification, is rapidly oxidised to nitrate by microorganisms in aerobic environments or reduced to nitrous oxide in anaerobic environments. Together with ammonium, nitrate N is the nitrogen form used by plants, microbes and other biota as a nutrient.

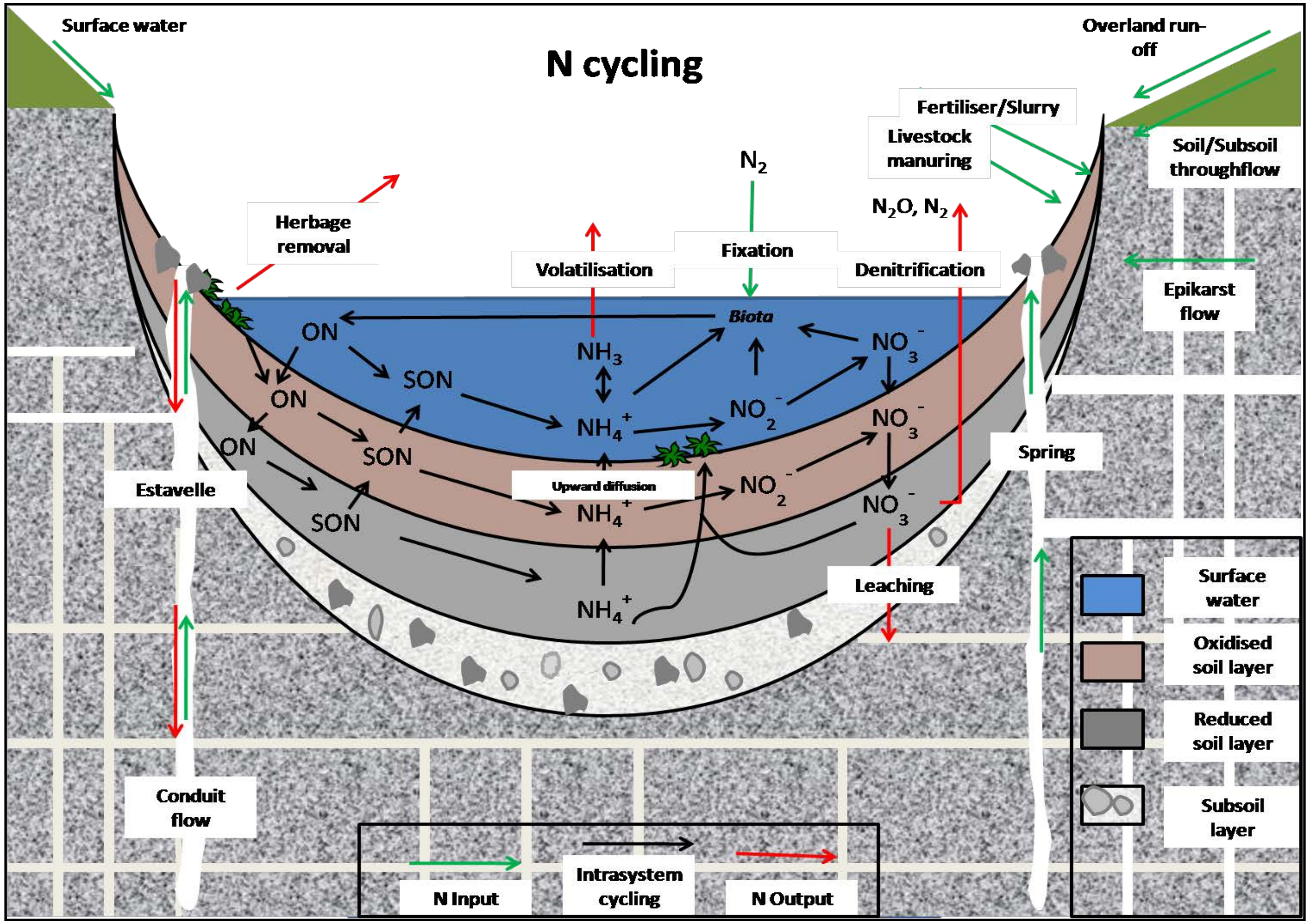


Figure 6.23 Hypothesised nitrogen cycling in turloughs (adapted from Reddy and DeLaune 2008)

6.7.1.3 Nitrogen Outputs

N is lost from turloughs via volatilisation, water outflow, gaseous losses, leaching and plant harvest. Gaseous forms of N include ammonia, nitrous oxide and dinitrogen, which are readily lost to the atmosphere and comprise < 1% of total nitrogen within a wetland. N is exported from wetland systems via ammonia volatilisation under alkaline conditions, where unionised ammonia in its gaseous form can be transported from soil and water column to the atmosphere. In addition, nitrous oxide and dinitrogen, produced during denitrification, can be emitted to the atmosphere. Other outputs include herbage removal, via grazing and hay cutting, and detrital export in wetland outflows. Chracteristically, turloughs lack a surface outflow and N in water outflows and in leachates will enter the groundwater body.

A hypothetical scheme of nitrogen fluxes in turloughs, summarising the above and adapted from Reddy & DeLaune (2008), is given in Figure 6.23.

6.7.2 Phosphorus Cycling in Turloughs

P has been identified as the major limiting nutrient in turlough floodwaters and understanding P dynamics in turloughs is important for understanding the drivers of turlough primary productivity. Depending on P accumulation, wetlands, and presumably turloughs, can function as both a source and a sink for P. P accumulation is regulated by numerous factors including vegetation, periphyton and plankton, soil physicochemical properties, hydraulic retention time, P loading and hydrological fluctuations.

6.7.2.1 P Inputs

P enters turloughs via estavelles, springs, surface water inputs, overland flow, soil/subsoil throughflow, livestock excretions and fertiliser/slurry application. Turloughs are vulnerable to P inputs from groundwaters as they generally occur in areas of karstified limestone bedrock with thin or absent subsoil, where P has little chance for attenuation. To trace the transport and transformation of P within wetlands, it is convenient to classify the forms of P entering these systems as particulate inorganic P (PIP), particulate organic P (POP), soluble organic P (SOP) and PO_3^4 (soluble inorganic P). The relative proportion of each is form in wetlands depends on the soil, vegetation and landuse characteristics of the drainage basin. Soluble inorganic P is considered bioavailable, whereas organic and PP forms generally must be transformed to inorganic forms before being considered bioavailable. As soils become saturated or overloaded with P, a significant portion of the stored P can be released and transported with water during runoff events. Direct inputs from overland flow and soil/subsoil thoughflow will only occur where turloughs are surrounded by sloping agricultural land. Dung deposition is the most significant source of P from livestock in grazed turloughs. Fertiliser and slurry application has never been widespread across turloughs but evidence of fertiliser pellets and slurry was noted in a limited number of sites during the course of this project. P additions can remain in soils and sediments for long-periods and the P legacy (potential release of P retained in soils and sediments) can extend the time required for a wetland to reach an alternate stable state to meet environmental objectives.

The fact that turloughs are P limited, and that P tends to remain in wetlands for extremely long periods, supports the argument for prohibition of fertiliser/slurry application to turlough land set out in European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2010 (S.I. No. 610 of 2010).

6.7.2.2 Intrasystem P Reservoirs and Transformations

Most P inputs to wetlands accumulate in the system and it is important to understand the biogeochemical processes regulating its availability and retention in wetlands. Short-term storage is mediated by assimilation into vegetation and periphyton and incorporation into detrital tissue. Long-term storage is mediated by soil assimilation and accretion of organic and mineral matter.

The speciation of P in water column and soils is pH dependent. The dominant form of P under acidic conditions is H_3PO_4 whereas the dominant species under alkaline conditions is $PO_3{}^4$. Turlough soils have a broad pH range and this situation is likely to influence the distribution of different forms of P. Dissolved P in soil water or the water column can be taken up by algae or plants, and interchanges with organic P via microbes, discrete phosphate minerals and metal oxides and clay mineral surfaces. The majority of P accumulates in soils and abiotic P retention is regulated by various physicochemical properties including pH, redox potential, iron, aluminium and calcium content of soils, organic matter content, P loading and ambient P content of soils. The distribution of P in soils is mainly controlled by hydrological factors, substrate and soil composition and redox conditions. Under most conditions, phosphate reactions do not involve the transfer of electrons therefore the redox potential does not directly affect the inorganic P speciation in most ecosystems. Redox potential, however, directly affects P solubility. In well drained mineral soils, some of the inorganic P is bound to oxidised forms of iron. Under anaerobic soil conditions, oxidised forms of Fe function as electron acceptors and are reduced to ferrous iron, resulting in P release. Adsorption (fast phase) and precipitation (slow phase) are the main retention mechanisms for inorganic P. Readily available P is present in soil pore water and the exchangeable pool. P in this pool is continuously replenished from other stable pools at various rates, depending on the solubility of phosphate minerals and physicochemical properties of soils. Slowly available P is present as compounds that are recently formed during reactions with Fe, Al, Ca and Mg compounds.

The solubility of these chemical precipitates is regulated by pH and redox potential. At any time about 80-90% of the soil P exists in very slowly available discrete mineral forms. Most of the remainder is in slowly available form and less than 1% would be readily available. As discussed in Section 6.5, several abiotic and biotic processes are involved in mobilising P between soil and overlying water column.

Soil type exerts a critical influence on the P retention characteristics of turloughs. Turloughs with mineral soils are more likely to accumulate more P than turloughs with organic soils as it is well documented that wetlands with mineral soils accumulate more P than wetlands with organic soils. The P retention abilities of mineral soils are directly related to amorphous and poorly crystalline forms of Fe and Al. Wetland soils are often characterised by high organic matter contents, thus soil properties and factors regulating the breakdown of organic matter determine the long-term storage of P in the organic pool. Organic P commonly dominates the total P in wetlands usually comprising more than half the soil P. The proportion and type of organic P in wetlands depend on soil type, type of organic loading from external sources, deposition from dead algal cells and detrital tissues from vegetation. Peat-dominated turloughs would be expected to have a higher proportion of organic P compared to turloughs with mineral soils. Organic P associated with humic and fulvic acids represents more than 40% of the total soil P. Only a small proportion of organic P is biologically active. The importance of organic P to biotic communities increases with P limitation.

To fully describe P behaviour in wetlands it is critical to understand the role of microbes, fauna and vegetation, and their interaction, in P cycling. Microorganisms incorporate dissolved P into cellular constituents, which then become integral parts of the particulate matter. Vegetation stores a significant amount of P in above and below ground biomass and is a major source of organic P to turloughs. Biotic process is the major pathway by which organic P is mineralised in wetlands. Microorganisms also can play a major role in retaining P in wetlands with organic matter inputs or those producing large quantities of detrital matter internally. Benthic periphyton utilises P from both soil and the water column, whereas floating periphyton receives P largely from the water column. The periphyton, rather than the macrophytes, functions as the primary scavenger for limiting nutrients such as P from the water column.

During macrophyte senescence the release of organic P is readily utilised by the periphytic community, which develops profusely on plant tissue and detritus. The scavenging capacity of the periphyton, which acts like a biological sieve, can be exceeded if P loading is very high or by rapid water movements. Once P enters the macrophyte-detritus-periphyton community it has a high probability of being recycled and retained. P assimilation and storage in plants depends on vegetative type and growth characteristics. Floating and submerged vegetation has limited potential for long-term P storage. Because of rapid turnover, P storage in biomass is short term, and much of the P is released back into the water column upon vegetative decomposition. Emergent macrophytes have an extensive network of roots and rhizomes and have great potential for P storage. P storage ns below ground biomass of emergent macrophytes is much longer term than that of the above ground biomass. Uptake of P by vegetation maintains low soluble P concentration in the soil profile.

6.7.2.3 Phosphorus Outputs

The P cycle does not have a significant gaseous loss mechanism, thus most added P accumulates in the system. As turloughs lack a surface outflow, most P in turlough outlows would be expected to exit the system via swallow holes and estavelles. Although wetlands accumulate large quantities of P, the outflow P concentration increases with P loading. P may also be removed from the system by grazing cattle and hay cutting.

A hypothetical scheme of phophorus fluxes in turloughs, summarising the above and adapted from Reddy & DeLaune (2008), is given in Figure 6.24.

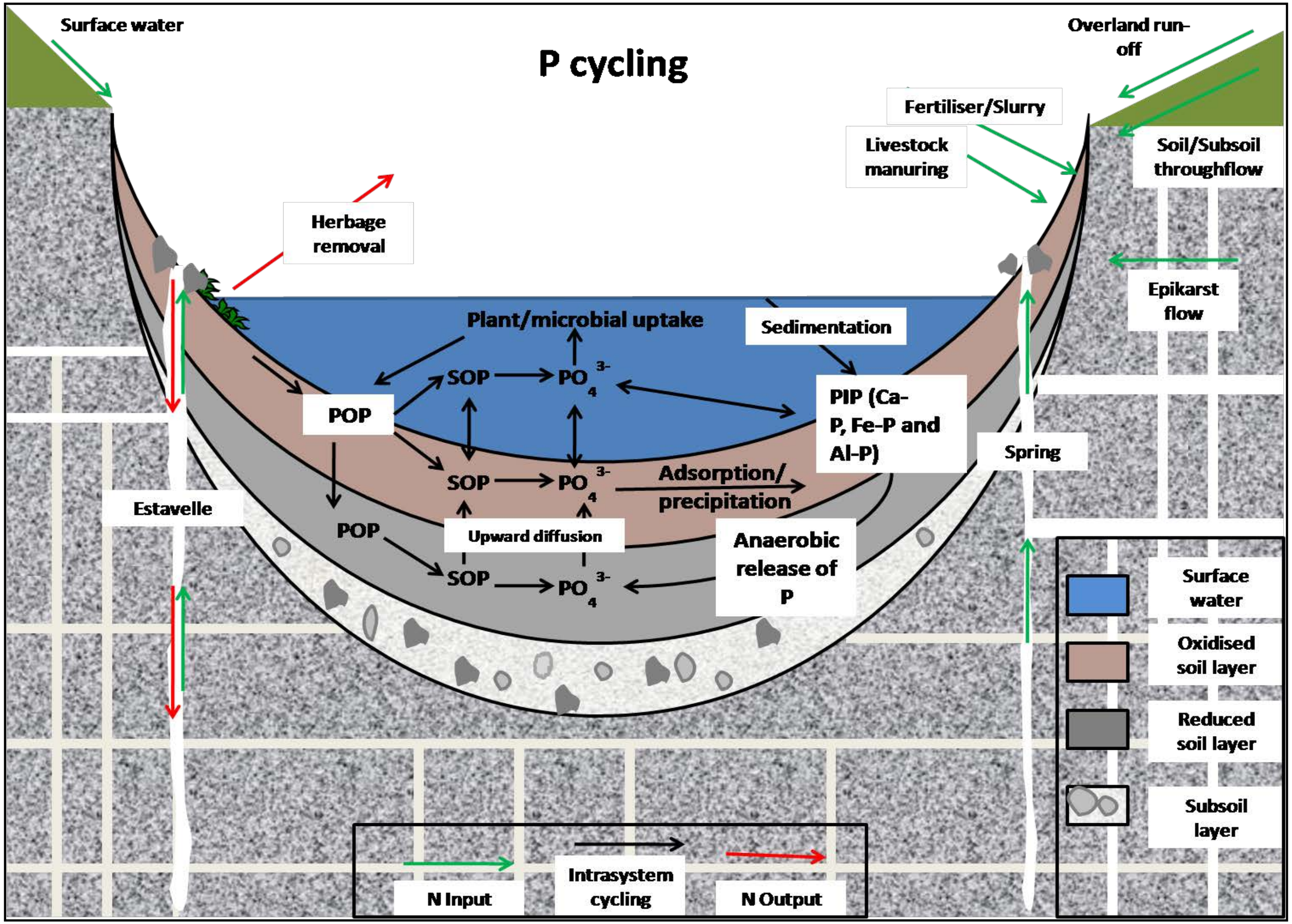


Figure 6.24 Hypothesised phosphorus cycling in turloughs (adapted from Reddy and DeLaune 2008)

6.8 Overall Summary

- A broad range of soil types occurred across the 22 sites. Turloughs with non-calcareous mineral soil types are associated with relatively large areas of limestone till subsoils and relatively shorter flood durations than turloughs with peaty or marly soil types. There was no clear distinction between the hydrochemistry or subsoil types of turloughs with peaty and marly soil types and more detailed information on the soil properties suggests that marl accumulation is common in peaty turloughs. Turloughs with marly soils did not have have distinctly more alkaline floodwaters than turloughs with peaty soils and grouping turloughs into peaty and marly types is arbitrary. Shell marl accumulation is common in turloughs and attempts to understand the drivers of $CaCO_3$ distribution in turlough soils should factor in drivers of snail populations in addition to drivers of marl deposition from floodwaters.

- No soil type was identified as a useful indicator of soil Total N, soil Total P flood duration or flood frequency. Organic matter was identified as an efficient predictor of soil Total N, however, and soils with high $CaCO_3$ contents were generally associated with long flood durations. Grazing and vegetation type had a significant positive effect on soil TP. Mineral soils were positively associated with grassland and grazing in addition to relatively shorter flood durations. The combination of a longer drained period and herbaceous grassland promotes relatively more intensive grazing at turloughs with mineral soils. Stocking densities are not excessive however.

- Soil properties were generally highly variable within and among turloughs and different soil properties varied to different extents. Limited spatial soil sampling within turloughs is insufficient to characterise the soil nutrients of individual sites for comparative purposes. However, such a sampling approach would be sufficient to categorise turlough soils as either mineral or non-mineral. Available nutrients also showed high degrees of variation along turlough flooding gradients. pH was identified as an efficient predictor of P availability, with P availability decreasing with increasing pH. Sampling period is important for detecting differences in P status among turloughs and soil sampling strategies should therefore be cognisant of temporal variability.

- Comparisons of soil nutrients among two contrasting turlough types yielded unexpected results. Turloughs under relatively more intense nutrient pressures did not have significantly higher soil N or P. Soils nutrient concentrations within both types of turloughs were low in an agricultural context and nutrient inputs from within-turlough landuse or catchment floodwaters are not apparently causing elevated soil nutrient concentrations in Coole Garryland turloughs.

- The P release experiments revealed that turlough soils with relatively higher inorganic P fractions do not release significant amounts of SRP to the water column. Particulate P contributions from relatively P-enriched soils can potentially influence floodwater TP concentrations, although further research is necessary to adequately quantify such contributions.

- Quantifying nutrient cycling in turloughs is potentially very challenging. Concomitant water quality data from the zone of groundwater contribution and within-turlough floodwaters would improve understanding of the influence on catchment factors on turlough floodwater quality. Nutrient mineralisation and P fractionation studies are necessary in order to understand how turloughs cycle nutrients in the sediments.

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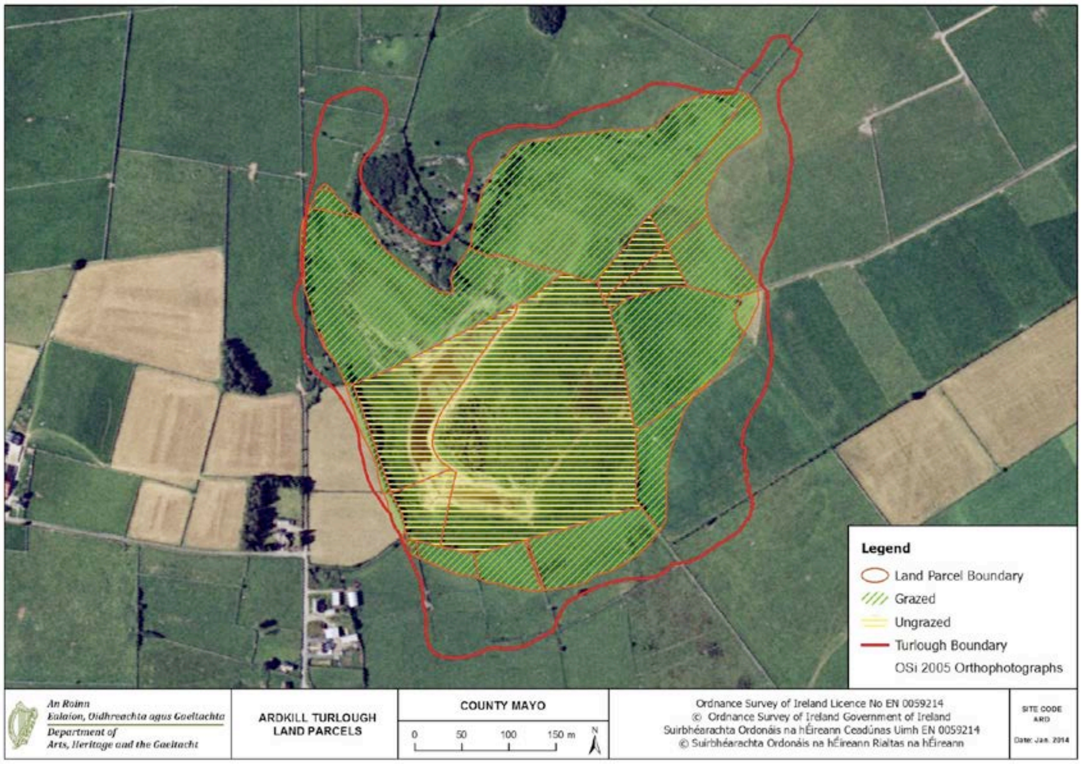
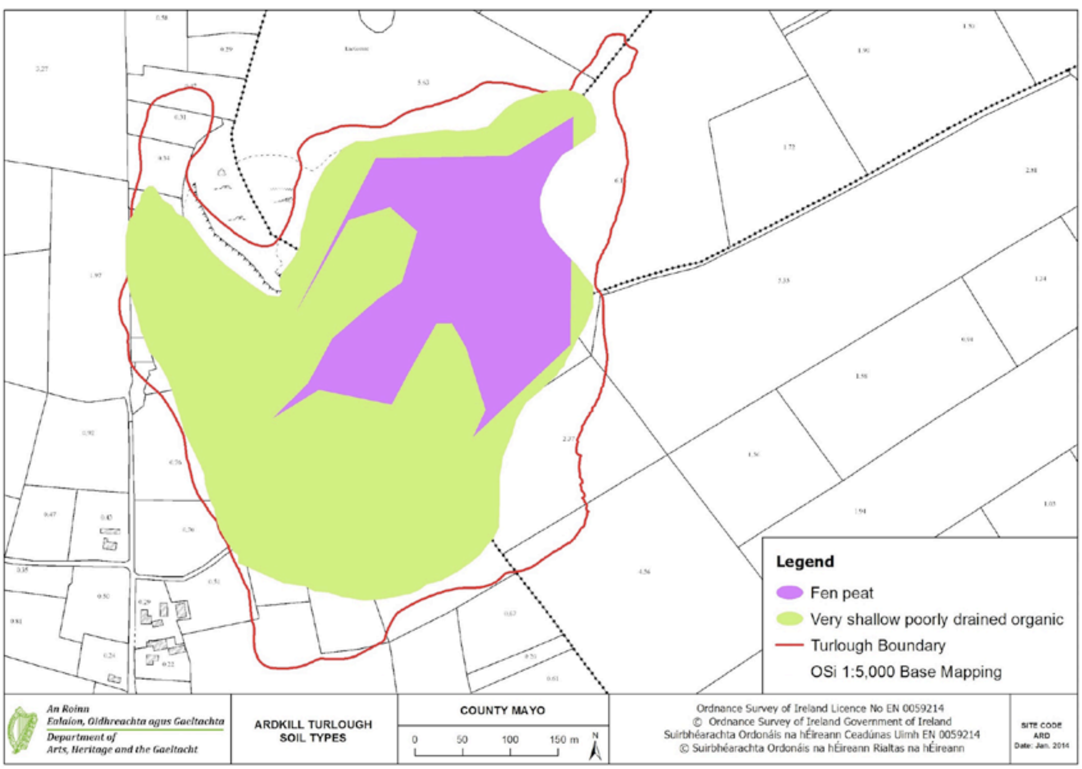
Appendix 6.1: Landuse and Soil Maps

Further maps are given in the individual site reports, Annex 2





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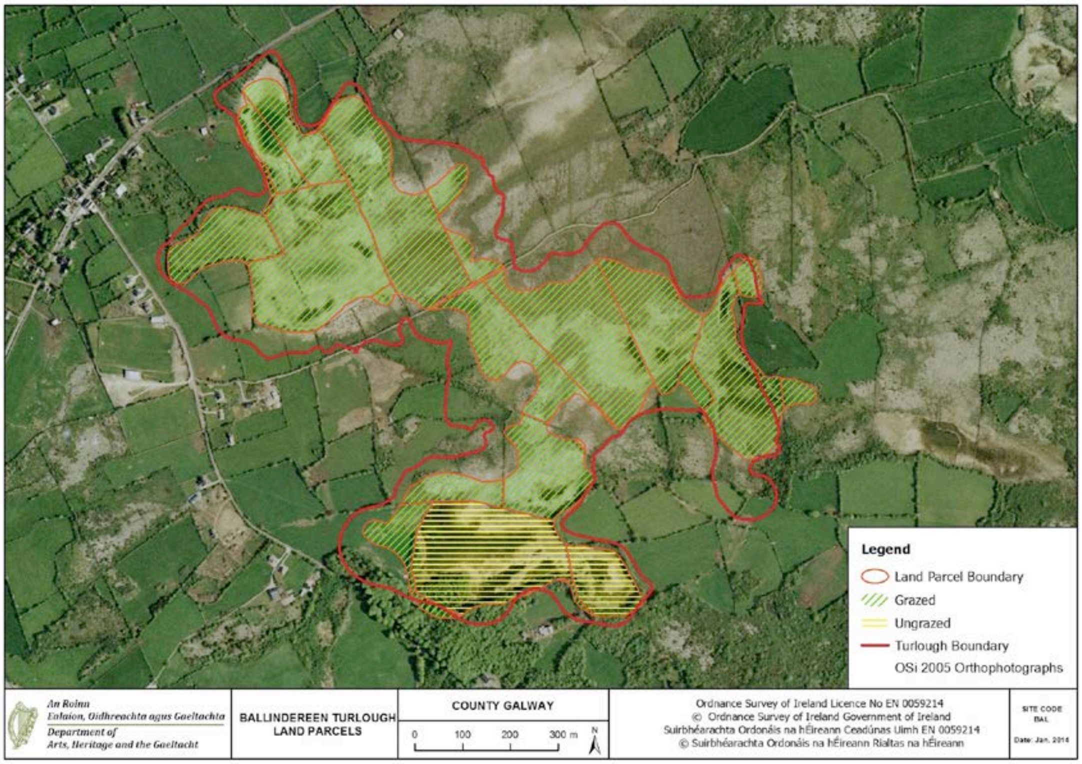

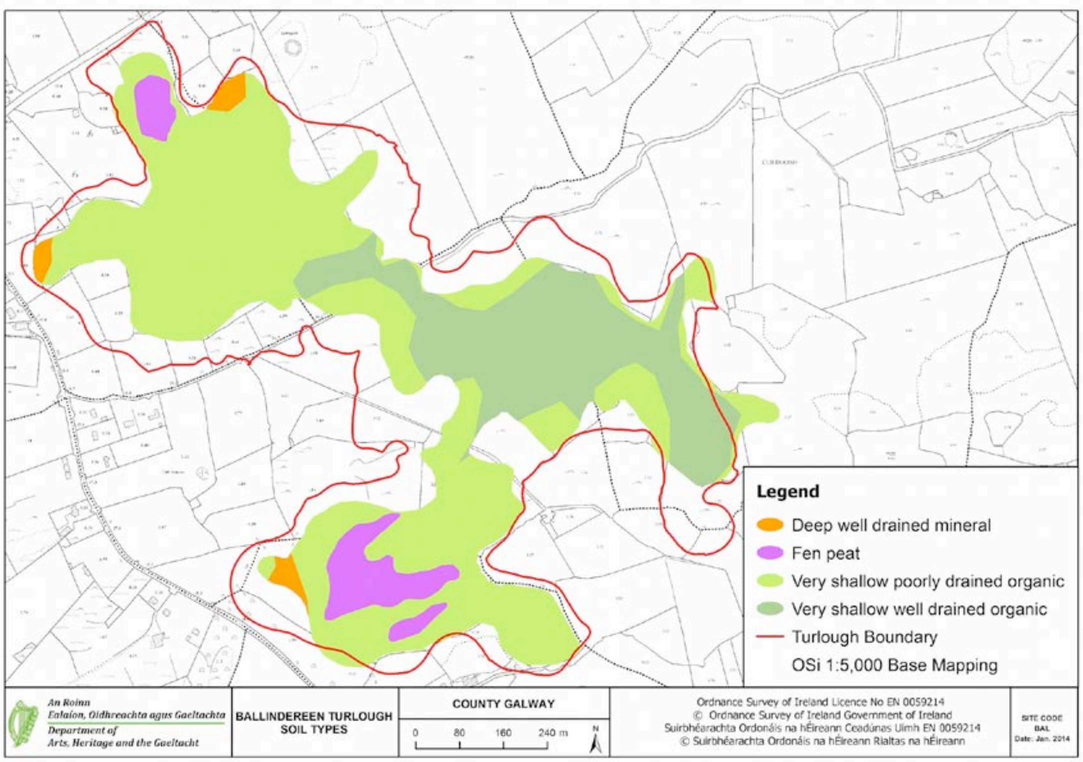

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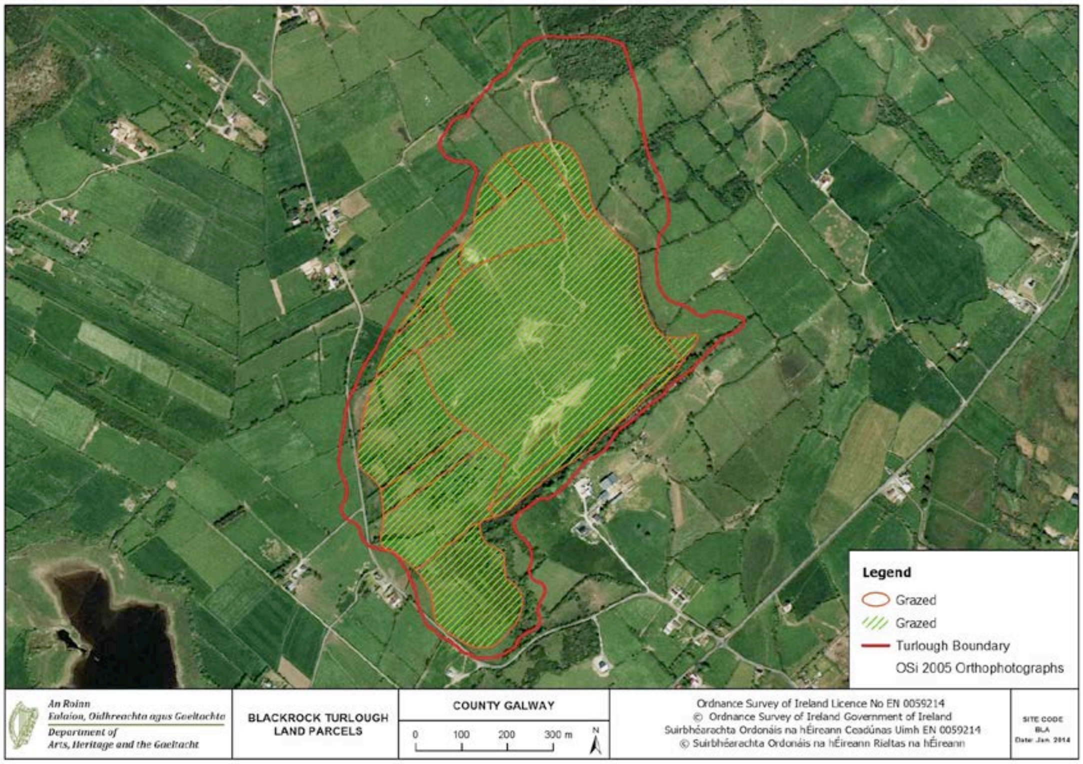

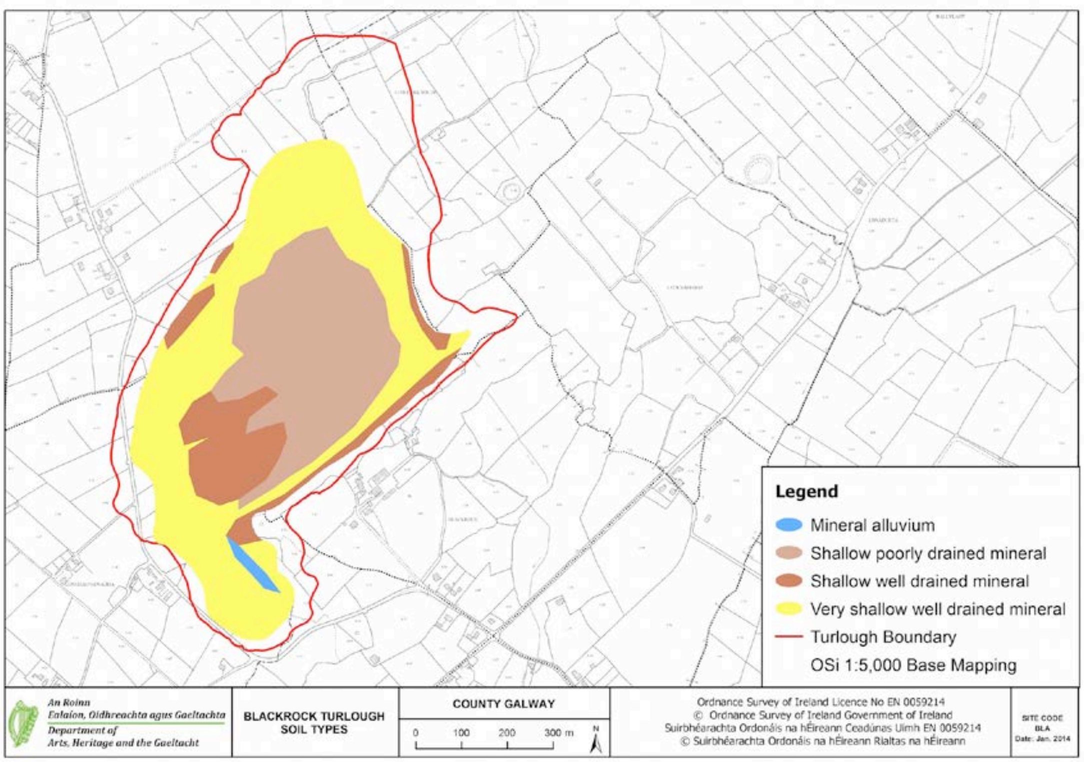

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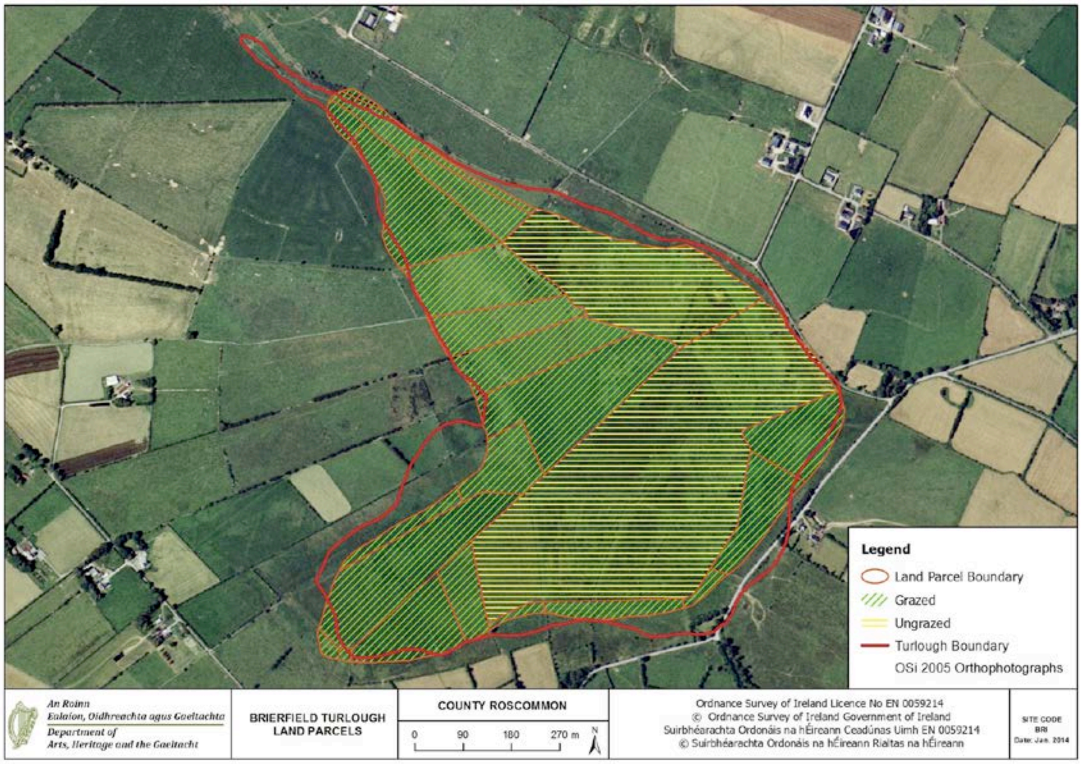

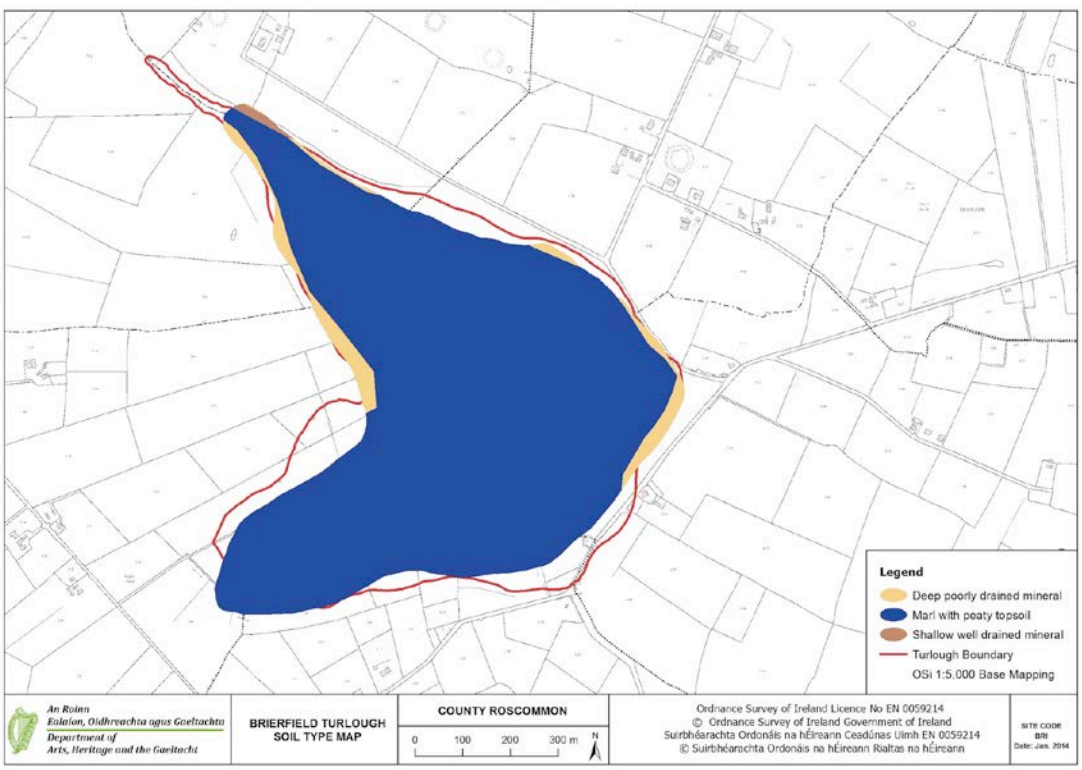

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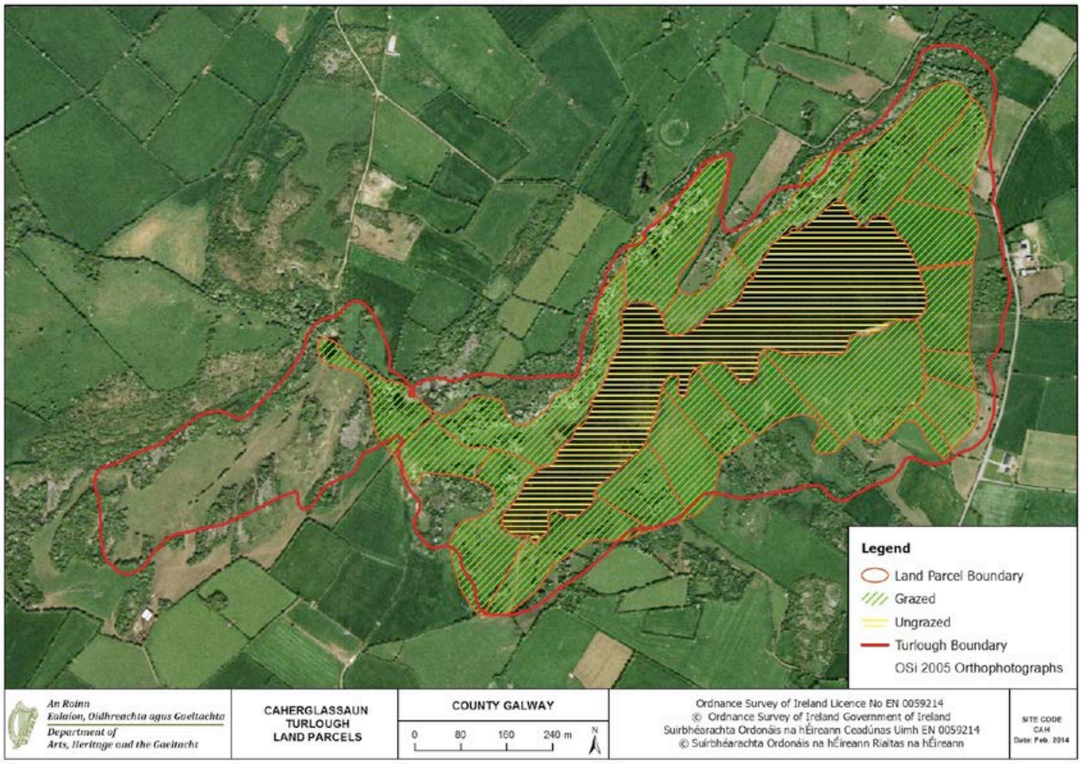
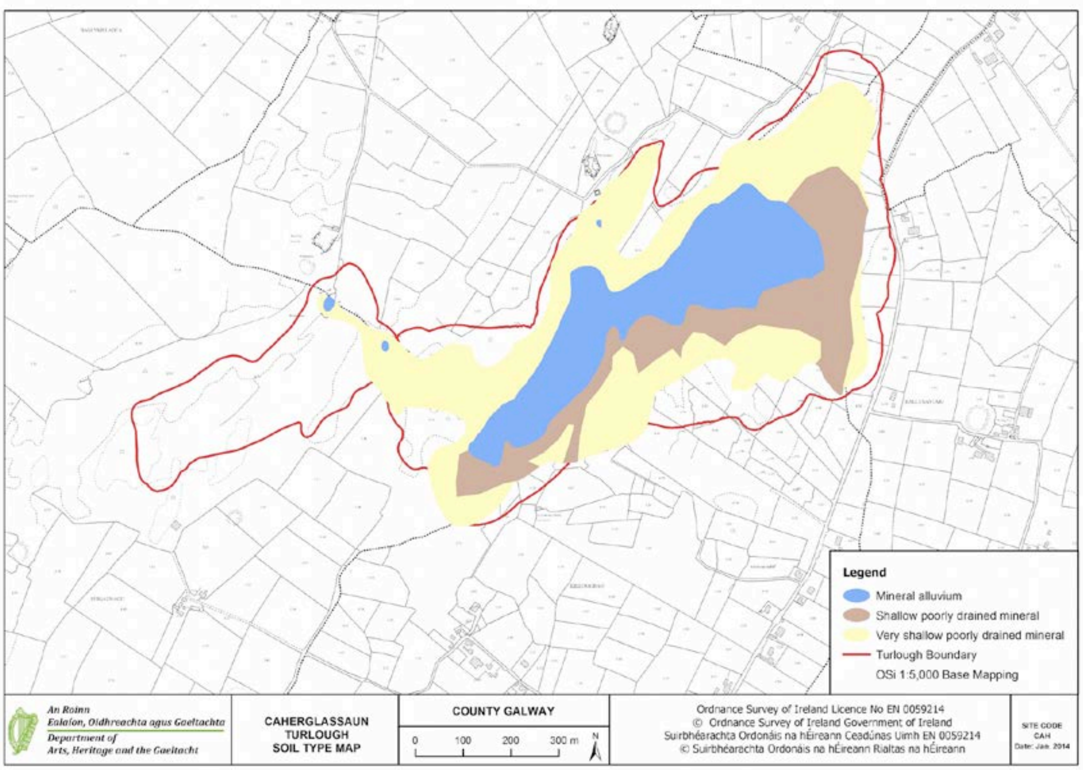
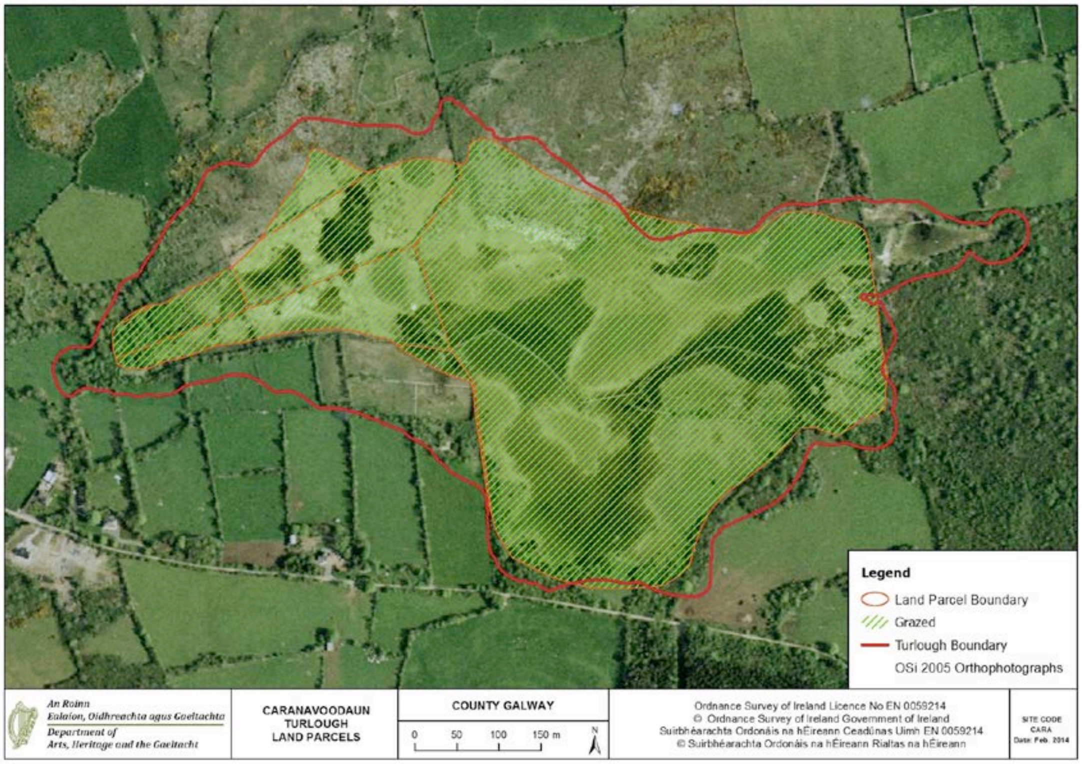
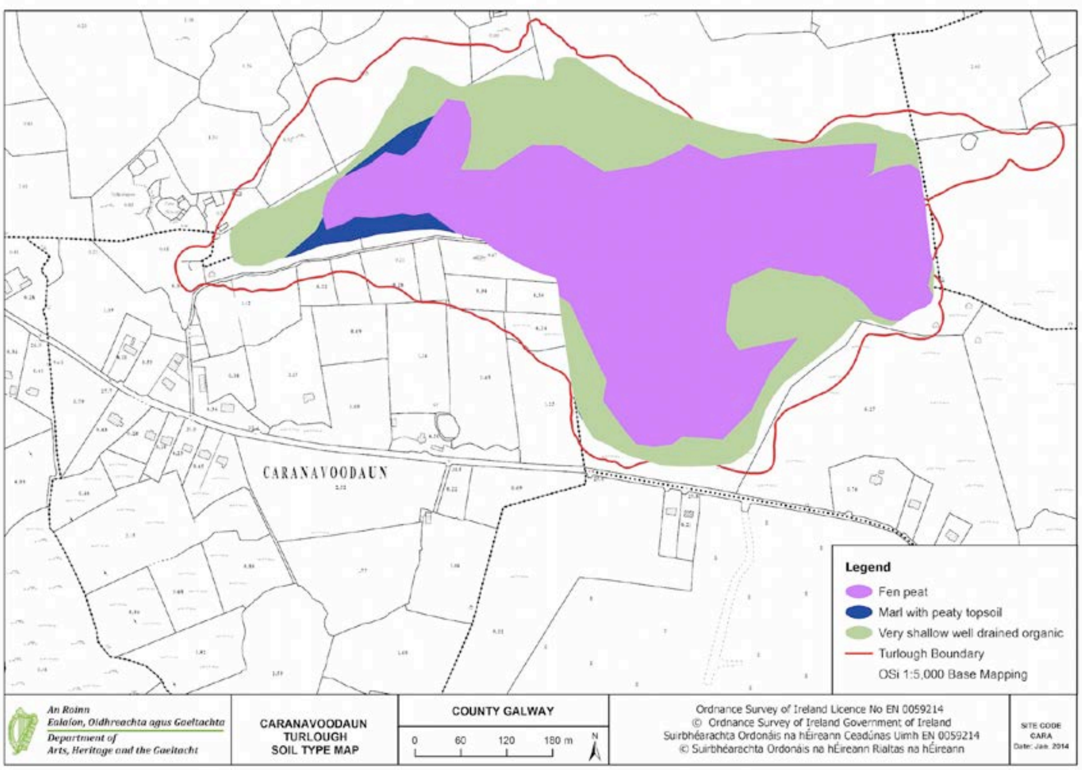


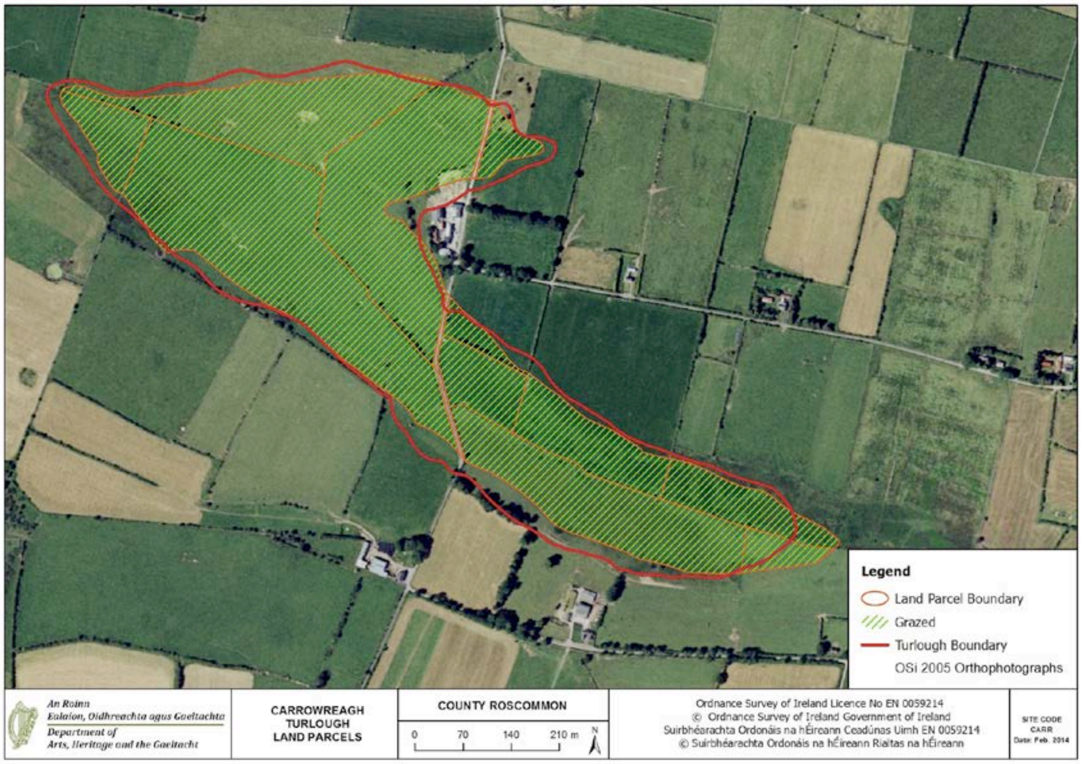


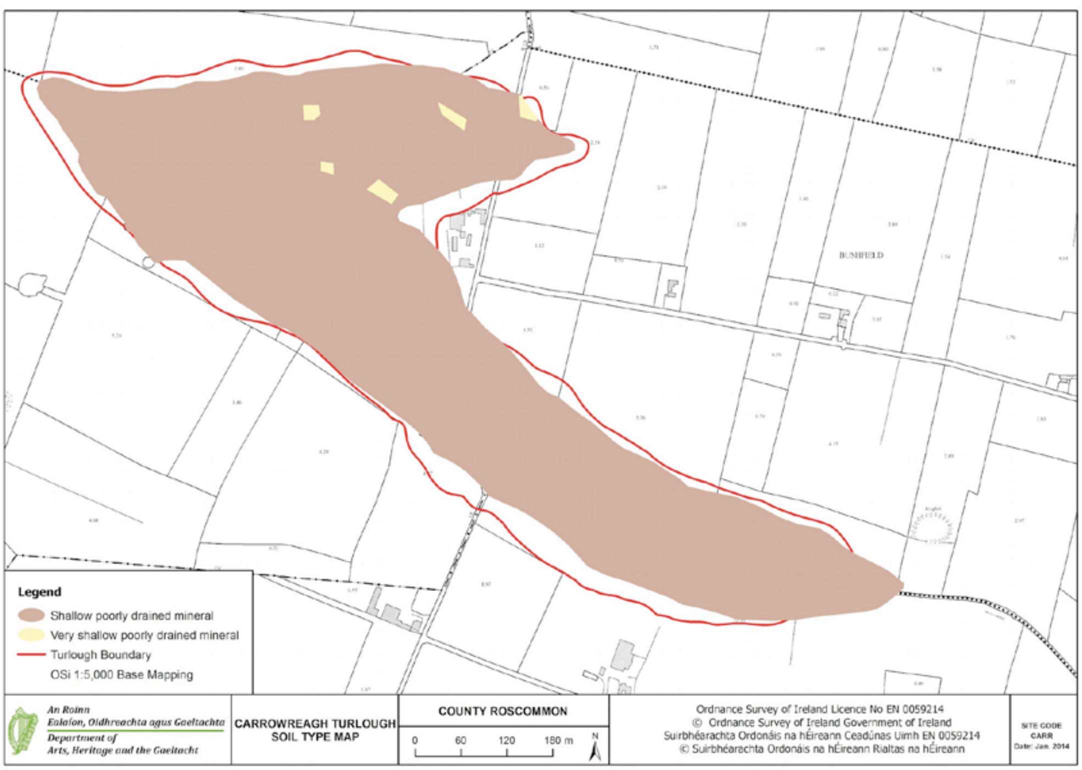
Caherglassan: Land parcels and soil types



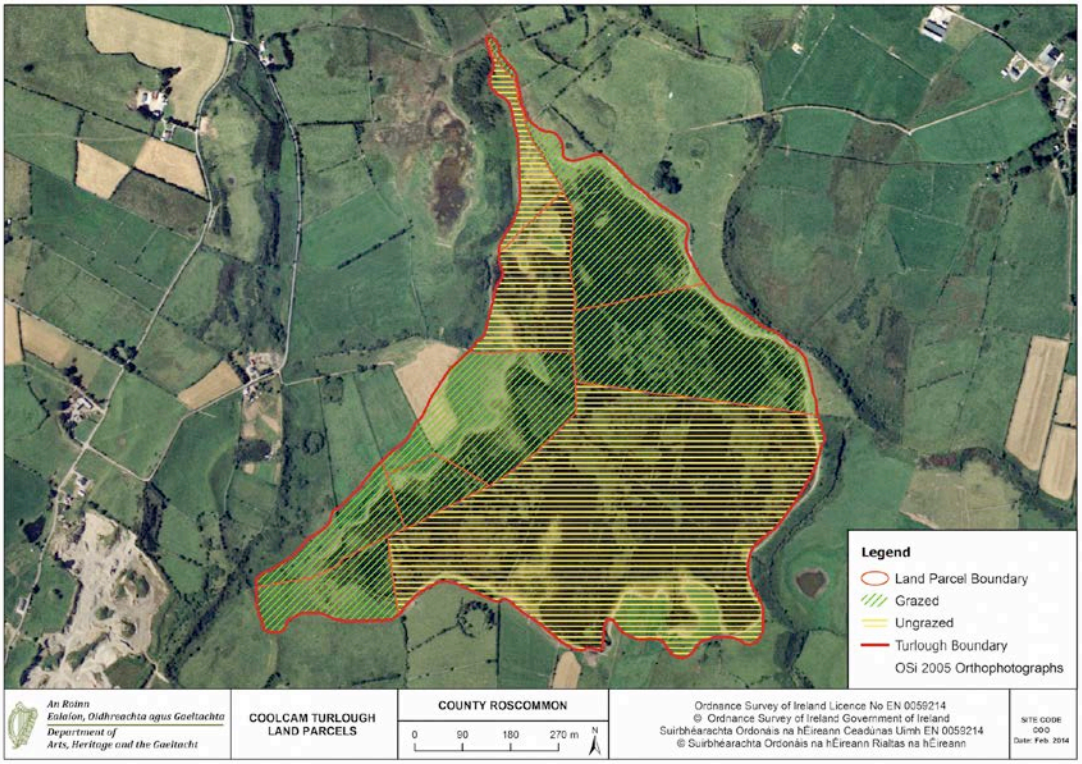


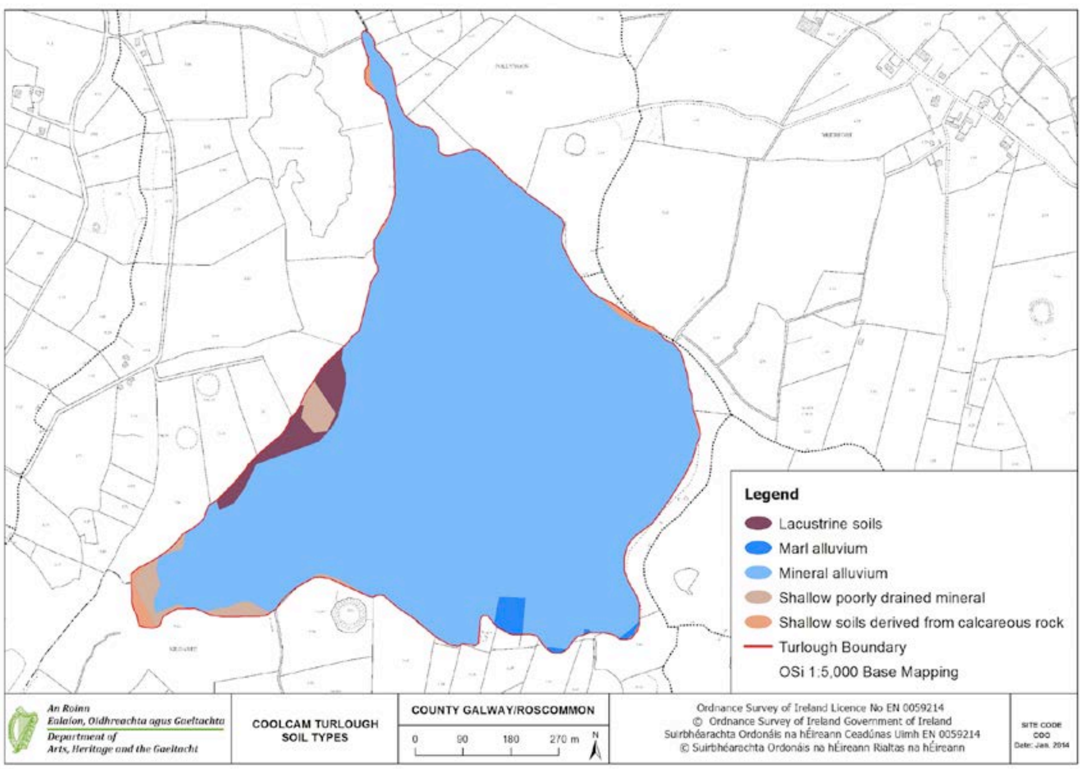
Caranavoodaun: Land parcels and soil types



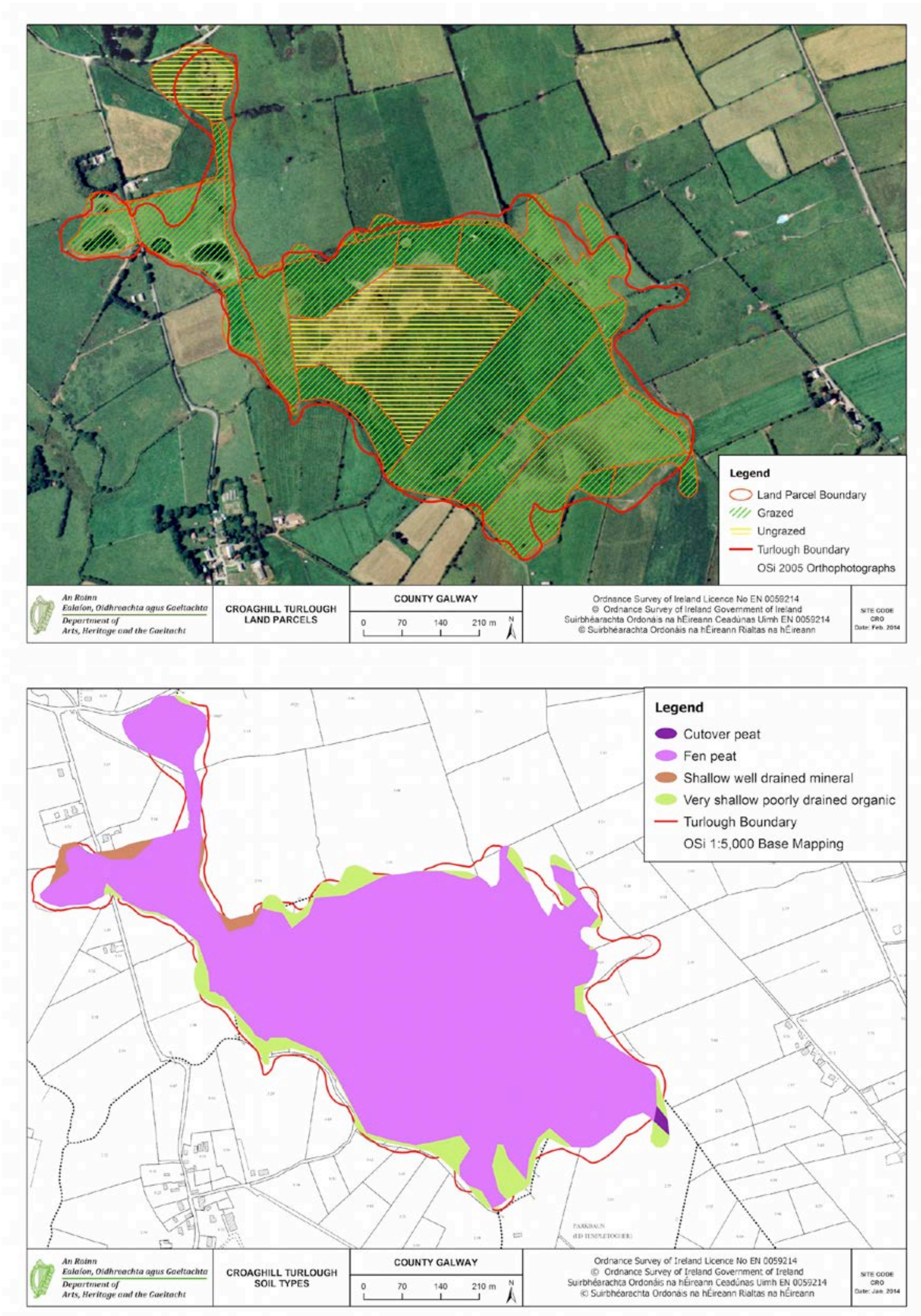


Carrowreagh: Land parcels and soil types

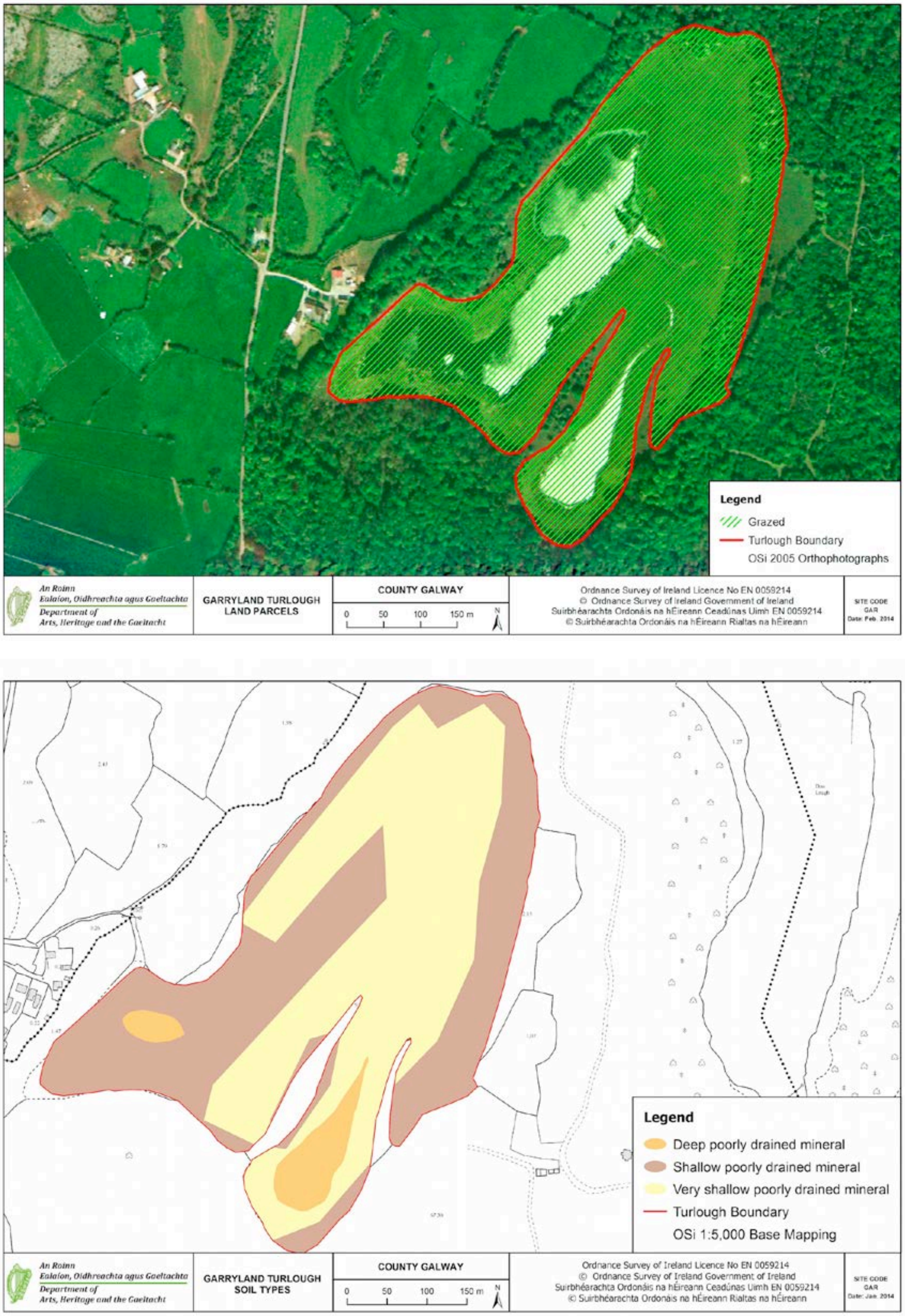




Coolcam: Land parcels and soil types



Croaghill: Land parcels and soil types



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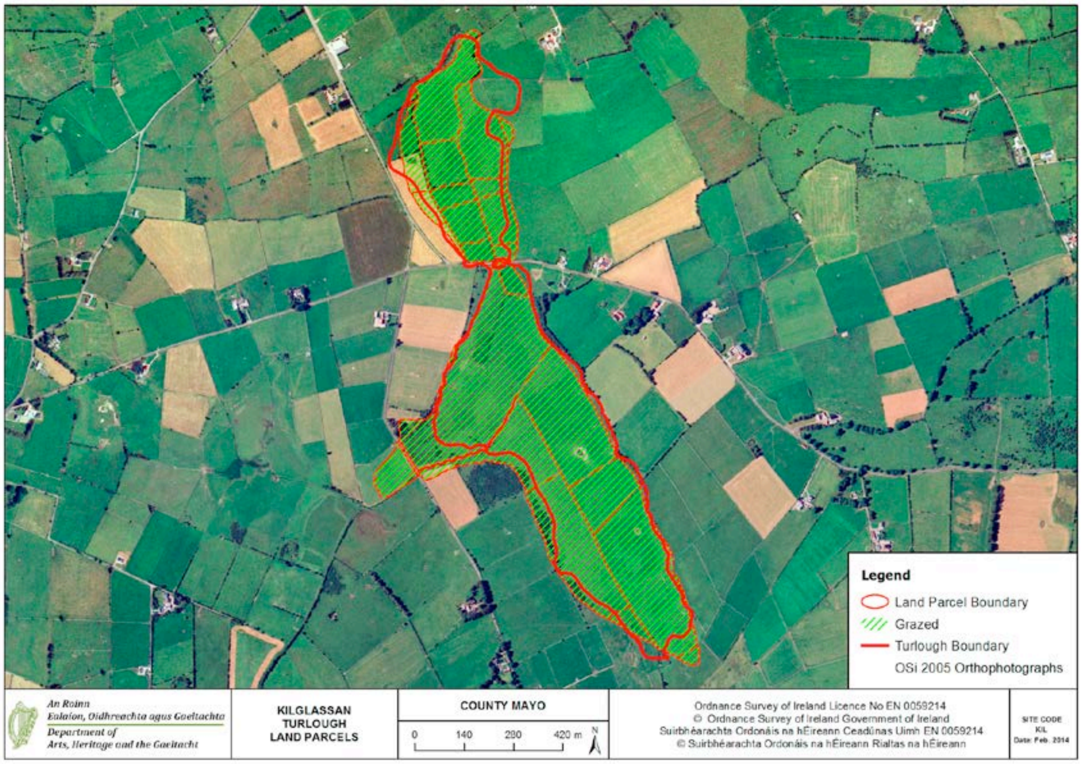
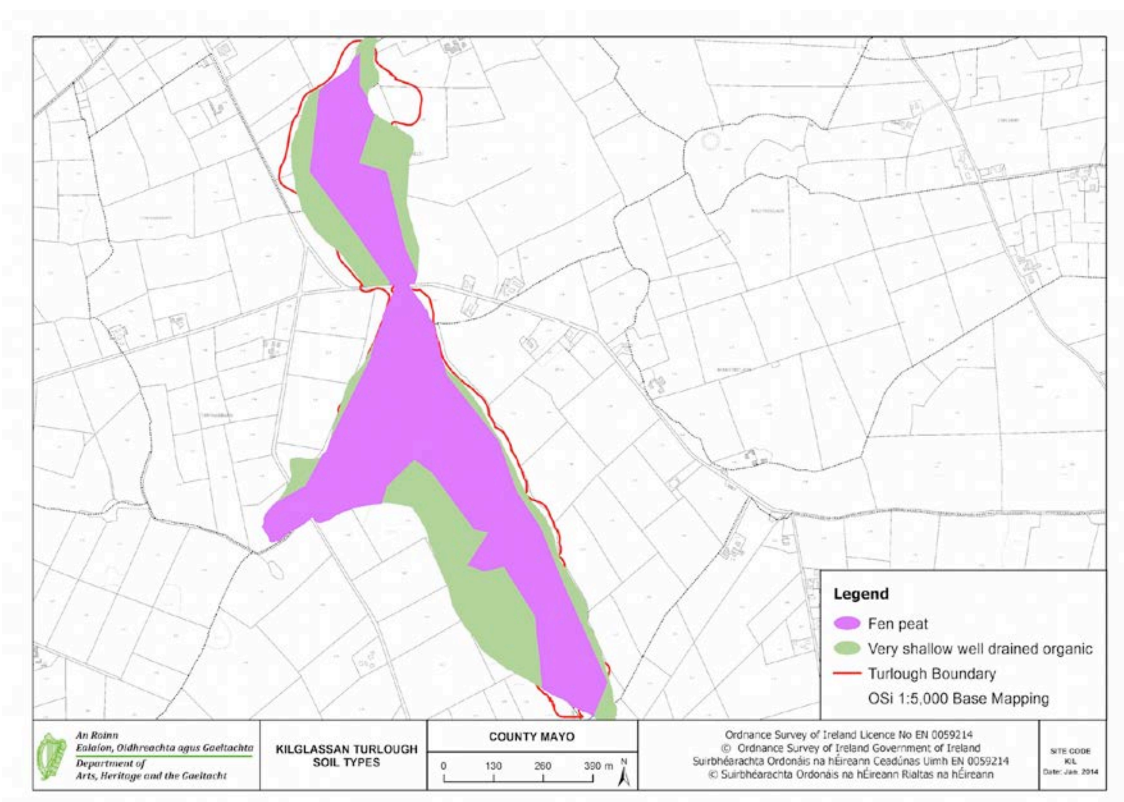
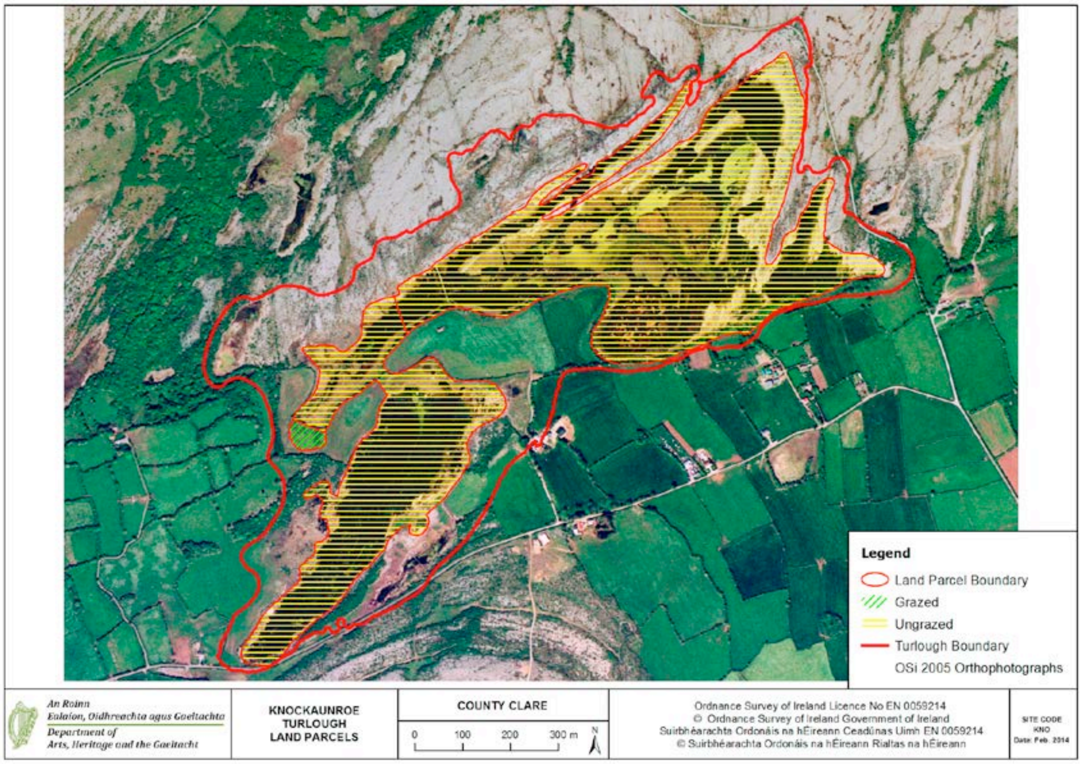
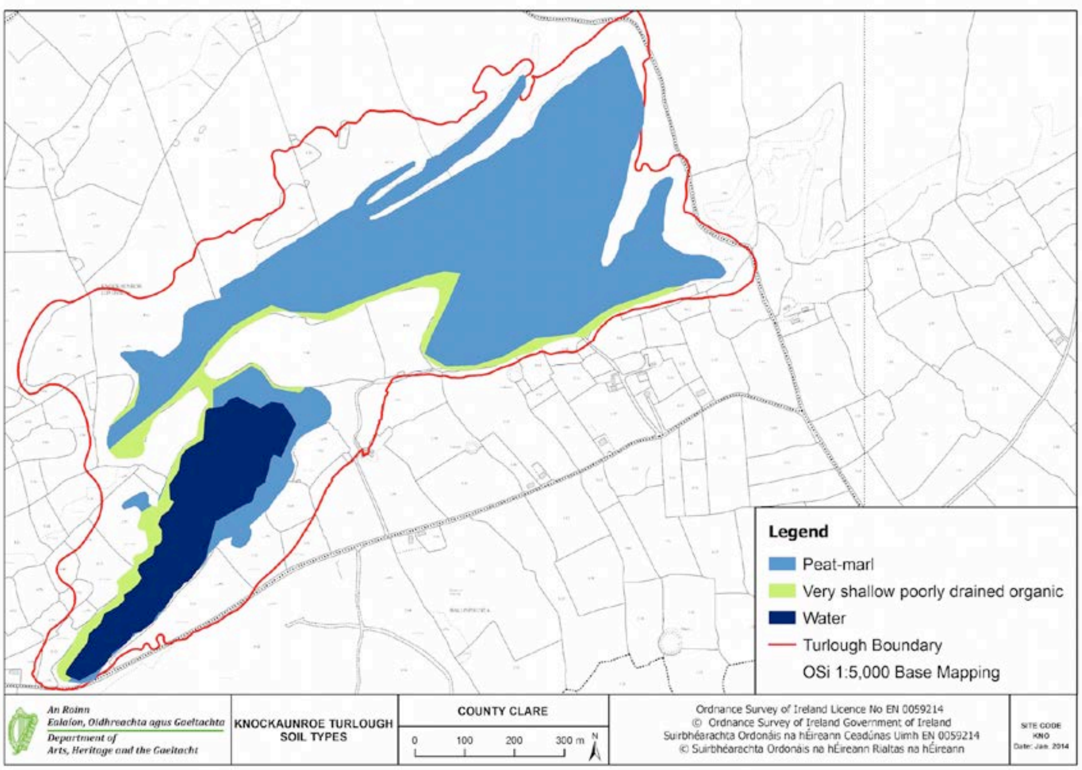


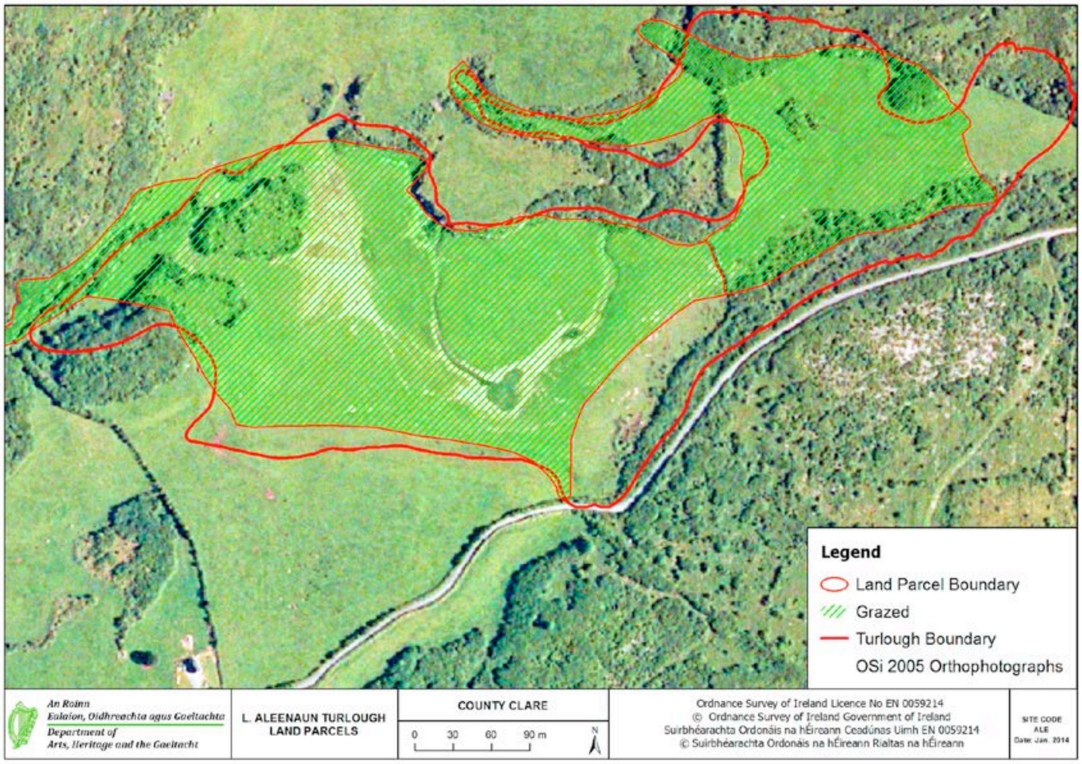


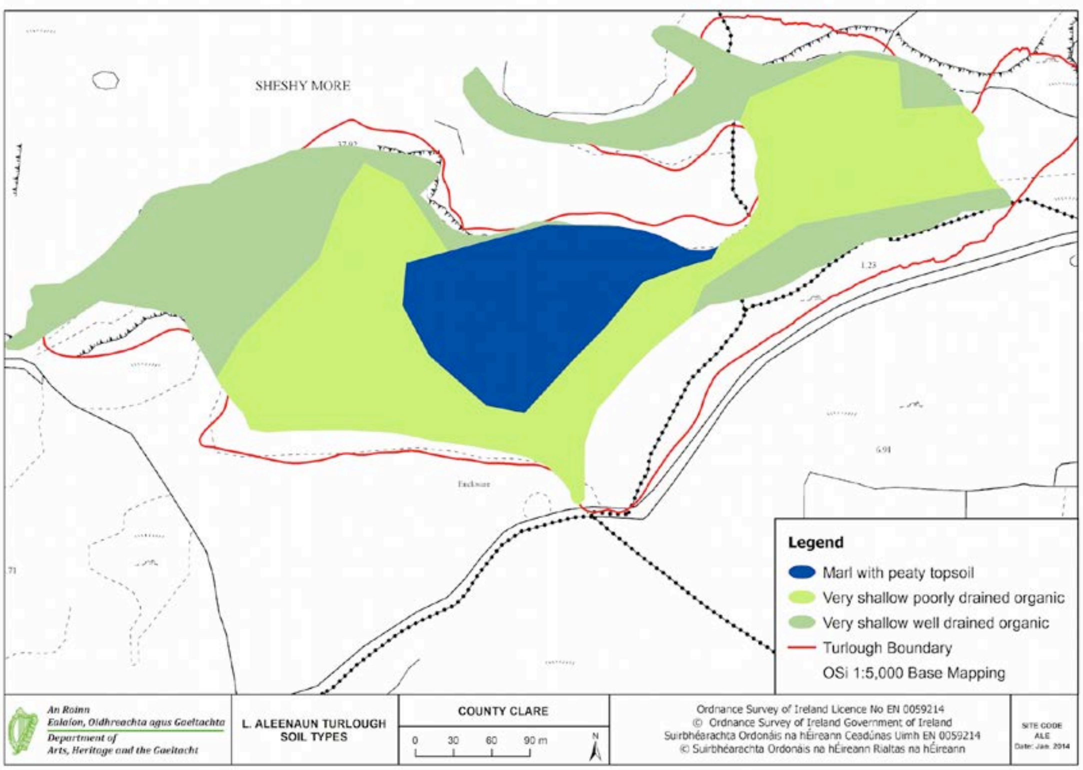
Kilglassan: Land parcels and soil types



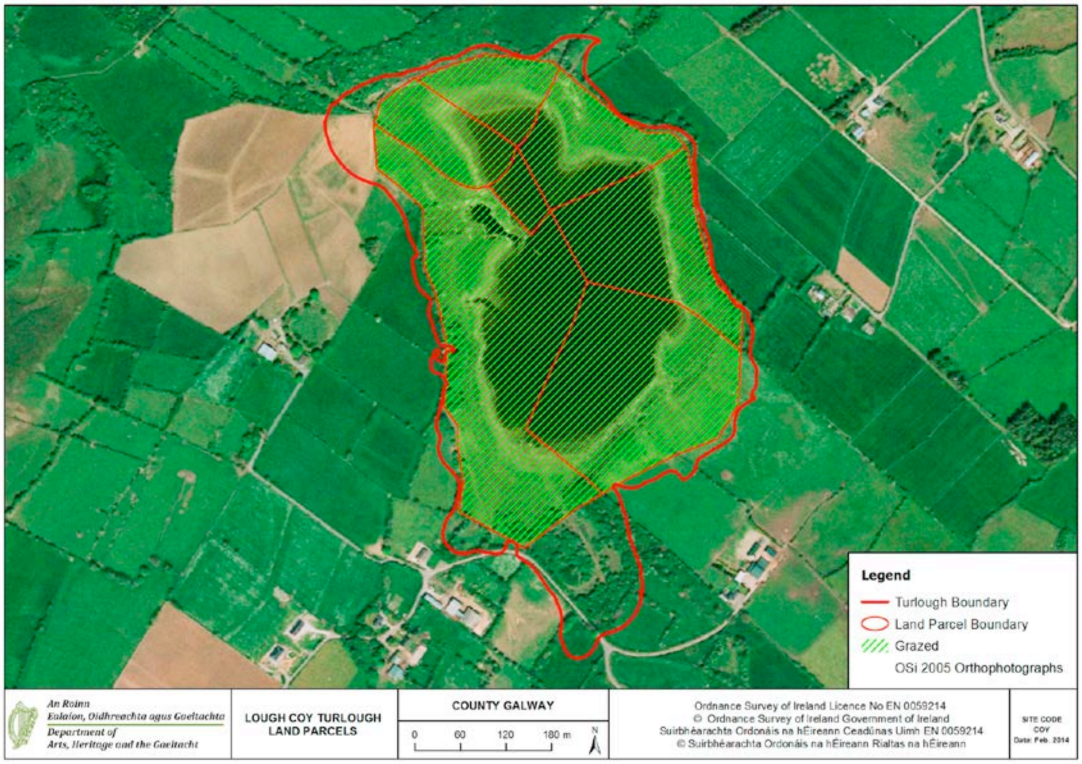


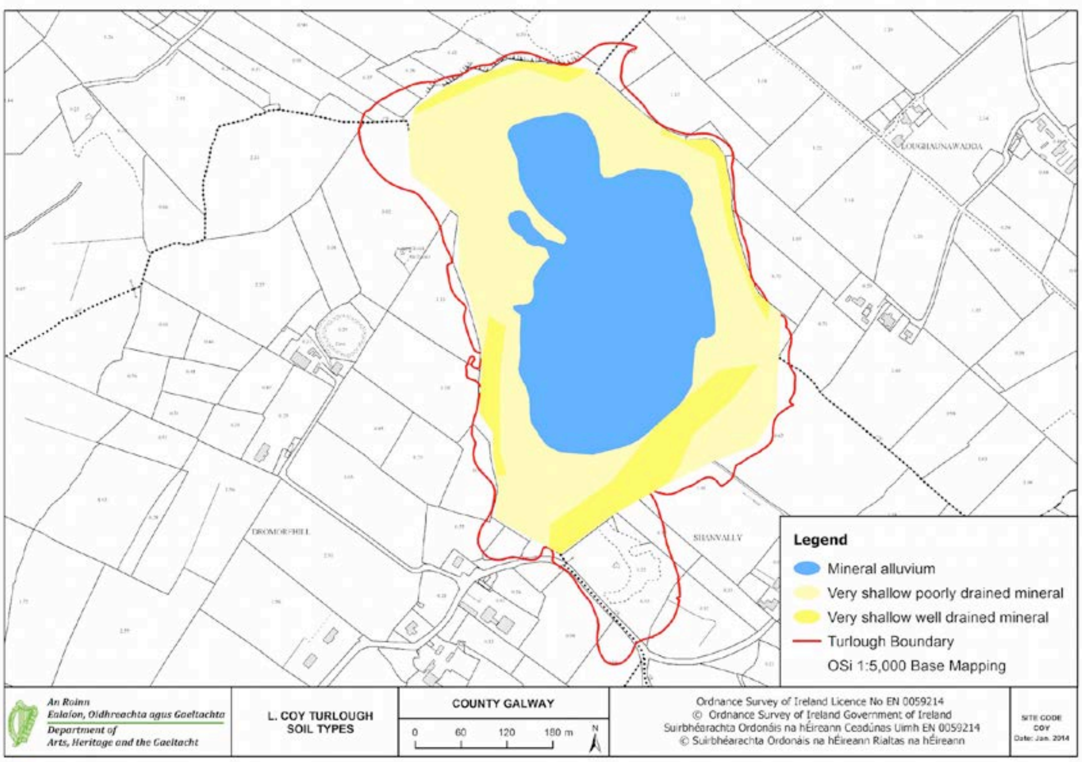
Knockaunroe: Land parcels and soil types





Lough Aleenaun: Land parcels and soil types





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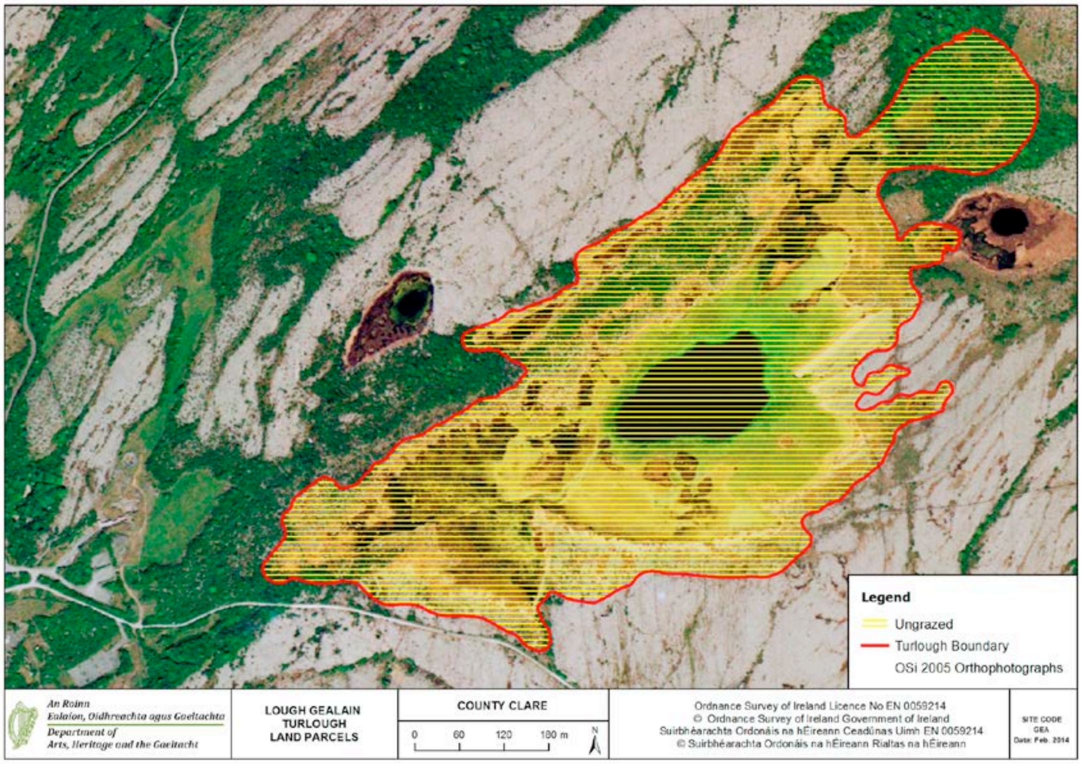
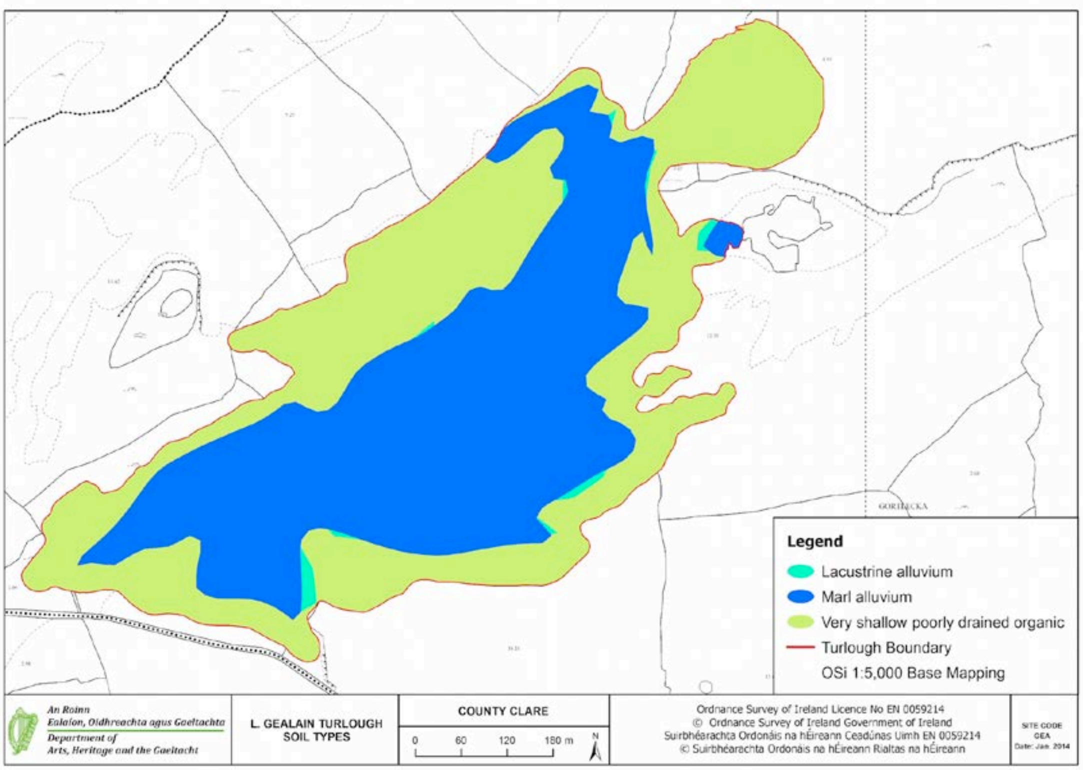
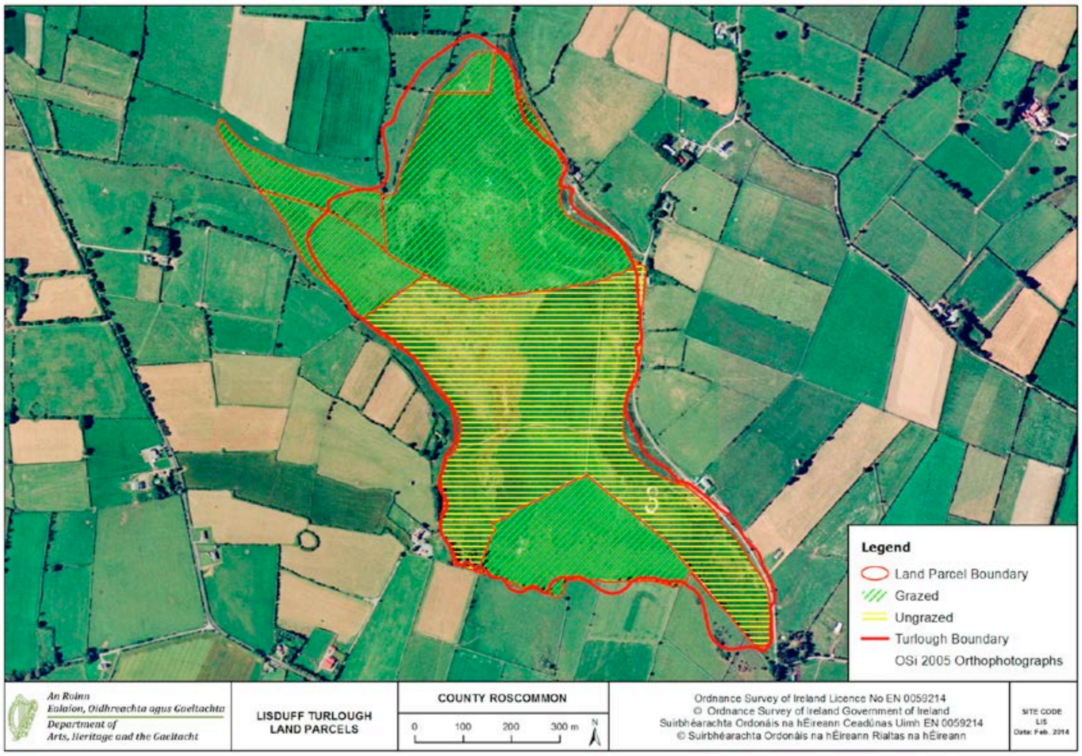
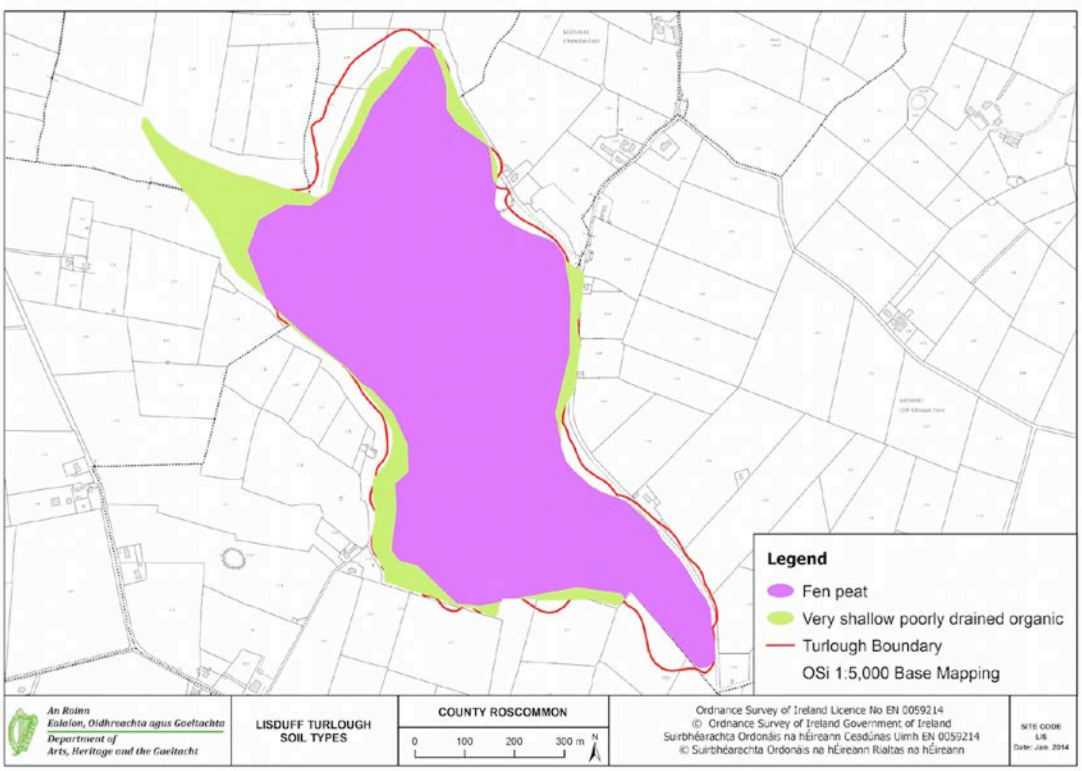


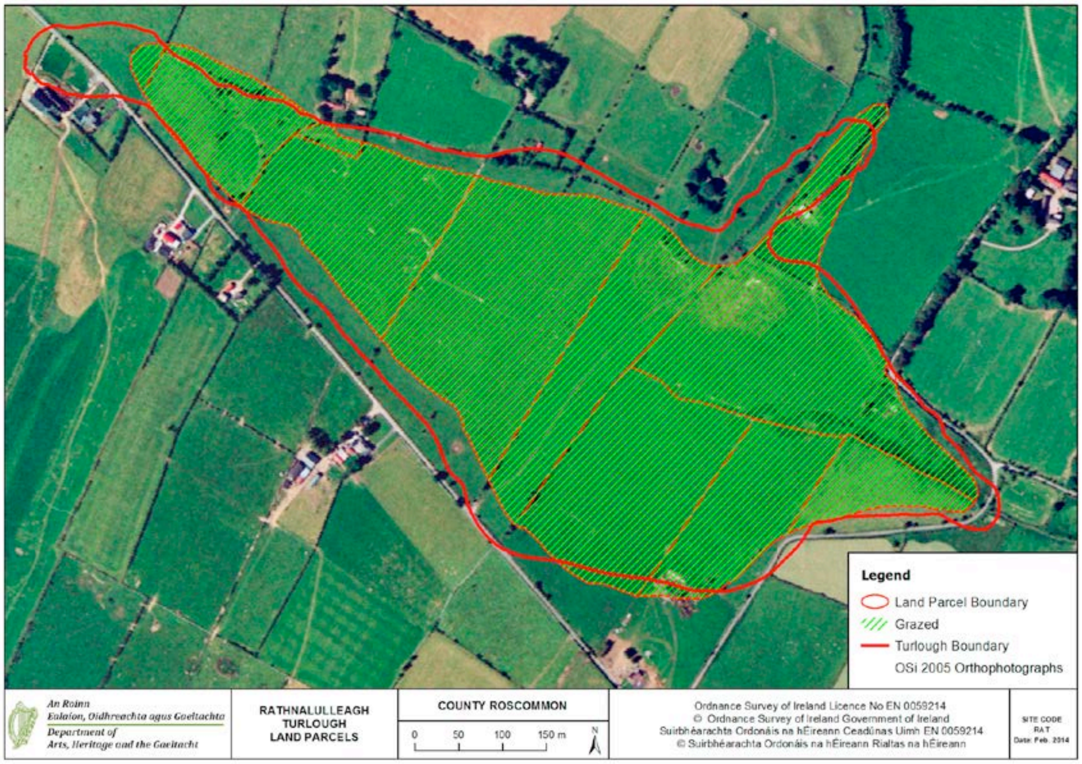


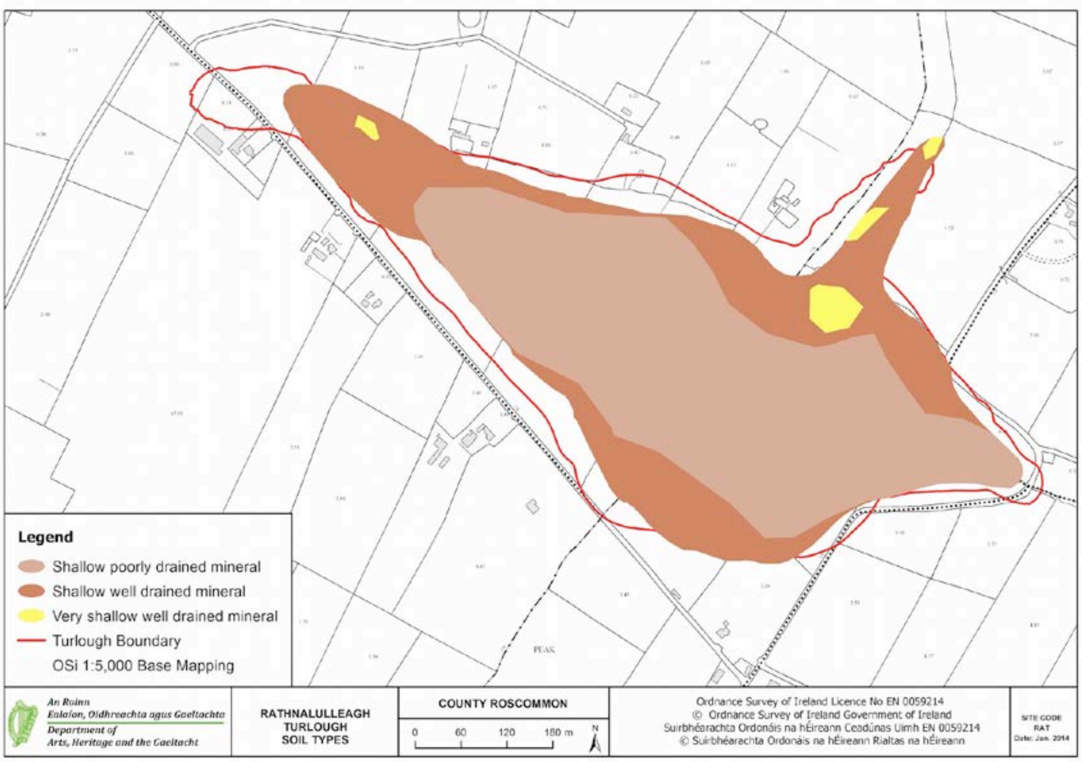
Lough Gealain: Land parcels and soil types



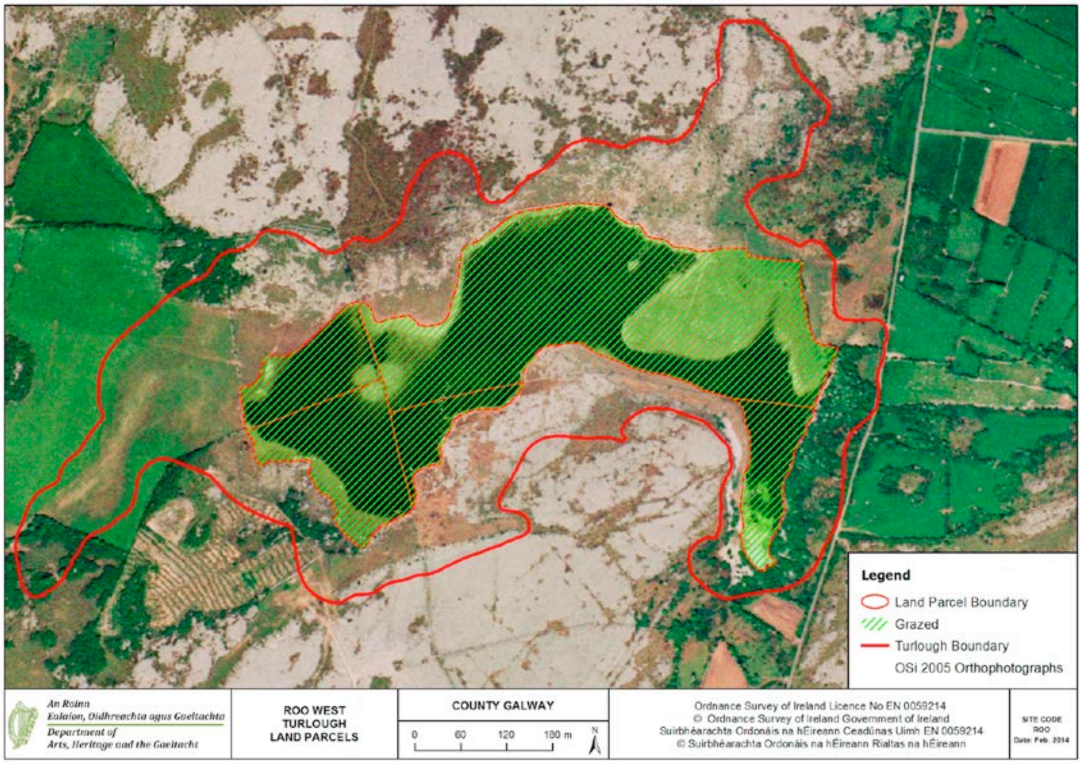


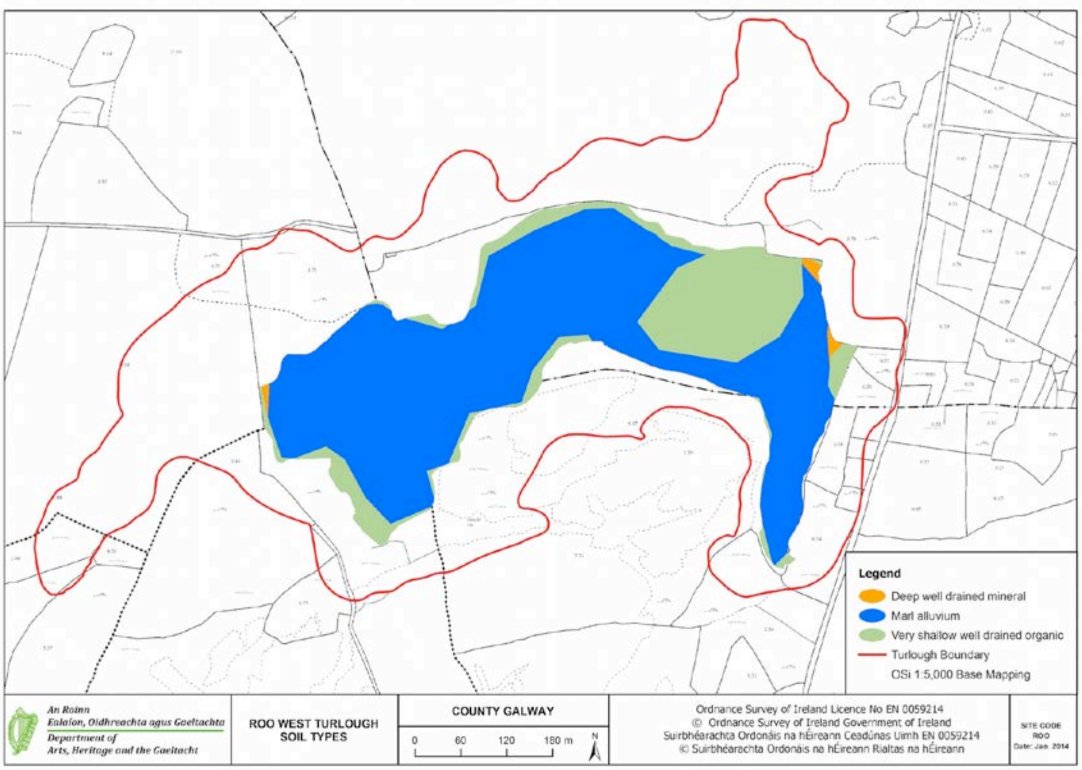
Lisduff: Land parcels and soil types





Rathnalulleagh: Land parcels and soil types





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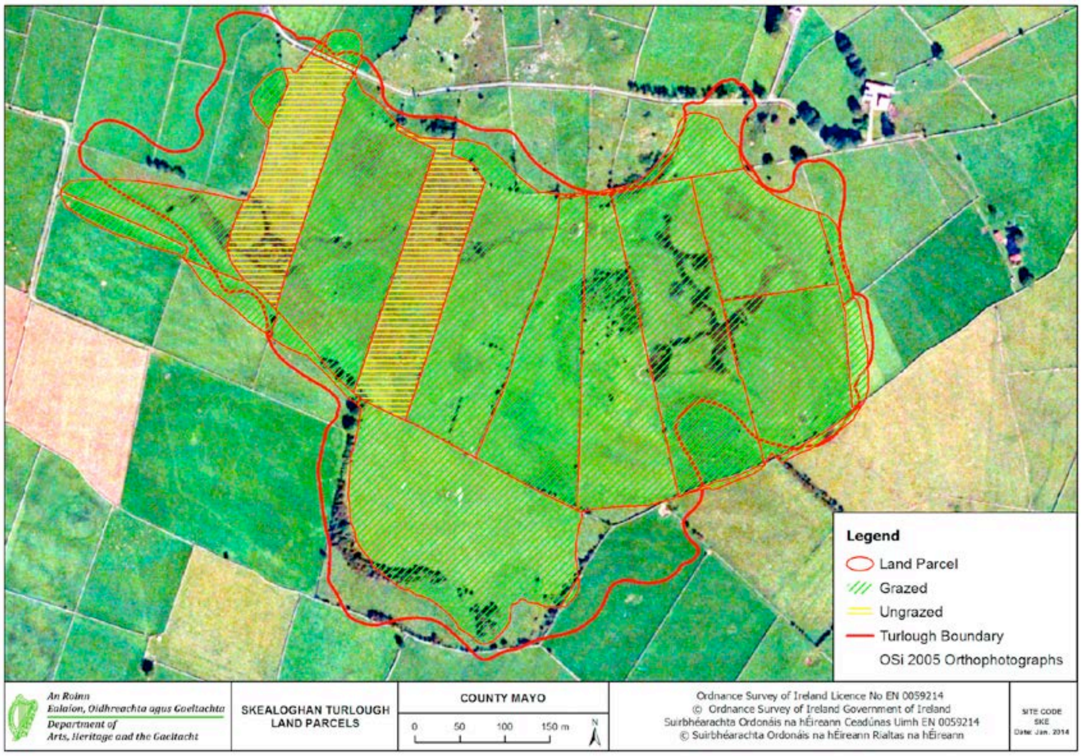
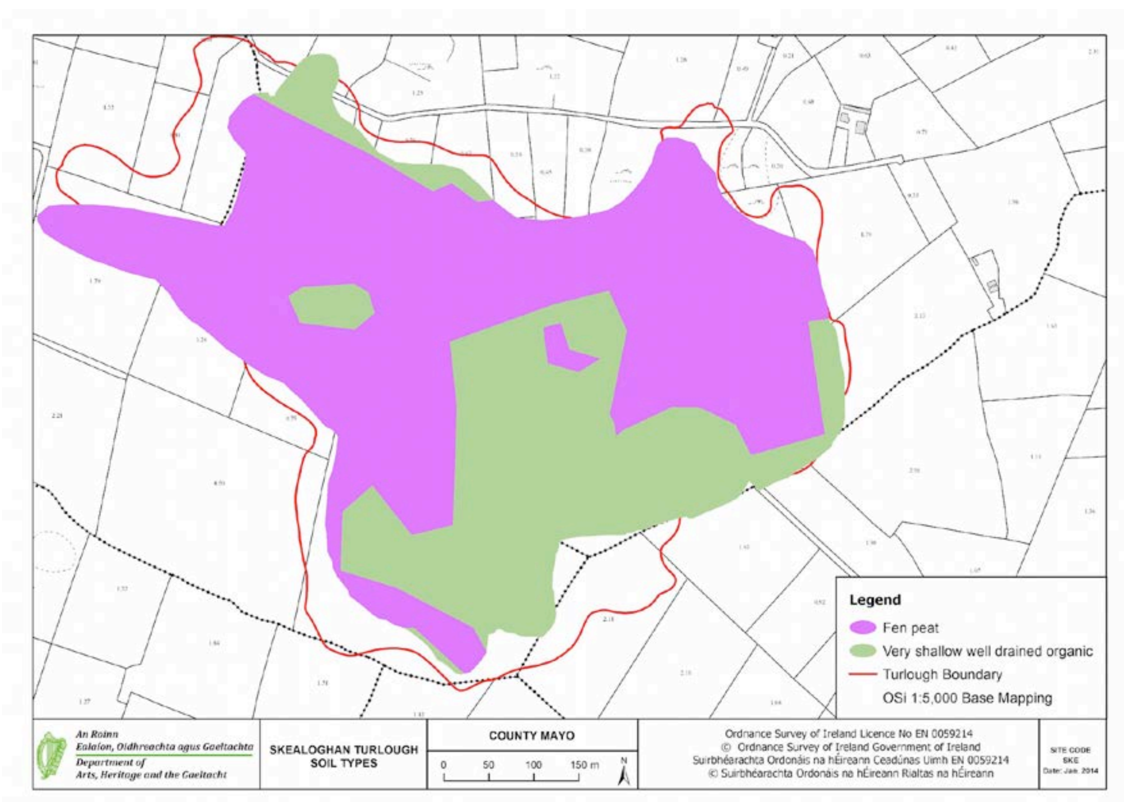
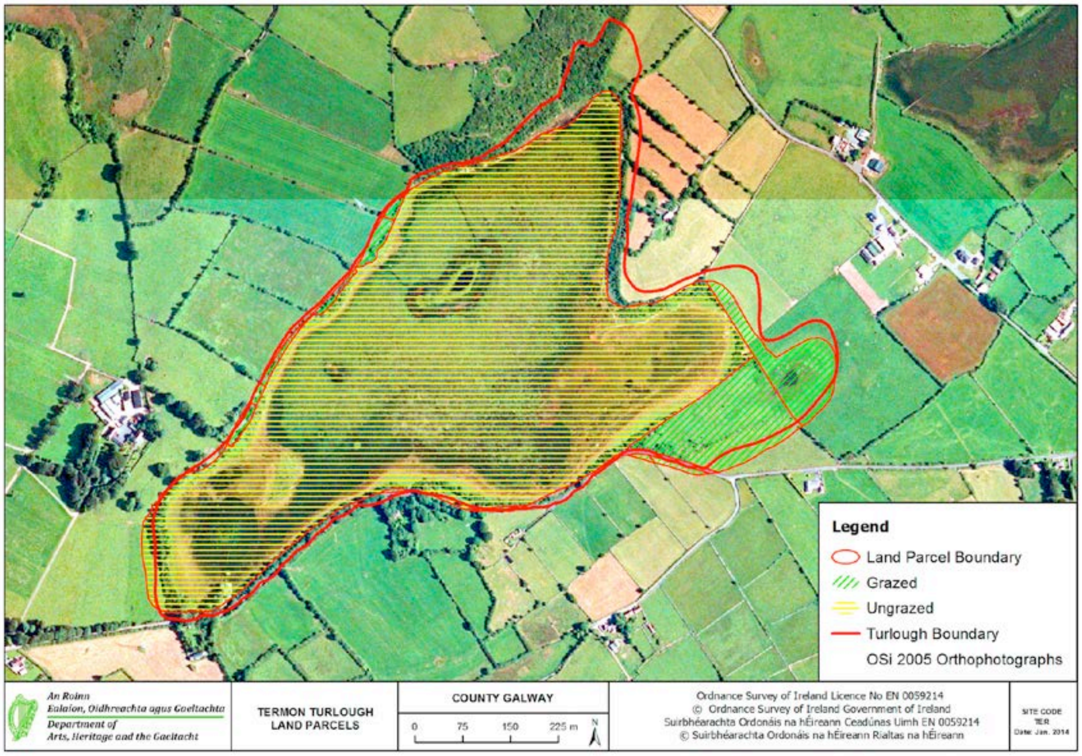
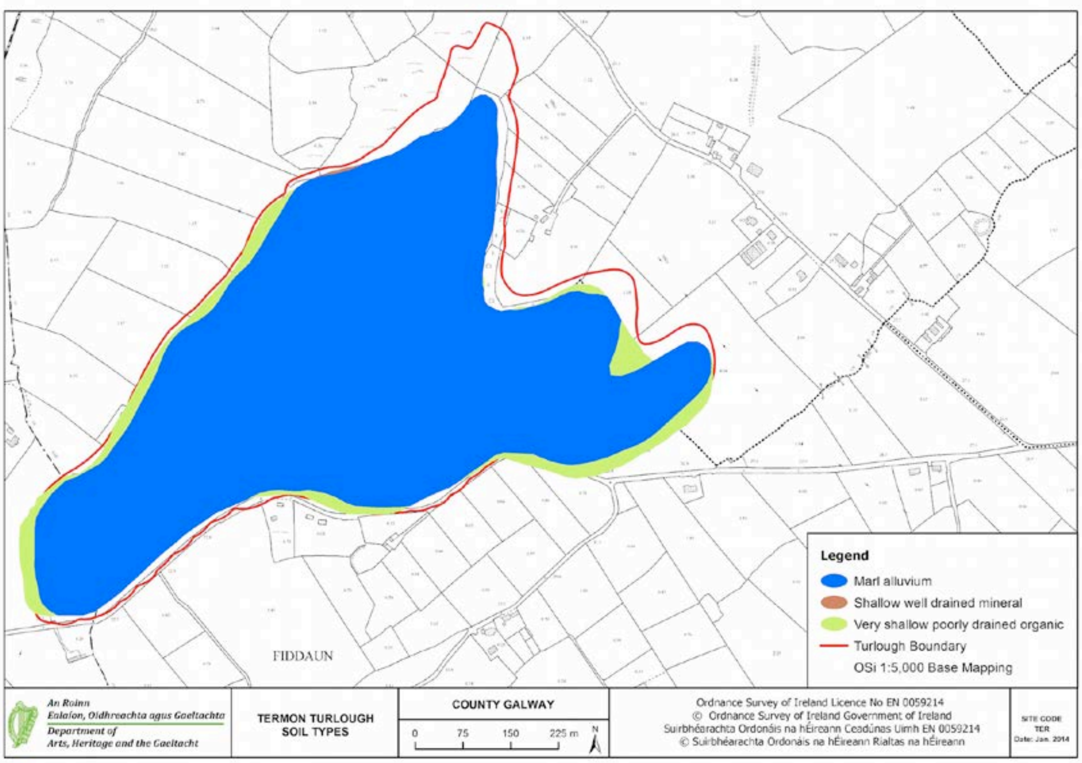


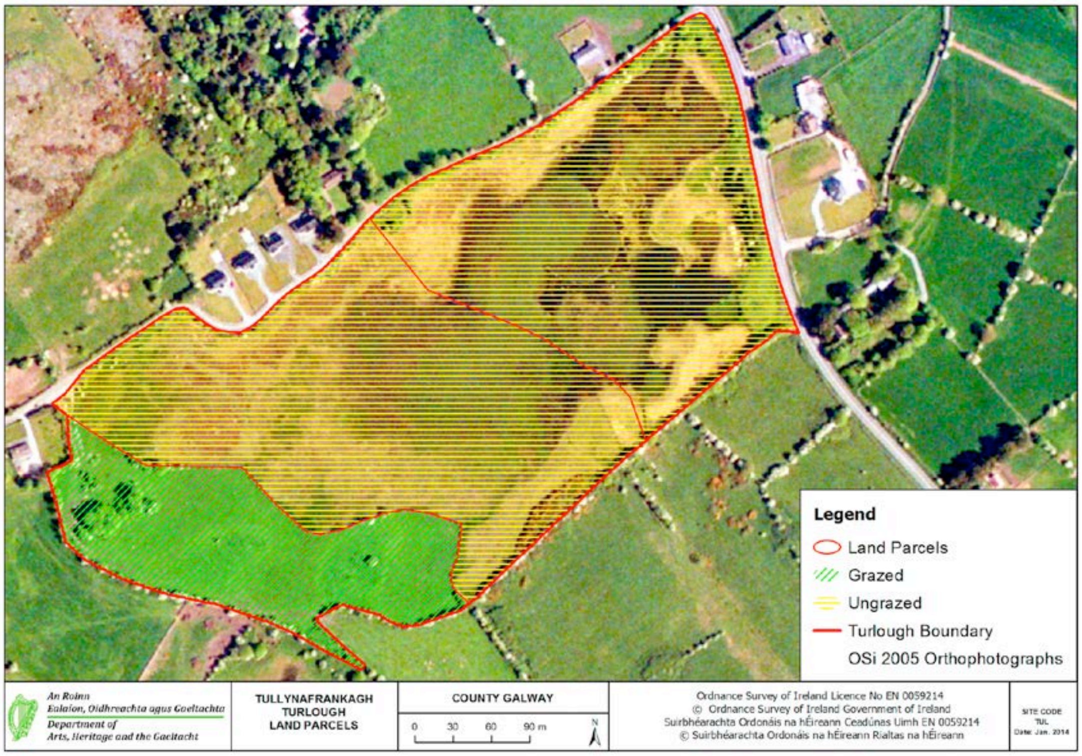


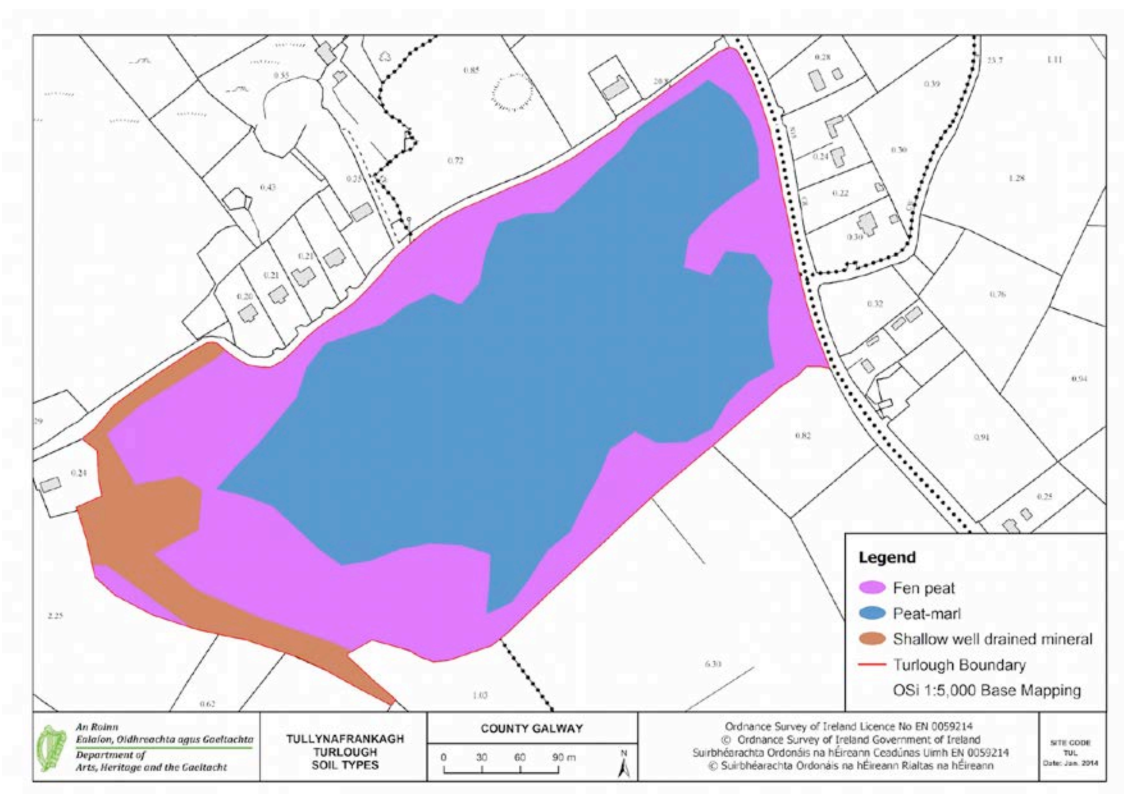
Skealoghan: Land parcels and soil types





Termon: Land parcels and soil types





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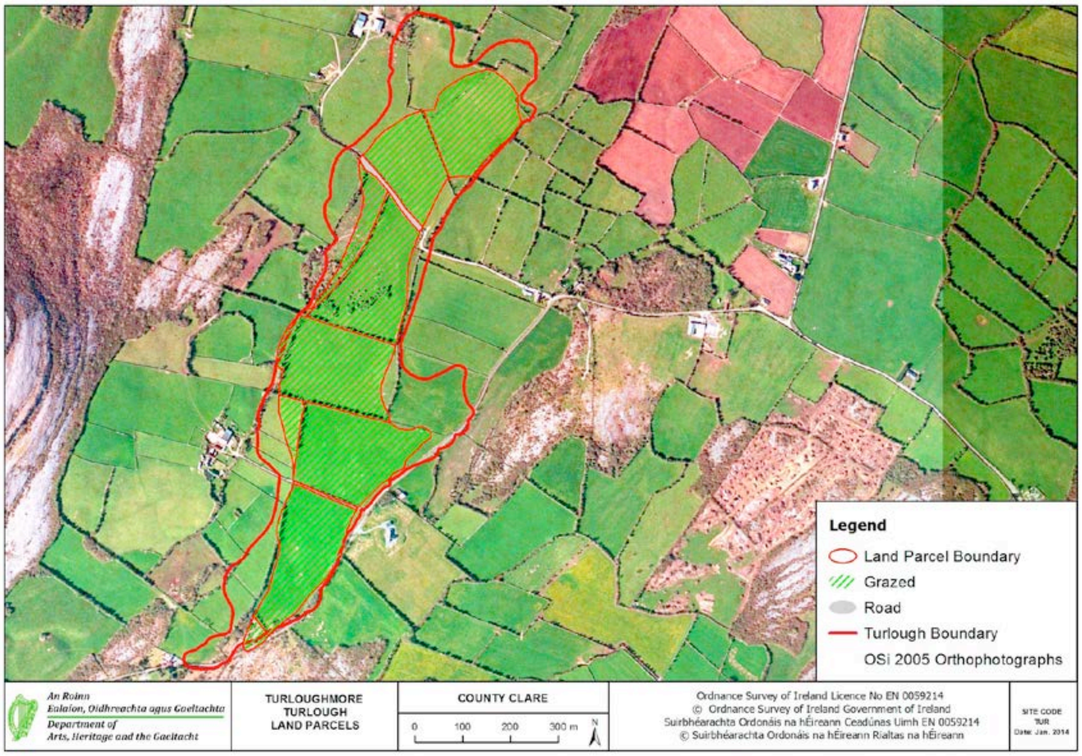

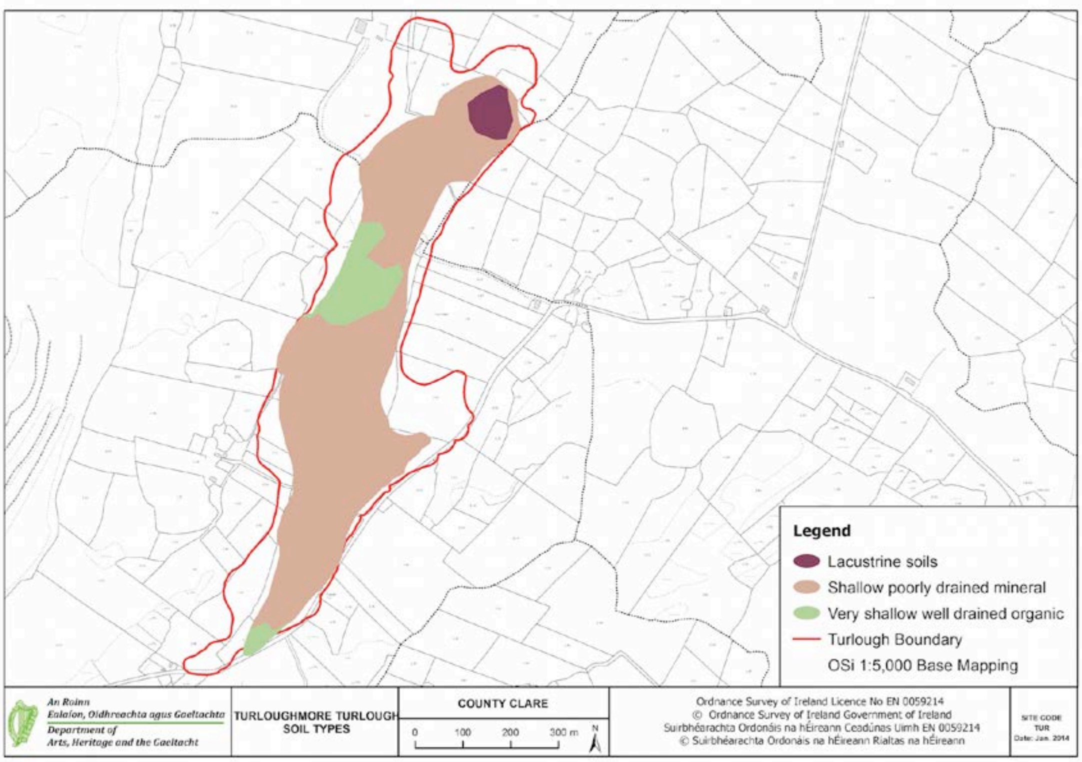

Turloughmore: Land parcels and soil types

Chapter 7. Turlough Vegetation: Description, Mapping and Ecology

N. Sharkey, S. Waldren, S. Kimberley, A. González, M. Murphy & A. O'Rourke

Flowering *Ranunculus repens* caught in an early summer rise in flood level, Coole Lough

Photo: S. Waldren

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7.1 Introduction to Turlough Vegetation

The turlough habitat is strikingly dynamic. The transformation from lake to dry, vegetated basin, and back again, creates a number of challenges for the biota of turloughs. As a result, the water regime (i.e. depth, duration and frequency of flooding) is considered the primary factor affecting plant species distribution, and hence the composition of plant communities, in wetlands (Casanova & Brock, 2000).

7.1.1 Ecotones/Zonation

The continually changing environment of turloughs means that they are considered as ecotones rather than ecosystems; that is, they are transitional zones between aquatic and terrestrial systems (Reynolds, 1996), and can be considered as the shores of underground lakes or the callows of underground rivers (Goodwillie, 2003). The fundamental premise of the ecotone concept, with respect to turloughs, lies in recognising that turloughs are not simply static zones where two communities join but are dynamic, constantly changing, have unique properties and must be understood in the spatial and temporal context of the changing ecological units (Risser, 1990).

Plant communities established in ecotones tend to be more diverse than those in adjacent ecosystems (Odum, 1971; Risser, 1990), although since they are neither stable nor mature, sudden perturbations in the environment can induce the opposite effect (Juge & Lachavanne 1996). This second scenario is more typical of turloughs due to rapid fluctuations in water level, and indeed, they display relatively low species diversity (Goodwillie, 2003). Turlough ecotones are highly variable with respect to their size, depth, groundwater connections and inundation patterns, and as a result of these specific environmental characteristics, they play host to unique assemblages of flora and fauna.

7.1.2 Vegetation Classification

Phytosociology is the science of "recognising and defining plant communities" (Kent , 2011). Early methods of classification, such as those of the Braun-Blanquet school, were subjective, based on ordering floristic tables by hand so as to place vegetation units that were similar to each other close together. More modern, numerical classification techniques are considered more objective, as the method is based on numerical values and therefore should be repeatable by different users producing the same result (Kent, 2011).

The most wide-ranging review of Irish vegetation communities to date, *The Vegetation of Ireland: A Catalogue Raisonné* (White & Doyle, 1982), collated available published and unpublished data in order to give an account of the vegetation types in Ireland according to phytosociological principles. The paper included plant associations which have been recorded in Ireland, associations believed to be in Ireland based on species lists, and associations not yet recorded in Ireland but which the authors suspected must be present. This review, however, did not attempt to define new plant communities, relying instead on fitting communities to those in the existing literature.

Fossit's *A Guide to the Habitats of Ireland* (2000) sets forth a hierarchical classification of Irish habitats, and is the most recent of the reviews of Irish habitats in its entirety. In this classification, habitats are defined based on characteristics of the vegetation, the physical environment and management (where applicable), and as such this classification is not a fine-scale description of plant communities.

The National Vegetation Classification (NVC) (Rodwell, 1991a, 1991b, 1992, 1995, 2000) is a very comprehensive classification of the terrestrial and aquatic vegetation of Great Britain, based on phytosociological principles. The NVC is widely used throughout the United Kingdom (Rodwell *et al*., 2000).

Ireland's flora lacks a number of species commonly found in Great Britain and continental Europe (Webb, 1983). This has resulted in a lesser amount of interspecific competition in a wide range of communities, and may also mean some species can tolerate a wider or different range of ecological conditions (Mooney and O'Connell, 1990). Ireland's climate also has an effect on plant life – the mild oceanic climate can result in a longer growing season, and a more widespread occurrence of Atlantic and sub-Atlantic species than might otherwise be predicted (Cross, 2006). These factors mean that it is likely that plant communities will be found in Ireland that will not be found elsewhere (White & Doyle, 1982), and that some NVC communities may not correspond with those found in Ireland.

Nomenclature in phytosociology follows strict rules. Associations are usually named by using one or two of the species thought to be typical, adding the suffix –etum to the generic name of one (usually the one considered dominant), followed by the author(s) who first published a description of the association (Weber *et al*., 2000). Similar rules are followed for higher levels of phytosociological units, or syntaxa. There are four principle ranks of syntaxa, these are arranged in a hierarchy, with Class being the largest unit, and Association generally the basic rank. For a list of suffixes and the phytosociological units to which they refer, see Table 7.1.

Table 7.1 Nomenclature followed in naming of phytosociological units (Weber *et al*., 2000)

Phytosociological unit	*Suffix used*
Class	-etea
Order	-etalia
Sub-order	-enalia
Alliance	-ion
Sub-alliance	-enion
Association	-etum
Sub-association	-etosum

7.1.3 Turlough Vegetation

Turlough vegetation is intrinsically linked to hydrology. During the 'dry' hydroperiod, turloughs are generally grass- or sedge-dominated basins, the base of which can, depending on the turlough, run the gamut from dry grassland to a permanent, but fluctuating, waterbody (Goodwillie, 1992). Some species can tolerate a range of soil moisture/flooding, and are usually found almost throughout the basin, for example *Agrostis stolonifera*, *Potentilla anserina*, and *Ranunculus repens*. Others have a more restricted range due to stricter habitat requirements, such as aquatic species which occur only in permanent water bodies.

While many turloughs can dry out completely during the dry period, some can retain water, even when the level of the water table has lowered significantly, as 'perched ponds' on impermeable substrate such as marl or glacial deposits. The presence of permanent waterbodies such as these enables the persistence of aquatic vegetation throughout the year in some turloughs.

Trees and shrubs are notably absent from the main basin, confined to the fringes of the turlough by both inundation and grazing pressures (Praeger, 1932; Goodwillie, 1992). The flora of turloughs changes along the flooding gradient, so that at the bottom of the turlough more aquatic plants are found. The composition of the vegetation gradually changes from wetland species to dry habitat species towards the upper boundaries of the turlough. This zonation of vegetation was first reported by Praeger (1932). There have since been many studies conducted on turlough vegetation; some of these will be explored in Section 7.1.4. Along the edges of the turlough, the vegetation resembles that of the surrounding non-flooded land (Goodwillie, 1992), as these upper areas are subjected to least inundation. The upper margins of the turloughs are also where shrubby and woody species such as *Rhamnus cathartica, Prunus spinosa*, and *Frangula alnus* can be found. In some ungrazed turloughs, e.g.

Brierfield, *Salix* spp. can be found at lower levels than would be expected, but in general, woody species will be killed by frequent flooding.

7.1.4 Phytosociology of Turlough Plants

There have been a number of previous vegetation studies on turloughs. Praeger (1932) was among the first to describe the vegetation communities. In an account of the plant communities of the Burren (Ivimey-Cook & Proctor, 1966), turloughs are described as *'dry and carpeted with a green turf closely grazed by cattle in summer, but sheets of water in winter or after a period of heavy rain'*. They recorded relevés in a number of turloughs in the area, compiled these into plant communities, and related these communities to those previously published in the literature. The turlough communities belonged to a number of different phytosociological classes, ranging from the aquatic to dry woodland, and these are summarised in Table 7.2.

O'Connell *et al*. (1984) conducted a phytosociological review of wetland communities in Ireland, including turlough communities. Relevés from a number of surveys were included in this review; the data were then classified in accordance with the Braun-Blanquet tabular method. Two main turlough plant communities were described; a *Potentilla anserina*/*Agrostis stolonifera*-dominated sward and a *Carex panicea*-dominated community. The forb-dominated community was related to higher trophic status and/or higher levels of disturbance, while the sedge-dominated community generally occurred at more oligotrophic sites.

MacGowran's (1985) study of turlough vegetation and pedology was a comprehensive survey of turlough plant communities of 16 turloughs in counties Galway, Clare and Mayo. He identified the major vegetation type as the 'turlough sward', a community which can be classified in the *Lolio-Potentillion anserinae* and in the *Caricion davallianae*. He also described the vegetation of the bottom of the turlough basin, which included communities of the *Phragmitetea, Potametea, Littorelletea* and *Bidentetea*.

In a review of turlough vegetation, Goodwillie (2003) described 24 turlough vegetation communities. These communities were based on two previous surveys, one which was conducted on 61 turloughs over 10ha (Goodwillie, 1992), and one carried out in the Gort area (Goodwillie *et al*., 1997). Each of these 24 communities can generally be assigned to one of two major phytosociological classes: the Scheuzerio-Caricetea fuscae, or the Plantaginetea majoris (Sheehy Skeffington & Gormally, 2007). These communities are also summarised in Table 6.2.

Proctor (2010) compared the turlough, fen and lake communities of Ivimey-Cook and Proctor (1966), Goodwillie (2003) with those of White and Doyle (1982) and the NVC (Rodwell, 1991a, 1991b, 1992, 2000, 1995). The relevant parts of this table (i.e. those concerning turloughs) are reproduced in Table 7.2

A recent study of the turlough plant communities in southeast Galway/north Clare distinguished 9 plant communities (Regan *et al*., 2007). This survey omitted extremely wet areas and limestone pavement in order to place the relevés adjacent to pitfall traps, which were used in a survey of invertebrates. The nine communities could be broadly divided into two groups; a sedge-dominated group and a forb-dominated group, with a *Carex nigra*-dominated group in between. Species were not found to be 'faithful', occurring in more than one group.

Table 7.2 Comparison of the fen and turlough communities from Ivimey-Cook and Proctor (1966), and Goodwillie (2003). The communities are arranged in the order of the phytosociological higher vegetation units in White and Doyle (1982). Original table from Proctor (2010)

White and Doyle (1982)	*Ivimey-Cook and Proctor (1966)*	*Goodwillie (2003)*	*British NVC equivalents*
Class: Potametea. Vegetation of rooted, floating or submerged aquatic plants	*Nymphaea alba-Nuphar luteum* nodum. [table ix includes various other aquatics]	8a. *Oenanthe aquatic/Hippuris* 8b. *Potamogeton/Elodea*	A3, A4, A5, A8, A10, A11 (1995)
Class: Littorelletea uniflorae. Vegetation of rooted plants in oligotrophic and dystrophic still or weakly flowing fresh clear waters	*Littorella uniflora-Baldellia ranunculoides* association (table x). *Eleocharis multicaulis-Scorpidium scorpioides* association (table x).	6a. *Baldellia/Littorella*	[A22] (1995)
Class: Bidentetea tripartiti. Vegetation mostly of summer annuals, weakly to strongly nitrophilous, especially on wet ground or in shallow water with a fluctuating water table	Five samples from sink-holes of turloughs in table vii and two in table xii probably belong here.	5b. *Polygonum amphibium, P. minus, Alopecurus geniculatus* etc. 6b. *Eleocharis acicularis/Limosella*	OV29-OV31 (2000)
Class: Plantaginetea majoris. Vegetation mostly of perennial plants (rosette and creeping hemicryptophytes) in disturbed environments; typical of ecotones or 'tension zones'	*Rumex crispus-Alopecurus geniculatus* nodum (table vii). *Carex nigra-Potentilla anserine* association (table xxxv).	3c. Tall herb 4a. *Potentilla reptans/Viola canina* 4b. *P. reptans/Carex nigra* 4c. Dry *Carex nigra* 4d. Wet *Carex nigra*	[MG11], MG13 (1992) SD17 (2000) ?MG8 (1992)
Class: Phragmitetea; Reedswamps and allied communities –			
Order: Nasturtio-Glycerietalia. Relatively short vegetation (<1m) in the contact zone between land and still or running water in relatively stable fertile habitats.	Table xvi lists one sample from a turlough west of Gort.	5a. Floodgrass; *Glyceria fluitans, Eleocharis palustris*	S22, S23 (1995)
Order: Phragmitetalia. Vegetation of tall emergent aquatics often monodominant in stagnant or slowly slowly moving water	*Scirpus lacustris-Phragmites communis* nodum (table ix).	8c. *Schoenoplectus/Phragmites*	S4, S8 (1995)

NVC communities are approximate equivalents, where communities comparable with those in the Burren have been described in Britain. Square brackets indicate incidental associations

Table 7.2 (contd.) Comparison of the fen and turlough communities from Ivimey-Cook and Proctor (1966), and Goodwillie (2003). The communities are arranged in the order of the phytosociological higher vegetation units in White and Doyle (1982). Original table from Proctor (2010)

White and Doyle (1982)	***Ivimey-Cook and Proctor (1966)***	***Goodwillie (2003)***	***British NVC equivalents***
Order: Magnocaricetalia. Vegetation dominated by large sedges. Often in a zone around open water behind reed swamps of *Phragmites* etc	*Cladium mariscus-Utricularia intermedia* nodum (table xv). *Carex elata* and *Juncus subnodulosus* stands (table xv).	8d. Magnocaricion 8e. *Cladium mariscus*	[S1], S9, S28 S2 (1995)
Class: Parvocaricetea. Vegetation of swamps and acid and calcareous fens, typically dominated by short (<50cm) *Carex* spp. or other small sedges, with water generally near the surface through most or all of the growing season	*Carex nigra-Acrocladium gigateum* association (table xxxi). *Schoenus nigricans-Cirsium dissectum* association (table xxxii). Burren *Carex demissa* nodum (table xxxiv). *Potentilla anserine-Drepanocladus lycopodioides* nodum (table xxxiv).	7a. Peaty *Carex nigra* 7b. *Schoenus/ Cirsium dissectum*	M9 M13 (1991b) [M10] (1991b)]SD17 (2000)
Class: Festuco-Brometea. Open or closed, species-rich, grazed vegetation on calcium-rich, dry, warm soils	*Antennaria dioica-Hieracium pilosella* nodum (table xxviii). [Other dry calcareous grasslands described by Ivimey-Cook and Proctor occur on dunes or in the high Burren.]	2c. Limestone grassland	CG9, [CG8] (1992)
Class: Molinio-Arrhenetheretea; Anthropogenic lowland meadows and pastures. Replacement communities of deciduous woodland on a variety of soils	*Potentilla fruticosa* stands (table xxiv). *Juncus acutiflorus-Senecio aquaticus* nodum (table xxv). Centareo-Cynosuretum (table xxvi).	2d. *Lolium* grassland 2e. Damp grassland 3a. Sedge heath 3b. *Carex hostiana/Molinia*	MG5-MG7 MG8-MG10 M23 M24 (1992)
Class: Rhamno-Prunetea. Vegetation of bushes and shrubs, often spiny; essentially degraded woodland or woodland-margin communities	[*Crataegus-Prunus spinosa* scrub was seen by these authors as fragmentary woodland; samples from *Potentilla fruticosa* stands (table xxiv) include *Prunus spinosa, Rhamnus catharticus* and *Frangula alnus.*]	2a. Turlough scrub	W21, W22 (1991a)
Class: Querco-Fagetea. Stratified deciduous forests with a species-rich herbaceous layer on mineral-rich well-drained soils	*Corylus avellana-Oxalis acetosella* association (table xxxviii).	1a. Dry woodland	W9, [W8] (1991a)
Unclassified		2b. Flooded pavement	

NVC communities are approximate equivalents, where communities comparable with those in the Burren have been described in Britain. Square brackets indicate incidental associations

This broad division between grass- and forb-dominated vegetation and sedge-dominated vegetation has been reported throughout the literature (for example MacGowran, 1985; O'Connell *et al*.; 1984; Goodwillie, 1992; Regan *et al*., 2007; Moran *et al*., 2008). The sedge-dominated communities have been found to be associated with lower trophic status, later release date of inundation, longer period of inundation and shallow or absent glacial deposits. In contrast, the forb-dominated communities occurred in areas with increased nutrient availability, deeper mineral deposits and decreased soil moisture (O'Connell *et al*., 1984; Regan *et al*., 2007; Moran *et al*., 2008).

Wet grasslands are another feature of turlough vegetation. They are subjected to more anthropogenic disturbance than some of the more permanently wet vegetation types. Characteristic species include rushes, such as *Juncus articulatus* and *Juncus acutiflorus*, a small number of grass species, such as *Agrostis stolonifera,* and small sedges such as *Carex nigra, Carex panicea* and *Carex flacca.* A number of forb species can also be characteristic of wet grasslands, such as *Cardamine pratensis, Galium palustre, Ranunculus repens* and *Mentha aquatica* (Fossitt, 2000).

7.1.5 Ellenberg Values

The presence or absence of a plant species can be a useful bioindicator, and can provide information on the environmental conditions in the habitat in which it is found. The presence of a plant in a certain habitat can, therefore, be used to describe the environmental conditions which prevailed over the lifetime of that plant. A number of ecologists have attempted to quantify this relationship between plant species and their environment by assigning species indicator values for various environmental variables to a plant species. The most well-known of these is Heinz Ellenberg, who has published a number of lists of indicator values for plants in central Europe (Ellenberg, 1979, 1988; Ellenberg *et al*., 1991). These values have been adjusted to be relevant for plants in the British Isles by Hill *et al*. (1999), they include indicators for substrate wetness, pH and fertility, ad for the light environment.

7.1.6 The C-S-R Model

Grime (1974, 1977, 1979) proposed a model to describe the 'strategies' by which plant species and vegetation can survive in varied habitats. The basic premise is that there are two main external factors which affect vegetation; *stress*, factors which affect the growth of the plant through limiting photosynthetic ability, such as water stress, nutrient shortage, etc., and *disturbance*, which can be natural or anthropogenic in origin, such as flooding, drought, mowing, etc. In areas of high stress and high disturbance, plants which adopt a short, opportunistic life cycle, such as ruderal species, gain the advantage. Where both stress and disturbance are low, those plants which can out-compete their neighbours become most successful. The third strategy is that of stress toleration, where stress is high but disturbance is low (Grime *et al*., 1988). Analysis of C-S-R strategies can give useful insights into vegetation ecology. As with Ellenberg indicator values, C-S-R values can be derived from relevee data using look-up databases.

7.2 Turlough Vegetation Ecology

7.2.1 Hydrology and Vegetation

Seasonally or intermittently flooded wetlands pose a number of challenges for the plants which live there, and hydrology, disturbance, spatial heterogeneity and productivity are all major factors which affect them (Pollock *et al.*, 1998). A constantly changing water regime changes the physical and chemical properties of soils (Ponnamperuma, 1984), which affects the relative competitive abilities of plant species, thereby influencing the species composition of vegetation communities (Pollock *et al*., 1998; Kennedy *et al*., 2003). Three main aspects of the hydrological regime have been shown to have the greatest effect on the ecology of wetlands; these are duration, depth and frequency of flooding (de Becker *et al*., 1999; Casanova & Brock, 2000; Thompson & Finlayson, 2001). These three aspects of the flooding regime are also assumed to be the main drivers of change in turlough vegetation communities, while the level of the summer water table has also been determined to be an important factor (O'Connell *et al.*, 1984; Goodwillie, 1992, 2003; Visser *et al*., 2006; Regan *et al*., 2007).

Depth of flooding will impact on the species which can survive in an area within a turlough, and therefore on the communities which are found there. Voesenek *et al*. (2004) found that tolerance to flooding through rapid growth of stems and petioles was a favourable trait in areas with shallow and prolonged flood events; this would not be a profitable use of resources in the bottom of deep turloughs or those which flood and empty rapidly and repeatedly. The rhizomes of some plants, such as *Schoenoplectus lacustris*, can survive months of total anoxia (Crawford, 2008). While flooding tolerance gives an advantage to certain plant species, the recession of floodwaters is also a disturbance. Adaptations which allow plants to tolerate inundation may reduce competitive ability in the absence of flooding; for example Koncalova (1990) suggested that the presence of aerenchyma could decrease the capacity for nutrient uptake of graminoids. Very frequent flood events may therefore impose an extra level of stress upon plants.

The timing of flooding may affect how it is tolerated by different plants; summer flooding, for example in response to an unusually heavy precipitation event, may be of a shorter duration than winter flooding, but the higher temperatures of the growing season can mean a greater metabolic oxygen demand, resulting in greater tissue damage under anoxic conditions than would be expected during a cooler season (Crawford, 2008).

Turlough vegetation generally exhibits a readily observed zonation, from the unaffected terrestrial communities outside the turlough boundary, to the communities at the bottom of the flooding gradient which experience the longest and deepest inundation (Goodwillie & Reynolds, 2003). Plant communities in the upper zones generally have some relationship with the vegetation communities outside the influence of the flooding regime, so that the vegetation in the upper zones of turloughs which occur within managed farmland reflects the vegetation of the managed fields outside it, with large amounts of *Lolium perenne* and *Trifolium repens*, for example.

While flood-tolerant trees are common in tropical areas (e.g. mangrove swamps), the colder winter temperatures of temperate regions place extra stresses on tree root systems, requiring trees to maintain their root systems in anaerobic conditions. Winter conditions in Ireland (long, wet, and mild) appear to be the least hospitable to flood-tolerant trees. Colder winters are less stressful; frozen soils reduce oxygen demand (Crawford, 1992), while flooded trees in warmer climates are less likely to become dormant, and can therefore maintain aeration of their roots. Conditions in north-western Europe, however, are such that winter flooding usually occurs before dormancy of tree roots, resulting in damage to the root system. Flooding thereby limits the encroachment of scrub and woody species into wetlands. In a study of the effects of flooding duration, frequency and depth on woody saplings, increasing inundation resulted in decreased presence of hardwoods, and this effect was especially strong if the inundation occurred during the growing season (Vreugdenhil *et al*., 2006). This can be observed in turloughs; even in sites where grazing is minimal a 'scrub line' is evident, beyond which new scrubby or woody species do not tend to become established. Some authors suggest grazing also plays an important part in limiting the encroachment of scrub into the turlough basin (Goodwillie, 2003; Sheehy Skeffington *et al*., 2006), although duration and extent of flooding would seem to be a more important factor, as noted by Praeger (1932). The life-history of trees and shrubs may also contribute to their vulnerability to flooding; an extreme event once every number of years may kill off any seedlings or saplings that have managed to become established.

7.2.2 Soils and Vegetation

Turloughs occurring in different catchments may also have different soil types; in a study on eight turloughs from two different catchment areas, Kimberley (2007) found that the hydrology, parent materials and hydrochemistry associated with the aquifers in the catchments influenced the soil types of turloughs found therein. Soils in the Coole-Garryland catchment area were mineral and moderately calcareous, while those in the East Burren were more organic and highly calcareous. Differences such as these can have huge effects on the species composition of plant communities. Nutrient status also differed between catchments, this may be attributed to differences in soil and underlying geology, but the nutrient content of floodwaters will also have an effect.

As with vegetation, turlough soils can exhibit zonation, with the soil type changing as the duration of flooding increases, i.e. with depth in the turlough basin. MacGowran (1985) found the soils in the upper reaches of turloughs to be generally light, freely draining rendzinas and rendzina-like soils, transitioning through more strongly gleyed soils to silty or marly substrates at the base. Peaty soils were found to be relatively extensive, but generally shallow (usually less than 30cm). The soil in the bottom of a turlough basin can be clay, sand, silt, peat or marl, or a combination of these, and is associated with the hydrological regime of the turlough (Coxon, 1987). Different substrates have different levels of permeability, which affects how quickly water drains from the soil when flooding recedes, and hence how waterlogged (or not) the soil remains. Some areas within turloughs may have impermeable layers of marl underneath other substrates, which can result in the overlying soil retaining water, or even perched water tables which persist throughout the year. Turlough soils and land use are fully described in *Chapter 6: Soils and Landuse*.

7.2.3 Water Chemistry and Vegetation

Turloughs are generally flooded by groundwater, rain and overland flow may also contribute to the hydrology, but are generally thought to be of lesser importance. The chemistry and nutrient status of turlough floodwaters are influenced by the catchment area.

Cunha Pereira *et al*. (2010) suggest that nutrient leaching from soils in the turlough catchment, rather than soils within the turlough basin, is the main source of nutrient input into turlough waters. Since turloughs are generally surrounded by agricultural land, this can be an important source of nutrients, and the quality of floodwaters is thought to be one of the main factors affecting trophic status of turloughs (Southern Water Global, 1998). Aside from inputs from agriculture, the geology and soils of catchments can also influence the nutrient status of floodwaters (Kimberley, 2007), and hence the trophic status of turloughs.

7.2.4 Nutrient Status and Vegetation

To date, trophic statuses of turloughs in the dry phase have been estimated based on the proportion of terrestrial plant communities with enrichment-sensitive species (Goodwillie, 1992; Working Group on Groundwater, 2004). Turloughs are generally thought of as mesotrophic, although there are more eutrophic turloughs, more oligotrophic turloughs, and gradations in between (Goodwillie, 2001). Even within a single turlough basin, there may be differences in nutrient content of soils; for example there may be richer patches of soil along the winter flood line or near swallow holes.

7.2.5 Land Management and Vegetation

The management and land use of turloughs, including regulating the amount of grazing which occurs on them, is an important factor in biodiversity maintenance. A number of management practices have been identified as damaging to turlough biota, such as turf cutting, drainage and fertiliser application. These have largely been stopped in turloughs due to legislation. Ní Bhriain *et al*. (2003) reported that, of ten farmers surveyed at Caherglassan turlough, eight had applied fertiliser to either land directly adjacent to or within the turlough basin itself.

Many wetlands have been used historically for grazing (Williams, 1990), and maintaining certain levels of grazing are likely to be important for maintaining biodiversity (Bignal & McCracken, 1996). The response of individual species to grazing differs, and they can be characterised as grazing increasers or grazing decreasers, depending on their shift in relative abundance (Vesk & Westoby, 2001). Vesk and Westoby found, however, that the response of a species can shift depending on environmental factors such as rainfall.

Grazing has a number of impacts on plants and plant communities, including defoliation, damage through trampling and the introduction of dung, which result in loss of biomass, seed dispersal and nutrient input (Gibson, 1988). These mechanisms can also open up the vegetation, allowing colonization by ruderal and annual species, which may also benefit from the increased nutrient concentration associated with dunging (Goodwillie *et al.,* 1997). Certain life-forms, such as rosette-forming species, may also be favoured by these conditions (Rodwell, 1991). Some species exhibit greater tolerance to herbivory, i.e. capacity for regrowth after grazing (del-Val and Crawley, 2004), while others are more palatable, and therefore selectively removed by grazers (Goodwillie, 2003). Grazing can have variable effects on plant communities in different circumstances. Through the direct consumption of competitive species and indirect effects on plant competition, herbivores are generally thought to increase plant biodiversity (Marty, 2005; Pyke & Marty, 2005). A number of factors are important, however, including type of livestock, density of livestock, length of time of grazing period, and when in the growing season grazing takes place.

Vertebrate herbivores are the largest grazers within the turlough ecotone, especially livestock such as cattle and sheep, and due to their size and the amount of biomass they consume, they are particularly influential on the plant communities they graze. Other grazers may also have an important influence, for example molluscs can have an impact on biodiversity (Frank, 2003), but in the context of this paper, ‘grazing’ refers to the use of the land as grazing pasture for livestock. Wild grazers such as hares can be common on turloughs and the surrounding land, but since their impacts are not quantified in this study, these are treated as 'background' grazing.

While a certain level of grazing is required in order to maintain turlough vegetation, overstocking can have detrimental effects on turlough biodiversity. Ní Bhriain *et al*. (2003) compared the vegetation of two turloughs (Caherglassan and Caranavoodaun) with differing stocking density, and found that a higher stocking density was correlated with a greater proportion of bare ground and more ruderals in Caherglassan when compared to an adjacent field with a lower stocking density. The intensity and timing of grazing can vary hugely both within and between turloughs (Ní Bhriain *et al*., 2003). The timing of grazing affects plant community composition; grazing during sensitive phases in the life cycle of species which are vulnerable to the effects of grazing may disproportionately affect these species (Noy-Meir *et al*., 1989, Hobbs & Huenneke, 1992). If livestock are put out to graze before vegetation regenerates after the recession of floodwaters, the waterlogged soils are more prone to damage through poaching, resulting in the proliferation of ruderal species (Goodwillie, 2001).

7.2.6 Interactions Between Environmental Factors

It is important to consider the disturbances that affect the vegetation of turloughs together, rather than separately. Multiple disturbances may act synergistically rather than additively (Hobbs & Huenneke, 1992), and in the case of turlough vegetation, the effects of hydrology, soil type and grazing in particular may be difficult to disentangle (Moran *et al*., 2008). Flooding levels will dictate availability of grazing land, and some soil types may support vegetation that is not usually grazed, either because it is inaccessible to livestock or unpalatable. The influence of hydrological regime and grazing on Skealoghan turlough was investigated by Moran et al. (2008). In this study, two main plant associations were found, the *Cirsio-Molinietum* and the *Ranunculo-Potentilletum anserinae*, both of which are well-represented in the vegetation communities defined and described in Section 7.5. Moran *et al*. found that the main factors affecting vegetation within the turlough were flooding regime and grazing, which in combination can influence soil properties such as the proportion of organic matter found within the soil. They found that the *Ranunculo-Potentilletum anserinae* association occurred at lower elevations within the turlough, and therefore experienced longer and deeper inundation than the *Cirsio-Molinietum* association. Management of stocking levels was found to influence vegetation composition, as grazing changes the structure of the vegetation and reduces the amount of litter accumulation, thereby affecting the competitive ability of the component species. The effects of soils and grazing on the vegetation could not be separated; peaty soils tend to have communities which are less suitable for grazing than mineral soils, and as a result these areas tend to have a reduced level of grazing by comparison. The *Cirsio-Molinietum* association was further divided into three groups based on floristic composition, and while the flood duration and depth was broadly similar for the three groups, there were differences in grazing intensity and soil composition between them.

Regan *et al*. (2007) examined the relationship between turlough vegetation communities and a number of environmental variables. They identified nine plant communities which were broadly divided into sedge-dominated communities characterised by frequent *Carex panicea* and *Carex flava* agg., and grass- and forb-dominated communities. Two groups with abundant *Carex nigra* and *Potentilla anserina* were said to represent a transitional community between the sedge-dominated and grass- and forb-dominated communities. They found that the sedge-dominated communities were associated with higher soil moisture, thinner or absent glacial deposits, later recession of floodwaters, shallower inundation and lower nutrient status than the grass- and forb-dominated communities.

7.3 Aims and Research Questions

The main aims of this chapter are to describe the structure and ecology of turlough vegetation:

1. Firstly, the vegetation communities of turloughs are described using multivariate approaches. The vegetation communities defined here are compared with those in the published literature.
2. Descriptions of the vegetation communities are given, along with their affinities to other communities and indications on their ecology based on variables derived from relevee data.
3. The vegetation communities are mapped within the 22 study turloughs.
4. The major ecological factors influencing the distribution of turlough vegetation communites are investigated, and the distributions of the species from which they are consitiuted.
5. Species and communities which might be useful as ecological indicators are determined, and the likely ecological requirements of species and communities of conservation importance examined.

These aims are met through the analysis of relevee data collected in the field to determine vegetation communities, mapping of these communities in the field using hand-held GPS mappers and incorporating the resulting data into geographical information systems (GIS), and comparing the relevee data and mapped communities with a environmental variable to determine ecological relationships. The relevee data were used to derive ecological information on the vascular plant species, while both relevee and map data were used to ecologically characterise the vegetation communities.

7.4 Methods

7.4.1 Site Selection

The study sites and the methods of their selection are described in detail in *Chapter 2: Site Selection*.

7.4.2 Vegetation Recording

Field work was conducted over three field seasons, 2006, 2007 and 2008. A small number of additional relevés were recorded in May of 2009. Species area curves were used to determine optimum quadrat size. The majority of the vegetation was grassland or short herbaceous vegetation, and a species curve found 1x1 quadrats to be satisfactory; this quadrat size would also allow comparison with previous turlough vegetation studies which had used 1m^2 quadrats (Lynn & Waldren, 2003; Caffarra, 2002; MacGowran, 1985).

Aerial photographs, taken during the summer of 2001 (OSI material, accessed via NPWS), and vegetation maps (Goodwillie, 1992) were consulted prior to field work, in order to have an initial understanding of the spread and position of vegetation types across the habitat.

Each turlough was walked over to determine (by eye) the range of vegetation types present. Each quadrat was placed so as to obtain a representative sample of the vegetation type. A minimum of 5 relevés were recorded in each vegetation type. Within each relevé, the vascular plant species present and their cover-abundance were recorded using the Domin (see Table 7.3). At the beginning of field work, a 25cm x 25cm quadrat was used to mark off one quarter of the larger quadrat to aid visual estimate of cover. Vascular plant nomenclature follows Parnell & Curtis (2012). Total bryophyte cover-abundance was recorded, but species were not determined. Information on mean vegetation height and type of herbivores present was also recorded. The amount of grazing was estimated, and given a score of 0-3, where 0 = no grazing (all growing tips on vegetation intact, no dung evident) and 3 = very heavy grazing, all vegetation cropped close to the ground. Poaching was recorded using a similar scale, where 0 = no poaching, 3 = 75% or more of the quadrat consisting of poached soil. The location of each relevé was recorded using a hand held Garmin Etrex GPS receiver (5m accuracy).

Table 7.3 Domin scores and corresponding rage of abundance used for recording relevés (after Kent, 2011)

Domin score	*Range of abundance*
+	Single individual (small unobtrusive individual)
1	1-2 individuals (larger, more obvious individual(s) than '+'
2	<1%
3	1-4%
4	4-10%;
5	11-25%;
6	26-33%
7	34-50%
8	51-75%
9	76-90%
10	91-100%

Identification of turlough vegetation can be problematic; hydrological stresses, shortened growing seasons and sometimes intensive grazing mean that specimens are often stunted (MacGowran, 1985; Goodwillie, 1992). The *Carex viridula* group was identified to subspecies where flowers were present, but since this distinction could not always be made in vegetative specimens, all were assigned to *C. viridula* agg. for analysis. *Viola persicifolia* readily hybridises with *Viola canina*, producing offspring with a range of traits from either parent. Identification of non-flowering specimens was therefore very difficult, and some were recorded as *Viola* sp. All species of *Viola* were assigned to *Viola* sp. for analysis. *Euphrasia* and *Taraxacum* were identified to genus level only, as these are very difficult groups, especially when vegetative.

The time of surveying can also affect vegetation recording; both length of time after last inundation and time within the growing season will affect the presence/absence of certain species. This is a common issue in ecological recording. One way in which this effect can be lessened is to sample at the same time each year. When sampling in the turlough environment, however, it is often necessary to time sampling according to the hydrology of the turlough rather than the calendar. This means that a larger range of species may be recorded in one vegetation type than if all recording took place at the same time of year.

7.4.3 Data Analysis

685 relevés were recorded over the summer periods of 2006, 2007 and 2008. An additional 25 relevés were recorded in May 2009. The dataset was supplemented by the inclusion of relevés from a previous study on two turloughs within the group (Feeney, 2007); 100 relevés

were included from this study. These relevés did not include information on bryophyte presence/absence. The analysed data set consisted of 813 relevés. To make all data points compatible, bryophyte cover/abundance information was omitted, as per the Feeney quadrats. To reduce noise within the dataset, species occurring in less than three relevés were omitted (McCune & Grace, 2002). This brought the total number of species down from 239 to 177. The data were then analysed using PC-ORD 5 (MjM Software, Oregon). The method followed was adapted from Perrin *et al.* (2006).

Non-metric Multidimensional Scaling (NMS) was used for ordination. Ordination techniques can be used to examine complex data sets by simplifying the factors affecting the data into a reduced number of dimensions that explain the majority of the variation. The distance between objects in the ordination space is a function of how similar they are; generally those objects which are close together are more similar than those which are far apart. This means that ordination can be a useful way in which to compare individual and groups of relevés. Environmental variables can also be overlayed on these plots to enable an examination of the relationships between relevés and environmental data. NMS is an iterative ordination technique which has been recommended over other methods of ordination for ecological community data, as it is flexible and is less prone to artefacts than other methods such as PCA and DCA (McCune & Grace 2002). Species data were relativised before conducting the NMS. The 'slow and thorough' autopilot mode, with the Quantitative Sørensen (Bray-Curtis) distance measure was used. This mode uses a random starting configuration, with a stability criterion of 0.0001 and 15 iterations to evaluate stability. 250 randomised runs were used for a Monte Carlo test to determine the probability of the final stress value being obtained by chance.

Outlier analysis was carried out in PC-ORD; outliers can greatly affect the outcome of analysis (McCune & Grace, 2002). No relevés fell beyond 3 standard deviations from the grand mean; all relevés were therefore included in the analysis.

Hierarchical, polythetic, agglomerative cluster analysis was used to group the data into vegetation types. This procedure calculates a distance matrix by measuring the dissimilarity or similarity between each pair of samples in the data matrix. The most similar samples are grouped together, and their attributes combined. This process is repeated until only two groups remain. The results can then be displayed as a dendrogram (McCune & Grace, 2002). The Quantitative Sørensen (Bray-Curtis) distance measure was selected, as this has been shown to be one of the most effective measures for ecological community analysis, and appropriate for use with ordinal (i.e. Domin scale) data (McCune & Grace, 2002). The Flexible Beta linkage method was used, with parameter β set to -0.25, as this gives the best approximation of 'natural' clusters (McCune & Grace, 2002).

To objectively determine the optimum level of clustering (i.e. the number of groupings which give the most information), Indicator Species Analysis (ISA) was used (Dufrêne & Legendre, 1997). ISA produces percentage indicator values for species, based on the premise that an ideal indicator species will be found in all samples within a predefined group, and that this indicator species will only occur within this group. At any given level of clustering, an indicator value is assigned to each species. The significance of this assignment is tested using Monte Carlo randomisations. Dufrêne & Legendre (1997) proposed that indicator values could be used as a stopping rule for clustering, i.e. indicator values would be low when groups are either too finely or too broadly defined. ISA, however, is not appropriate for ordinal data, i.e. Domin scores (Podani, 2006). In order to overcome this, the Domin 2.6 transformation (Currall, 1987), which is more accurate than direct averaging, was applied to the data. ISA was run on the output from the hierarchical clustering cycles yielding 2-30 groups with 1000 randomisations used in the Monte Carlo tests. The criteria used to determine the optimum number of clusters were number of significant indicators ($p \leq 0.05$) and the sum of significant indicator values at each stage of grouping. The optimum number of groups is arrived at by comparing the average p-value across all species (McCune & Grace, 2002).

Synoptic tables were used to describe the floristic composition of the groups, following the style of the British National Vegetation Classification (Rodwell, 1991a). Frequency and range of Domin scores (for each species in that community) are indicated in the table. 'Frequency' is taken here to mean how often the species is found in samples within a community.

Modular Analysis of Vegetation Information System (MAVIS; Smart, 2000) was used to objectively assign the vegetation types to the British National Vegetation Classification group to which they were most similar. This software was also used to calculate weighted averages of Ellenberg indicator values for each quadrat. Using averaged data in this way gives a more reliable indicator of environmental conditions than data for individual species, as there is less overlap of ecological tolerances when a number of species are considered together than the overlap of ecological tolerances of a single species (Diekmann, 2003). The Ellenberg indicator values and the range of environmental conditions to which they refer are presented in Table 7.4.

Table 7.4 Ellenberg indicator values used in the analysis

Parameter	*Range*	*Minimum value*	*Maximum value*
L – Light	1-9	Plant in deep shade	Plant in full light
F – Moisture (Wetness)	1-12	Extreme dryness	Submerged plant
R – Reaction (soil pH or water pH)	1-9	Extreme acidity	Extremely calcareous
N – Nitrogen (Fertility)	1-9	Extremely infertile sites	Eutrophic sites

As well as Ellenberg indicator values, MAVIS also generates CSR values for each quadrat. These are values based on the triangular CSR model which classifies vegetation based on three established plant strategies; Competitors, Stress-tolerators and Ruderal species (Grime *et al*., 1988).

The non-parametric Spearman's rank correlation coefficient was calculated for the ordination axes and Ellenberg and CRS values using SPSS (Release 18.0.0).

7.4.4 Vegetation Mapping

The methodology was based on the recommendations in draft versions of Smith *et al*. (2011). Twenty-two turloughs were surveyed during the summers of 2009 and 2010.

7.4.4.1 Field Preparations

Ordnance Survey (OS) aerial orthorectified photographs and maps, previous vegetation maps (mostly digitised maps from Goodwillie, 1992), and topographical contour maps (generated through the hydrological component of the project) of the site to be mapped in the field were consulted. This helped to give a general overview of the geographic location, size, topography, and vegetation of a site. Turlough plant community species lists (generated by analysis of relevés recorded as part of the vegetation component of the project) and community identification keys were printed and laminated, to be used in the field for identifying turlough vegetation types. Trimble handheld GPS devices (Nomad and GeoExplorer models) were used for field recording and loaded with georeferenced (to Irish Grid) TIFF images of all available aerial photos and OS maps for turloughs. Data files were created, using Trimble GPS Pathfinder Office Software®, which incorporated previous vegetation maps and topographical maps (where available) and a menu of feature types used to record point feature data in the field.

7.4.4.2 Fieldwork

On arrival at each site, the vegetation was inspected by walking through a small part of the turlough. This provided a sample of the general type(s) of vegetation present and what to potentially expect from the rest of the site. Subsequent to preliminary walk-throughs, vegetation types at each site were identified with the aid of species lists and keys and recorded using one or more Vegetation Point feature types using handheld GPS devices. If interpretation of vegetation was made difficult by various factors (phenological, hydrological, disturbance, etc.), this was noted and a general species list was usually taken (using the DAFOR relative abundance scale). Unknown plant specimens were placed into zip-lock plastic bags for later identification.

Boundaries between vegetation types were recorded roughly along the centre of the observed zone of transition between two types of community. They were recorded along the putative boundary at intervals of 5 m, 10 m, 20 m or 30 m, depending on particular local topography and spatial configuration of vegetation. Two types of boundary point were recorded, Diffuse (transition >3m wide) and Distinct (transition <3 m wide). Boundaries for vegetation were only recorded in the field if the area of vegetation in question was above the recommended minimum values (area 400 m^2, width 4 m) for small-scale surveys in Smith *et al*. (2011). To save time, physical boundaries such as fences, walls, and the edges of distinct habitat types such as woodland and limestone pavement, were not usually recorded in the field, but were reconstructed afterwards with the aid of aerial photos and/or OS maps (in which they were usually well represented).

Features of general interest at each site were also recorded using a pre-compiled list in the data file and comments were often added to provide additional information. Examples of features recorded include putative swallow holes, fences, walls, drains, and water level points. These data were often helpful in ground-truthing landscape elements which were represented on aerial photos or OS maps, and helped improve the habitat information available for the surveyed turloughs. Digital photographs were also taken at ground level in various locations at most sites. These recorded the general topography, vegetation, water levels and various other features of the turlough as surveyed on the day, and were often used subsequently to help improve the confidence of digital spatial representations of vegetation.

7.4.4.3 Post-Field

Once fieldwork was completed each day, data files and digital photographs were transferred to a computer to ensure that data recorded in the field were backed up and safe. Receiver Independent Exchange Format (RINEX) data were downloaded from the Ordnance Survey of Ireland website (www.osi.ie). These files were used to differentially-correct the field data files with GPS Pathfinder Office software and hence help improve positional accuracy (post-processing). Data were sourced from the nearest base station to the surveyed turlough, and files were download which covered the time period when fieldwork was carried out. Any plant specimens gathered during fieldwork were examined and identifications attempted with the aid of appropriate keys and literature.

7.4.5 Creation of Vegetation Maps using GIS

7.4.5.1 Map Preparations

ArcGIS® software was used to generate digital vegetation maps using GPS data recorded in the field, all spatial data to be viewed or edited were assigned to the Irish Grid coordinate system. Differentially-corrected data files were exported as ESRI shapefiles using GPS Pathfinder Office software. Point shapefiles were generated during export and loaded into ArcMap® and a map file for the turlough was saved. Three polyline shapefiles were created and added to the map, these represented (1) diffuse vegetation boundaries, (2) distinct vegetation boundaries, and (3) land parcel boundaries. Geo-referenced (to Irish Grid) TIFF images representing aerial photos and Ordnance Survey (OS) maps covering the turlough area were also added. A polyline shapefile representing the topographical contour lines for the site was also added. The uppermost contour line in this dataset represents the highest flood limit of the turlough as surveyed during the project, and this line was extracted as a separate layer which represented the site boundary. OS vector maps were loaded to the map and the OS vector map lines within the turlough boundary which were needed to create vegetation polygons were copied to the previously created land parcel polyline dataset.

7.4.5.2 Creation of Vegetation Boundaries

Vegetation boundary polylines were drawn to link all boundary points. Diffuse boundary polylines were used as the default boundary type to link boundary points and draw boundaries. Only when two or more confirmed distinct (<3 m wide) field boundary points occurred next to each other along a vegetation boundary, was a distinct boundary polyline used to link them. Boundaries representing the edges of well-defined habitat such as woodland, scrub, and limestone pavement were drawn using information from OS aerial photos and maps - these boundaries were generally not recorded in the field in order to save time. OS vector map lines were also sometimes used to map these areas, where these were present and deemed accurate. Boundary polylines were also drawn to represent (with potentially reduced accuracy) other vegetation boundaries that could not be recorded directly in the field due to various factors (e.g. flooding, inaccessibility). In these cases lines were drawn primarily using the information available in aerial photography (OS ortho photography and Google Maps® satellite images), occasionally supplemented by information from digital photos taken in the field. All vegetation boundary polylines were extended and snapped to the nearest land parcel or site boundary polyline. This ensured that all spaces were fully enclosed by lines and that these lines could then be used to create a polygon dataset. All edits to boundary polylines were then saved in the map file.

7.4.5.3 Creation of Vegetation Polygons

A vegetation polygon shapefile was created with the Feature to Polygon tool in ArcMap, using the site boundary polyline shapefile as the feature to be converted. This resulted in a single polygon representing the entire area of the turlough. Several fields were added to the attribute table of this shapefile, representing site name, community type, comments, x/y coordinates, and area in hectares. All boundary polylines and all or most of the land parcel polylines (depending on usefulness) were then selected and the vegetation polygon was split into separate smaller polygons using this selection via the Construct Features tool on the Topology toolbar in ArcMap.

Separate polygons were each attributed to a vegetation type, using the information recorded in vegetation identification points or via a deductive process using field data and information from aerial and ground-level photographs. Relevant comments applicable to the particular vegetation polygon were added. Polygons which did not correspond to any vegetation type defined by the project (via relevé analysis) were labelled Other/unknown and further information was added in the comments field, such as the closest Fossitt (2000) habitat to the vegetation in question. Any polygons created during this process which were smaller than the minimum mappable unit of 0.04 hectares (400 m^2; Smith *et al.* 2011) were merged with the nearest vegetation polygon above this size within the same land parcel unit. Exceptions to this were when the polygon represented part of a larger patch of vegetation continuing outside the turlough boundary, or when it represented a small area of permanent open water (e.g. a pond – these were retained as features of interest).

7.4.6 Environmental Drivers of Turlough Vegetation

7.4.6.1 Hydrology

Data on the hydrological regime of each turlough were obtained from Owen Naughton, who collected all of the hydrological data described in this section. A brief description of methods are given below, for detailed methodologies see Naughton (2011) and *Chapter 3: Hydrology*, Section 3.8.

Water level information was obtained using a variety of Schlumberger Divers®, which were placed at or near the lowest point in each turlough. These divers measure the pressure of the water column, and the air above it, which allows the depth of water to be calculated. Changes in air pressure affect diver readings; this was compensated for using BaroDiver® (DI500) and Met Eireann synoptic station data. Divers were placed and retrieved over a three year period; the longest continuous period for which data for a large number of turloughs was January 2007 to December 2008, and so this was the period used in analyses.

Topographic surveys of the turloughs were conducted while water levels were at their lowest in the summer months, using Trimble R6 and 4700 differential GPS systems. An average of over one thousand topographic points was taken at each site. These points were used to create digital terrain models, allowing the overall volume of the turlough to be calculated. The GPS coordinates for each quadrat were compared with the digital terrain models to give an elevation (metres above ordnance datum) for each quadrat. This allowed detailed hydrological information to be extracted from the dataset, producing figures for number of days spent inundated, maximum depth of flooding, etc. (*Chapter 3*, section 3.8)

7.4.6.2 Hydrological Variables Used

A number of variables were selected to represent the depth, duration, frequency and timing of flooding. Depth was represented by the mean maximum depth of inundation for each turlough (the mean was taken from the winter maxima for two years). Duration of flooding was the number of days over the two year period for which the water level reached the level of the quadrat. A flood event, for the purposes of this study, is defined as a period of ≥ 48 hours where the level of the water is ≥ the level of the quadrat. In waterlogged soils, dissolved O_2 in the soil water can be used up within hours or days (Ponnamperuma, 1972, 1984), and previous studies have used 48 hours as the minimum length of time of inundation when considering flood events (Vreugdenhil *et al.*, 2006). Frequency of flooding was therefore the number of flood events experienced by each quadrat over the two year hydrological record. In order to assess the effect of timing of flooding, the end of the longest flooding period, the beginning of the longest flooding period, the longest duration without flooding were all calculated. In order to assess the effect of date of emptying and date of filling on turlough vegetation, the start of the longest continuous wet period and the start of the longest continuous dry period were also calculated for each relevé. The hydrological variables used in analyses and the abbreviations used in this chapter are given in Table 7.5.

Table 7.5 A description of each of the hydrological variables used in this chapter.

Variable name	*Description*	*Abbreviation*
Maximum quadrat depth	The mean of two years records of the maximum depth of water recorded for each quadrat.	MDQuad
Duration of flooding	The number of days each quadrat was inundated to 0 cm, 10 cm, 25 cm and 50 cm.	DurXcm
Frequency of flooding	The number of flood events (≥ 48 hours) which occurred at each quadrat, at depths of 0 cm, 10 cm, 25 cm and 50 cm.	FreqXcm
Length of longest dry period	The length, in days, of the longest continuous dry period.	LongDry
Start of longest dry period	The date, in Julian days, of the start of the longest continuous dry period	DryDate
Start of longest wet period	The date, in Julian days, of the start of the longest continuous wet period	WetDate

7.4.6.3 Soil Descriptions

Soil types were described and classified; the methodology is presented in *Chapter 6: Turlough Soils and Landuse*. These data were then used by Sarah Kimberley to create soil type maps of each of the turloughs in the study, using the boundaries of parent soil material as a proxy for the boundaries between soil types. In this study, relevés were overlaid on soil type maps using ArcMap Release 9.3 (ESRI, 2008), and joined to the soil type map to assign a soil type to each relevé.

7.4.6.4 Soil Nutrients

Six soil samples were taken by from each turlough, two each from the upper, middle and lower elevation zones, to a maximum depth of 20 cm. Vegetation communities (as defined by Goodwillie (1992)) were used to determine the sampling zones. Samples were then analysed for total phosphorus, total nitrogen, pH, organic matter content, non-calcareous sand/silt/clay fraction and calcium carbonate content. Table 7.6 shows variables measured and abbreviations used.

Table 7.6 Soil variables and abbreviations.

Variable	*Abbreviation*
Total phosphorus (mg kg^{-1})	Soil TP
Total nitrogen (mg kg^{-1})	Soil TN
pH	Soil pH
Organic matter (% dry weight)	OM
Inorganic matter (% dry weight)	INORG
$CaCO_3$ (% dry weight)	$CaCO_3$

7.4.6.5 *Water Chemistry*

Turlough water samples were obtained using a weighted 5 litre plastic bottle which was attached to a rope and thrown out from the turlough shore. Sampling was carried out monthly from October 2006 to June 2007. All values presented in this chapter are the means for this period (for details on methodologies used, see *Chapter 4: Water Chemistry and Algal Biomass*). The variables measured and abbreviations used are presented in Table 7.7.

Table 7.7 Water chemistry variables and abbreviations.

Variable	*Abbreviation*
Total phosphorus ($\mu g\ l^{-1}$)	Water TP
Molybdate Reactive Phosphorus ($\mu g\ l^{-1}$)	Water MRP
Total nitrogen ($mg\ l^{-1}$)	Water TN
Nitrate ($mg\ l^{-1}$)	Nitrate
Alkalinity ($mg\ l^{-1}$ $CaCO_3$)	Alkalinity
Calcium ($mg\ l^{-1}$)	Calcium

Turloughs were assigned to trophic categories based on thresholds from the Organisation of Economic Co-Operation and Development (1982) lake trophic classifications. Threshold values are given in Table 7.8.

Table 7.8 OECD boundary values for trophic categories (OECD, 1982)

Trophic category	*Mean TP ($\mu g\ l^{-1}$)*
Ultra-oligotrophic	≤ 4.0
Oligotrophic	≤ 10.0
Mesotrophic	10-35
Eutrophic	35-100
Hypertrophic	≥ 100

7.4.6.6 *Management*

Management questionnaires were given to landowners to determine, among other things, which land-parcels were grazed and which were not. A 'land-parcel' here refers to a field or group of fields which are open to livestock and managed in the same way by the land-owner. While grazing affects vegetation, an important caveat to bear in mind is that the grazed or ungrazed designation refers to the whole land-parcel, and not just the relevé. For example, in a large land-parcel which includes grassland, there may also be open water; this is unlikely to be grazed by livestock, but will be included under the 'grazed' heading. Some points within the turlough may also be isolated from the livestock by water, effectively becoming islands, during the wet phase. Some land may be unsuitable for grazing or unattractive to livestock; i.e. a land-parcel may be too wet to allow cattle onto it. Land-parcel maps indicating whether each land-parcel was grazed or not were created by Sarah Kimberley. As for the soil type data, relevés were overlaid on land use maps using ArcMap Release 9.3 (ESRI, 2008), and joined to the management data. Each relevé was then assigned to a grazing regime depending on the land-parcel to which they belonged.

7.4.6.7 Derived Variables

Ellenberg indicator values, Grime's C-S-R values and species richness were calculated for each relevé (see section 7.4.3 further details).

7.4.6.8 Data Analysis

Environmental variables

For each of the recorded and derived variables, summary statistics were calculated for each vegetation type. These were presented in tabular format and as boxplots.

Vegetation data

Twelve relevés were never inundated over the recording period; these were removed from the data set (they were included in the vegetation dataset in Section 7.4.3 as it is likely they are flooded during extreme events). There was no complete topographic survey for Tullynafrankagh turlough and as a result vegetation data could not be related to hydrological variables. These 34 relevés were also removed from the dataset. The hydrological record for Kilglassan was incomplete; these relevés were therefore deleted. There were no hydrological records for Roo West for 2007 due to a malfunctioning diver; these 27 relevés were deleted. There were no hydrological records for Ballindereen for 2008 due to a malfunctioning diver; these 31 relevés were deleted. Ten relevés had no GPS coordinates; these were deleted. This left 670 relevés with accurate hydrological data for both 2007 and 2008. The reduction in the dataset due to incomplete or missing hydrological data resulted in some of the species being present at very low frequencies; to reduce noise, rare species (i.e. those which were present in fewer than 4 quadrats) were deleted, leaving 160 species.

Outlier analysis was conducted on this reduced dataset in PC-ORD 5 (MjM Software, Oregon), using the Sorenson distance measure. No relevés had an average distance of more than 3 standard deviations from the mean of the distribution; all relevés were therefore included in the analysis. The analysis was also carried out on the species, and no outlying species (>3 standard deviations) were found.

Non-Metric Multidimensional Scaling (NMS) ordination was carried out using PC-ORD 5, as described in Section 7.4.3. This analysis was carried out in order to visualise the relationships between vegetation communities and environmental variables, by adding the environmental and derived variables to the second matrix and then overlaying the environmental variables onto the ordination as a biplot. It was also used to give an indication of the strength of the relationships by calculating correlations with the ordination axes.

A Multi-Response Permutation Procedure was carried out on the species abundance matrix to confirm differences between groups. A Mantel test was then used to examine the relationship between vegetation and environmental matrices for each quadrat. This test examines the differences between two matrices to test if the relationship between them is more different than would be expected by chance using a randomization procedure (Sokal & Rohlf, 1995).

Discriminant analysis is a procedure which tests whether a multivariate data matrix supports the splitting of samples into a series of *a priori* groups. Independent variables are combined into new variables; each relevé is then allocated a score based on these new variables, or discriminant functions (Kinnear & Gray, 2006). Discriminant analysis was carried out on the data using SPSS (Release 18.0.0). The stepwise form of discriminant analysis was used instead of direct (standard) or hierarchical (sequential) discriminant function analysis. Direct and hierarchical discriminant analysis were not used as in direct discriminant analysis, the predictor variables are all analysed simultaneously, while in hierarchical discriminant analysis the variables are analysed in an order chosen by the researcher. In stepwise discriminant function analysis, however, the most highly correlated variable is entered first by the stepwise programme, then the second and so on until an additional variable adds no significant amount to the canonical R^2 value. Given that this is an exploratory study, with no pre-existing information on which variables are most important, assigning an order to the variables was not possible, and so stepwise discriminant analysis was deemed the most appropriate method. Tests of significance are measured by Wilks' lambda. The selection criteria for entry and removal of variables were: F value for entry is 3.84, and F value for removal is 2.71.

BIO-ENV is a permutational procedure that aims to identify the combination of environmental variables that produces the highest correlation between a species matrix and an environmental data matrix (Clarke & Ainsworth, 1993). BIO-ENV was carried out using PRIMER v.6. Vegetation data were $\log^{(x+1)}$ transformed, and environmental variables were log transformed before analysis (Clarke & Gorley, 2006). All data were also normalised as recommended by Clarke and Gorley prior to analysis. A resemblance matrix was calculated for the species matrix using Bray-Curtis distance. The Spearman rank coefficient was selected for use in BIO-ENV as the measure of correlation between the species abundance matrix and the environmental variables matrix.

7.4.7 Species Distribution in Relation to Flooding Duration and Water TP

The releve data collected for description of vegetation communities were used to examine species abundance in relation to various environmental variables. Preliminary analyses, and detailed analysis of the ecological drivers of vegetation community distribution, suggested that duration of flooding to substrate surface and total phosphorus in the flood water (water TP) were likely to be the most important variables, few species showed any obvious trends with other environmental variables recorded. Subsequent analyses therefore focused on duration of flooding as the major hydrological variable, and water TP as the major nutrient variable.

Absences of species from many of the releves, a common problem in vegetation ecology, made investigation of trends for most species difficult. In addition, there was only a single measure of water TP for each turlough; the spatial variation of TP in floodwater was not recorded but is likely to show little variation. Duration of flooding and water TP were therefore divided into five categories (Table 7.9), for water TP the data were log transformed prior to categorization; categories were developed by dividing the range of flooding duration or log(TP) by five. Other categories were also investigated: three categories produced simpler results but tended to obscure some important detail in both flooding duration and TP. Log transformation of TP gave a better range of categories than untransformed data.

Thus the releves could be divided into five flood duration categories, and five TP categories in this way: this enabled frequency of occurrence to be calculated and is expressed as a percentage of all relevees within any category combination. Rare species, which occurred in only ten or fewer relevees, were omitted from the analysis.

Table 7.9. Method of categorization of duration of flooding and log(water TP); values in normal type are calculated statistics, with derived categories in italics.

Value	*Flooding duration*		*Value*	*Log(water TP)*
Max	731.0		Max	1.914
Min	10.0		Min	0.606
Range	721.0		Range	1.308
Range/5	144.2		Range/5	0.262
Very short	*10.0 - 154.2*		*Very low*	*0.606 - 0.868*
Short	*154.2 - 298.4*		*Medium low*	*0.868 - 1.130*
Medium	*298.4 - 442.6*		*Medium*	*1.130 - 1.391*
Long	*442.6 - 586.8*		*Medium high*	*1.391 - 1.653*
Very long	*586.8 - 731.0*		*Very High*	*1.653 - 1.914*

The relationship between species cover/abundance and flooding duration was investigated in more detail in a series of belt transects recorded at Blackrock (high nutrient levels) and Caranavoodaun (low nutrient levels). Two belt transects were laid out in each turlough to cover a steep and a shallow gradient down each turlough. Transects consisted of a series of contiguous 1 x 1 m quadrats. Species cover/abundance was recorded as percentage cover of each species to faciltate additional statistical analyses not reported here; for further details see O'Rourke (2010). The positions of each quadrat centre were recorded by differential GPS (see *Chapter 3: Hydrology*), and these data were used to derive duration and frequency of flooding data.

7.4.8 Ecological Distribution of Mapped Communities

Hydrological data were estimated for each vegetation community by first overlaying a 5 x 5 m grid over each turlough. The community at each grid intercept was obtained from the overlaid vegetation map, and flooding duration and frequency from the hydrological data overlaid with the modeled topography of each turlough. This gave many thousands of samples (depending on turlough area) and these samples were used to calculate the variation in duration and frequency of flooding experienced by each of the mapped vegetation communities

The area of each mapped community was derived from GIS for each turlough. Total area of defined vegetation units was calculated (excluding 'other/unknown' and 'open water' categories), and used to calculate a proportion of the mapped vegetation area of each turlough covered by the different communities. The mean proportions were calculated across all turloughs falling within the log TP category described in the previous section variation. Duration of flooding and water TP were therefore divided into five categories (Table 7.9). By basing the analysis on proportions rather than absolute areas of each community, each turlough is effectively given equal weight and the values are not dominated by larger areas occurring within physically larger turloughs.

7.4.9 Using Vegetation to Estimate Trophic Status of Each Turlough

Ellenberg indicator values have previously been used to calculate the trophic status of turloughs, based on Ellenberg fertility scores for the major species recorded in each vegetation type and vegetation maps presented in Goodwillie (1992). However, the method used did not account for all species present in a vegetation community, nor does it account for the abundance of each species. Here we used the vegetation survey relevé data (670 relevés) described previously as the basis for calculating various derived ecological variables using MAVIS. Ellenberg's Fertility index was weighted for the species abundances (Domin value scores) for each relevé, and then a mean value of Ellenberg's Fertility calculated for each community type, based on the relevés assigned to each.

Relevé data were then assigned to mapped community type based on the groups determined by cluster analysis described previously; for most mapped communities there was a direct correspondence with the cluster analysis group, but in some cases cluster groups were merged to define mapped communities (section 7.4.2). Corresponding relevés were not available for woodland and scrub, and so the area of these communities were ignored for this analysis. Similarly, the area of mapped open water was also excluded, as this was not adequately sampled to determine the variation of communities found in this habitat. The areas mapped as 'unknown/other' were also excluded, these included a variety of features, some of which were inclusions of non-turlough habitat (eg. a raised hill, or a road) within the turlough boundary. For all other mapped communities, the relevé data were used to derive an abundance-weighted Ellenberg fertility score; this score could potentially vary from 1 (very low fertility) to 10 (very high fertility). The values for each relevé were used to calculate mean, standard deviation, maxima and minima for each community.

The area of each mapped community type was calculated from the vegetation maps using ArcGIS as reported above. These areas were used to derive the proportion of the mapped area of the turlough occupied by each community type (excluding 'woodland and scrub', 'open water' and 'other/unknown' as described above). The products of these proportions for each community and the calculated community Ellenberg index were then used to calculate an aggregate Ellenberg fertility score for each turlough; again this could potentially vary between 1 (indicating very low fertility) and 10 (indicating very high fertility).

The relationship between Ellenberg fertility score of each turlough and a range of other variables was examined using Pearson Product-Moment correlation. Total P and Molybdate-reactive P (MRP) in water were log transformed to provide a better linear fit with Ellenberg fertility value.

We also assigned mapped communities to trophic status categories using the analyses described in Section 7.4.7, and used these values to calculate the proportion of the summed oligotrophic (pO) and oligo-mesotrophic (pOM) community areas in each turlough. As many turloughs lacked these oligo and oligo-mesotrophic communities, we also calculated a value that summed the oligo- and oligo-mesotrophic communities and from this value subtracted the sum of the eutrophic communities (pOM-E).

Finally, we calculated an index of trophic status based on the presence and proportion of various indicator species. These species were selected based on their frequency in relation to log of water TP categories (see section 7.4.7), but were also based on scatterplots of abundance and log TP. The aim here was to provide a simple index which could be derived much more rapidly than through mapping vegetation units or calculating Ellenberg values based on relevé data. Several permutations in the method of calculation were tested, the final method adopted is indicated in table 7.10 below. Each turlough was assessed for all species listed: for the more widespread species their frequency was calculated as the proportion of releves within a turlough that contained that species; by definition, these more widespread species occurred in a range of ecological settings, though with different abundances – calculation of frequency in this way gives a simple measure of relative abundance. For species that occurred in fewer than 10 of the 22 turloughs, their presence anywhere in the turlough was used (ie. presence or absence); these were often species with more specialised ecological requirements. Weighting values for each species were then defined, based on their predominance in lower TP (negative weights) or higher TP (positive weights). Some species which occurred most frequntly at intermediate TP values were given a weighting of zero. The mean of all species weighting values was then calculated to provide the index of trophic status; this therefore includes those species with the intermediate weighting score of zero in the calculation of the index.

Table 7.10. Species used to construct an index of trophic status and the weighting value applied. The weighting value was applied to either frequency (Y) or presence data (N).

Species	*Weight*	*Frequency*	*Comment*
Baldellia ranunculoides	-2	Y	Mostly low TP
Bellis perennis	1	N	Most frequent in medium to high TP
Calluna vulgaris	-2	Y	Low TP only
Carex flacca	-2	Y	General decline in frequency with increasing TP
Carex hirta	2	Y	Increase in frequency with TP
Carex hostiana	-2	Y	General decline in frequency with increasing TP
Carex panicea	-2	Y	General decline in frequency with increasing TP
Carex viridula agg.	-2	Y	Low TP only
Cerastium fontanum	2	Y	High TP only
Cirsium dissectum	-2	Y	General decline in frequency with increasing TP
Festuca arundinacea	1	Y	Moderate increase in frequency with TP
Filipendula ulmaria	2	Y	Increase in frequency with TP
Iris pseudacorus	2	N	High TP only
Juncus articulatus	-1	Y	Moderate decline in frequncy with TP
Littorella uniflora	-2	N	Low TP only
Lolium perenne	0	Y	Most frequent in medium TP
Mentha aquatica	-1	Y	Moderate decline in frequncy with TP
Molinia caerulea	-2	Y	General decline in frequency with increasing TP
Myosotis scorpioides	2	Y	Increase in frequency with TP
Oenanthe aquatica	2	N	High TP only
Parnassia palustris	-1	N	Medium-low TP
Plantago major	0	N	Most frequent in medium TP
Plantago maritima	-1	N	Medium-low TP
Poa annua	1	N	Most frequent in medium to high TP
Polygonum amphibium	1	Y	Most frequent in medium to high TP
Potentilla anserina	2	Y	Increase in frequency with TP
Potentilla erecta	-2	Y	General decline in frequency with increasing TP
Ranunculus flammula	-1	Y	More abundant in medium-low TP
Ranunculus repens	2	Y	Increase in frequency with TP
Rumex acetosa	1	Y	Most frequent in medium to high TP
Rumex crispus	1	Y	Most frequent in medium to high TP
Schoenus nigricans	-2	N	Low TP only
Senecio aquaticus	0	Y	Most frequent in medium TP
Stellaria media	1	Y	Most frequent in medium to high TP
Succisa pratensis	-2	Y	General decline in frequency with increasing TP
Teucrium scordium	-2	N	Low TP only

7.5 Results

7.5.1 Vegetation Description

The final dataset analysed contained 813 relevés and 177 species.

7.5.1.1 Cluster Analysis

Hierarchical, polythetic, agglomerative cluster analysis was used to arrange the species data into groups with similar vegetation. Indicator species analysis (Dufrêne and Legendre, 1997) indicated that the optimum cut-off in the cluster analysis was at the 8 group stage (this was the level of clustering at which the p-value was lowest and the number of significant indicators was highest). However, this resulted in groups which were too large and diverse to be informative. The next-best level of clustering was at the 28-group stage (see Figure 7.1). This gave clusters which made ecological sense, and so it was decided to use this as the cut-off point for the cluster analysis. To avoid confusion, the word 'cluster' will be used to refer to the eight initial clusters, while 'group' will refer to the further division of 28 communities. Figure 7.2 shows the relationship between each of the 28 vegetation communities or groups and the 8 initial clusters.

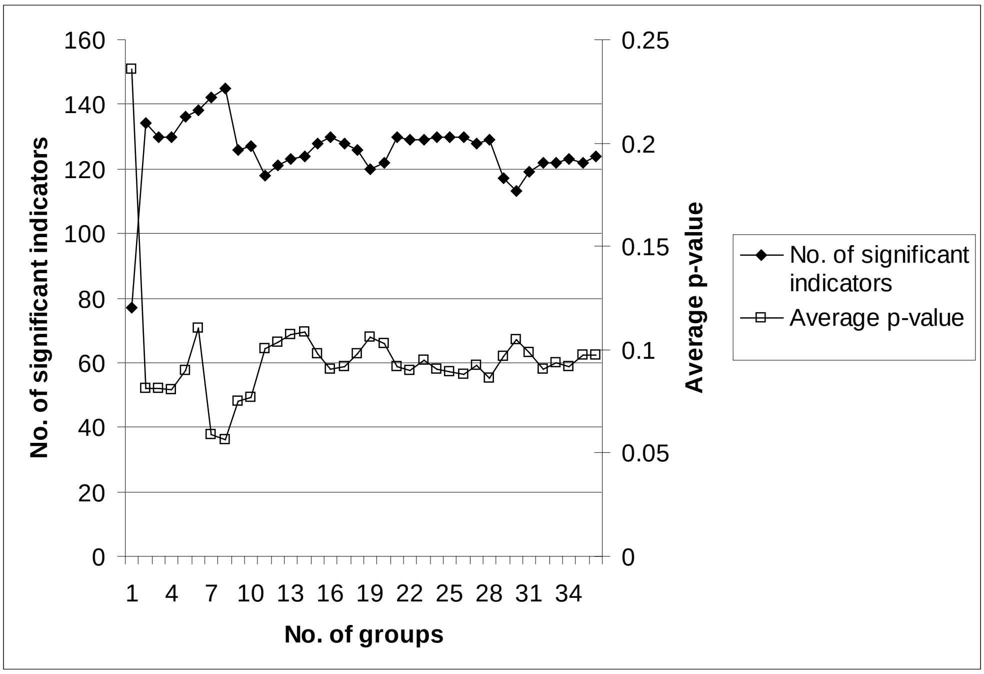


Figure 7.1 Variation in the number of significant indicators identified by ISA and the average p-value of all species at each stage of the cluster analysis.

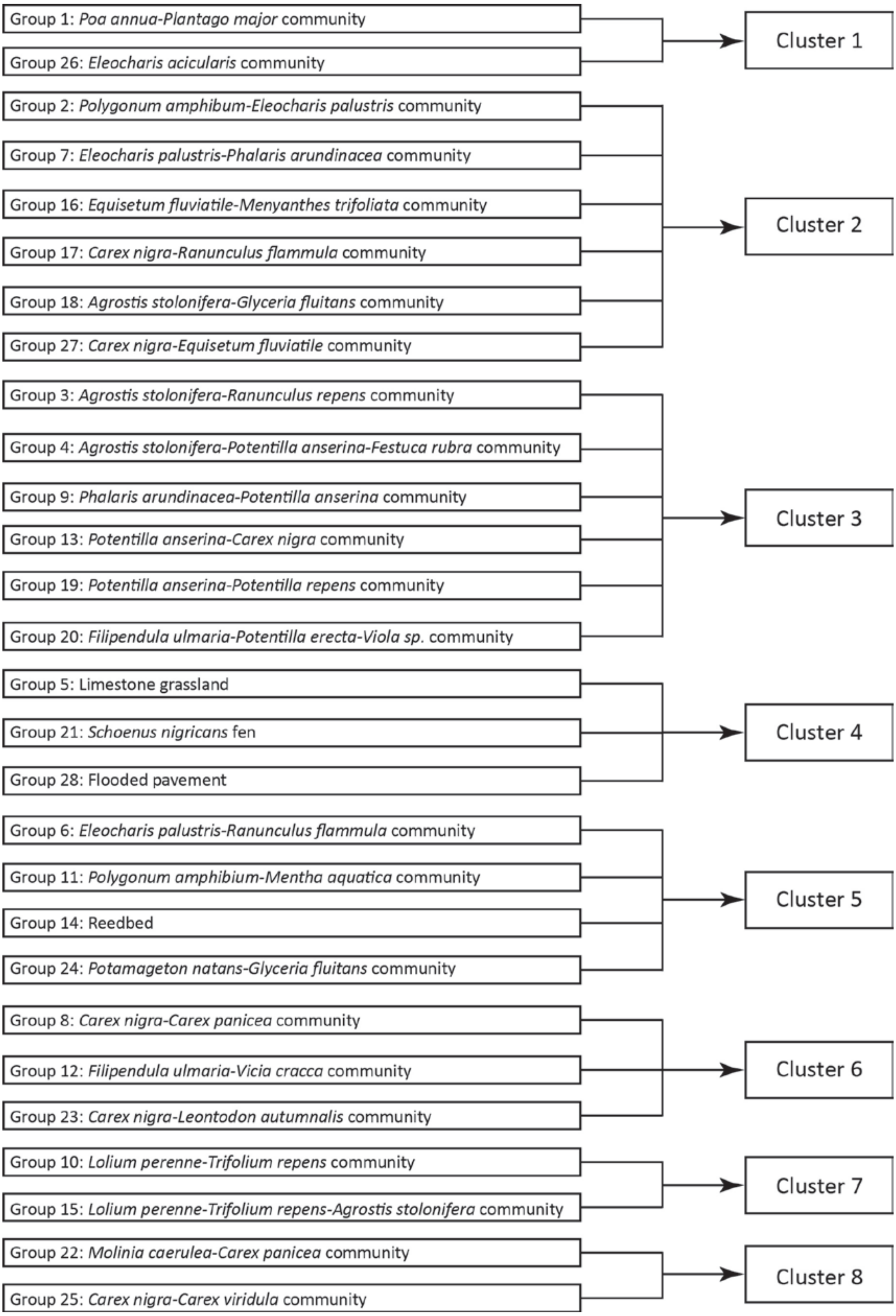


Figure 7.2 Chart showing the relationships between the 28 vegetation communities identified and the 8 major clusters

The mean number of species per relevé (a measure of species richness) was calculated for each community. See Figure 7.3 for a graph comparing these results between relevés. The mean number of species varied from just 4 for Group 24, to 18 for Group 12.

7.5.1.2 Nonmetric Multidimensional Scaling

NMS recommended a 3-dimensional solution with a final stress of 20.9%. Clarke's 'rule of thumb' suggests that values exceeding 20 are difficult to interpret with confidence (Clarke, 1993). Stress tends to increase when large datasets are used, however, and given the size of the dataset used in this instance, the final stress is probably indicative of a good solution (McCune & Grace, 2002, Perrin *et al*., 2006). A Monte Carlo test showed that the probability of a similar stress value being obtained by chance was low (p=0.0040). The final instability was very low (p<0.00000), indicating that the ordination was a stable solution.

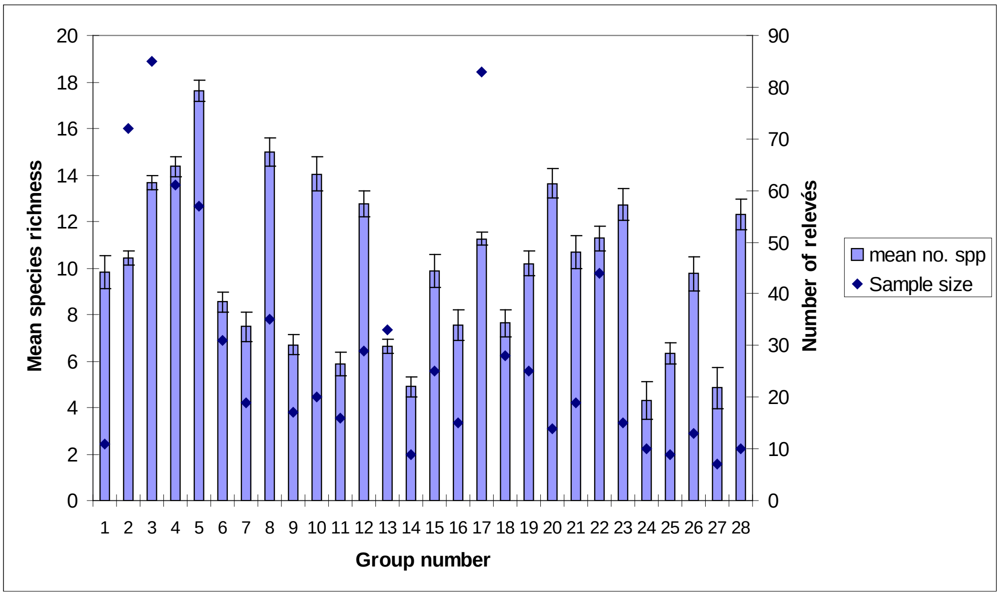


Figure 7.3 Mean species richness (± standard error) and sample size for each of the twenty eight communities indicated by cluster analysis.

With so many groups and relevés, both presentation and interpretation of the ordination can be difficult. To facilitate both, ordination diagrams showing only the eight major clusters are presented here. See Figure 7.2 for a flowchart detailing which of the 28 vegetation communities described here belong to which of the eight major clusters shown in the ordination diagrams.

Ellenberg values for Light, Wetness, Fertility and pH, and CSR values (Grime *et al*., 1988) and species data were overlaid on the ordination as a joint plot. The major correlation vectors were aligned with the axes by rotating the axes; this improves ease of interpretation (McCune & Grace, 2002). The species and derived variables which are displayed in the joint plot on the ordination diagrams are those which had a Pearson's correlation coefficient of greater than 0.2. This is useful for visualising the relationship between the relevés and the variables, but Spearman rank correlations are a more appropriate measure for non-parametric data. Spearman rank correlation coefficients were calculated for the derived variables and the species in SPSS Release 18.0.0 (see Table 7.11).

The eight main clusters identified corresponded reasonably well to defined areas on the ordinations. Dimension 1, which represented the largest proportion of variance in the data (r^2 = 0.181; Figure 7.4), is highly negatively correlated with Wetness (r = -0.906, p ≤ 0.001);

quadrats located on the left-hand side of the ordination diagram have a higher mean Ellenberg value for Wetness than those on the right-hand side. Cluster 5, represented by the open blue diamonds on the far left-hand side of the diagram, contains vegetation communities which require permanent water, such as the Reedbed community and the *Potamogeton natans-Glyceria fluitans* community. Cluster 2, represented by the green triangles, contains quadrats with a lower Wetness value; these are also water-dependant communities, such as the *Equisetum fluviatile-Menyanthes trifoliata* community. At the other end of Dimension 1 are Clusters 4 and 7, examples of which are the Limestone grassland community and the *Lolium perenne-Trifolium repens* community, respectively. These communities occur at higher levels within the turlough basin, thereby experiencing relatively little inundation. Dimension 1 was also negatively correlated with two water-dependent species: *Mentha aquatica* ($r = -0.553$, $p \leq 0.001$) and *Eleocharis palustris* ($r = -0.561$, $p \leq 0.001$).

Table 7.11. Spearman rank correlation coefficients between the NMS ordination dimensions and the variables in the second matrix (the species presented here are those which had a Pearson's correlation coefficient of >0.2 and were displayed on the ordination diagram)

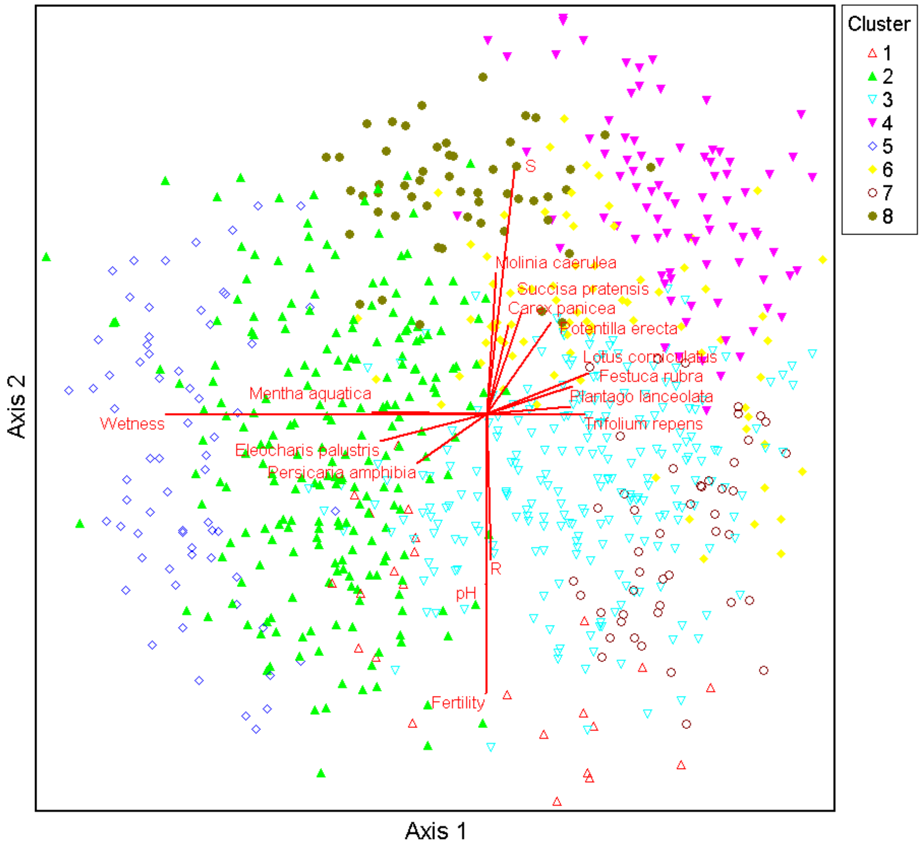
Variable	*Dimension 1*	*Dimension 2*	*Dimension 3*
Wetness	**-0.906***	-0.047	-0.156*
Light	-0.179*	0.226*	-0.083
Fertility	-0.065	**-0.818***	0.234
pH	-0.060	**-0.667***	0.116
C	-0.293*	-0.466*	-0.089
S	0.275*	**0.758***	-0.257*
R	0.099	**-0.536***	0.460*
Species richness	**0.529***	0.305*	0.248
Carex panicea	0.245*	**0.504***	0.004
Eleocharis palustris	**-0.561***	-0.287*	0.038
Festuca rubra	**0.500***	0.298*	0.273*
Lotus corniculatus	**0.544***	0.354*	-0.073
Mentha aquatica	**-0.553***	0.108	-0.081
Molinia caerulea	0.157*	**0.587***	-0.206*
Plantago lanceolata	0.493*	0.182*	0.169*
Polygonum amphibium	-0.451*	-0.406*	-0.039
Potentilla erecta	0.423*	0.484*	-0.059
Succisa pratensis	0.327*	**0.500***	0.088
Trifolium repens	0.532*	0.028	0.351*

* Significant correlation when corrected for multiple comparisons
Those correlation coefficients which are both significant and greater than 0.5 are highlighted for ease of comparison

Dimension 2 corresponds negatively with Ellenberg Fertility values ($r = -0.818$, $p \leq 0.001$), pH values ($r = -0.667$, $p \leq 0.001$) and positively with the Grimes 'S' or stress tolerator values ($r = 0.536$, $p \leq 0.001$). Quadrats which occur towards the bottom of Dimension 2 tend to contain species which require higher soil fertility, a higher pH, or are 'R' strategists. Cluster 1, for example, contains the *Poa annua – Plantago major* community, which is characterised by a high proportion of ruderal species. At the opposite end of Dimension 2 are the clusters representing communities which occur on limestone (Cluster 4) or contain higher proportions of stress tolerating species which occur on lower nutrient status substrates, i.e. the *Carex*-dominated communities of Cluster 6.

Dimension 3, which represents the smallest amount of variance at $r^2 = 0.112$, was not significantly correlated with any of the derived variables or the species.

A



B

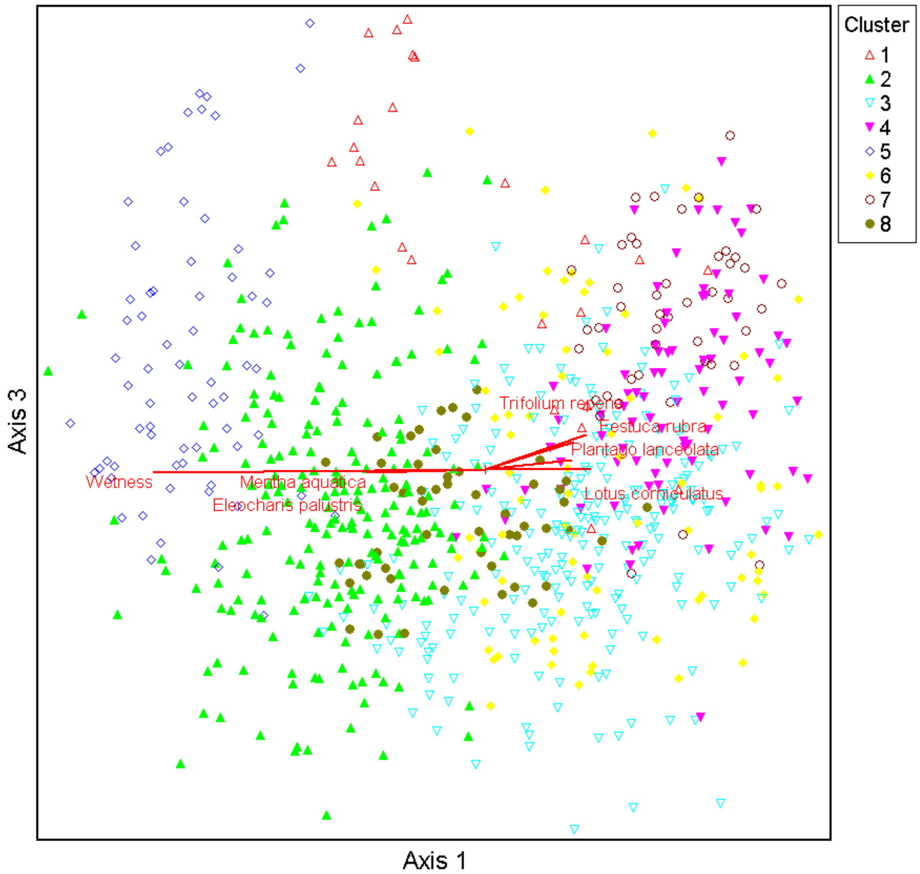


Figure 7.4 a,b

C

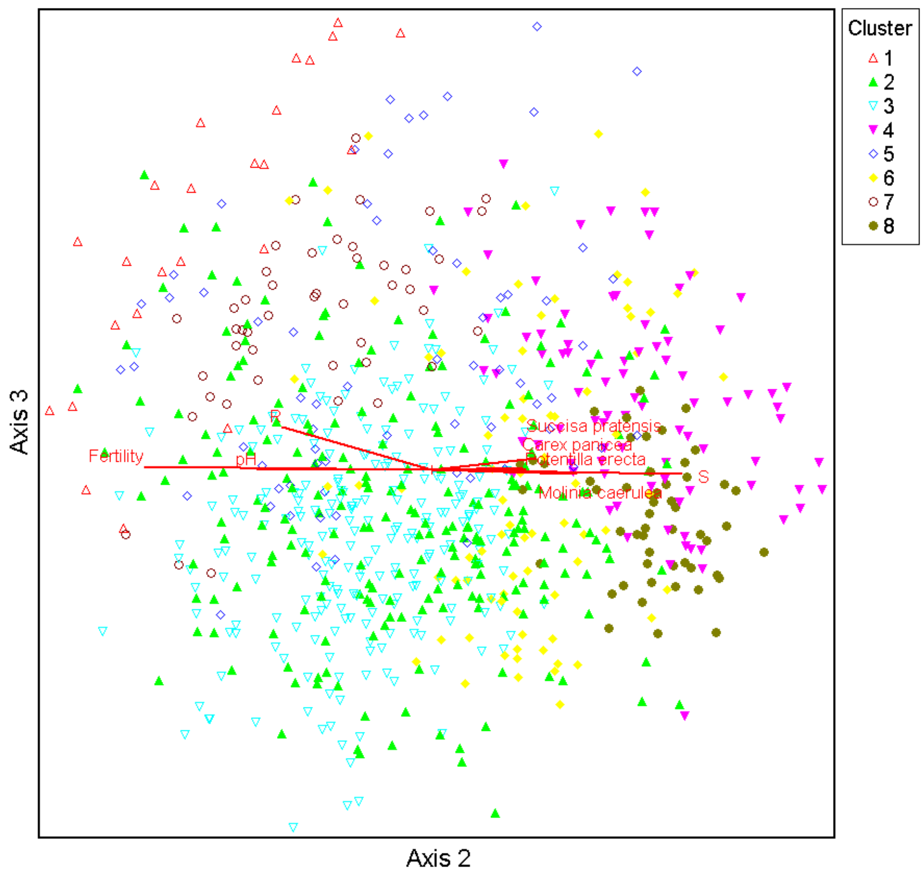


Figure 7.4. Nonmetric Multidimensional Scaling ordination of (A) dimensions 1 and 2 (r^2 = 0.320), (B) dimensions 1 and 3 (r^2 = 0.293) and (C) dimensions 2 and 3 (r^2 = 0.251), showing the 8 major clusters derived by cluster analysis and a biplot of hydrological variables. Species that were strongly corelated (r > 0.2) with the axes are also plotted. r^2 values of axes: 1 = 0.181, 2 = 0.139, 3 = 0.112; total = 0.432

7.5.1.3 Vegetation Description

The 28 communities produced from the cluster analysis are described in this section. Communities are presented in order of position on the flooding gradient, beginning at the top of the gradient. Because there are floristic similarities between the groups in each of the initial 8 clusters, these clusters will be used to group the communities for description.

For each vegetation community, a short description of the species present, location on the flooding gradient (upper, middle or lower zone) and landuse will be given. Where a species has an indicator value of greater than or equal to 20%, this is also presented. Floristic tables giving species abundance and frequency information are presented for each community.

7.5.1.4 Comparison with Communities Described in the Literature

Vegetation communities were identified to class level using White's (1982) key for the identification of Irish plant communities.

Where possible, the communities described in this chapter will be compared with communities described by Ivimey-Cook and Proctor (1966), O'Connell *et al.* (1984), O'Sullivan (1982), Goodwillie (1992, 2003) and Regan *et al*. (2007). Goodwillie gave detailed descriptions of the vegetation communities in his earlier work on turloughs (1992), while in his more recent review of turlough vegetation (2003) only lists the diagnostic species for each vegetation type. Furthermore, in the later work, only 24 communities were described, as opposed to 32 from the 1992 study, and some were renumbered and/or renamed. In this comparison of the plant communities with previous work, both names will be given if they differ between the works. Comparison with NVC communities was made by using the keys provided in the texts. Affinities to NVC communities were also generated by MAVIS, these too are presented in the text. Comparisons are made directly after the description of the community; a table summarising comparisons drawn is presented in Table 7.56. Programmes such as MAVIS, however, must be used with caution. While MAVIS provides an objective comparison with existing communities, affinities suggested by MAVIS may not always concur with those an experienced ecologist might suggest. The presence or absence of key species may result in the community that is actually the best ecological fit getting a 'goodness-of-fit' score which is lower than some other communities which may not correspond so closely (Kirby, 2001).

When classifying vegetation, a number of caveats need to be considered. It can be difficult to assign a sample unit, or relevé, to an existing phytosociological classification, as individual units rarely show an exact match to the classification units. In addition, Ireland's biogeographical isolation has resulted in a relatively depauperate flora, lacking many of the species used in the NVC classifications, which can make direct comparisons problematic.

7.5.1.5 Floristic Tables

The floristic tables for each vegetation community are presented in the following section. 'Frequency' refers the percentage of relevés assigned to the community that contained a given species, and is not related to the abundance of that species in the samples. The frequency classes used in the tables are those used in the NVC, and are denoted by Roman numerals: I = 1-20% frequency, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%. Following the terminology of the NVC (Rodwell, 1991a), for a given community, species which occur at frequency classes IV to V to are referred to as constants. The other classes are described as: III – common/frequent, II – occasional and I – scarce. In the tables, the species are sorted according to frequency, and then alphabetically.

Agrostis stolonifera was the only species that was constant across the data set, with a frequency of 68%. *Potentilla anserina, Galium palustre, Ranunculus repens* and *Carex nigra* were common species across the whole data set.

7.5.1.6 Cluster 7

Cluster 7 consists of two grassland communities, both with frequent *Lolium perenne, Agrostis stolonifera* and *Trifolium repens*. These are communities which occur around the upper fringes of the turlough. Mean values for Ellenberg and Grime's CSR values for these communities are presented in Table 7.12.

Table 7.12 Mean Ellenberg and Grime's CSR values for the groups in Cluster 7 (± standard deviation)

Group	Light	Wetness	pH	Fertility	C	S	R
10	7.3 ± 0.1	5.5 ± 0.3	6.0 ± 0.1	5.1 ± 0.4	2.85 ± 0.12	2.25 ± 0.28	3.01 ± 0.18
15	7.3 ± 0.2	5.9 ± 0.5	6.3 ± 0.3	5.8 ± 0.3	3.02 ± 0.24	1.66 ± 0.24	2.94 ± 0.30

Group 10 – *Lolium perenne-Trifolium repens* community (Table 7.13)

8 turloughs – Ardkill (1), Brierfield (2), Carrowreagh (2), Lough Aleenaun (5), Rathnalulleagh (3), Skealoghan (1), Tullynafrankagh (1), Turloughmore (5)

Description

This was a relatively short (c. 20 cm) species-rich sward, with a mean species richness of 14 (see Figure 7.3). The total number of species recorded in this community was 62. *Lolium perenne* and *Trifolium repens* were present with the highest frequency, and both were relatively abundant in all relevés. Other constant species, albeit at generally lower abundance, were *Agrostis stolonifera, Bellis perennis, Cardamine pratense, Festuca rubra, Leontodon autumnalis, Plantago lanceolata* and *Prunella vulgaris. Ranunculus acris, Ranunculus repens* and *Taraxacum officinale* agg. were frequent.

Bellis perennis, Lolium perenne and *Prunella vulgaris* were all indicator species, with indicator values of 51%, 37% and 25% respectively.

Location on flooding gradient

This community was located in the upper zones of the turlough basins, generally fringing the turlough, and as such it experiences the least amount of inundation. The mean Ellenberg value for wetness is 5.5 for this community (see Table 7.12), which is a value associated with moist sites (Hill et al., 1999).

Landuse

This vegetation type is found around the edges of the more eutrophic turloughs. The mean Ellenberg indicator value for Fertility, is 5.1 (see Table 7.12), which is indicative of a site of intermediate fertility (Hill *et al*., 1999). Some of the species found here, such as *Lolium perenne* and *Trifolium repens* are indicative of semi-improved grassland. These areas are grazed when the flooding level permits.

Table 7.13 Floristic table for the *Lolium perenne-Trifolium repens* community

No. of relevés	20		
No. of species	62		
Group	10		
Lolium perenne	V (3-7)	*Cirsium vulgare*	I (3-4)
Trifolium repens	V (3-9)	*Danthonia decumbens*	I (3)
Agrostis stolonifera	IV (3-4)	*Elymus repens*	I (4)
Bellis perennis	IV (2-5)	*Festuca arundinacea*	I (3)
Cardamine pratensis	IV (0.1-5)	*Festuca pratensis*	I (4)
Festuca rubra	IV (3-5)	*Filipendula ulmaria*	I (3)
Leontodon autumnalis	IV (3-5)	*Galium palustre*	I (2-3)

Plantago lanceolata	IV (3-6)	*Hydrocotyle vulgaris*	I (4)
Prunella vulgaris	IV (3-5)	*Hypochoeris radicata*	I (2)
Ranunculus acris	III (3-4)	*Juncus acutiflorus*	I (3)
Ranunculus repens	III (2-6)	*Juncus articulatus*	I (4)
Taraxacum officinale agg.	III (2-4)	*Leontodon hispidus*	I (2)
Carex hirta	II (3-4)	*Lotus corniculatus*	I (2-3)
Cerastium fontanum	II (0.1-4)	*Phleum bertolonii*	I (4)
Cirsium arvense	II (0.1-5)	*Phleum pratensis*	I (3-4)
Cynosurus cristatus	II (3-4)	*Poa pratensis*	I (3)
Holcus lanatus	II (2-4)	*Poa trivialis*	I (4)
Plantago major	II (2-4)	*Potentilla anserina*	I (3)
Rumex acetosa	II (2-4)	*Potentilla erecta*	I (3)
Achillea millefolium	I (1-4)	*Potentilla reptans*	I (3-4)
Agrostis capillaris	I (4)	*Rumex crispus*	I (3-4)
Alchemilla filicaulis	I (3)	*Rumex obtusifolius*	I (3)
Carex disticha	I (3)	*Sagina procumbens*	I (2)
Carex flacca	I (3-4)	*Senecio aquaticus*	I (2)
Carex hostiana	I (2)	*Succisa pratensis*	I (3)
Carex nigra	I (2-3)	*Teucrium scordium*	I (2)
Carex panicea	I (3)	*Trifolium pratense*	I (2-4)
Cirsium dissectum	I (4)	*Urtica dioica*	I (3)
Cirsium palustre	I (3-4)	*Veronica serpyllifolia*	I (3)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 15 – *Agrostis stolonifera-Trifolium repens-Lolium perenne* community (Table 7.14)

9 turloughs – Ardkill (5), Ballindereen (1), Carrowreagh (2), Coolcam (3), Croaghill (2), Lough Aleenaun (2), Rathnalulleagh (2), Tullynafrankagh (1), Turloughmore (8)

Description

This community is another grassy sward, similar to Group 10. The mean vegetation height was c. 20 cm, and *Agrostis stolonifera, Trifolium repens* and *Lolium perenne* were constant, with frequent *Potentilla anserina* and *Ranunculus repens. Lolium perenne* was the only species with an indicator value of greater than 20%, at 22%.

While similar to the *Lolium perenne-Trifolium repens* community, and occurring in many of the same turloughs, this community shows more evidence of disturbance. A lower total number of species were found in this vegetation type (a mean of 10 species per relevé, compared with 14 for the *Lolium perenne-Trifolium repens* community), along with a greater number of ruderal species, such as *Matricaria discoidea* and *Capsella bursa-pastoris*. The total number of species recorded was 57. It is possible that grazing animals have poached the area when the turlough was flooded, thereby creating the disturbance required by the ruderals to colonise the area. It is common to see paths worn by cattle around the level of winter flooding in turloughs in the summer.

Location on flooding gradient

This vegetation community is located in the upper zone of the turlough basin, and has a mean Ellenberg Wetness value of 5.9 (Table 7.12), which is indicative of a slightly wetter environment than that of the *Lolium perenne-Trifolium repens* community.

Landuse

As with the previous vegetation type, this community occurs around the upper fringes of turloughs, and is grazed when the water level permits. It has a similar mean Ellenberg Fertility value as Group 10, at 5.8 (Table 7.12).

Table 7.14 Floristic table for the *Agrostis stolonifera-Trifolium repens-Lolium perenne* community

No. of relevés	26		
No. of species	57		
Group	15		
Agrostis stolonifera	V (3-9)	*Juncus bufonius*	I (2)
Trifolium repens	V (3-8)	*Lathyrus pratensis*	I (5)
Lolium perenne	IV (3-9)	*Leontodon autumnalis*	I (2-4)
Potentilla anserina	III (2-8)	*Leontodon saxatilis*	I (3)
Ranunculus repens	III (3-6)	*Linum catharticum*	I (3)
Alopecurus geniculatus	II (3-6)	*Lotus corniculatus*	I (2)
Cardamine pratensis	II (1-4)	*Matricaria discoidea*	I (1)
Cerastium fontanum	II (2-4)	*Phalaris arundinacea*	I (3)
Cirsium arvense	II (1-5)	*Phleum bertolonii*	I (2-3)
Holcus lanatus	II (1-4)	*Phleum pratensis*	I (3-5)
Myosotis scorpioides	II (2-4)	*Plantago lanceolata*	I (3)
Rumex crispus	II (1-5)	*Plantago major*	I (1-5)
Agrostis capillaris	I (3-4)	*Poa annua*	I (4)
Bellis perennis	I (3-4)	*Poa pratensis*	I (2-4)
Capsella bursa-pastoris	I (2)	*Polygonum lapathifolium*	I (1)
Carex disticha	I (2-4)	*Potentilla reptans*	I (3)
Carex hirta	I (2-3)	*Prunella vulgaris*	I (2)
Cirsium palustre	I (1-4)	*Ranunculus acris*	I (3-4)
Cirsium vulgare	I (1-3)	*Rorippa amphibia*	I (3)
Cynosurus cristatus	I (3-4)	*Rumex acetosa*	I (1-4)
Deschampsia caespitosa	I (5)	*Rumex obtusifolius*	I (1-5)
Elymus repens	I (3-5)	*Sagina procumbens*	I (0.1)
Festuca rubra	I (3-4)	*Senecio aquaticus*	I (3)
Galium palustre	I (1-3)	*Stellaria media*	I (2-3)
Hydrocotyle vulgaris	I (3)	*Taraxacum officinale* agg.	II (2-3)
Iris pseudacorus	I (2)	*Urtica dioica*	I (1-4)
Juncus acutiflorus	I (2)	*Veronica serpyllifolia*	I (1)
Juncus articulatus	I (2)	*Vicia cracca*	I (2-5)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Comparison with previous studies

These communities both belong to the *Molinio-Arrhenetheretea*, anthropogenic lowland meadows and pastures (White and Doyle, 1982), and both contain *Lolium perenne, Cirsium* *arvense* and a little *Achillea millefolium*, which would seem to place both communities within the *Cynosurion cristati* alliance.

Group 10 – *Lolium perenne-Trifolium repens* community

Class: *Molinio-Arrhenatheretea*

This community was similar to the *Lolio-Cynosuretum* described by O'Sullivan (1982). Both this community and Group 15 contain the differential species *Cirsium palustre* and *Carex hirta*, which seems to place them in the *cirsietosum* sub-association.

This community is very similar to Goodwillie's *Lolium* grassland (2003, 1992). He describes it as occurring around the fringes of the more eutrophic turloughs, which fits with where this community was recorded in the present study. Proctor (2010) places Goodwillie's *Lolium* grassland into White and Doyle's Molinio-Arrhenetheretea (White & Doyle, 1982).

Table 7.15 shows the goodness-of-fit scores for these communities with the NVC classifications, as calculated by MAVIS. MG6a and MG6, the *Lolium perenne-Cynosurus cristatus* grassland and the typical sub-community of same emerged as the strongest comparison with Group 10, with goodness-of-fit scores of 59.73% and 58.44% respectively.

Group 15 – *Lolium perenne-Trifolium repens-Agrostis stolonifera* community

Class: *Molinio-Arrhenatheretea*

This community was recorded in some of the same turloughs as the *Lolium perenne-Trifolium repens* community, albeit at lower elevations, and as such is subjected to a longer duration of inundation. It is very similar to Group 10, but also has some elements of Goodwillie's 2B Poor Grassland (1992) or Damp Grassland (Goodwillie, 2003). There was a lower number of species overall in this community when compared to Group 10. It seems to be a wetter/more disturbed variant of the *Lolium perenne-Trifolium repens* community.

The NVC communities MG11 *Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland and MG11a *Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland – *Lolium perenne* sub-community emerge as the NVC communities to which Group 15 has the strongest affinity when MAVIS was used (see Table 7.15). Rodwell (1992) states that MG11 and MG11a are often subjected to inundation, and can grade into the *Lolio-Cynosuretum*, such as Group 10, on drier ground.

Table 7.15 Affinities with NVC communities as produced by MAVIS

Group	*NVC*	*Percentage*	*Community*
10	MG6a	59.73	*Lolium perenne-Cynosurus cristatus* grassland
	MG6	58.44	*Lolium perenne-Cynosurus cristatus* grassland Typical sub-community
	MG11a	57.52	*Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland *Lolium perenne* sub-community
15	MG11	65.89	*Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland
	MG11a	65.84	*Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland – *Lolium perenne* sub-community
	SD17a	59.39	*Potentilla anserina-Carex nigra* dune slack – *Festuca rubra-Ranunculus repens* sub-community

7.5.1.7 Cluster 6

Cluster 6 contains communities with a mix of grasses, sedges and forbs. All communities contain constant *Filipendula ulmaria*, as well as at least some *Carex nigra, Carex flacca,* and *Carex panicea.* These communities have slightly higher mean Ellenberg Wetness values than those in Cluster 7 (see Table 7.16).

Table 7.16 Mean Ellenberg and Grime's CSR values for the groups in Cluster 6 (± standard deviation)

Group	Light	Wetness	pH	Fertility	C	S	R
8	7.2 ± 0.2	7.3 ± 0.5	5.2 ± 0.4	3.5 ± 0.6	2.64 ± 0.35	2.95 ± 0.46	1.92 ± 0.34
12	7.1 ± 0.2	6.6 ± 0.4	5.9 ± 0.4	4.5 ± 0.4	3.15 ± 0.29	2.54 ± 0.29	2.08 ± 0.30
23	7.1 ± 0.3	6.8 ± 0.5	6.1 ± 0.3	4.6 ± 0.6	2.98 ± 0.42	2.48 ± 0.41	2.11 ± 0.36

Group 8 – *Carex nigra-Carex panicea* community (Table 7.17)

10 turloughs – Ardkill (3), Brierfield (6), Ballindereen (1), Carrowreagh (7), Croaghill (5), Coolcam(1), Knockaunroe (2), Lisduff (3), Skealoghan (5), Tullynafrankagh (1)

Description

This is a small-sedge community, with a sward height of c. 45 cm. *Carex nigra, Hydrocotyle vulgaris, Carex panicea, Filipendula ulmaria, Molinia caerulea* and *Potentilla erecta* are all constant species. *Agrostis stolonifera, Galium palustre, Lotus corniculatus, Ranunculus repens* and *Trifolium repens* are frequent.

This community has a high level of species diversity; a total of 82 species were recorded, and the mean number of species per relevé was 15.

Location on flooding gradient

This vegetation community is located in the upper zone of the turlough basins. It has a mean Ellenberg Wetness value of 7.3 (see Table 7.16), which suggests this community occurs on soils which remain damp but are not constantly wet (Hill *et al*., 1999).

Landuse

This community is little grazed, as indicated by the sward height; it seems to occur on minimally managed land. The low mean Ellenberg Fertility value of 3.5 (see Table 7.16) is indicative of 'more or less infertile sites' (Hill *et al*., 1999).

Table 7.17 Floristic table for the *Carex nigra-Carex panicea* community

No. of relevés	35		
No. of species	82		
Group	8		
Carex nigra	V (3-6)	*Dactylorhiza incarnata*	I (2-4)
Hydrocotyle vulgaris	V (3-5)	*Deschampsia caespitosa*	I (3-4)
Carex panicea	IV (3-5)	*Elymus repens*	I (2)
Filipendula ulmaria	IV (3-8)	*Equisetum fluviatile*	I (1-3)
Molinia caerulea	IV (3-8)	*Equisetum palustre*	I (3)
Potentilla erecta	IV (2-5)	*Eriophorum angustifolium*	I (3-4)

Agrostis stolonifera	III (2-7)	*Festuca arundinacea*	I (3-4)
Galium palustre	III (2-4)	*Galium boreale*	I (3-4)
Lotus corniculatus	III (2-6)	*Galium verum*	I (3)
Ranunculus repens	III (2-6)	*Glyceria fluitans*	I (3)
Trifolium repens	III (3-6)	*Holcus lanatus*	I (2-3)
Cardamine pratensis	II (1-4)	*Iris pseudacorus*	I (3)
Carex flacca	II (3-5)	*Juncus articulatus*	I (3-4)
Carex hostiana	II (3-6)	*Juncus bulbosus*	I (2-4)
Festuca rubra	II (2-4)	*Juncus conglomeratus*	I (4)
Juncus acutiflorus	II (2-7)	*Juncus inflexus*	I (4)
Leontodon autumnalis	II (2-4)	*Lathyrus pratensis*	I (3)
Mentha aquatica	II (2-4)	*Leontodon saxatilis*	I (2)
Potentilla anserina	II (3-7)	*Lolium perenne*	I (4)
Prunella vulgaris	II (2-4)	*Lythrum salicaria*	I (4)
Senecio aquaticus	II (3-4)	*Menyanthes trifoliata*	I (4)
Succisa pratensis	II (3-6)	*Myosotis scorpioides*	I (2)
Vicia cracca	II (2-6)	*Parnassia palustris*	I (3-4)
Achillea ptarmica	I (3)	*Phalaris arundinacea*	I (3-4)
Alopecurus geniculatus	I (3)	*Plantago lanceolata*	I (3-6)
Anagallis tenella	I (2-4)	*Plantago maritima*	I (2)
Bellis perennis	I (3)	*Polygonum amphibium*	I (2-3)
Briza media	I (3-4)	*Potentilla palustris*	I (3)
Caltha palustris	I (4-5)	*Ranunculus acris*	I (2-5)
Cardamine flexuosa	I (2-3)	*Ranunculus flammula*	I (2-4)
Carex disticha	I (4)	*Rumex acetosa*	I (3-4)
Carex leporina	I (3)	*Sagina procumbens*	I (2)
Carex pulicaris	I (3-4)	*Stellaria palustris*	I (4)
Carex viridula agg.	I (2-4)	*Taraxacum officinale* agg.	I (3)
Centaurea nigra	I (4)	*Trifolium pratense*	I (3-5)
Cirsium arvense	I (2)	*Triglochin palustris*	I (2-3)
Cirsium dissectum	I (2-6)	*Valeriana officinale*	I (3-4)
Crataegus monogyna	I (1)	*Viola* species	I (1)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 12 – *Filipendula ulmaria-Vicia cracca* community (Table 7.18)

9 turloughs – Ardkill (9), Brierfield (6), Caranavoodaun (1), Carrowreagh (1), Coolcam (1), Croaghill (1), Kilglassan (1), Rathnalulleagh (6), Tullynafrankagh (2)

Description

This was an ungrazed community, easily distinguished by the height of the vegetation (mean vegetation height 70 cm) and the presence of *Vicia cracca* growing up through the long grasses and other herbs. This was a relatively diverse community, with a mean species richness of 13 species.

Constant species were *Filipendula ulmaria, Vicia cracca, Agrostis stolonifera* and *Potentilla anserina*, with frequent *Lotus corniculatus, Molinia caerulea, Trifolium repens, Potentilla erecta* and *Festuca arundinacea*.

Vicia cracca was an indicator species, with an indicator value of 26%.

Location on flooding gradient

This community is located in the upper zones of the turlough basins; the mean Ellenberg Wetness values is 6.6 (see Table 7.16), suggesting this community occurs on soils which are slightly damp (Hill *et al*., 1999).

Landuse

This community is usually ungrazed, as evidenced by the height of the sward. It occurs on moderately fertile sites; with a mean Ellenberg indicator value for Fertility of 4.5 (see Table 7.16).

Table 7.18 Floristic table for the *Filipendula ulmaria-Vicia cracca* community.

No. of relevés	28		
No. of species	73		
Group	12		
Filipendula ulmaria	V (4-9)	*Danthonia decumbens*	I (3-4)
Agrostis stolonifera	IV (4-5)	*Eleocharis palustris*	I (3)
Potentilla anserina	IV (3-7)	*Equisetum fluviatile*	I (3)
Vicia cracca	IV (3-7)	*Equisetum palustre*	I (3-5)
Festuca arundinacea	III (4-8)	*Festuca pratensis*	I (4-5)
Lotus corniculatus	III (3-6)	*Fraxinus excelsior*	I (1)
Molinia caerulea	III (4-7)	*Galium boreale*	I (4-5)
Potentilla erecta	III (2-6)	*Galium verum*	I (4)
Trifolium repens	III (3-7)	*Hydrocotyle vulgaris*	I (3-5)
Carex flacca	II (3-5)	*Iris pseudacorus*	I (5-7)
Carex nigra	II (3-5)	*Juncus acutiflorus*	I (2)
Carex panicea	II (4-5)	*Juncus articulatus*	I (4)
Deschampsia caespitosa	II (4-6)	*Juncus conglomeratus*	I (6)
Elymus repens	II (4-5)	*Juncus effusus*	I (6-7)
Festuca rubra	II (4-6)	*Juncus inflexus*	I (5-6)
Galium palustre	II (3-6)	*Leontodon autumnalis*	I (4)
Holcus lanatus	II (4-5)	*Leontodon saxatilis*	I (3)
Lathyrus pratensis	II (3-5)	*Lolium perenne*	I (4-5)
Phleum pratense	II (5)	*Mentha aquatica*	I (5)
Plantago lanceolata	II (4-7)	*Myosotis scorpioides*	I (4-5)
Ranunculus acris	II (4-5)	*Phalaris arundinacea*	I (4-7)
Valeriana officinalis	II (4-6)	*Plantago major*	I (4)
Caltha palustris	I (3)	*Poa pratensis*	I (4)
Cardamine pratensis	I (3-4)	*Potentilla reptans*	I (4-5)
Carex disticha	I (3-5)	*Prunus spinosa*	I (4-7)
Carex viridula	I (3-5)	*Rubus caesius*	I (5)
Carex hirta	I (4)	*Rubus fruticosus* agg.	I (5)
Carex hostiana	I (4)	*Rumex acetosa*	I (3-5)
Carex leporina	I (4)	*Salix aurita*	I (5)
Centaurea nigra	I (4)	*Schoenus nigricans*	I (6)
Cirsium arvense	I (4)	*Senecio aquaticus*	I (3-5)
Cirsium dissectum	I (2)	*Stellaria media*	I (3-4)
Cirsium palustre	I (3)	*Stellaria palustris*	I (3-4)
Cirsium vulgare	I (2)	*Succisa pratensis*	I (3-6)
Cynosurus cristatus	I (3)	*Taraxacum officinale* agg.	I (1-4)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 23 – *Carex nigra-Leontodon autumnalis* community (Table 7.19)

3 turloughs – Ballindereen (6), Kilglassan (2), Knockaunroe (7)

Description

This vegetation type was dominated by forbs and sedges. The sward was relatively tall, at 40 cm, and the constant species are *Leontodon autumnalis, Potentilla anserina, Carex nigra, Filipendula ulmaria, Phalaris arundinacea, Agrostis stolonifera* and *Hydrocotyle vulgaris*. *Carex flacca, Carex panicea, Galium palustre, Lotus corniculatus, Plantago lanceolata* and *Ranunculus repens* were all frequent in the community. There is relatively high species richness; the mean number of species per relevé is 13.

Indicator species are *Rubus fruticosus* agg. (27%) and *Teucrium scordium* (25%).

Location on flooding gradient

This community occurs in the upper middle of the flooding gradient. The mean Ellenberg value for Wetness is 6.8 (see Table 7.16).

Landuse

This community is lightly grazed, if at all. The mean Ellenberg value for Fertility is 4.6 (see Table 7.16).

Table 7.19 Floristic table for the *Carex nigra-Leontodon autumnalis* community

No. of relevés	15		
No. of species	47		
Group	23		
Leontodon autumnalis	V (1-4)	*Cynosurus cristatus*	I (4)
Agrostis stolonifera	IV (2-6)	*Deschampsia caespitosa*	I (2-4)
Carex nigra	IV (2-5)	*Fraxinus excelsior*	I (0.1-1)
Filipendula ulmaria	IV (2-4)	*Galium boreale*	I (3)
Hydrocotyle vulgaris	IV (2-6)	*Holcus lanatus*	I (7)
Phalaris arundinacea	IV (3-8)	*Juncus acutiflorus*	I (2)
Potentilla anserina	IV (2-6)	*Juncus conglomeratus*	I (4)
Carex flacca	III (2-5)	*Knautia arvensis*	I (4)
Carex panicea	III (2-5)	*Leontodon hispidus*	I (1-3)
Galium palustre	III (1-3)	*Littorella uniflora*	I (2-4)
Lotus corniculatus	III (3-4)	*Lythrum salicaria*	I (3)
Plantago lanceolata	III (2-4)	*Molinia caerulea*	I (3-4)
Ranunculus repens	III (3)	*Ophioglossum vulgatum*	I (2)
Achillea ptarmica	II (2-3)	*Phleum bertolonii*	I (3)
Mentha aquatica	II (2-5)	*Poa annua*	I (3)
Potentilla reptans	II (2-3)	*Potentilla erecta*	I (2)
Rhamnus cathartica	II (2-7)	*Prunus spinosa*	I (2-3)
Rubus fruticosus	II (2-4)	*Rumex acetosa*	I (3)
Teucrium scordium	II (2-4)	*Samolus valerandi*	I (4)
Carex hostiana	I (3)	*Taraxacum officinale* agg.	I (3)
Cirsium palustre	I (3)	*Trifolium repens*	I (2-4)
Crataegus monogyna	I (2)	*Viola* species	I (1-2)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Comparison with previous studies

The three groups in this cluster appear to belong to the *Plantaginetalia majoris* (White & Doyle, 1982). All three of the groups also show some affinity with the SD17 *Potentilla anserina-Carex nigra* dune slack community, and associated sub-communities, of the NVC (Rodwell, 2000) (see Table 7.20). Dune slack communities share some characteristic species with these turlough communities, and are subjected to similar environmental conditions. Dune slacks can experience flooding in the winter, and remain wet in the summer as the water regime is linked to the water table (Ranwell, 1959). They are also likely to be relatively oligotrophic, as nutrients may be leached from the sandy soils (Rodwell, 2000).

Group 8 – *Carex nigra-Carex panicea* community

Class: *Scheuchzerio-Caricetea fuscae*

Of the communities described by Ivimey-Cook and Proctor (1966), this community corresponds most closely with the *Carex demissa* nodum of the *Scheuchzerio-Caricetea fuscae.* This community seems to belong to the species-rich variant of the *Carex panicea-Carex flava* agg. community described by O'Connell *et al.* (1984). Group 8 is most similar to Goodwillie's 5B Sedge Fen (Goodwillie, 1992), but did not fall easily into any of the communities described by Regan *et al*. (2007).

Group 8 shows the highest affinity for SD17 *Potentilla anserina-Carex nigra* dune slack community, however, there is no *Molinia caerulea* listed in the floristic table for SD17, while it occurs as a constant in Group 8. The second-best fit, according to MAVIS, is with M23a, the *Juncus acutiflorus* sub-community of the *Juncus effusus/acutiflorus-Galium palustre* rush-meadow. On inspection of the floristic tables, however, this is not a good match; *Juncus effusus* and *Holcus lanatus* are both present at very high frequencies in M23a, but absent or present at a very low frequency in Group 8. Proctor (2010) likewise gives M23 as the NVC equivalent to Goodwillie's 3B Sedge Heath, although the four dominant species in M23 are missing from 3B Sedge Heath.

Group 12 – *Filipendula ulmaria-Vicia cracca*

Class: *Molinio-Arrhenatheretea*

Ivimey-Cook and Proctor (1966) describe a *Juncus acutiflorus-Senecio aquaticus* nodum of the *Filipendulo-Petasition* that is dominated by *Filipendula ulmaria* to which this community seems related.

This community did not seem to correspond too closely with any of those described by O'Connell *et al.* (1984), although there were some similarities with the *Ranunculo-Potentilletum anserinae.*

This community was very similar to Goodwillie's Tall Herb (2003, 1992). Some species were notably absent, however, namely *Polygonum amphibium, Lysimachia vulgaris,* and *Caltha palustris*, all of which Goodwillie describes as 'water-demanding'. *Phalaris arundinacea* was found in Group 12, though not to the extent described in the Tall Herb community.

Group 8 seemed most similar to Regan *et al*'s Group 6 (2007), which they regard as a vegetation community representing a transition between sedge- and forb-dominated vegetation.

There are some similarities with the NVC community SD17 *Potentilla anserina-Carex nigra* dune slack community, as well as M27 *Filipendula ulmaria-Angelica sylvestris* mire (see Table 7.20).

Group 23 – *Carex nigra-Leontodon autumnalis* community

Class: *Plantaginetea majoris*

This community is similar to the *Carex nigra-Potentilla anserina* association described by Ivimey-Cook and Proctor (1966).

Group 23 is part of the *Ranunculuo-Potentilletum anserinae* (O'Connell *et al*., 1984), and seems to belong to the *Carex nigra* variant. This community does not seem to correspond very closely with any of those described by Goodwillie (1992). There is some affinity with 5B *Potentilla reptans* (species-poor), although relatively little *P. reptans* was recorded. Group 23 seemed most similar to Regan *et al*.'s Group 7 (2007), one of their forb-dominated communities. Of the NVC communities, this is most similar to the SD17 *Potentilla anserina-Carex nigra* dune slack community (see Table 7.20).

Table 7.20 Affinities with NVC communities for Cluster 6

Group	*NVC*	*Percentage*	*Community*
8	SD17	58.11	*Potentilla anserina-Carex nigra* dune slack community
	M23a	51.08	*Juncus effusus/acutiflorus-Galium palustre* rush-pasture – *Juncus acutiflorus* sub-community
	SD17b	51.07	*Potentilla anserina-Carex nigra* dune slack – *Carex flacca* sub-community
12	SD17	53.35	*Potentilla anserina-Carex nigra* dune slack
	M27	51.74	*Filipendula ulmaria-Angelica sylvestris* mire
	MG9	50.72	*Holcus lanatus-Deschampsia caespitosa* grassland
23	SD17	44.64	*Potentilla anserina-Carex nigra* dune slack
	SD17d	43.91	*Potentilla anserina-Carex nigra* dune slack – *Hydrocotyle vulgaris-Ranunculus flammula* sub-community
	SD15b	40.67	*Salix repens-Calliergon cuspidatum* dune slack – *Equisetum variegatum* sub-community

7.5.1.8 Cluster 4

Cluster 4 contained relevees from a seemingly diverse group of habitats; Limestone grassland, *Schoenus nigricans* fen and Flooded pavement. There were, however, similarities between all three in relation to the suite of species they support. All contained frequent *Succisa pratensis* and at least some *Festuca rubra, Galium verum, Lotus corniculatus, Molinia caerulea, Potentilla erecta* and *Plantago maritima.* All communities in this cluster have a relatively low mean Ellenberg value for Fertility (see Table 7.21), the communites are most frequent in the more oligotrophic turloughs.

Table 7.21 Mean Ellenberg and Grime's CSR values for the groups in Cluster 4 (± standard deviation)

Group	*Light*	*Wetness*	*pH*	*Fertility*	*C*	*S*	*R*
5	7.3 ± 0.2	5.9 ± 0.5	5.4 ± 0.5	3.3 ± 0.6	2.21 ± 0.43	3.50 ± 0.54	2.02 ± 0.41
21	7.3 ± 0.2	7.2 ± 0.6	4.9 ± 0.7	2.3 ± 0.3	2.33 ± 0.29	3.52 ± 0.25	1.42 ± 0.20
28	7.1 ± 0.3	5.7 ± 0.6	5.5 ± 0.4	3.2 ± 0.6	1.96 ± 0.34	3.86 ± 0.35	1.42 ± 0.34

Group 5 - Limestone grassland (Table 7.22)

13 turloughs – Ardkill (1), Ballindereen (5), Brierfield (1), Caranavoodaun (16), Carrowreagh (1), Coolcam (2), Knockaunroe (6), Lough Gealain (1), Rathnalulleagh (3), Roo West (8), Skealoghan (2), Tullynafrankagh (8), Turloughmore (3)

Description

This was a species-rich vegetation type, with the highest number of species per community (117), and the highest species richness (18; see Figure 6.3). The sward was relatively short, at c. 15 cm. Constant species were *Lotus corniculatus, Potentilla erecta, Plantago lanceolata, Festuca rubra, Carex flacca, Trifolium repens, Succisa pratensis and Carex panicea*. Frequent species were *Leontodon hispidus, Prunella vulgaris, Leontodon autumnalis, Agrostis stolonifera, Molinia caerulea, Galium verum* and *Plantago maritima*.

Indicator species were *Leontodon hispidus* (43%) and *Plantago maritima* (22%).

Location on flooding gradient

The Limestone grassland community occurs on the upper fringes of turloughs with shallow soils, which are generally underlain with limestone. This community has a mean Ellenberg Wetness value of 5.9 (see Table 7.21), which is suggestive of a somewhat damp, though not constantly wet, substrate (Hill *et al*., 1999).

Landuse

This community occurs in a range of turloughs, and is generally lightly grazed, either by livestock or by wild and feral grazers, as in the case of Knockaunroe. The low mean Ellenberg value for Fertility of 3.3 (see Table 7.21) is associated with infertile sites (Hill *et al*., 1999).

Table 7.22 Floristic table for the Limestone grassland community.

No. of relevés	57		
No. of species	117		
Group	5		
Festuca rubra	V (4-8)	*Festuca arundinacea*	I (3-7)
Lotus corniculatus	V (4-6)	*Festuca pratensis*	I (5)
Plantago lanceolata	V (1-7)	*Filipendula vulgaris*	I (4-5)
Potentilla erecta	V (3-6)	*Fraxinus excelsior*	I (1-5)
Carex flacca	IV (2-6)	*Galium boreale*	I (4)
Carex panicea	IV (3-7)	*Galium palustre*	I (3)
Succisa pratensis	IV (2-7)	*Geranium sanguineum*	I (4)
Trifolium repens	IV (2-6)	*Geum rivale*	I (5)
Agrostis stolonifera	III (3-8)	*Glechoma hederacea*	I (3)
Galium verum	III (2-6)	*Holcus lanatus*	I (2-5)

Leontodon autumnalis	III (2-7)	*Hydrocotyle vulgaris*	I (1-6)
Leontodon hispidus	III (3-7)	*Hypochoeris radicata*	I (4)
Molinia caerulea	III (3-7)	*Juncus acutiflorus*	I (4)
Plantago maritima	III (4-6)	*Juncus articulatus*	I (3-4)
Prunella vulgaris	III (2-7)	*Knautia arvensis*	I (5)
Bellis perennis	II (1-5)	*Lathyrus pratensis*	I (5)
Carex hostiana	II (3-7)	*Leontodon saxatilis*	I (3-6)
Centaurea nigra	II (3-6)	*Leucanthemum vulgare*	I (2-5)
Danthonia decumbens	II (3-5)	*Linum catharticum*	I (1-5)
Filipendula ulmaria	II (2-6)	*Mentha aquatica*	I (1-3)
Lolium perenne	II (2-5)	*Odontites vernus*	I (2)
Trifolium pratense	II (1-5)	*Parnassia palustris*	I (3-4)
Viola species	II (1-5)	*Phalaris arundinacea*	I (2-5)
Achillea millefolium	I (3-6)	*Phleum bertolonii*	I (3-5)
Achillea ptarmica	I (1-5)	*Phleum pratense*	I (4)
Agrostis capillaris	I (4-6)	*Plantago major*	I (1-2)
Alchemilla filicaulis	I (5)	*Poa pratensis*	I (4-6)
Alopecurus geniculatus	I (3)	*Poa trivialis*	I (3)
Anagallis tenella	I (2)	*Potentilla anserina*	I (1-8)
Antennaria dioica	I (3-4)	*Potentilla fruticosa*	I (4)
Briza media	I (3-5)	*Potentilla reptans*	I (1-5)
Calluna vulgaris	I (5-7)	*Prunus spinosa*	I (1-4)
Campanula rotundifolia	I (3-4)	*Ranunculus acris*	I (2-5)
Cardamine pratensis	I (1-4)	*Ranunculus flammula*	I (1-4)
Carex hirta	I (4-5)	*Ranunculus repens*	I (1-4)
Carex nigra	I (3-7)	*Rhamnus cathartica*	I (2-3)
Carex pulicaris	I (4)	*Rhinanthus minor*	I (2-4)
Carex viridula agg.	I (3-6)	*Rosa spinosissima*	I (2-3)
Cerastium fontanum	I (1-4)	*Rubus fruticosus* agg.	I (5)
Cirsium arvense	I (3-6)	*Rumex acetosa*	I (3)
Cirsium dissectum	I (1-6)	*Salix repens*	I (5)
Cirsium palustre	I (5)	*Schoenus nigricans*	I (3-5)
Crataegus monogyna	I (1-4)	*Senecio aquaticus*	I (4)
Cynosurus cristatus	I (3-6)	*Stellaria media*	I (3)
Dactylorhiza incarnata	I (1-4)	*Taraxacum officinale* agg.	I (1-5)
Deschampsia caespitosa	I (4-5)	*Thymus polytrichus*	I (3-5)
Elymus repens	I (3)	*Veronica serpyllifolia*	I (5)
Equisetum palustre	I (4)	*Vicia cracca*	I (3-5)
Euphrasia species	I (2-5)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 21 – *Schoenus nigricans* fen (Table 7.23)

5 turloughs – Ballindereen (5), Knockaunroe (2), Lough Gealain (5), Roo West (6), Tullynafrankagh (1)

Description

This vegetation type was one of the more easily distinguishable in the field, due to conspicuous tufts of *Schoenus nigricans*. The mean vegetation height was 35 cm.

The constant species were *Schoenus nigricans, Molinia caerulea, Potentilla erecta* and *Succisa pratensis*. Frequent species were *Carex flacca, Galium boreale* and *Lotus corniculatus*. Indicator species were *Schoenus nigricans* (43%), *Succisa pratensis* (26%) and *Molinia* *caerulea* (20%). A total of 44 species were recorded in 19 relevés, with a mean number of species per relevé of 11.

Location on flooding gradient

This community is located in the upper zone of the turlough basin. The mean Ellenberg value for Wetness (7.2, see Table 7.21) suggests that this community occurs on damp, but not constantly wet, soils (Hill *et al*., 1999).

Landuse

This community is generally grazed, or at least accessible by cattle. Many of the species are tough and unpalatable, however, and do not seem to be favoured for grazing. The very low mean Ellenberg Fertility value, 2.3 (see Table 7.21), is associated with very infertile sites (Hill *et al*., 1999).

Table 7.23 Floristic table for the *Schoenus nigricans* fen.

No. of relevés	19		
No. of species	44		
Group	21		
Molinia caerulea	V (5-8)	*Carex hostiana*	I (3-5)
Potentilla erecta	V (4-5)	*Dactylorhiza incarnata*	I (1)
Schoenus nigricans	V (3-8)	*Euphrasia* species	I (3)
Succisa pratensis	V (4-5)	*Filipendula ulmaria*	I (4)
Carex flacca	III (4-5)	*Galium palustre*	I (3)
Galium boreale	III (3-4)	*Geranium sanguineum*	I (3-5)
Lotus corniculatus	III (3-5)	*Hydrocotyle vulgaris*	I (4)
Agrostis stolonifera	II (3-5)	*Linum catharticum*	I (3-4)
Carex viridula agg.	II (4)	*Mentha aquatica*	I (3)
Carex nigra	II (3-4)	*Plantago lanceolata*	I (4)
Carex panicea	II (4-5)	*Plantago major*	I (5)
Cirsium dissectum	II (4-5)	*Prunella vulgaris*	I (3)
Festuca rubra	II (4-5)	*Prunus spinosa*	I (1-4)
Galium verum	II (4-5)	*Ranunculus flammula*	I (4)
Leontodon autumnalis	II (3-4)	*Ranunculus repens*	I (4)
Parnassia palustris	II (3-5)	*Rhinanthus minor*	I (4)
Plantago maritima	II (3-4)	*Rubus fruticosus* agg.	I (3)
Potentilla fruticosa	II (4-7)	*Salix repens*	I (5)
Achillea ptarmica	I (3-4)	*Thymus polytrichus*	I (3-4)
Calluna vulgaris	I (5-6)	*Trifolium repens*	I (3-4)
Campanula rotundifolia	I (2)	*Viola* species	I (1-4)
Cardamine pratensis	I (3)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 28 – Flooded pavement (Table 7.24)

Turloughs: Knockaunroe (1)

Description

This community occurs on exposed limestone pavement at the fringes of oligotrophic turloughs, though relevés were only recorded at Knockaunroe. *Viola canina, Potentilla fruticosa, Festuca rubra* and *Succisa pratensis* were the constant species. Other species included scrubby ones such as *Prunus spinosa* and *Rhamnus cathartica*, with occasional *Fraxinus excelsior*, as well as plants typical of the Burren region such as *Thymus polytrichus* and *Geranium sanguineum*. The clints and grykes in limestone pavement provides a variety of habitats, and this community is relatively diverse (mean no. of species per relevé is 13).

Indicator species were *Potentilla fruticosa* (59%), *Thymus polytrichus* (46%), *Prunus spinosa* (37%), *Rhamnus cathartica* (24%) and *Viola* species (20%).

This community was recorded in a number of other turloughs in Goodwillie's survey (1992). Uncertainty as to the boundary of some of the turlough basins, as well as a lack of time in the field, meant that this vegetation type was only recorded in Knockaunroe during the course of this study. In addition, the limestone pavement areas fringing turloughs often grade into scrubby vegetation and woodland, the surveying of which was beyond the scope of this project.

Location on flooding gradient

This community is located in the upper zones of the turlough basin, where open limestone pavement abuts the flood zone. The mean Ellenberg Wetness value of 5.7 (in Table 7.21) is indicative of slightly damp soils (Hill *et al*., 1999).

Landuse

This vegetation type is not intensively managed, although feral goats are probably important grazers (Dunford, 2002). The low mean Ellenberg Fertility value (3.2; Table Table 7.21) is associated with infertile sites (Hill *et al*., 1999).

Table 7.24 Floristic table for the Flooded Pavement community.

No. of relevés	10		
No. of species	42		
Group	28		
Viola species	V (3-5)	*Rhinanthus minor*	II (2-3)
Festuca rubra	IV (4-7)	*Vicia cracca*	II (2-4)
Potentilla fruticosa	IV (5-8)	*Achillea ptarmica*	I (3)
Succisa pratensis	IV (3-6)	*Carex viridula* agg.	I (3)
Carex flacca	III (3-4)	*Carex hostiana*	I (3)
Carex nigra	III (3-5)	*Crataegus monogyna*	I (6)
Carex panicea	III (3-5)	*Danthonia decumbens*	I (3)
Galium boreale	III (3-4)	*Euphrasia* species	I (4)
Leontodon autumnalis	III (2-4)	*Geranium sanguineum*	I (4)
Molinia caerulea	III (3-6)	*Glechoma hederacea*	I (2)
Prunus spinosa	III (3-6)	*Linum catharticum*	I (3)
Rhamnus cathartica	III (2-5)	*Phleum pratense*	I (5)
Thymus polytrichus	III (4)	*Plantago lanceolata*	I (4)
Agrostis stolonifera	II (2-4)	*Plantago maritima*	I (4)
Fraxinus excelsior	II (2-4)	*Potentilla erecta*	I (4)

Galium verum	II (3-4)	*Rubus caesius*	I (5)
Lotus corniculatus	II (2-4)	*Rubus fruticosus* agg.	I (2)
Prunella vulgaris	II (3-4)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Comparison with previous studies

Group 5 – Limestone grassland

Class: *Molinio-Arrhenatheretea*

This community seems to belong to the *Cynosurion cristati*, as described by O'Sullivan (1982). The presence of *Carex flacca, Lotus corniculatus* and *Centaurea nigra* place this community in the *Centaureo-Cynosuretum,* more specifically the *galietosum* sub-association.

This community is very similar to Goodwillie's (2003) 2C Limestone Grassland. Of the NVC communities, this is most similar to CG10 *Festuca ovina-Agrostis capillaris-Thymus polytrichus* grassland (Rodwell, 1992), in particular the *Carex pulicaris-Carex panicea* sub-community.

Filipendula vulgaris, a red data book species, was found within this community.

Group 21 – *Schoenus nigricans* fen

Class: Parvocaricetea (White & Doyle) Scheuchzerio-Caricetea fuscae (O'Connell, and Rodwell)

This community was similar to the *Schoenus nigricans-Cirsium dissectum* association of Ivimey-Cook and Proctor (1966). It corresponds well with O'Connell *et al*'s (1984) *Cirsio-Schoenetum nigricantis molinietosum*, especially the Typicum and *Plantago maritima* variants; however, *Pinguicula vulgaris* is included in the floristic table by O'Connell *et al.,* but was not recorded in this study, and was not reported by Goodwillie or MacGowran in their descriptions of the community.

This community is very similar to Goodwillie's 4D *Schoenus* fen (1992)/7B *Schoenus/Cirsium dissectum* (2003). It also corresponds very well with Regan *et al*.'s Group 1 (2007), which also has abundant *Schoenus nigricans* and *Molinia caerulea.*

Subjectively, this community seems most similar to the NVC community M13 *Schoenus nigricans-Juncus subnodulosus* mire, and this is one of the top three NVC communities MAVIS calculated as having a good fit (see Table 7.25).

Group 28 – Flooded pavement

More a habitat than a vegetation community, this was not previously described by O'Connell *et al.* (1984), nor did it seem to be described in the NVC (Rodwell, 1991a, 1991b, 1992, 1995, 2000). In a review of the coverage of the NVC, Limestone pavement is described as a combination of various vegetation communities, rather than a community itself, i.e. the vegetation of grikes should be considered apart from the rest of the pavement, etc. (Rodwell *et al*., 2000). This approach was not adopted for this study, the pavement was surveyed as a whole.

Ivimey-Cook and Proctor (1966) describe *Potentilla fruticosa* stands occurring around lakes in the Burren; they go on to say that in open *P. fruticosa* scrub of this sort, the species lists are similar to fens and grasslands occurring at similar levels, and indeed, the species list for this community is similar to that of Group 5. This community was most similar to Goodwillie's 3C Flooded pavement (1992) or 2A Turlough scrub (Goodwillie, 2003).

Table 7.25 MAVIS-generated goodness-of-fit scores for the three communities in Cluster4.

Group	*NVC*	*Percentage*	*Community*
5	CG3	46.7	*Bromus erectus* grassland
	MG5b	46.18	*Cynosurus cristatus-Centaurea nigra* grassland
	MG5	46.09	*Cynosurus cristatus-Centaurea nigra* grassland
21	MC10c	43.68	*Festuca rubra-Plantago* spp maritime grassland
	M25	39.94	*Molinia caerulea-Potentilla erecta* mire
	M13a	39.93	*Schoenus nigricans-Juncus subnodulosus* mire
28	MC10b	33.98	*Festuca rubra-Plantago* spp maritime grassland
	MC10c	33.06	*Festuca rubra-Plantago* spp maritime grassland
	H7c	32.89	*Calluna vulgaris-Scilla verna* heath

7.5.1.9 Cluster 1

Cluster 1 contains two groups – the *Poa annua-Plantago major* community and the *Eleocharis acicularis* community. Both of these groups are characterised by a high proportion of bare ground (median Domin scores were 3.5 and 6 respectively) and a high degree of poaching (median Domin scores were 2 and 3 respectively), as well as a high proportion of ruderal species. Both groups contain at least some *Polygonum aviculare* and *Rorippa islandica.* Although these two groups are somewhat similar floristically, they differ in their location within the turlough; the *Poa annua-Plantago major* community occurs on trampled ground and is not strictly confined to a certain place on the flooding gradient, while the *Eleocharis acicularis* community occurs on wet mud near permanent water, and is therefore located at the bottom of the flooding gradient. The difference in mean Ellenberg values for Wetness between these two communities reflects this (see Table 7.26).

Table 7.26 Mean Ellenberg and Grime's CSR values for the groups in Cluster 1 (± standard deviation).

Group	*Light*	*Wetness*	*pH*	*Fertility*	*C*	*S*	*R*
1	7.2 ± 0.1	5.9 ± 0.6	6.3 ± 0.2	6.4 ± 0.3	2.04 ± 0.42	1.37 ± 0.22	3.93 ± 0.41
26	7.2 ± 0.2	7.3 ± 0.9	6.4 ± 0.2	5.8 ± 0.4	2.39 ± 0.66	1.31 ± 0.27	3.39 ± 0.75

Group 1 – *Poa annua-Plantago major* community (Table 7.27)

6 turloughs – Ardkill (2), Blackrock (1), Carrowreagh (3), Coolcam (2), Lough Aleenaun (1), Turloughmore (2)

Description

This community was found in areas where the integrity of the soil had been damaged through poaching, allowing the large proportion of ruderal species found in this type to colonise. Constant species were *Plantago major, Polygonum aviculare, Agrostis stolonifera, Poa annua* and *Matricaria discoidea*, with frequent *Potentilla anserina, Stellaria media* and *Ranunculus repens*. The species list consists of perennials that can rapidly colonise from the surrounding grassland (e.g. *Agrostis stolonifera* and *Potentilla anserina*) and opportunistic ruderals (e.g. *Capsella bursa-pastoris*). The vegetation was generally short in stature, with an average height of c. 10 cm.

Indicator species were *Matricaria discoidea* (62%), *Polygonum aviculare* (62%), *Plantago major* (36%), *Poa annua* (34%), *Stellaria media* (23%) and *Capsella bursa-pastoris* (22%).

Location on flooding gradient

This community was found on trampled ground in the upper reaches of the turlough basins; as suggested by the mean Ellenberg Wetness value of 5.9 (Table 7.26).

Landuse

This community was frequently found in very poached areas, especially along paths and near to gates. The highest mean Ellenberg Fertility value (6.4) is found in this community (see Table 7.26); this is approaching a value of 7 which is indicative of 'richly fertile' sites (Hill *et al*., 1999). Areas experiencing a high degree of poaching, such as those where this community is found, are also likely to have relatively concentrated nutrient inputs through dunging.

Table 7.27 Floristic table for the *Poa annua-Plantago major* community.

No. of relevés	11		
No. of species	33		
Group	1		
Plantago major	V (3-6)	*Festuca arundinacea*	I (4-5)
Polygonum aviculare	V (4-7)	*Gnaphalium uliginosum*	I (4)
Agrostis stolonifera	IV (4-7)	*Juncus articulatus*	I (3)
Matricaria discoidea	IV (2-6)	*Leontodon autumnalis*	I (4)
Poa annua	IV (4-7)	*Lolium perenne*	I (4-5)
Potentilla anserina	III (4-8)	*Phalaris arundinacea*	I (2-4)
Ranunculus repens	III (2-5)	*Poa pratensis*	I (4-5)
Stellaria media	III (4-5)	*Polygonum amphibium*	I (3-5)
Alopecurus geniculatus	II (3-6)	*Polygonum hydropiper*	I (5)
Capsella bursa-pastoris	II (2-4)	*Potentilla reptans*	I (4)
Carex hirta	II (3-5)	*Rorippa islandica*	I (4)
Juncus bufonius	II (3-6)	*Rorippa palustris*	I (5)
Myosotis scorpioides	II (4-5)	*Rumex crispus*	I (3-4)
Polygonum persicaria	II (3-4)	*Rumex obtusifolius*	I (3-5)
Agrostis capillaris	I (5)	*Senecio aquaticus*	I (3)
Cirsium palustre	I (2)	*Trifolium repens*	I (4-5)
Cirsium vulgare	I (2)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 26 - *Eleocharis acicularis* community (Table 7.28)

1 turlough – Garryland (13)

Description

This community was recorded from relevés only in Garryland, though it was mapped in several others. It corresponds very closely with the *Eleocharis acicularis* community identified by Goodwillie (Goodwillie, 1992). *Eleocharis acicularis* is not a common turlough plant, and in Goodwillie's survey this vegetation community occupied just 0.2% of the surveyed land area, occurring only in turloughs around Gort and in Rahasane. It has previously been recorded in 5 of the turloughs included in this survey; Blackrock, Caherglassan, Garryland, Lough Aleenaun and Lough Coy (Goodwillie, 1992). It forms relatively small patches on drying mud near water, usually at the very base of the turlough, and as such its presence/absence during a survey is very dependent on water levels. The mean vegetation height is 5 cm. Timing of survey work in different turloughs is likely to have resulted in under-sampling of this community as it frequently occurs in the deepest zones of turlough (though not so at Garryland); however, this community was subsequently located and mapped in other turloughs.

The constant species were *Eleocharis acicularis, Agrostis stolonifera, Rorippa islandica*, *Lythrum portula, Callitriche* sp. and *Ranunculus trichophyllus*. *Gnaphalium uliginosum, Mentha aquatica, Polygonum hydropiper* and *Polygonum minus* were common.

Indicator species were *Eleocharis acicularis* (100%), *Rorippa islandica* (64%), *Lythrum portula* (53%), *Polygonum minus* (46%), *Polygonum hydropiper* (38%), *Limosella aquatica* (31%), *Gnaphalium uliginosum* (27%) and *Callitriche* sp. (25%).

Location on flooding gradient

This community occurred around a permanent pool in the southern end of Garryland basin, on a muddy, silty substrate that appeared to have been recently flooded. Interestingly, while this community occurs at the base of the turlough, the mean Ellenberg Wetness value for the group is 7.3 (see Table 7.26), associated with constantly moist, but not wet, soils. The Grime's R value is high, at 3.39, suggesting a large ruderal component to this community. This community, therefore, seems to consist of species which complete their life-cycle while the flooding has subsided.

Landuse

Garryland turlough is located in Coole Park, and is surrounded by woodland. The turlough basin is very closely grazed by sheep and cattle. Cattle come to drink at the permanent pools when the turlough is in the dry phase, which means that the soil there can be extremely poached. The high level of disturbance from this poaching and the fluctuating water levels seems to result in a high frequency of opportunistic annuals in this community type, such as *Rorippa islandica* and *Gnaphalium uliginosum*. The mean Ellenberg Fertility value of 5.8 suggests that this is a relatively fertile site (Hill *et al*., 1999).

Table 7.28 Floristic table for the *Eleocharis acicularis* community.

No. of relevés	13		
No. of species	27		
Group	26		
Agrostis stolonifera	V (3-6)	*Polygonum aviculare*	II (4-5)
Eleocharis acicularis	V (3-9)	*Polygonum persicaria*	II (3-4)
Callitriche species	IV (1-3)	*Potentilla anserina*	II (1-4)
Lythrum portula	IV (1-4)	*Rorippa amphibia*	II (1-2)
Ranunculus trichophyllus	IV (1-4)	*Bellis perennis*	I (1)
Rorippa islandica	IV (1-3)	*Juncus articulatus*	I (2)
Gnaphalium uliginosum	III (1-4)	*Poa annua*	I (3)
Mentha aquatica	III (1-4)	*Polygonum amphibium*	I (3)
Polygonum hydropiper	III (4-5)	*Ranunculus repens*	I (1)
Polygonum minus	III (3-5)	*Sparganium emersum*	I (4)
Eleocharis palustris	II (3-5)	*Trifolium repens*	I (3)
Galium palustre	II (2-3)	*Urtica dioica*	I (2)
Limosella aquatica	II (1-4)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Comparison with previous studies

Group 1 – *Poa annua-Plantago major* community

Class: *Polygono-Poetea annuae*

The *Poa annua-Plantago major* community is also quite similar to the *Lolium perenne-Plantago major* association of the *Plantaginetalia majoris* described by Ivimey-Cook and Proctor (1966). *Lolium perenne*, however, is recorded as 'constant' in their community while 'scarce' here. This community is not included in Goodwillie's most recent review of turlough vegetation (2003), although it is present as 'Dry weed' in the survey of turloughs over 10 ha (Goodwillie, 1992). The *Poa annua-Plantago major* community is most similar to Group 9 of Regan *et al*. (2007), although they recorded little or no *Matricaria discoidea*.

This community corresponds very well with the NVC OV21 *Poa annua-Plantago major* community as well as the *Polygonum aviculare-Ranunculus repens* sub-community and the *Lolium perenne* sub-community (Rodwell, 2000) (see Table 7.29).

Group 26 – *Eleocharis acicularis* community

Class: *Littorelletea uniflorae*

An *Eleocharis acicularis*-dominated community was recorded by Ivimey-Cook and Proctor (1966), with a similar suite of species. This community is identical to that described by Goodwillie as 9B *Eleocharis acicularis* (1992) or 6B *Eleocharis acicularis/Limosella* (2003). White and Doyle also mention an *Eleocharis acicularis* community.

Of the NVC communities, the *Eleocharis acicularis* community was most similar to OV31 *Rorippa palustris-Filaginella uliginosa* community, at 41.67% goodness-of-fit (see Table 7.29). While the two communities share a large number of species, the proportions are quite different, and *Eleocharis acicularis* does not occur in OV31.

Table 7.29 Affinities with NVC communities for Cluster 1.

Group	NVC	Percentage	Community
1	OV21	63.2	*Poa annua-Plantago major* community
	OV21c	62.1	*Poa annua-Plantago major* community – *Polygonum aviculare-Ranunculus repens* sub-community
	OV21b	59.2	*Poa annua-Plantago major* community – *Lolium perenne* sub-community
26	OV31	41.67	*Rorippa palustris-Filaginella uliginosa* community
	OV28	36.17	*Agrostis stolonifera-Ranunculus repens* community
	OV28a	34.32	*Agrostis stolonifera-Ranunculus repens* community *Polygonum hydropiper-Rorippa sylvestris* sub-community

7.5.1.10 Cluster 3

Cluster 3 was mostly wet grassland communities. All contained constant *Potentilla anserina,* with all communities containing at least some *Carex nigra, Agrostis stolonifera, Filipendula ulmaria* and *Ranunculus repens.* These communities all seem to belong to the classic 'turlough sward', O'Connell *et al.*'s (1984) *Ranunculo-Potentilletum anserinae.* The various derived variables show some variation between the groups (Table 7.30).

Table 7.30 Mean Ellenberg and Grime's CSR values for the groups in Cluster 3 (± standard deviation).

Group	Light	Wetness	pH	Fertility	C	S	R
3	7.2 ± 0.2	6.7 ± 0.6	6.1 ± 0.3	5.2 ± 0.6	3.00 ± 0.32	2.04 ± 0.36	2.57 ± 0.39
4	7.3 ± 0.2	6.2 ± 0.4	6 ± 0.3	4.7 ± 0.7	2.67 ± 0.28	2.41 ± 0.43	2.67 ± 0.36
9	7.1 ± 0.2	7.3 ± 0.6	6.7 ± 0.3	5.9 ± 0.4	3.79 ± 0.40	1.80 ± 0.32	1.83 ± 0.43
13	7.4 ± 0.3	7.4 ± 0.6	6.0 ± 0.7	4.8 ± 1.1	2.82 ± 0.34	2.38 ± 0.67	2.25 ± 0.66
19	7.3 ± 0.2	6.1 ± 0.5	6.5 ± 0.3	5.2 ± 0.4	2.83 ± 0.14	2.07 ± 0.21	2.88 ± 0.18
20	7.3 ± 0.1	6.2 ± 0.4	5.9 ± 0.3	4.0 ± 0.4	2.71 ± 0.24	2.56 ± 0.27	2.42 ± 0.40

Group 3 – *Agrostis stolonifera-Ranunculus repens* community (Table 7.31)

15 turloughs – Ardkill (16), Brierfield (7), Caherglassan (8), Carrowreagh (12), Coolcam (4), Garryland (5), Kilglassan (5), Lisduff (1), Lough Coy (7), Rathnalulleagh (5), Skealoghan (1), Termon (1), Tullynafrankagh (1)

Description

This was a widespread community, found in 15 of the 22 turloughs surveyed. The community was a relatively short (c. 25 cm) forb-dominated sward, with a mean number of species per relevé of 14. The vegetation type was comprised of a high number of constant species; *Potentilla anserina, Agrostis stolonifera, Ranunculus repens, Galium palustre, Filipendula ulmaria, Carex nigra, Leontodon autumnalis, Carex hirta* and *Trifolium repens*, with frequent *Phalaris arundinacea*.

Location on flooding gradient

This community is found in the upper to middle zones of the turlough basins, and the mean Ellenberg Wetness value (6.7; Table 7.30) is indicative of damp but not wet soils (Hill *et al.*, 1999).

Landuse

This vegetation type is generally moderately grazed, and the mean Ellenberg Fertility value (5.2; Table 6 Table 7.30) suggests intermediate site fertility.

Table 7.31 Floristic table for the *Agrostis stolonifera-Ranunculus repens* community.

No. of relevés	85		
No. of species	100		
Group	3		
Agrostis stolonifera	V (3-9)	*Galium boreale*	I (3-4)
Potentilla anserina	V (3-8)	*Galium verum*	I (4)
Ranunculus repens	V (3-8)	*Geum rivale*	I (4-5)
Carex hirta	IV (3-6)	*Glyceria fluitans*	I (3)
Carex nigra	IV (3-8)	*Holcus lanatus*	I (5)
Filipendula ulmaria	IV (1-7)	*Hypochoeris radicata*	I (4)
Galium palustre	IV (1-5)	*Iris pseudacorus*	I (5-7)
Leontodon autumnalis	IV (1-7)	*Juncus acutiflorus*	I (4-5)
Trifolium repens	IV (1-9)	*Juncus articulatus*	I (3-5)
Phalaris arundinacea	III (2-8)	*Juncus effusus*	I (4-5)
Cardamine pratensis	II (1-5)	*Knautia arvensis*	I (5)
Hydrocotyle vulgaris	II (3-6)	*Lathyrus pratensis*	I (3)
Lotus corniculatus	II (3-7)	*Leontodon hispidus*	I (4)
Mentha aquatica	II (2-5)	*Lolium perenne*	I (4-5)
Myosotis scorpioides	II (1-5)	*Lysimachia vulgaris*	I (5)
Plantago major	II (3-7)	*Molinia caerulea*	I (4-6)
Potentilla reptans	II (3-7)	*Oenanthe aquatica*	I (1-3)
Rumex acetosa	II (3-6)	*Ophioglossum vulgatum*	I (2-5)
Rumex crispus	II (2-5)	*Phleum bertolonii*	I (3-5)
Agrostis capillaris	I (4-8)	*Phleum pratense*	I (4-5)
Alopecurus geniculatus	I (3-5)	*Plantago lanceolata*	I (4-7)
Apium inundatum	I (4)	*Poa annua*	I (3-7)
Apium nodiflorum	I (5)	*Poa pratensis*	I (4)
Bellis perennis	I (4-5)	*Polygonum amphibium*	I (2-6)
Briza media	I (3)	*Polygonum hydropiper*	I (1)
Cardamine flexuosa	I (3)	*Polygonum persicaria*	I (4-5)
Carex disticha	I (4-7)	*Potentilla erecta*	I (3-4)
Carex flacca	I (4)	*Potentilla palustris*	I (5)
Carex viridula agg.	I (3-5)	*Prunella vulgaris*	I (4-6)
Carex hostiana	I (3)	*Ranunculus acris*	I (4)
Carex leporina	I (4)	*Ranunculus flammula*	I (5)
Carex panicea	I (3-6)	*Rhinanthus minor*	I (3)
Carex rostrata	I (8)	*Rorippa amphibia*	I (2)
Centaurea nigra	I (4)	*Rorippa palustris*	I (7)
Cerastium fontanum	I (1-4)	*Senecio aquaticus*	I (4-5)
Cirsium arvense	I (4)	*Stellaria media*	I (1-5)
Cirsium dissectum	I (2)	*Stellaria palustris*	I (4)
Cirsium vulgare	I (2)	*Succisa pratensis*	I (2-4)
Deschampsia caespitosa	I (3-6)	*Taraxacum officinale* agg.	I (1-5)

Eleocharis palustris	I (3-5)	*Trifolium pratense*	I (5-6)
Elymus repens	I (3-5)	*Valeriana officinalis*	I (3)
Equisetum fluviatile	I (3-4)	*Veronica scutellata*	I (2-4)
Equisetum palustre	I (3)	*Veronica serpyllifolia*	I (4)
Festuca arundinacea	I (4-6)	*Vicia cracca*	I (3-8)
Festuca pratensis	I (3-5)	*Viola* species	I (4-6)
Festuca rubra	I (5-7)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 4 – *Agrostis stolonifera-Potentilla anserina-Festuca rubra* community (Table 7.32)

13 turloughs – Ardkill (1), Ballindereen (3), Blackrock (10), Caherglassan (10), Coolcam, Croaghill (2), Garryland (6), Kilglassan (4), Knockaunroe (4), Lough Aleenaun (4), Lough Coy (8), Rathnalulleagh (3), Skealoghan (2), Turloughmore (4)

Description

This vegetation type is widespread, and was recorded in 13 of the 22 turloughs. The community is generally moderately grazed, and the sward is short (c. 15 cm). The constant species are *Agrostis stolonifera, Leontodon autumnalis, Potentilla anserina, Ranunculus repens, Trifolium repens, Lotus corniculatus* and *Filipendula ulmaria*. Frequent species are *Galium palustre, Plantago lanceolata, Carex panicea* and *Festuca rubra*.

This is a diverse community, with 86 species recorded overall, and the mean number of species per relevé is high (14, see Figure 7.3).

Location on flooding gradient

This community was generally found in the middle to upper zones of the turlough basin, and has a mean Ellenberg Wetness value of 6.2 (see Table 7.30).

Landuse

Grazed when the flooding allows, this community has an Ellenberg indicator value for Fertility indicating moderate fertility (4.7; see Table 7.30).

Table 7.32 Floristic table for the *Agrostis stolonifera-Potentilla anserina-Festuca rubra* community.

No. of relevés	61		
No. of species	96		
Group	4		
Agrostis stolonifera	V (2-8)	*Glechoma hederacea*	I (1)
Leontodon autumnalis	V (3-7)	*Gnaphalium uliginosum*	I (4)
Filipendula ulmaria	IV (0.1-7)	*Holcus lanatus*	I (3-4)
Lotus corniculatus	IV (1-6)	*Hydrocotyle vulgaris*	I (2-5)
Potentilla anserina	IV (3-8)	*Juncus acutiflorus*	I (3)
Ranunculus repens	IV (2-7)	*Juncus articulatus*	I (2-4)
Trifolium repens	IV (2-8)	*Juncus bufonius*	I (4)
Carex panicea	III (2-8)	*Juncus conglomeratus*	I (4)
Festuca rubra	III (3-6)	*Leontodon hispidus*	I (2-4)
Galium palustre	III (2-4)	*Leontodon saxatilis*	I (2-3)

Plantago lanceolata	III (3-6)	*Lolium perenne*	I (2-5)
Cardamine pratensis	II (0.1-3)	*Mentha aquatica*	I (1-4)
Carex nigra	II (2-5)	*Molinia caerulea*	I (4-5)
Cerastium fontanum	II (1-3)	*Myosotis scorpioides*	I (3)
Elymus repens	II (3-5)	*Odontites vernus*	I (4)
Galium verum	II (2-6)	*Oenanthe aquatica*	I (2)
Plantago major	II (1-5)	*Phalaris arundinacea*	I (2-4)
Potentilla erecta	II (1-5)	*Phleum bertolonii*	I (2)
Rumex acetosa	II (2-6)	*Phleum pratense*	I (2-4)
Rumex crispus	II (1-4)	*Plantago maritima*	I (3)
Viola species	II (0.1-3)	*Plantago media*	I (4-5)
Achillea millefolium	I (3)	*Poa annua*	I (3-5)
Achillea ptarmica	I (0.1-3)	*Poa pratensis*	I (3-4)
Agrostis capillaris	I (3-4)	*Poa trivialis*	I (2-5)
Alchemilla filicaulis	I (3)	*Polygonum persicaria*	I (1)
Alopecurus geniculatus	I (2-3)	*Potentilla fruticosa*	I (5)
Apium inundatum	I (4)	*Potentilla reptans*	I (1-4)
Bellis perennis	I (4)	*Prunella vulgaris*	I (0.1-4)
Capsella bursa-pastoris	I (2)	*Prunus spinosa*	I (4)
Carex disticha	I (3-4)	*Ranunculus acris*	I (3-4)
Carex flacca	I (3-7)	*Ranunculus flammula*	I (1-4)
Carex hirta	I (1-4)	*Rhinanthus minor*	I (2)
Carex hostiana	I (2-5)	*Rumex obtusifolius*	I (2-5)
Carex viridula agg.	I (2-4)	*Sagina nodosa*	I (2-3)
Cirsium arvense	I (1)	*Salix aurita*	I (2)
Cirsium dissectum	I (2-3)	*Senecio aquaticus*	I (3-4)
Cynosurus cristatus	I (3-4)	*Stellaria media*	I (1-4)
Deschampsia caespitosa	I (4-7)	*Succisa pratensis*	I (1-3)
Eleocharis palustris	I (4)	*Taraxacum officinale* agg.	I (0.1 4)
Euphrasia spp.	I (2-3)	*Teucrium scordium*	I (3-4)
Festuca arundinacea	I (3-6)	*Trifolium pratense*	I (3)
Festuca pratensis	I (3-4)	*Veronica serpyllifolia*	I (2-3)
Galium boreale	I (1-4)	*Vicia cracca*	I (3)
Geum rivale	I (1-4)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 9 – *Phalaris arundinacea-Potentilla anserina* community (Table 7.33)

5 turloughs – Ardkill (10), Brierfield (3), Rathnalulleagh (2), Skealoghan (1), Tullynafrankagh (1)

Description

This vegetation type was generally tall, with a mean height of 85 cm. *Phalaris arundinacea* and *Potentilla anserina* were the constant species in this vegetation community, with frequent *Filipendula ulmaria, Vicia cracca, Ranunculus repens* and *Carex hirta*. This seems to be a *P. arundinacea*-dominated variant of the tall herb community. *Phalaris arundinacea* was an indicator species for this vegetation community (20%).

Location on flooding gradient

This vegetation type is located in the middle of the flooding gradient; the Ellenberg Wetness value for this group of 7.3 (see Table 7.30) indicates this community occurs on damp sites (Hill *et al*., 1999).

Landuse

As evidenced by the tall height of the vegetation, this community occurs in ungrazed turloughs, or in ungrazed portions of turloughs. The mean Fertility value is approaching 6 (see Table 7.30) indicating this community may occur on sites with relatively high fertility.

Table 7.33 Floristic table for the *Phalaris arundinacea-Potentilla anserina* community.

No. of relevés	17		
No. of species	29		
Group	9		
Phalaris arundinacea	V (4-9)	*Carex nigra*	I (5)
Potentilla anserina	V (2-9)	*Eleocharis palustris*	I (8)
Carex hirta	III (3-7)	*Equisetum fluviatile*	I (5)
Filipendula ulmaria	III (3-7)	*Galium palustre*	I (2-3)
Ranunculus repens	III (4-5)	*Hypochoeris radicata*	I (1)
Vicia cracca	III (3-9)	*Iris pseudacorus*	I (5)
Elymus repens	II (3-7)	*Lathyrus pratensis*	I (4-5)
Hydrocotyle vulgaris	II (4-5)	*Lysimachia vulgaris*	I (3-5)
Polygonum amphibium	II (2-6)	*Lythrum salicaria*	I (6)
Rubus caesius	II (5-8)	*Rorippa amphibia*	I (3)
Agrostis stolonifera	I (3-5)	*Rubus fruticosus* agg.	I (6)
Cardamine flexuosa	I (1)	*Stellaria media*	I (3-5)
Carex disticha	I (4)	*Urtica dioica*	I (3-6)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 13 – *Potentilla anserina-Carex nigra* community (Table 7.34)

11 turloughs – Ardkill (3), Blackrock (2), Brierfield (2), Caherglassan (1), Carrowreagh (2), Coolcam (1), Croaghill (2), Garryland (8), Lisduff (2), Lough Coy (7), Turloughmore (3)

Description

This community occurs in a number of turloughs, it was found in half of the 22 turloughs surveyed. The sward is short (c. 20 cm) and relatively homogeneous; from the 33 relevés made, 36 species were recorded. The mean species richness is among the lowest found in this study, at 7 (see Figure 7.3). *Potentilla anserina, Agrostis stolonifera* and *Carex nigra* are constants, with frequent *Polygonum amphibium*.

Location on flooding gradient

This community is found in the middle of the flooding gradient, with a mean Ellenberg Wetness indicator value of 7.4 (see Table 7.30), which suggests this community occurs on damp soil (Hill *et al*., 1999).

Landuse

This vegetation type is moderately to heavily grazed. The Ellenberg Fertility score is approaching 5 (see Table 7.30), which indicates this community occurs in areas with intermediate fertility (Hill *et al*., 1999).

Table 7.34 Floristic table for the *Potentilla anserina-Carex nigra* community.

No. of relevés	33		
No. of species	36		
Group	13		
Potentilla anserina	V (5-9)	*Glyceria fluitans*	I (3-4)
Agrostis stolonifera	IV (3-7)	*Hydrocotyle vulgaris*	I (3-6)
Carex nigra	IV (5-9)	*Juncus acutiflorus*	I (3)
Polygonum amphibium	III (2-7)	*Juncus bulbosus*	I (4)
Carex hirta	II (4-6)	*Leontodon autumnalis*	I (4)
Eleocharis palustris	II (3-7)	*Matricaria discoidea*	I (2)
Galium palustre	II (3-5)	*Molinia caerulea*	I (4)
Mentha aquatica	II (3-4)	*Myosotis scorpioides*	I (2-4)
Phalaris arundinacea	II (4-7)	*Oenanthe aquatica*	I (4)
Ranunculus repens	II (1-5)	*Polygonum aviculare*	I (4-5)
Stellaria media	II (3-5)	*Polygonum persicaria*	I (4)
Cardamine pratensis	I (3-4)	*Potentilla reptans*	I (4-6)
Carex hostiana	I (3-7)	*Prunella vulgaris*	I (1)
Carex panicea	I (3-5)	*Rumex crispus*	I (3-4)
Cerastium fontanum	I (2)	*Rumex obtusifolius*	I (4-5)
Elymus repens	I (4-6)	*Taraxacum officinale* agg.	I (2-4)
Equisetum fluviatile	I (3-5)	*Trifolium repens*	I (4)
Filipendula ulmaria	I (3-6)	*Viola* species	I (1)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 19 – *Potentilla anserina-Potentilla reptans* community (Table 7.35)

2 turloughs – Blackrock (21), Garryland (4)

Description

This was a herb-dominated community, with a mean sward height of c. 10 cm and with constant and abundant *Potentilla reptans*, usually occurring near the bottom of the turlough basin. Alongside *P. reptans*, *Agrostis stolonifera, Potentilla anserina* and *Ranunculus repens* were constant species. *Carex nigra, Rumex crispus, Trifolium repens, Cerastium fontanum, Lotus corniculatus, Galium palustre* and *Leontodon autumnalis* were all frequent in this vegetation type.

The indicator species for this cluster was *Potentilla reptans* (37%).

Location on flooding gradient

This community is generally located in the middle to the bottom of the flooding gradient. The mean Ellenberg value for Wetness (6.1, see Table 6.24) is indicative of a damp site (Hill *et al.*, 1999).

Landuse

This community is generally grazed. The Ellenberg value for Fertility (5.2, see Table 6.24) suggests that this community occurs on sites of intermediate fertility (Hill *et al.*, 1999).

Table 7.35 Floristic table for the *Potentilla anserina-Potentilla reptans* community.

No. of relevés	25		
No. of species	41		
Group	19		
Agrostis stolonifera	V (3-8)	*Cirsium arvense*	I (2)
Potentilla anserina	V (4-10)	*Cirsium dissectum*	I (2-3)
Potentilla reptans	V (3-10)	*Elymus repens*	I (4)
Ranunculus repens	IV (2-5)	*Festuca arundinacea*	I (4)
Carex nigra	III (2-4)	*Festuca rubra*	I (4)
Cerastium fontanum	III (2-4)	*Galium boreale*	I (1-5)
Galium palustre	III (2-4)	*Galium verum*	I (4)
Leontodon autumnalis	III (0.1-3)	*Geum rivale*	I (3)
Lotus corniculatus	III (3-7)	*Gnaphalium uliginosum*	I (2)
Rumex crispus	III (2-5)	*Leontodon saxatilis*	I (3)
Trifolium repens	III (2-5)	*Mentha aquatica*	I (0.1-4)
Filipendula ulmaria	II (2-5)	*Phalaris arundinacea*	I (2-4)
Plantago lanceolata	II (3-5)	*Poa annua*	I (3-5)
Plantago major	II (3-4)	*Polygonum aviculare*	I (3)
Rumex acetosa	II (3-4)	*Prunella vulgaris*	I (2-3)
Viola species	II (2-8)	*Rorippa palustris*	I (4)
Cardamine pratensis	I (3)	*Rumex obtusifolius*	I (3)
Carex flacca	I (3-4)	*Stellaria media*	I (2)
Carex hirta	I (2-4)	*Succisa pratensis*	I (2)
Carex panicea	I (3-4)	*Trifolium pratense*	I (4)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 20 – *Filipendula ulmaria-Potentilla erecta-Viola* community (Table 7.36)

1 turlough – Blackrock (14), though mapped in several others

Description

This was a herb-rich community, recorded in Blackrock turlough, in which *Viola* sp., *Filipendula ulmaria, Potentilla anserina, Lotus corniculatus* and *Potentilla erecta* were constant. *Carex nigra, Galium palustre, Rumex acetosa* and *Plantago media* were all frequent.

Indicator species were *Plantago media* (61%), *Sagina nodosa* (54%), *Viola* species (45%) and *Rumex acetosa* (22%).

Location on flooding gradient

This community occurs in the middle of the flooding gradient, and has an Ellenberg Wetness score of 6.2 (see Table 7.30), indicating that this is a damp area.

Landuse

This community is well grazed. The mean Ellenberg Fertility value of 4 (see Table 7.30) suggests that this community occurs on sites with slightly less than moderate fertility (Hill *et al.*, 1999).

Table 7.36 Floristic table for the *Filipendula ulmaria-Potentilla erecta-Viola* community.

No. of relevés	14		
No. of species	30		
Group	20		
Filipendula ulmaria	V (4-7)	*Ranunculus repens*	III (3-4)
Lotus corniculatus	V (4-6)	*Sagina nodosa*	III (0.1-4)
Potentilla anserina	V (4-7)	*Carex panicea*	II (3-4)
Potentilla erecta	V (3-7)	*Cerastium fontanum*	II (0.1-4)
Viola species	V (4-5)	*Juncus bufonius*	II (3)
Carex nigra	IV (4-7)	*Plantago lanceolata*	II (3-4)
Galium palustre	IV (3-5)	*Cardamine pratensis*	I (3)
Plantago media	IV (3-5)	*Festuca rubra*	I (2)
Rumex acetosa	IV (3-4)	*Mentha aquatica*	I (4)
Agrostis stolonifera	III (2-5)	*Ophioglossum vulgatum*	I (2-3)
Galium boreale	III (3-4)	*Plantago major*	I (3-4)
Galium verum	III (4)	*Rhamnus cathartica*	I (0.1)
Leontodon autumnalis	III (3-4)	*Rorippa palustris*	I (2)
Poa annua	III (3-5)	*Rumex crispus*	I (4)
Potentilla reptans	III (4-7)	*Trifolium repens*	I (4)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Comparison with previous studies

All of the groups in this cluster belong to the class *Plantaginetea majoris*, more specifically to the *Ranunculo-Potentilletum anserinae* association. Each of the groups in this cluster show at least some affinity with the NVC SD17 *Potentilla anserina-Carex nigra* dune slack community, apart from group 9.

Group 3 – *Agrostis stolonifera-Ranunculus repens* community

Class: *Plantaginetea majoris*

This community is very similar to the *Carex nigra-Potentilla anserina* association of Ivimey-Cook and Proctor (1966). It belongs to the typical variant of O'Connell *et al.*'s *Ranunculo-Potentilletum anserinae* (1984).

This community corresponds well with Goodwillie's 6A Dry *Carex nigra* (1992) or 4C Dry *Carex nigra* (2003). It was most similar to Regan *et al.*'s Group 7, a forb-dominated community.

The highest goodness-of-fit score given by MAVIS for this community was for the SD17 *Potentilla anserina-Carex nigra* dune slack community (see Table 7.37).

Group 4 – *Agrostis stolonifera-Potentilla anserina-Festuca rubra* community

Class: *Plantaginetea majoris*

This community was similar to the *Potentilla anserina-Drepanocladus lycopodioides* nodum of Ivimey-Cook and Proctor (1966), with the caveat that moss species were not identified. There are also similarities with O'Connell *et al.'s Drepanocladus lycopioides* variant of the *Ranunculo-Potentilletum anserinae* (1984), but again, since mosses were not identified during this survey, the characteristic species *Drepanocladus lycopioides* was not recorded.

This community does not correspond very well with any one Goodwillie community. There are similarities with Goodwillie's 2B Poor Grassland (1992) or 2E Damp Grassland (2003), and also with 3B Sedge heath (Goodwillie, 1992).

The *Agrostis stolonifera-Potentilla anserina-Festuca rubra* community seems to be most similar to Regan et al.'s Group 7, although no *Festuca rubra* was recorded in any of their communities. There are also similarities with Group 8.

This community was most similar to the NVC SD17a *Potentilla anserina-Carex nigra* dune slack community, *Festuca rubra-Ranunculus repens* sub-community (see Table 7.37).

Group 9 – *Phalaris arundinacea-Potentilla anserina* community

Class: *Plantaginetea majoris*

There are some similarities to the *Potentilla anserina-Drepanocladus lycopodioides* nodum of the *Caricion davallaianae* as described by Ivimey-Cook and Proctor.

There are similarities to the *Ranunculo-Potentilletum anserinae*, although *Phalaris arundinacea* is never present at the high frequency found in this community in any of the sub-communities described by O'Connell *et al.* (1984).

Group 9 did not correspond well with any of the communities described by Regan et al. (2007); in none of their communities was *Phalaris arundinacea* recorded at a greater frequency than 40%, and the average percentage cover was just 1% in these communities.

This vegetation type, as well as Group 20, had similarities with Goodwillie's 3A Tall Herb (Goodwillie, 1992). Group 9, however, had more of the 'water-demanding' species described by Goodwillie, such as *Phalaris arundinacea*, *Polygonum amphibium* and *Lysimachia vulgaris*, suggesting that this was perhaps a wetter variant of Group 20. The two communities were, in fact, recorded in many of the same turloughs, and the mean Ellenberg Wetness score for Group 20 was 6.2, while it was 7.3 for Group 9. This may suggest that Group 9 experiences a wetter environment than Group 20.

There are some similarities with the NVC S28 *Phalaris arundinacea* tall-herb fen (Rodwell, 1995) (see Table 7.37), but also with M27 *Filipendula ulmaria-Angelica sylvestris* mire.

Group 13 – *Potentilla anserina-Carex nigra* community
Class: *Plantaginetea majoris*

Ivimey-Cook and Proctor's *Carex nigra-Potentilla anserina* association (Ivimey-Cook & Proctor, 1966) is very similar to this community. This is another community that belongs to the *Ranunculo-Potentilletum anserinae*, and is most similar to the *Polygonum amphibium* variant (O'Connell *et al*., 1984), although *Polygonum amphibium* does not achieve the dominance reported by O'Connell *et al*.

This vegetation type corresponds reasonably well with Goodwillie's 6B Wet *Carex nigra* (1992), or 4D Wet *Carex nigra* (Goodwillie, 2003). It is also very similar to Regan *et al*.'s (2007) Group 5, a *Carex nigra*-dominated community.

This community had the greatest affinity for SD17d *Potentilla anserina-Carex nigra* dune slack community – *Hydrocotyle vulgaris-Ranunculus flammula* sub-community (see Table 7.37).

Group 19 – *Potentilla anserina-Potentilla reptans* community

Class: *Plantaginetea majoris*

Ivimey-Cook and Proctor do not seem to explicitly describe this community, although there are some similarities with some of the relevés in their *Carex nigra-Potentilla anserina* association (Ivimey-Cook & Proctor, 1966). This community is part of the *Ranunculo-Potentilletum anserinae* (O'Connell *et al*., 1984), and is similar to the species-poor *Potentilla reptans* variant. O'Connell *et al.* suggest that the large ruderal component of this community (mainly *Potentilla anserina* and *Rumex crispus*) may be due to nutrient enrichment. This community was very similar to Goodwillie's 5B *Potentilla reptans* (species-poor) community (1992), or 4B *Potentilla reptans/Carex nigra* (2003), although there was less *Phalaris arundinacea* and more *Potentilla reptans*. The *Potentilla anserina-Potentilla reptans* community was most similar to Regan *et al*.'s (2007) Group 7.

There were similarities between this community and the NVC SD17 *Potentilla anserina-Carex nigra* dune slack community – *Hydrocotyle vulgaris-Ranunculus flammula* sub-community, but also with MG11a, the *Lolium perenne* sub-community of the *Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland (see Table 7.37).

Group 20 – *Filipendula ulmaria-Potentilla erecta-Viola* sp. community

Class: *Plantaginetea majoris*

This community seems to fit well with the species-rich variant of O'Connell *et al.*'s *Ranunculo-Potentilletum anserinae* (1984). Group 20 also corresponds well with Goodwillie's 4B *Potentilla reptans* (species rich) (1992), also known as 4A *Potentilla reptans/Viola canina* (2003). There are some similarities with Regan *et al.*'s Group 7 (2007). The highest goodness-of-fit score produced by MAVIS for this community was for the SD17 *Potentilla anserina-Carex nigra* dune slack community (see Table 7.37).

Table 7.37 Affinities with NVC communities generated by MAVIS for Cluster 3.

Group	*NVC*	*Percentage goodness-of-fit*	*Community*
3	SD17	53.58	*Potentilla anserina-Carex nigra* dune slack community
	SD17a	50.16	*Potentilla anserina-Carex nigra* dune slack community – *Festuca rubra-Ranunculus repens* sub-community
	M27	47.24	*Filipendula ulmaria-Angelica sylvestris* mire
4	SD17a	53.21	*Potentilla anserina-Carex nigra* dune slack community – *Festuca rubra-Ranunculus repens* sub-community
	SD17	52.75	*Potentilla anserina-Carex nigra* dune slack community
	SD17b	47.78	*Potentilla anserina-Carex nigra* dune slack community – *Carex flacca* sub-community
9	S28	41.79	*Phalaris arundinacea* tall-herb fen
	M27	41.45	*Filipendula ulmaria-Angelica sylvestris* mire
	OV26	41.41	*Epilobium hirsutum* community
13	SD17d	55.03	*Potentilla anserina-Carex nigra* dune slack community – *Hydrocotyle vulgaris-Ranunculus flammula* sub-community
	SD17	51.48	*Potentilla anserina-Carex nigra* dune slack community
	S19	50.75	*Eleocharis palustris* swamp
19	SD17a	50.11	*Potentilla anserina-Carex nigra* dune slack community – *Festuca rubra-Ranunculus repens* sub-community
	MG11a	49	*Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland – *Lolium perenne* sub-community
	MG11	48.17	*Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland
20	SD17	40.21	*Potentilla anserina-Carex nigra* dune slack community
	SD17a	38.65	*Potentilla anserina-Carex nigra* dune slack community – *Festuca rubra-Ranunculus repens* sub-community
	SD17c	36.74	*Potentilla anserina-Carex nigra dune* slack community – *Caltha palustris* sub-community

7.5.1.11 Cluster 2

Cluster 2 contained a number of water-dependant communities. These groups all contain at least some species which are obligately aquatic plants. All communities contained at least some *Equisetum fluviatile*, albeit at varying frequencies and abundances. These communities generally have a high mean Ellenberg Wetness score, and a relatively low mean Ellenberg Fertility score (see Table 7.38).

Table 7.38 Mean Ellenberg and Grime's CSR values for the groups in Cluster 2 (± standard deviation).

Group	Light	Wetness	pH	Fertility	C	S	R
2	7.3 ± 0.2	8.2 ± 0.7	6.2 ± 0.3	5.2 ± 0.7	2.99 ± 0.27	1.81 ± 0.38	2.68 ± 0.30
7	7.3 ± 0.2	8.5 ± 0.5	6.2 ± 0.5	5.2 ± 0.9	3.56 ± 0.65	2.06 ± 0.62	1.71 ± 0.43
16	7.5 ± 0.3	9.0 ± 0.6	5.6 ± 0.8	4.4 ± 0.8	2.83 ± 0.40	2.59 ± 0.71	1.80 ± 0.40
17	7.4 ± 0.2	7.9 ± 0.6	5.7 ± 0.5	4.0 ± 0.7	2.86 ± 0.38	2.49 ± 0.48	2.24 ± 0.38
18	7.2 ± 0.4	8.6 ± 0.9	6.1 ± 0.4	5.4 ± 0.8	2.95 ± 0.34	1.60 ± 0.51	2.71 ± 0.48
27	7.6 ± 0.4	9.3 ± 0.8	4.9 ± 0.6	3.4 ± 0.9	2.60 ± 0.39	3.23 ± 0.54	1.39 ± 0.43

Group 2 – *Polygonum amphibium-Eleocharis palustris* community (Table 7.39)

12 turloughs – Lough Aleenaun (18), Brierfield (7), Carrowreagh (3), Croaghill (7), Coolcam (2), Knockaunroe (11), Kilglassan (8), Lisduff (6), Skealoghan (5), Tullynafrankagh (1), Termon (4)

Description

Polygonum amphibium, as its name suggests, can tolerate aquatic and damp terrestrial habitats. This community was found in areas that retain shallow water during the summer months (the mean water depth at time of sampling was c. 20cm), with the emergent vegetation reaching around 35 cm. *P. amphibium, Agrostis stolonifera, Potentilla anserina, Galium palustre, Eleocharis palustris,* and *Ranunculus repens* were the constant species, with frequent *Mentha aquatica* and *Carex nigra.*

Location on flooding gradient

This community occurs in the middle to lower zones of turloughs, and was generally found to have shallow standing water when sampled. The mean Ellenberg Wetness value for this community is 8.2 (see Table 7.38), which is intermediate between a damp and wet site (Hill *et al*., 1999).

Landuse

This community was found in the lower zone of turloughs that are generally grazed by cattle. The presence of water throughout the dry period, however, means that grazing of this vegetation type is not extensive, although cattle are likely to water here and this results in poaching and disturbance. The mean Ellenberg Fertility value of 5.2 is indicative of an intermediate level of fertility (Hill *et al*., 1999).

Table 7.39 Floristic table for the *Polygonum amphibium-Eleocharis palustris* community.

No. of relevés	72		
No. of species	76		
Group	2		
Agrostis stolonifera	V (4-9)	*Filipendula ulmaria*	I (2-6)
Eleocharis palustris	IV (2-8)	*Glechoma hederacea*	I (3)
Galium palustre	IV (1-6)	*Hippuris vulgaris*	I (5-7)
Polygonum amphibium	IV (2-9)	*Iris pseudacorus*	I (3-7)
Potentilla anserina	IV (1-8)	*Juncus acutiflorus*	I (3-5)

Ranunculus repens	IV (2-6)
Carex nigra	III (3-6)
Mentha aquatica	III (1-7)
Cardamine pratensis	II (3-6)
Glyceria fluitans	II (2-6)
Hydrocotyle vulgaris	II (2-9)
Juncus articulatus	II (3-5)
Myosotis scorpioides	II (2-7)
Oenanthe aquatica	II (3-7)
Phalaris arundinacea	II (4-7)
Ranunculus flammula	II (3-7)
Rorippa amphibia	II (3-7)
Agrostis capillaris	I (6)
Alisma plantago-aquatica	I (1-5)
Alopecurus geniculatus	I (3-6)
Apium inundatum	I (3-4)
Apium nodiflorum	I (5)
Baldellia ranunculoides	I (3-5)
Caltha palustris	I (5-7)
Carex disticha	I (4-7)
Carex elata	I (4-6)
Carex flacca	I (4)
Carex viridula agg.	I (3-5)
Carex hirta	I (4-5)
Carex hostiana	I (3-7)
Carex rostrata	I (5)
Eleogiton fluitans	I (4)
Equisetum fluviatile	I (2-4)
Festuca arundinacea	I (4)
Festuca rubra	I (4)
Juncus bulbosus	I (3-4)
Juncus inflexus	I (6)
Lemna trisulca	I (4)
Leontodon autumnalis	I (5)
Littorella uniflora	I (6)
Lolium perenne	I (4)
Lysimachia vulgaris	I (6)
Lythrum salicaria	I (2)
Ophioglossum vulgatum	I (3)
Plantago lanceolata	I (5)
Polygonum persicaria	I (3-4)
Polygonum lapathifolium	I (2)
Potamogeton gramineus	I (4-6)
Potentilla reptans	I (5)
Ranunculus lingua	I (6)
Ranunculus trichophyllus	I (3-4)
Rumex crispus	I (3-6)
Rumex obtusifolius	I (4-6)
Senecio aquaticus	I (1)
Sparganium emersum	I (5-6)
Sparganium erectum	I (4-5)
Stellaria media	I (2-7)
Stellaria palustris	I (4-5)
Taraxacum officinale agg.	I (1-4)
Teucrium scordium	I (3-5)
Trifolium repens	I (4-5)
Veronica beccabunga	I (1-5)
Veronica catenata	I (3)
Veronica scutellata	I (1-4)
Veronica serpyllifolia	I (3-5)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 7 – *Eleocharis palustris-Phalaris arundinacea* (Table 7.40)

3 turloughs – Ardkill (8), Brierfield (9), Tullynafrankagh (2)

Description

This is a tall, ungrazed community, with a mean vegetation height 80 cm. This community has a similar suite of species to Cluster 2 but with more frequent *Phalaris arundinacea*.

Constant species are *Eleocharis palustris, Phalaris arundinacea* and *Galium palustre*, with frequent *Carex nigra, Polygonum amphibium, Potentilla anserina, Equisetum fluviatile* and *Agrostis stolonifera*. *Phalaris arundinacea* was an indicator species (26%).

Location on flooding gradient

This community occurs towards the bottom of the flooding gradient. The mean Ellenberg Wetness score of 8.5 (see Table 7.38) is indicative of a wet site (Hill *et al*., 1999).

Landuse

This community, as shown by the vegetation height, is little grazed. The mean Ellenberg Fertility value of 5.2 (see Table 7.38) suggests that this community occurs on sites of intermediate fertility (Hill *et al*., 1999).

Table 7.40 Floristic table for the *Eleocharis palustris-Phalaris arundinacea* community.

No. of relevés	19		
No. of species	28		
Group	7		
Eleocharis palustris	V (3-7)	*Caltha palustris*	I (3-4)
Phalaris arundinacea	V (4-9)	*Carex disticha*	I (4)
Galium palustre	IV (2-5)	*Carex hirta*	I (4)
Agrostis stolonifera	III (3-8)	*Filipendula ulmaria*	I (4)
Carex nigra	III (2-7)	*Lysimachia vulgaris*	I (3-5)
Equisetum fluviatile	III (3-6)	*Lythrum salicaria*	I (5)
Polygonum amphibium	III (3-5)	*Menyanthes trifoliata*	I (6-7)
Potentilla anserina	III (2-7)	*Myosotis scorpioides*	I (2)
Cardamine pratensis	II (3-4)	*Ranunculus lingua*	I (5)
Hydrocotyle vulgaris	II (3-4)	*Rorippa amphibia*	I (2)
Mentha aquatica	II (2-6)	*Salix aurita*	I (5-6)
Ranunculus repens	II (2-5)	*Salix repens*	I (7)
Alisma plantago-aquatica	I (6)	*Stellaria media*	I (2)
Apium nodiflorum	I (6)	*Veronica scutellata*	I (3)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 16 – *Equisetum fluviatile-Menyanthes trifoliata* community (Table 7.41)

6 turloughs – Ardkill (1), Brierfield (7), Kilglassan (3), Lisduff (1), Skealoghan (2), Tullynafrankagh (1)

Description

This community occurs in areas likely to retain shallow standing water during the summer months; the mean water depth was 10 cm at time of sampling, while the mean vegetation height is 40cm. *Equisetum fluviatile, Menyanthes trifoliata* and *Agrostis stolonifera* are constant species, with frequent *Mentha aquatica*. Occasional species are *Galium palustre, Hydrocotyle vulgaris, Oenanthe aquatica* and *Veronica catenata*.

Indicator species are *Menyanthes trifoliata* (81%) and *Equisetum fluviatile* (31%).

Location on flooding gradient

This community is located at the bottom of the flooding gradient, generally in areas with shallow standing water. It is also sometimes found in drainage ditches. The mean Ellenberg value for Wetness is 9 for this community (see Table 7.38), which is indicative of a wet site (Hill *et al*., 1999).

Landuse

Due to the wetness of this community, it is little grazed. The mean Ellenberg Fertility score is relatively low, at 4.4 (see Table 7.38).

Table 7.41 Floristic table for the *Equisetum fluviatile-Menyanthes trifoliata* community

No. of relevés	15		
No. of species	37		
Group	16		
Equisetum fluviatile	V (3-7)	*Iris pseudacorus*	I (7)
Menyanthes trifoliata	V (5-9)	*Juncus acutiflorus*	I (3)
Agrostis stolonifera	IV (3-9)	*Juncus articulatus*	I (5)
Mentha aquatica	III (4-5)	*Juncus effusus*	I (5-6)
Galium palustre	II (3-5)	*Lysimachia vulgaris*	I (4)
Hydrocotyle vulgaris	II (3-6)	*Lythrum portula*	I (3)
Oenanthe aquatica	II (4-8)	*Phalaris arundinacea*	I (5)
Veronica catenata	II (3-7)	*Polygonum amphibium*	I (2-4)
Apium nodiflorum	I (4-5)	*Potamogeton natans*	I (4)
Cardamine flexuosa	I (6)	*Potentilla anserina*	I (4)
Cardamine pratensis	I (4-5)	*Ranunculus flammula*	I (3-4)
Carex nigra	I (4-5)	*Ranunculus lingua*	I (4-5)
Carex rostrata	I (4-6)	*Ranunculus repens*	I (4)
Eleocharis palustris	I (4-5)	*Rorippa amphibia*	I (4-5)
Festuca arundinacea	I (2)	*Salix repens*	I (4)
Glyceria fluitans	I (4-5)	*Schoenoplectus lacustris*	I (5-6)
Hippuris vulgaris	I (6-7)	*Veronica serpyllifolia*	I (3)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 17 – *Carex nigra-Ranunculus flammula* community (Table 7.42)

12 turloughs – Ballindereen (2), Brierfield (1), Caranavoodaun (15), Coolcam (8), Croaghill (6), Kilglassan (2), Knockaunroe (9), Lisduff (7), Roo West (9), Skealoghan (4), Termon (10), Tullynafrankagh (10)

Description

This community was widespread, and was recorded in over half of the turloughs surveyed. The sward is lightly grazed, and generally reached a height of 30 cm. *Mentha aquatica, Hydrocotyle vulgaris* and *Potentilla anserina* are the constant species. *Agrostis stolonifera, Carex nigra, Ranunculus flammula* and *Galium palustre* are frequent.

Caltha palustris, Potentilla palustris and *Salix repens* are notable in this community, the first two for their instantly recognisable leaves and flowers, and *S. repens* for the large size of occasional specimens within the community.

Location on flooding gradient

This community is located towards the bottom of the flooding gradient, and generally had either a few centimetres of surface water or a waterlogged substrate at time of sampling. The mean Ellenberg Wetness value for this community is 7.9 (see Table 7.38), indicative of a relatively wet site (Hill *et al.*, 1999).

Landuse

This community is sometimes grazed by livestock. The mean Ellenberg Fertility value of 4 (see Table 7.38) is relatively low, and indicative of less fertile sites (Hill *et al.*, 1999).

Table 7.42 Floristic table for the *Carex nigra-Ranunculus flammula* community.

No. of relevés	83		
No. of species	74		
Group	17		
Hydrocotyle vulgaris	V (3-7)	*Filipendula ulmaria*	I (4-7)
Mentha aquatica	V (3-7)	*Glyceria fluitans*	I (3-6)
Potentilla anserina	V (2-9)	*Juncus acutiflorus*	I (3-6)
Agrostis stolonifera	IV (1-7)	*Juncus bulbosus*	I (1-5)
Carex nigra	IV (3-9)	*Juncus effusus*	I (4)
Galium palustre	IV (1-6)	*Lathyrus pratensis*	I (4)
Ranunculus flammula	IV (2-7)	*Leontodon saxatilis*	I (3)
Carex viridula agg.	III (2-8)	*Lysimachia vulgaris*	I (4-7)
Juncus articulatus	III (3-7)	*Menyanthes trifoliata*	I (4-9)
Ranunculus repens	III (2-6)	*Myosotis scorpioides*	I (2-5)
Carex panicea	II (2-7)	*Oenanthe aquatica*	I (4-5)
Leontodon autumnalis	II (1-5)	*Phragmites australis*	I (5-8)
Littorella uniflora	II (2-9)	*Polygonum amphibium*	I (3-6)
Molinia caerulea	II (3-8)	*Potamogeton gramineus*	I (3)
Phalaris arundinacea	II (3-7)	*Potentilla erecta*	I (3-5)
Achillea ptarmica	I (3-4)	*Potentilla palustris*	I (3-7)
Agrostis capillaris	I (5)	*Potentilla reptans*	I (4-7)
Alisma plantago-aquatica	I (3-4)	*Prunella vulgaris*	I (4)
Anagallis tenella	I (1)	*Prunus spinosa*	I (5)
Baldellia ranunculoides	I (2-5)	*Ranunculus trichophyllus*	I (3)
Caltha palustris	I (4-6)	*Salix repens*	I (4)
Cardamine pratensis	I (3-6)	*Samolus valerandi*	I (1-6)
Carex elata	I (4-6)	*Schoenus nigricans*	I (4)
Carex flacca	I (3-8)	*Senecio aquaticus*	I (5-6)
Carex hirta	I (4-5)	*Stellaria palustris*	I (4-5)
Carex hostiana	I (3-4)	*Succisa pratensis*	I (5)
Carex rostrata	I (5)	*Teucrium scordium*	I (3-6)
Cirsium dissectum	I (2-5)	*Trifolium repens*	I (3-5)
Eleocharis multicaulis	I (5-8)	*Triglochin palustris*	I (4)
Eleocharis palustris	I (3-8)	*Veronica beccabunga*	I (3)
Equisetum fluviatile	I (3-5)	*Veronica scutellata*	I (1-4)
Equisetum palustre	I (6)	*Vicia cracca*	I (3-6)
Eriophorum angustifolium	I (5)	*Zannichellia palustris*	I (3-5)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 18 – *Agrostis stolonifera-Glyceria fluitans* community (Table 7.43)

12 turloughs – Ballindereen (2), Brierfield (1), Carrowreagh (3), Croaghill (5), Garryland (1) Kilglassan (1), Knockaunroe (2), Lisduff (1), Lough Aleenaun (3), Rathnalulleagh (3), Skealoghan (3), Tullynafrankagh (3)

Description

This community was generally aquatic; the mean water depth across all the relevés was 20 cm (at time of sampling), with the some of the vegetation emerging slightly above that. *Agrostis stolonifera* and *Glyceria fluitans* are the constant species, with frequent *Eleocharis palustris* and *Galium palustre*.

Glyceria fluitans had an indicator value of 31%.

Location on flooding gradient

This community is located at the base or near the bottom of the turloughs, in areas that are likely to retain some standing water throughout the season, as was recorded during sampling. The mean Ellenberg value for Wetness is 8.6 (see Table 7.38), which suggests that this community occurs on wet sites.

Landuse

Although this community occurs in areas which are accessible by livestock, grazing is limited due to the presence of standing water. The mean Ellenberg Fertility score is 5.4 (see Table 7.38), which is indicative of a site moderately high fertility (Hill *et al.*, 1999).

Table 7.43 Floristic table for the *Agrostis stolonifera-Glyceria fluitans* community.

No. of relevés	28		
No. of species	51		
Group	18		
Agrostis stolonifera	V (3-9)	*Leontodon autumnalis*	I (4)
Glyceria fluitans	IV (4-8)	*Lythrum portula*	I (4)
Eleocharis palustris	III (3-9)	*Molinia caerulea*	I (4)
Galium palustre	III (3-6)	*Oenanthe aquatica*	I (5)
Cardamine flexuosa	II (3-7)	*Phalaris arundinacea*	I (5-6)
Equisetum fluviatile	II (4-6)	*Plantago major*	I (1)
Mentha aquatica	II (3-6)	*Poa annua*	I (4)
Myosotis scorpioides	II (4-7)	*Polygonum aviculare*	I (5)
Polygonum amphibium	II (3-8)	*Polygonum persicaria*	I (4-5)
Ranunculus repens	II (3-6)	*Potentilla anserina*	I (3-5)
Alisma plantago-aquatica	I (3-5)	*Ranunculus flammula*	I (4-5)
Alopecurus geniculatus	I (4)	*Ranunculus trichophyllus*	I (1-5)
Apium inundatum	I (5)	*Rorippa amphibia*	I (4-6)
Apium nodiflorum	I (4-5)	*Rorippa palustris*	I (4-7)
Baldellia ranunculoides	I (4-5)	*Rumex crispus*	I (2)
Callitriche species	I (4)	*Rumex obtusifolius*	I (5)
Caltha palustris	I (4)	*Senecio aquaticus*	I (1)

Cardamine pratensis	I (4)	*Sparganium erectum*	I (5-6)
Carex nigra	I (3-5)	*Stellaria media*	I (3-4)
Gnaphalium uliginosum	I (1-2)	*Trifolium repens*	I (4-5)
Juncus acutiflorus	I (4-5)	*Veronica catenata*	I (4)
Juncus articulatus	I (3-4)	*Veronica scutellata*	I (4-5)
Juncus effusus	I (6)	*Zannichellia palustris*	I (4)
Lemna minor	I (3)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 27 – *Carex nigra-Equisetum fluviatile* community (Table 7.44)

3 turloughs – Garryland (4), Lisduff (2), Skealoghan (1)

Description

This community has a relatively low number of species, but again, this may be due to the small sample size. The sward is relatively ungrazed, and the mean vegetation height is 30 cm. Constant species are *Equisetum fluviatile* and *Carex nigra*, and the community is easily recognised due to the dominance of these two species. Frequent species are *Eleocharis palustris* and *Carex vesicaria*.

Indicator species are *Carex vesicaria* (43%) and *Equisetum fluviatile* (23%).

Location on flooding gradient

This vegetation type is located towards the bottom of the flooding gradient, and when surveyed, usually had some surface water or a waterlogged substrate. The mean Ellenberg value for Wetness is high, at 9.3 (see Table 7.38), indicating that this is a community which may occur on wet sites.

Landuse

This community occurs in areas accessible by cattle, but is little grazed. The mean Ellenberg Fertility value is low, at 3.4 (see Table 7.38), which suggests that this community may occur on infertile sites (Hill *et al*., 1999).

Table 7.44 Floristic table for the *Carex nigra-Equisetum fluviatile* community.

No. of relevés	7		
No. of species	16		
Group	27		
Carex nigra	V (5-9)	*Glyceria fluitans*	I (4)
Equisetum fluviatile	V (3-6)	*Juncus acutiflorus*	I (4)
Carex vesicaria	III (7-9)	*Littorella uniflora*	I (5)
Eleocharis palustris	III (3-5)	*Mentha aquatica*	I (4)
Hydrocotyle vulgaris	II (3-4)	*Phalaris arundinacea*	I (3)
Juncus bulbosus	II (5)	*Polygonum hydropiper*	I (3)
Ranunculus flammula	II (5-6)	*Schoenoplectus lacustris*	I (9)
Carex viridula	I (5)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Comparison with previous studies

Group 2 – *Polygonum amphibium-Eleocharis palustris* community

Class: *Plantaginetea majoris*

Group 2 is most similar to the *Polygonum amphibium* variant of the *Ranunculo-Potentilletum anserinae* as described by O'Connell *et al.* (1984). This community was similar to 7A *Polygonum amphibium* (grassy) from Goodwillie's 1992 survey, and seems to belong to his 5B *Polygonum amphibium* community (2003).

This community appears to belong to the A10 *Polygonum amphibium* NVC community (Rodwell, 1995), although the NVC community with the highest affinity calculated by MAVIS was SD17d, the *Hydrocotyle vulgaris-Ranunculus flammula* sub-community of the *Potentilla anserina-Carex nigra* dune-slack community.

Group 7 – *Eleocharis palustris-Phalaris arundinacea community*

Class: *Plantaginetea majoris*

This community was similar to Goodwillie's 7A *Polygonum amphibium* (grassy) community (Goodwillie, 1992), although *Polygonum amphibium* is not as frequent, while *Eleocharis palustris, Phalaris arundinacea* and *Galium palustre* are all more frequent than in 7A. While this community has a similar suite of species to Group 2, this community is in general much taller, and did not have standing water present at the time of sampling.

The NVC community to which this has the greatest degree of affinity, according to MAVIS, is the S19 *Eleocharis palustris* swamp.

Group 16 – *Equisetum fluviatile-Menyanthes trifoliata* community

Class: *Phragmitetea*

This community seems to belong to the *Glycerio-Sparganion* alliance of the *Phragmitetea*, which was not described in depth by Ivimey-Cook and Proctor (1966). They did, however, present a table with three relevés representing this community, and Group 16 seems to fit here.

O'Connell *et al.* provide synoptic tables for their reedswamp and tall sedge communities, to which Group 16 seems to belong. The character and differential species listed by them, however, were not present in Group 16 in sufficient quantities to allow a distinction between the groups.

This community was most similar to Goodwillie's 11B Peaty Pond (1992), who also placed this community in the *Glycerio-Sparganion*.

This community was very similar to the NVC S10 *Equisetum fluviatile* swamp (Rodwell, 1995), although the NVC community for which the highest goodness-of-fit score that was generated by MAVIS was S19 the *Eleocharis palustris* swamp, as shown in Table 7.45.

Group 17 – *Carex nigra-Ranunculus flammula* community

Class: *Plantaginetea majoris*

Group 17 is most similar to the Typical *Carex nigra* variant of the *Ranunculo-Potentilletum anserinae* as described by O'Connell *et al*. (1984). This community is most similar to 6D Peaty *Carex nigra* (Goodwillie, 1992) or 7A Peaty *Carex nigra* (Goodwillie, 2003).

The *Carex nigra-Ranunculus flammula* community was similar to Groups 3 and 4 from Regan *et al*. (2007).

Proctor (2010) gives the NVC equivalent of this community as M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire (Rodwell, 1991b), and there are similarities, but Group 17 has 'scarce' *Carex rostrata*, while it is listed as 'constant' in the floristic table for M9.

Group 18 – *Agrostis stolonifera-Glyceria fluitans* community

Class: *Phragmitetea*

This community was most similar to Goodwillie's 9A Temporary Pond (1992), which seems to be renamed later as 5A Floodgrass (2003).

On comparison with the floristic tables describing NVC communities, the *Agrostis stolonifera-Glyceria fluitans* community was found to be similar to the NVC S22 *Glyceria fluitans* water margin vegetation (Rodwell, 1995), although *Agrostis stolonifera,* one of the constant species in this vegetation type, is listed as 'scarce' in the floristic table for S22. It may be that the fluctuating water levels allow *A. stolonifera* a competitive edge. There were also similarities with NVC vegetation type S23 – 'Other water-margin vegetation' (Rodwell, 1995). MAVIS, however, did not give high goodness-of-fit scores for either of these communities, and instead found affinity with S19 *Eleocharis palustris* swamp.

Group 27 – *Carex nigra-Equisetum fluviatile* community

Class: *Phragmitetea*

This community also had similarities to Goodwillie's 11B Peaty Pond (1992), although in this case there was no *Menyanthes trifoliata* and abundant and frequent *Carex nigra*. These two species also confound any comparison with the NVC S10 *Equisetum fluviatile* swamp (Rodwell, 1995). A relatively low number of relevés were recorded for this community (7), and it is possible that these represent a transition zone between the *Equisetum fluviatile-Menyanthes trifoliata* community and a more *Carex nigra*-dominated community. The NVC community with the highest goodness-of-fit score was S19, the *Eleocharis palustris* swamp (see Table 7.45).

Table 7.45 Affinities with NVC communities for Cluster 2.

Group	NVC	Percentage	Community
2	SD17d	51.52	*Potentilla anserina-Carex nigra* dune slack
	SD17	48.94	*Potentilla anserina-Carex nigra* dune slack
	SD17a	44.89	*Potentilla anserina-Carex nigra* dune slack
7	S19	54.93	*Eleocharis palustris* swamp
	SD17d	51.9	*Potentilla anserina-Carex nigra* dune slack
	S19a	48.47	*Eleocharis palustris* swamp
16	S19	49.59	*Eleocharis palustris* swamp
	S27a	49.48	*Carex rostrata-Potentilla palustris* tall-herb swamp
	S12	48.84	*Typha latifolia* swamp
17	SD17d	54.62	*Potentilla anserina-Carex nigra* dune slack
	SD15	48.92	*Salix repens-Calliergon cuspidatum* dune slack
	SD17	48.91	*Potentilla anserina-Carex nigra* dune slack
18	S19	50.78	*Eleocharis palustris* swamp
	S19a	46.51	*Eleocharis palustris* swamp
	S12	45.14	*Typha latifolia* swamp
27	S19	50.54	*Eleocharis palustris* swamp
	S8c	46.58	*Scirpus lacustris* swamp
	S19a	46.24	*Eleocharis palustris* swamp

7.5.1.12 Cluster 8

Cluster 8 contains Groups 22 and 25, both of which have a high frequency of *Molinia caerulea,* and both also contain at least some *Carex hostiana, Cirsium dissectum* and *Ranunculus flammula.* Both of these communities have low mean Ellenberg Fertility values (see Table 7.46).

Table 7.46 Mean Ellenberg and Grime's CSR values for the groups in Cluster 8 (± standard deviation).

Group	Light	Wetness	pH	Fertility	C	S	R
22	7.5 ± 0.3	7.7 ± 0.6	5.0 ± 0.7	2.7 ± 0.6	2.17 ± 0.4	3.56 ± 0.53	1.60 ± 0.38
25	7.6 ± 0.2	8.3 ± 0.2	5.6 ± 0.7	2.1 ± 0.1	2.08 ± 0.26	3.80 ± 0.36	1.23 ± 0.20

Group 22 - *Molinia caerulea-Carex panicea* community (Table 7.47)

6 turloughs – Ballindereen (6), Caranavoodaun (10), Knockaunroe (18), Lisduff (5), Roo West (4), Tullynafrankagh (1)

Description

This community has a relatively short sward (25 cm) comprised of a mix of sedges, grasses and forbs. The constant species are *Carex panicea, Molinia caerulea, Carex hostiana* and *Mentha aquatica. Agrostis stolonifera, Carex flacca, Cirsium dissectum, Hydrocotyle vulgaris, Leontodon autumnalis, Lotus corniculatus, Potentilla anserina, Potentilla erecta* and *Ranunculus flammula* are all frequent.

Carex hostiana is an indicator species (24%).

Location on flooding gradient

This community is generally located in the middle to the bottom of the flooding gradient. The mean Ellenberg Wetness value of 7.7 (see Table 7.46) is indicative of damp to wet soils (Hill *et al*., 1999).

Landuse

This community occurs on Fen peat or peat marl, and is little grazed. The mean Ellenberg Fertility value is low, at 2.7 (see Table 7.46), which is indicative of infertile sites (Hill *et al*., 1999).

Table 7.47 – Floristic table for the *Molinia caerulea-Carex panicea* community.

No. of relevés	44		
No. of species	59		
Group	22		
Carex panicea	V (2-8)	*Galium boreale*	I (3)
Molinia caerulea	V (2-9)	*Hypochoeris radicata*	I (0.1)
Carex hostiana	IV (1-9)	*Juncus acutiflorus*	I (2)
Mentha aquatica	IV (0.1-4)	*Juncus articulatus*	I (1-5)
Agrostis stolonifera	III (1-6)	*Juncus bulbosus*	I (2)
Carex flacca	III (2-5)	*Leontodon hispidus*	I (2)
Cirsium dissectum	III (0.1-5)	*Linum cathartica*	I (2-3)
Hydrocotyle vulgaris	III (0.1-6)	*Lythrum salicaria*	I (2)
Leontodon autumnalis	III (1-4)	*Ophioglossum vulgatum*	I (2)
Lotus corniculatus	III (2-5)	*Parnassia palustris*	I (3)
Potentilla anserina	III (1-7)	*Phalaris arundinacea*	I (1-3)
Potentilla erecta	III (2-5)	*Phleum bertolonii*	I (1-2)
Ranunculus flammula	III (0.1-4)	*Plantago lanceolata*	I (1-4)
Carex nigra	II (2-8)	*Plantago maritima*	I (2-4)
Carex viridula agg.	II (2-7)	*Polygonum amphibium*	I (3)
Galium palustre	II (0.1-4)	*Potentilla reptans*	I (1-4)
Succisa pratensis	II (1-5)	*Prunella vulgaris*	I (4)
Achillea ptarmica	I (1-3)	*Prunus spinosa*	I (0.1-5)
Alopecurus geniculatus	I (2)	*Ranunculus repens*	I (0.1-5)
Anagallis tenella	I (1)	*Salix repens*	I (2-6)
Carex hirta	I (3)	*Samolus valerandi*	I (2)
Cirsium arvense	I (4)	*Schoenus nigricans*	I (0.1-6)
Danthonia decumbens	I (2)	*Teucrium scordium*	I (1-2)
Eleocharis palustris	I (3)	*Trifolium pratense*	I (2)
Elymus repens	I (2)	*Trifolium repens*	I (1-4)
Equisetum fluviatile	I (1)	*Veronica beccabunga*	I (1-2)
Festuca arundinacea	I (3)	*Viola* species	I (0.1-3)
Fraxinus excelsior	I (0.1-3)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 25 – *Carex nigra-Carex viridula* community (Table 7.48)

2 turloughs – Caranavoodaun (7), Knockaunroe (2)

Description

The mean vegetation height of this community is 35 cm. Relatively few species were recorded, just 16 in 9 relevés. This is quite a small sample number, however, and further relevés may be required to further define this vegetation type. *Carex nigra, Carex viridula* agg., *Molinia caerulea, Ranunculus flammula* and *Schoenus nigricans* are all constant species, and in fact dominated the vegetation. There are no frequent species in this community. *Carex hostiana, Hydrocotyle vulgaris, Mentha aquatica* and *Phalaris arundinacea* are all occasional species.

Indicator species are *Carex viridula* agg. (41%), and *Schoenus nigricans* (28%).

Location on flooding gradient

This community is located towards the bottom of the flooding gradient, and the mean Ellenberg value for Wetness, at 8.3 (see Table 7.46), is indicative of a damp to wet site (Hill et al., 1999).

Landuse

This is a community which is only lightly grazed. The mean Ellenberg Fertility value is the lowest found, at 2.1 (see Table 7.46), and suggests this community occurs on infertile sites.

Table 7.48 – Floristic table for the *Carex nigra-Carex viridula* community.

No. of relevés	9		
No. of species	16		
Group	25		
Carex nigra	V (4-7)	*Phalaris arundinacea*	II (2)
Carex viridula agg.	V (2-8)	*Agrostis stolonifera*	I (2)
Molinia caerulea	V (3-6)	*Cirsium dissectum*	I (3)
Ranunculus flammula	V (0.1-5)	*Galium palustre*	I (2)
Schoenus nigricans	IV (3-9)	*Juncus articulatus*	I (3)
Carex hostiana	II (2-6)	*Leontodon autumnalis*	I (3)
Hydrocotyle vulgaris	II (2)	*Menyanthes trifoliata*	I (3)
Mentha aquatica	II (2)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Comparison with previous studies

Group 22 – *Molinia caerulea-Carex panicea* community

Class: *Scheuchzerio-Caricetea fuscae*

Of the communities described by O'Connell *et al*. (1984), this community seems to correspond best with the *Carex panicea-Carex flava* agg. community. This community seems to be identical to Goodwillie's 5D Sedge Fen (1992) or 3B *Carex hostiana/Molinia* (2003). Of the communities described by Regan *et al.* (2007), the *Molinia caerulea-Carex panicea* community was most similar to Group 2, although Regan *et al*. did not record *Carex hostiana* in any of their communities.

This community was also very similar to the NVC M24 *Molinia caerulea-Cirsium dissectum* fen-meadow (Rodwell, 1991b), although the NVC communities with which it has the greatest affinity according to MAVIS are dune slack communities (see Table 7.49).

Group 25 – *Carex nigra-Carex viridula* agg. community

Class: *Scheuchzerio-Caricetea fuscae*

This community seems to belong to the *Carex demissa* nodum of the *Caricion davallianae* (Ivimey-Cook & Proctor, 1966). It also has similarities with the species-poor variant of the *Carex panicea-Carex flava* agg. community of O'Connell et al. (1984), although *Carex panicea* is not present. This community seems similar to Goodwillie's 5E *Carex flava (Carex viridula* agg.*)* community (Goodwillie, 1992). The community represented only 1% of the surveyed area in that report, however, and was not described in the 2003 review of turlough vegetation.

There are some similarities with Group 1 as described by Regan *et al*. (2007).

According to MAVIS, the community to which Group 25 has the greatest affinity is SD17d, the *Hydrocotyle vulgaris-Ranunculus flammula* sub-community of the *Potentilla anserina-Carex nigra* dune slack community (see Table 7.49). This was given a very low goodness-of-fit score, however, and does not correspond very well with this community.

Table 7.49 Affinities with NVC for Cluster 8.

Group	*NVC*	*Percentage*	*Community*
22	SD15	48.13	*Salix repens-Calliergon cuspidatum* dune slack community
	SD14	46.53	*Salix repens-Campylium stellatum* dune slack community
	SD14b	44.08	*Salix repens-Campylium stellatum* dune slack community – *Rubus caesius-Galium palustre* sub-community
25	SD17d	37.28	*Potentilla anserina-Carex nigra* dune slack community – *Hydrocotyle vulgaris-Ranunculus flammula* sub-community
	M13a	33.01	*Schoenus nigricans-Juncus subnodulosus* mire – *Festuca rubra-Juncus acutiflorus* sub-community
	M29	31.92	*Hypericum elodes-Potamogeon polygonifolius* soakway

7.5.1.13 Cluster 5

Cluster 5 contains communities that seem to be the most reliant on permanent water during the dry phase of the turlough; all communities had an average water depth at time of sampling of 20 cm. All of the communities contain aquatic plants, and all contain at least some *Potamogeton natans* and *Glyceria fluitans*. The mean Ellenberg Wetness score is high in all cases, while the mean Fertility score is relatively low (see Table 7.50)

Table 7.50 Mean Ellenberg and Grime's CSR values for the groups in Cluster 8 (± standard deviation)

Group	Light	Wetness	pH	Fertility	C	S	R
6	7.4 ± 0.3	9.5 ± 0.5	6.1 ± 0.3	4.7 ± 0.9	3.08 ± 0.14	1.96 ± 0.54	2.53 ± 0.41
11	7.1 ± 0.1	9.2 ± 0.5	6.3 ± 0.2	5.7 ± 0.3	3.24 ± 0.27	1.24 ± 0.22	2.64 ± 0.32
14	7.5 ± 0.4	9.4 ± 0.6	6.3 ± 0.6	4.8 ± 0.7	3.34 ± 0.30	2.23 ± 0.55	1.98 ± 0.56
24	7.0 ± 0.0	10.3 ± 0.5	6.0 ± 0.0	4.3 ± 0.4	3.83 ± 0.21	1.87 ± 0.18	1.34 ± 0.43

Group 6 – *Eleocharis palustris-Ranunculus flammula* community (Table 7.51)

8 turloughs – Ardkill (3), Coolcam (3), Croaghill (2), Kilglassan (3), Knockaunroe (10), Lisduff (2), Skealoghan (2), Termon (6)

Description

This is one of the more water-dependent communities sampled. In contrast with group 2, which also features *Polygonum amphibium,* this community is weighted more towards the aquatic, with such constant species as *Mentha aquatica*, *Eleocharis palustris and Ranunculus flammula.* The aforementioned *Polygonum amphibium* is frequent, along with *Glyceria fluitans, Galium palustre* and *Juncus articulatus*. When surveyed, this community had an average water depth of 20 cm, with the emergent vegetation generally rising 30 cm above this.

Elodea canadensis, an invasive aquatic alien, is found in this community, although not very frequently.

Location on flooding gradient

This community is found in the lower zones of turloughs, usually in shallow water. It can form large stands, especially in shallower basins or those with a flat bottom. The high mean Ellenberg Wetness score (9.5, see Table 7.50) is indicative of a wet site, that may lack standing water for some of the year (Hill *et al*., 1999).

Soil type

The substrate this community grows on is generally marl and silt.

Landuse

Due to the wet nature of this community, it is not intensively grazed. Several of the plant species appear to be palatable to livestock, however. It is often subject to poaching by cattle seeking water, and subsequent enrichment through dunging. The mean Ellenberg value for Fertility is almost 5 (see Table 7.50), which suggests this community occurs on sites of intermediate fertility.

Table 7.51 Floristic table for the *Eleocharis palustris-Ranunculus flammula* community.

No. of relevés	31		
No. of species	45		
Group	6		
Eleocharis palustris	V (3-9)	*Hippuris vulgaris*	I (4-5)
Mentha aquatica	V (3-7)	*Hydrocotyle vulgaris*	I (3-5)
Ranunculus flammula	IV (2-6)	*Juncus bulbosus*	I (5)
Galium palustre	III (3-5)	*Lemna minor*	I (4)
Glyceria fluitans	III (4-7)	*Littorella uniflora*	I (3-8)
Juncus articulatus	III (3-8)	*Lythrum portula*	I (3)
Polygonum amphibium	III (3-5)	*Myosotis scorpioides*	I (3-4)
Agrostis stolonifera	II (3-7)	*Phalaris arundinacea*	I (2)
Alisma plantago-aquatica	II (2-7)	*Polygonum persicaria*	I (4)
Baldellia ranunculoides	II (3-6)	*Potamogeton gramineus*	I (4-6)
Equisetum fluviatile	II (4-6)	*Potentilla anserina*	I (3)
Oenanthe aquatica	II (4-7)	*Ranunculus repens*	I (3)
Potamogeton natans	II (3-6)	*Ranunculus trichophyllus*	I (3-5)
Apium inundatum	I (3)	*Rorippa amphibia*	I (2-9)
Cardamine flexuosa	I (4)	*Samolus valerandi*	I (3-4)
Carex elata	I (7)	*Schoenoplectus lacustris*	I (9)
Carex viridula	I (4-6)	*Sparganium emersum*	I (3-5)
Carex hostiana	I (4)	*Sparganium erectum*	I (4-5)
Carex nigra	I (3-6)	*Teucrium scordium*	I (3)
Chara species	I (4)	*Veronica beccabunga*	I (4)
Eleocharis multicaulis	I (4)	*Veronica scutellata*	I (4)
Eleogiton fluitans	I (7)	*Zannichellia palustris*	I (6)
Elodea canadensis	I (5-8)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 11 – *Polygonum amphibium-Mentha aquatica* community (Table 7.52)

3 turloughs – Ardkill (7), Croaghill (4), Lough Aleenaun (5)

Description

This community occurrs in areas likely to retain shallow water during the dry phase; when surveyed the water was generally around 20 cm deep. The average vegetation height is 25 cm, though *Oenanthe aquatica* can grow much taller. Constant species are *Polygonum amphibium* and *Mentha aquatica*, with frequent *Eleocharis palustris* and *Oenanthe aquatica*.

Polygonum amphibium has an indicator value of 28% in this community.

Location on flooding gradient

This vegetation type occurs at the bottom of the flooding gradient, and has a mean Ellenberg indicator value for Wetness of 9.2, suggesting that this occurs on very wet sites (Hill *et al*., 1999).

Landuse

As with all of the communities found in standing water, this one is not intensively managed. Cattle come to drink from the water, and this causes disturbance to the substrate, resulting in turbid water which reduces the light available to submerged plants. There is also nutrient input to the habitat via dunging of cattle. The mean Ellenberg Fertility value is 5.7 (see Table 7.50), indicating that this is a community which occurs on relatively fertile sites (Hill *et al*., 1999).

Table 7.52 Floristic table for the *Polygonum amphibium-Mentha aquatica* community.

No. of relevés	16		
No. of species	39		
Group	11		
Polygonum amphibium	V (5-8)	*Hydrocotyle vulgaris*	I (5)
Mentha aquatica	IV (4-8)	*Lemna minor*	I (4)
Eleocharis palustris	III (3-5)	*Lemna trisulca*	I (3)
Oenanthe aquatica	III (2-7)	*Myosotis scorpioides*	I (4)
Agrostis stolonifera	II (3-5)	*Phalaris arundinacea*	I (4-5)
Callitriche species	II (4-5)	*Polygonum hydropiper*	I (2)
Glyceria fluitans	II (4-5)	*Potamogeton natans*	I (7)
Ranunculus repens	II (4-5)	*Potentilla anserina*	I (2)
Ranunculus trichophyllus	II (6-7)	*Rorippa palustris*	I (4)
Rorippa amphibia	II (3-5)	*Rumex obtusifolius*	I (4-5)
Cardamine pratensis	I (3-4)	*Sparganium emersum*	I (4-6)
Carex nigra	I (3)	*Sparganium erectum*	I (4)
Galium palustre	I (2-4)	*Veronica catenata*	I (4-6)
Hippuris vulgaris	I (4)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 14 - Reedbed (Table 7.53)

3 turloughs – Ardkill (1), Knockaunroe (2), Termon (6)

Description

The constant species in this community are *Schoenoplectus lacustris* and *Mentha aquatica*, with frequent *Carex elata* and *Eleocharis palustris*. Both *S. lacustris* and *C. elata* are tall plants, and the former can reach heights of up to 1-2 m.

Indicator species are *Schoenoplectus lacustris* (48%), *Carex elata* (46%) and *Chara* sp. (30%).

Location on flooding gradient

This community is located at the very bottom of the flooding gradient, and when surveyed standing water was present. The mean Ellenberg value for Wetness is 9.4 for this community (see Table 7.50), indicating it occurs on wet sites (Hill *et al*., 1999).

Landuse

This community is not grazed. The mean Ellenberg value for Fertility is 4.8 (see Table 7.50), which indicates this community occurs on sites of intermediate fertility.

Additional notes

It should be noted that this community was undersampled due to physical difficulties in getting to the vegetation – the water was often too deep and/or the substrate too soft to safely record the vegetation. Stands of *S. lacustris* and *Phragmites australis* have been recorded in a number of turloughs (Goodwillie, 1992; O'Connell *et al.*, 1984).

Table 7.53 Floristic table for the Reedbed community.

No. of relevés	9		
No. of species	21		
Group	14		
Mentha aquatica	IV (3-4)	*Baldellia ranunculoides*	I (4)
Schoenoplectus lacustris	IV (5-9)	*Equisetum fluviatile*	I (3)
Carex elata	III (4-9)	*Galium palustre*	I (3)
Eleocharis palustris	III (4-7)	*Glyceria fluitans*	I (4)
Chara species	II (4)	*Hippuris vulgaris*	I (4)
Lythrum salicaria	II (4-5)	*Hydrocotyle vulgaris*	I (3)
Polygonum amphibium	II (3-5)	*Lemna trisulca*	I (3)
Potamogeton gramineus	II (3-4)	*Phragmites australis*	I (4)
Ranunculus flammula	II (3-4)	*Potamogeton natans*	I (3)
Agrostis stolonifera	I (3)		

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Group 24 – *Potamogeton natans-Glyceria fluitans* (Table 7.54)

3 turloughs – Croaghill (3), Caranavoodaun (6), Termon (1)

Description

This is the most water-dependent of the vegetation types recorded. The mean water depth of the areas surveyed was 20 cm, though some of the ponds (which appear to be permanent waterbodies during the 'dry' phase of the turlough) can be quite large. The mean vegetation height is 25 cm.

Potamogeton natans and *Glyceria fluitans* are constant species, with occasional *Baldellia ranunculoides, Oenanthe aquatica* and *Sparganium emersum.* Indicator species for this community are *Potamogeton natans* (82%) and *Sparganium emersum* (20%).

Location on flooding gradient

This community occurs in permanent pools at the very bottom of the flooding gradient. At 10.3, the mean Ellenberg Wetness value for this community is the highest found (see Table 7.50), and is indicative of a shallow water site which may have drier periods (Hill *et al.*, 1999).

Landuse

Permanent pools in turloughs are often utilised as water sources for grazing livestock; this can result in poaching at the perimeter of the water body. The mean Ellenberg value for Fertility is relatively low, at 4.3 (see Table 7.50), which is indicative of sites with low to intermediate fertility (Hill *et al*., 1999).

Table 7.54 Floristic table for the *Potamogeton natans-Glyceria fluitans* community.

No. of relevés	10		
No. of species	16		
Group	24		
Potamogeton natans	V (7-9)	*Eleocharis palustris*	I (3-4)
Glyceria fluitans	IV (3-8)	*Galium palustre*	I (4)
Baldellia ranunculoides	II (1-4)	*Hippuris vulgaris*	I (5)
Oenanthe aquatica	II (2-6)	*Juncus acutiflorus*	I (4)
Sparganium emersum	II (4-7)	*Lemna minor*	I (3-4)
Agrostis stolonifera	I (3)	*Mentha aquatica*	I (4)
Alisma plantago-aquatica	I (3-4)	*Polygonum amphibium*	I (4)
Apium inundatum	I (4)	*Sparganium erectum*	I (3-4)

Species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Comparison with previous studies

Group 6 – *Eleocharis palustris-Ranunculus flammula* community

Class: *Littorelletea uniflorae*

Ivimey-Cook and Proctor (1966) describe a *Littorella uniflora-Baldellia ranunculoides* association to which this community may belong, however they did not record *Eleocharis palustris* at as high a frequency as it is found in Group 6. This community was very similar to Goodwillie's 9C Marl Pond (1992), or 6A *Baldellia/Littorella* (2003), and to the NVC S19 *Eleocharis palustris* swamp (Rodwell, 1995) (see Table 7.55).

Group 11 – *Polygonum amphibium-Mentha aquatica* community

Class: *Plantaginetea majoris*

This community seems to belong to the *Polygonum amphibium* variant of the *Ranunculo-Potentilletum anserinae* as described by O'Connell *et al.* (1984), although it is a more aquatic community, with little *Potentilla anserina.*

This community was similar to Goodwillie's 8A *Polygonum amphibium* community. His 10A *Oenanthe aquatica* (1992) may also be represented here, although *Oenanthe aquatica* was not present at the same frequency reported by him. It showed the greatest affinity for the NVC S19 *Eleocharis palustris* swamp (Rodwell, 1995) (see Table 7.55).

Group 14 – Reedbed
Class: *Phragmitetea*

Reedswamp communities are usually defined by a single dominant reed or sedge species (O'Connell *et al*., 1984). The Reedbed community described here seems to contain relevés from two reedswamp associations; the *Scirpetum lacustris* and the *Cladietum marisci* (O'Connell *et al*., 1984; Ivimey-Cook & Proctor, 1966). There is also possibly one relevé from the *Phragmitetum communis*.

Goodwillie (2003) also describes reedswamp communities to which these relevés could belong; 8C *Schoenoplectus/Phragmites*, 8D *Magnocaricion* and 8E *Cladium mariscus.*

The greatest affinity with the NVC communities according to MAVIS were to S8 *Scirpus lacustris* swamp, S19a the *Eleocharis palustris* sub-community of the *Eleocharis palustris* swamp, and S4 *Phragmites australis* reed bed and swamp (see Table 7.55).

Group 24 – *Potamogeton natans-Glyceria fluitans*

Class: *Potametea* OR *Phragmitetea*

This is a community which occurs in and around seemingly permanent water at the base of turloughs. It may represent a transition between two communities, and as such was difficult to assign to published communities in some cases.

Ivimey-Cook and Proctor (1966) describe similar communities within the *Eu-Potamion* alliance, although no *Glyceria fluitans* was recorded. There were also similarities with the *Glycerio-Sparganion* alliance of the *Phragmitetea*, although Ivimey-Cook and Proctor state that this alliance is not well represented within the Burren, and only three relevés are presented. O'Connell *et al.* (1984) also describe a *Glycerietum fluitantis* association within the *Glycerio-Sparganion* into which this community may fit; there are, however, no records for *Potamogeton natans* in these relevés.

This community is most similar to Goodwillie's 12 Open Water community (Goodwillie, 1992) or the 8B *Potamogeton/Elodea* (2003). Goodwillie (1992) places this community within the *Potametea*, and states that it seems to be an amalgam of associations.

This community showed the greatest affinity for the NVC communities S22 and S22a, the *Glyceria fluitans* water margin vegetation and the *Glyceria fluitans* sub-community of same (see Table 7.55). There is also some similarity with the NVC A9 *Potamogeton natans* community (Rodwell, 1995) given the dominance of *P. natans*. The associated flora, however, do not conform rigidly to any of the sub-groups, and in this case Rodwell recommends regarding the vegetation as a mosaic of the *P. natans* community and other aquatic communities.

Table 7.55 Affinities with NVC for Cluster 5.

Group	NVC	Percentage	Community
6	S19	50.1	*Eleocharis palustris* swamp
	S19a	47.77	*Eleocharis palustris* swamp – *Eleocharis palustris* sub-community
	S12b	43.52	*Typha latifolia* swamp – *Mentha aquatica* sub-community
11	S19	44.94	*Eleocharis palustris* swamp
	S19a	40.82	*Eleocharis palustris* swamp – *Eleocharis palustris* sub-community
	S12	39.11	*Typha latifolia* swamp
14	S8	49.69	*Scirpus lacustris* swamp
	S19a	45.69	*Eleocharis palustris* swamp – *Eleocharis palustris* sub-community
	S4	44.8	*Phragmites australis* swamp and reed beds
24	S22	50	*Glyceria fluitans* water margin vegetation
	S22a	46.51	*Glyceria fluitans* water margin vegetation – *Glyceria fluitans* sub-community
	A9b	45.57	*Potamogeton natans* community – *Elodea canadensis* sub-community

Table 7.56 Comparison of plant communities from this study with those previously published in the literature

Cluster	*Group*	*Name*	*Class (White & Doyle, 1984)*	*Ivimey-Cook & Proctor (1966)*	*O'Connell et al. (1984)*	*Goodwillie (1992)*	*Regan et al. (2007)*	*NVC*
1	1	*Poa annua-Plantago major* community	*Polygono-Poetea annuae*	*Lolium perenne-Plantago major* association	NA	5A Dry annuals	NA	OV21 *Poa annua-Plantago major* community
2	2	*Polygonum amphibium-Eleocharis palustris* community	*Plantaginetea majoris*		*Ranunculo-Potentilletum anserinae, P. amphibium* variant	7A *P. amphibium*	NA	A10 *Polygonum. amphibium,* SD17
3	3	*Agrostis stolonifera-Ranunculus repens* community	*Plantaginetea majoris*	*Carex nigra-Potentilla anserina* association	*Ranunculo Potentilletum anserinae,* typical variant	6A Dry *Carex nigra*	Group 7	SD17 *Potentilla anserina-Carex nigra* dune slack community
3	4	*Agrostis stolonifera-Potentilla anserina-Festuca rubra* community	*Plantaginetea majoris*	*Potentilla anserina-Drepanocladus lycopioides* nodum	*Ranunculo Potentilletum anserinae, Drepanocladus lycopioides* variant	3B Sedge heath?	Group 7/8?	SD17a
4	5	Limestone grassland	*Molinio-Arrhenatheretea*	*Cynosurion cristati, Centaureo-Cynosuretum* (O'Sullivan, 1984)	NA	2C Limestone grassland	NA	CG10 *Festuca ovina-Agrostis capillaris-Thymus polytrichus*
5	6	*Eleocharis palustris-Ranunculus flammula* community	*Littorellettea uniflorae*	*Littorella uniflora-Baldellia ranunculoides* association*?*	NA	9C Marl Pond	NA	S19 *Eleocharis palustris* swamp
2	7	*Eleocharis palustris-Phalaris arundinacea* community	*Plantaginetea majoris*			7A *P. amphibium* (grassy)	NA	S19 *Eleocharis palustris* swamp
6	8	*Carex nigra-Carex panicea* community	*Scheuchzerio-Caricetea fuscae*	*Carex demissa* nodum	*Carex panicea-Carex flava* agg.	5B Sedge fen	NA	SD17 *Potentilla anserina-Carex nigra* dune slack community
3	9	*Phalaris arundinacea-Potentilla anserina* community	*Plantaginetea majoris*	*Potentilla anserina-Drepanocladus lycopioides* nodum	*Ranunculo Potentilletum anserinae?*	3A Tall herb	NA	S28, M27
7	10	*Lolium perenne-Trifolium repens* community	*Molinio-Arrhenatheretea*	*Lolio-Cynosuretum* (O'Sullivan, 1984)	NA	2A *Lolium* grassland	NA	MG6 *Lolium perenne-Cynosurus cristatus* grassland
5	11	*Polygonum amphibium-Mentha aquatica* community	*Plantaginetea majoris*		*Ranunculo-Potentilletum anserinae, P. amphibium* variant	8A *Polygonum. amphibium,* 10A *Oenanthe aquatica*?	NA	S19 *Eleocharis palustris* swamp
6	12	*Filipendula ulmaria-Vicia cracca* community	*Molinio-Arrhenatheretea*	*Juncus acutiflorus-Senecio aquaticus* nodum		3A Tall herb	Group 6?	SD17 *Potentilla anserina-Carex nigra* dune slack community, M27 *Filipendula ulmaria-Angelica sylvestris* mire
3	13	*Potentilla anserina-Carex nigra* community	*Plantaginetea majoris*	*Carex nigra-Potentilla anserina* association	*Ranunculo Potentilletum anserinae, P. amphibium* variant	6B Wet *Carex nigra*	Group 5	SD17d *Hydrocotyle vulgaris-Ranunculus flammula sub-*community
5	14	Reedbed	*Phragmitetea*		*Scirpetum lacustris, Cladietum marisci*	11A Reedbed	NA	S8 *Scirpus lacustris* swamp

Table 7.56 (contd.) Comparison of plant communities from this study with those previously published in the literature

Cluster	*Group*	*Name*	*Class (White & Doyle, 1984)*	*Ivimey-Cook & Proctor (1966)*	*O'Connell et al. (1984)*	*Goodwillie (1992)*	*Regan et al. (2007)*	*NVC*
7	15	*Lolium perenne-Trifolium repens-Agrostis stolonifera* community	*Molinio-Arrhenatheretea*		NA	2B Poor grassland	NA	MG11 *Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland
2	16	*Equisetum fluviatile-Menyanthes trifoliata* community	*Phragmitetea*	*Glycerio-Sparganion*	Reedswamp and tall sedge communities	11B Peaty pond	NA	S10 *Equisetum fluviatile* swamp, S19 *Eleocharis palustris* swamp
2	17	*Carex nigra-Ranunculus flammula* community	*Plantaginetea majoris*		*Ranunculo Potentilletum anserinae, Carex nigra* variant	6D Peaty *Carex nigra*	Group 3/4?	M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire
2	18	*Agrostis stolonifera-Glyceria fluitans* community	*Phragmitetea*			9A Temporary pond	NA	S22 *Glyceria fluitans* water margin vegetation, S23 Other water margin vegetation, S19 *Eleocharis palustris* swamp
3	19	*Potentilla anserina-Potentilla reptans* community	*Plantaginetea majoris*	*Carex nigra-Potentilla anserina* association?	*Ranunculo-Potentilletum anserinae*, species poor *Potentilla reptans* variant	5B *Potentilla reptans* (species-poor)	Group 7	SD17d *Hydrocotyle vulgaris-Ranunculus flammula sub-*community
3	20	*Filipendula ulmaria-Potentilla erecta-Viola* sp. community	*Plantaginetea majoris*		*Ranunculo-Potentilletum anserinae*, species rich *Potentilla anserina* variant	4B *Potentilla reptans* (species rich)	Group 7?	SD17 *Potentilla anserina-Carex nigra* dune slack community
4	21	*Schoenus nigricans* fen	*Scheuchzerio-Caricetea fuscae*	*Schoenus nigricans-Cirsium dissectum* association	*Cirsio-Schoenetum nigricantis molinietosum*	4D *Schoenus* fen	Group 1	M13 *Schoenus nigricans-Juncus subnodulosus mire*
8	22	*Molinia caerulea-Carex panicea* community	*Scheuchzerio-Caricetea fuscae*		*Carex panicea-Carex flava* agg.	5D Sedge Fen	Group 2	M24 *Molinia caerulea-Cirsium dissectum*
6	23	*Carex nigra-Leontodon autumnalis* community	*Plantaginetea majoris*	*Carex nigra-Potentilla anserina* association	*Ranunculo Potentilletum anserinae, Carex nigra* variant	5B *Potentilla reptans* (species-poor)?	Group7	SD17 *Potentilla anserina-Carex nigra* dune slack community
5	24	*Potamogeton natans-Glyceria fluitans* community	*Potametea*	*Eu-Potamion* alliance	*Glycerietum fluitans?*	12 Open water	NA	S22, S22a, A9 *Potamogeton natans*
8	25	*Carex nigra-Carex viridula* community	*Scheuchzerio-Caricetea fuscae*	*Carex demissa* nodum	*Carex panicea-Carex flava agg.*, Species poor variant	5E *Carex flava*	Group 1?	SD17d *Hydrocotyle vulgaris-Ranunculus flammula sub-*community
1	26	*Eleocharis acicularis* community	*Littorellettea uniflorae*	*Eleocharis acicularis* stands	*NA*	9B *Eleocharis acicularis*	NA	OV31 *Rorippa palustris-Filaginella uliginosa* community
2	27	*Carex nigra-Equisetum fluviatile* community	*Phragmitetea*			11B Peaty pond?	NA	S19 *Eleocharis palustris* swamp
4	28	Flooded pavement				3C Flooded pavement	NA	

7.5.2 Environmental Variables Derived From Vegetation

7.5.2.1 Ellenberg values

Mean Ellenberg values vary by cluster (see Table 7.57). For Light, the values range from 7.2 to 7.5, but the standard deviation suggests that this is not a significant difference. The largest range is in Wetness; which ranges from a mean value of 5.7 for Cluster 7 to 9.5 for Cluster 5.

Table 7.57 Mean Ellenberg indicator values and Grimes' CSR values for each cluster, ± standard deviation.

Cluster	*Light*	*Wetness*	*pH*	*Fertility*	*C*	*S*	*R*
1	7.2 ± 0.2	6.6 ± 1.0	6.4 ± 0.2	6.1 ± 0.5	2.23 ± 0.58	1.34 ± 0.24	3.64 ± 0.66
2	7.4 ± 0.3	8.3 ± 0.8	5.9 ± 0.5	4.7 ± 1.0	2.96 ± 0.42	2.15 ± 0.63	2.34 ± 0.53
3	7.2 ± 0.2	6.6 ± 0.7	6.1 ± 0.5	5.0 ± 0.8	2.91 ± 0.41	2.20 ± 0.47	2.52 ± 0.49
4	7.3 ± 0.2	6.2 ± 0.8	5.3 ± 0.6	3.1 ± 0.7	2.21 ± 0.40	3.54 ± 0.48	1.82 ± 0.46
5	7.3 ± 0.3	9.5 ± 0.6	6.2 ± 0.3	4.9 ± 0.8	3.27 ± 0.33	1.81 ± 0.55	2.30 ± 0.61
6	7.2 ± 0.2	6.9 ± 0.5	5.6 ± 0.5	4.1 ± 0.7	2.89 ± 0.41	2.71 ± 0.45	2.02 ± 0.34
7	7.3 ± 0.2	5.7 ± 0.4	6.2 ± 0.3	5.5 ± 0.5	2.95 ± 0.21	1.91 ± 0.39	2.97 ± 0.25
8	7.5 ± 0.2	7.8 ± 0.6	5.1 ± 0.7	2.6 ± 0.6	2.15 ± 0.38	3.60 ± 0.51	1.54 ± 0.38

Wetness, Fertility and Grime's S value had the highest Spearman's correlation coefficients (see Table 7.11); these will be examined in more detail.

7.5.2.2 Wetness

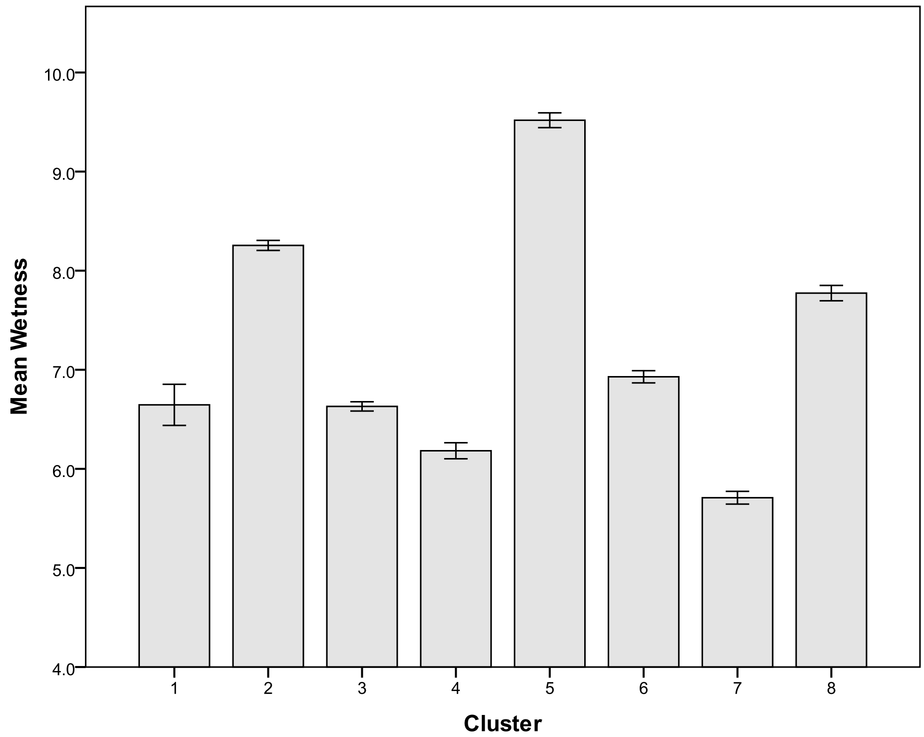


Figure 7.5 Barchart of mean Ellenberg Wetness values per cluster, ± standard error.

As mentioned above, there is a large degree of variation in mean Ellenberg scores for Wetness among the 8 Clusters; this is represented graphically in Figure 7.5. Cluster 5, which contains communities that occur in the bottom of turloughs, and generally had some standing water when surveyed, has the largest mean Wetness value, at 9.5. At the other end of the scale is Cluster 7, which contains dry grassland communities, and has a mean Wetness value of 5.7.

From Table 7.58, it can be seen that each cluster has a significantly different mean Wetness value to every other cluster, with the exception of Cluster 1, which is not significantly different to Clusters 3, 4 and 6.

Table 7.58 Mann-Whitney U test p-values for Wetness, corrected for multiple comparisons. Significant p-values ($p < 0.05$) are in bold.

Cluster	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1							
2	**0.000**						
3	0.868	**0.000**					
4	0.041	**0.000**	**0.000**				
5	**0.000**	**0.000**	**0.000**	**0.000**			
6	0.032	**0.000**	**0.000**	**0.000**	**0.000**		
7	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	
8	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

7.5.2.3 Fertility

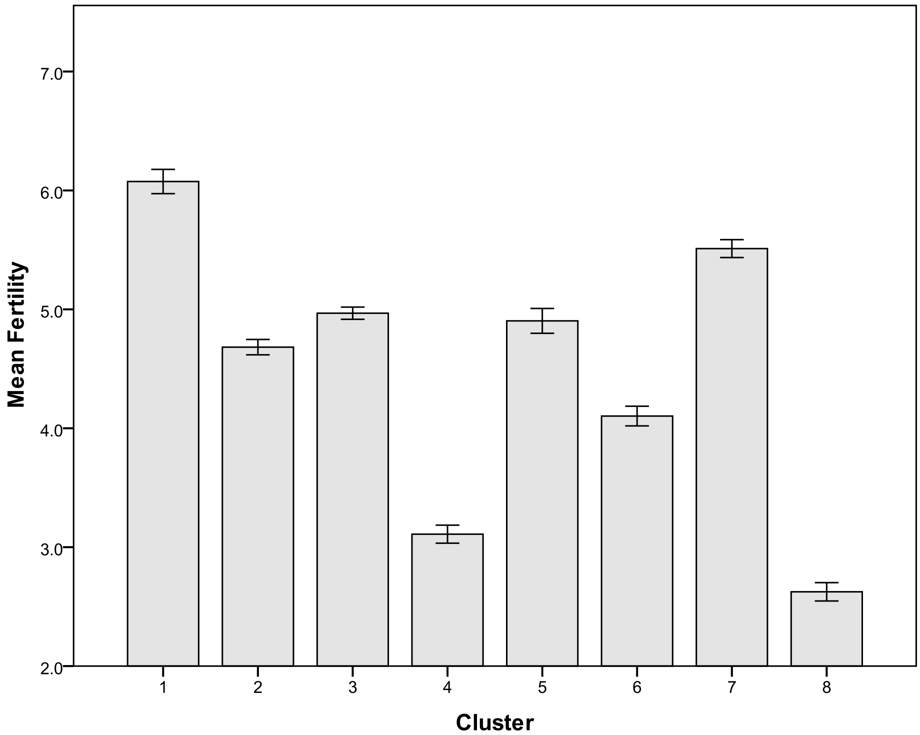


Figure 7.6 Barchart showing mean Ellenberg Fertility values per cluster, ± standard error.

The mean Ellenberg value for Fertility ranged from 2.6 for Cluster 8 to 6.1 for Cluster 1 (see Table 7.57, Figure 7.6). Cluster 5 is not significantly different to Clusters 2 or 3 (see Table 7.59), but each other cluster is significantly different to all other clusters.

Clusters 8 and 4 have the lowest mean Fertility values; these are clusters which contain communities within the *Scheuchzerio-Caricetea fuscae*, and are generally found on less eutrophic soils. By contrast, Cluster 1 has the highest mean Fertility value; this cluster contains a number of ruderal species which are characteristic of highly productive, highly disturbed environments. Cluster 7 also has a high mean Fertility value, this cluster contains two grassland communities which may be influenced by the management of farmland surrounding the turloughs; the presence of such species as *Lolium perenne* and *Trifolium repens* indicate that these are areas with a higher level of available nutrients.

Table 7.59 Mann-Whitney U tests Fertility, significant p-values ($p < 0.05$) in bold (corrected for multiple comparisons).

Cluster	1	2	3	4	5	6	7
1							
2	**0.000**						
3	**0.000**	**0.001**					
4	**0.000**	**0.000**	**0.000**				
5	**0.000**	0.102	0.675	**0.000**			
6	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**		
7	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	
8	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

7.5.2.4 Grime's S value

Grime's S value was the variable with the third highest level of correlation with the NMS axes. The mean values for Grime's S values are highest for Clusters 4 and 8 (see Figure 7.7); these are significantly higher than the other clusters (see Table 7.60). These values suggest that these clusters contain a high proportion of species which are stress-tolerators. In contrast, Clusters 1, 5 and 7 have a low proportion of stress-tolerators.

Table 7.60 Mann-Whitney U test S values, significant p-values ($p < 0.05$) are bold (corrected for multiple comparisons).

Cluster	1	2	3	4	5	6	7
1							
2	**0.000**						
3	**0.000**	0.223					
4	**0.000**	**0.000**	**0.000**				
5	**0.000**	**0.000**	**0.000**	**0.000**			
6	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**		
7	**0.000**	0.014	**0.000**	**0.000**	0.156	**0.000**	
8	**0.000**	**0.000**	**0.000**	0.765	**0.000**	**0.000**	**0.000**

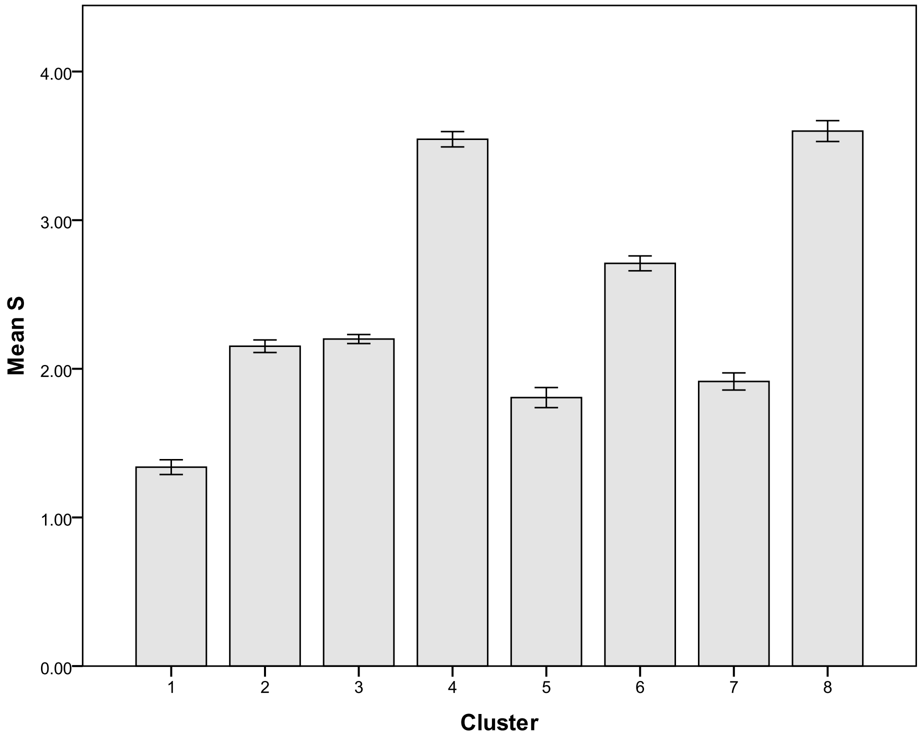


Figure 7.7 Barchart of mean Grime's S values per cluster.

Table 7.61 Summary statistics for derived variables for each vegetation group.

Group	*Light*	*Wetness*	*pH*	*Fertility*	*C*	*S*	*R*	*Species richness*
1	7.2 ± 0.1	5.9 ± 0.6	6.3 ± 0.2	6.4 ± 0.3	2.04 ± 0.42	1.37 ± 0.22	3.93 ± 0.41	10 ± 2
2	7.3 ± 0.2	8.2 ± 0.7	6.2 ± 0.3	5.2 ± 0.7	2.99 ± 0.27	1.81 ± 0.38	2.68 ± 0.30	10 ± 3
3	7.2 ± 0.2	6.7 ± 0.6	6.1 ± 0.3	5.2 ± 0.6	3.00 ± 0.32	2.04 ± 0.36	2.57 ± 0.39	14 ± 3
4	7.3 ± 0.2	6.2 ± 0.4	6.0 ± 0.3	4.7 ± 0.7	2.67 ± 0.28	2.41 ± 0.43	2.67 ± 0.36	14 ± 3
5	7.3 ± 0.2	5.9 ± 0.5	5.4 ± 0.5	3.3 ± 0.6	2.21 ± 0.43	3.50 ± 0.54	2.02 ± 0.41	18 ± 3
6	7.4 ± 0.3	9.5 ± 0.5	6.1 ± 0.3	4.7 ± 0.9	3.08 ± 0.14	1.96 ± 0.54	2.53 ± 0.41	8 ± 2
7	7.3 ± 0.2	8.5 ± 0.5	6.2 ± 0.5	5.2 ± 0.9	3.56 ± 0.65	2.06 ± 0.62	1.71 ± 0.43	8 ± 3
8	7.2 ± 0.2	7.3 ± 0.5	5.2 ± 0.4	3.5 ± 0.6	2.64 ± 0.35	2.95 ± 0.46	1.92 ± 0.34	15 ± 3
9	7.1 ± 0.2	7.3 ± 0.6	6.7 ± 0.3	5.9 ± 0.4	3.79 ± 0.40	1.80 ± 0.32	1.83 ± 0.43	7 ± 2
10	7.3 ± 0.1	5.5 ± 0.3	6.0 ± 0.1	5.1 ± 0.4	2.85 ± 0.12	2.25 ± 0.28	3.01 ± 0.18	15 ± 3
11	7.1 ± 0.1	9.2 ± 0.5	6.3 ± 0.2	5.7 ± 0.3	3.24 ± 0.27	1.24 ± 0.22	2.64 ± 0.32	6 ± 2
12	7.1 ± 0.2	6.6 ± 0.4	5.9 ± 0.4	4.5 ± 0.4	3.15 ± 0.29	2.54 ± 0.29	2.08 ± 0.30	13 ± 3
13	7.4 ± 0.3	7.4 ± 0.6	6.0 ± 0.7	4.8 ± 1.1	2.82 ± 0.34	2.38 ± 0.67	2.25 ± 0.66	7 ± 2
14	7.5 ± 0.4	9.4 ± 0.6	6.3 ± 0.6	4.8 ± 0.7	3.34 ± 0.30	2.23 ± 0.55	1.98 ± 0.56	5 ± 1
15	7.3 ± 0.2	5.9 ± 0.5	6.3 ± 0.3	5.8 ± 0.3	3.02 ± 0.24	1.66 ± 0.24	2.94 ± 0.30	10 ± 4
16	7.5 ± 0.3	9.0 ± 0.6	5.6 ± 0.8	4.4 ± 0.8	2.83 ± 0.40	2.59 ± 0.71	1.80 ± 0.40	8 ± 3
17	7.4 ± 0.2	7.9 ± 0.6	5.7 ± 0.5	4.0 ± 0.7	2.86 ± 0.38	2.49 ± 0.48	2.24 ± 0.38	12 ± 2
18	7.2 ± 0.4	8.6 ± 0.9	6.1 ± 0.4	5.4 ± 0.8	2.95 ± 0.34	1.60 ± 0.51	2.71 ± 0.48	8 ± 3
19	7.3 ± 0.2	6.1 ± 0.5	6.5 ± 0.3	5.2 ± 0.4	2.83 ± 0.14	2.07 ± 0.21	2.88 ± 0.18	10 ± 3
20	7.3 ± 0.1	6.2 ± 0.4	5.9 ± 0.3	4.0 ± 0.4	2.71 ± 0.24	2.56 ± 0.27	2.42 ± 0.40	13 ± 2
21	7.3 ± 0.2	7.2 ± 0.6	4.9 ± 0.7	2.3 ± 0.3	2.33 ± 0.29	3.52 ± 0.25	1.42 ± 0.20	13 ± 3
22	7.5 ± 0.3	7.7 ± 0.6	5.0 ± 0.7	2.7 ± 0.6	2.17 ± 0.40	3.56 ± 0.53	1.60 ± 0.38	11 ± 3
23	7.1 ± 0.3	6.8 ± 0.5	6.1 ± 0.3	4.6 ± 0.6	2.98 ± 0.42	2.48 ± 0.41	2.11 ± 0.36	12 ± 2
24	7.0 ± 0	10.3 ± 0.5	6.0 ± 0	4.3 ± 0.4	3.83 ± 0.21	1.87 ± 0.18	1.34 ± 0.43	4 ± 2
25	7.6 ± 0.2	8.3 ± 0.2	5.6 ± 0.7	2.1 ± 0.1	2.08 ± 0.26	3.80 ± 0.36	1.23 ± 0.20	6 ± 2
26	7.2 ± 0.2	7.3 ± 0.9	6.4 ± 0.2	5.8 ± 0.4	2.39 ± 0.66	1.31 ± 0.27	3.39 ± 0.75	10 ± 3
27	7.6 ± 0.4	9.3 ± 0.8	4.9 ± 0.6	3.4 ± 0.9	2.60 ± 0.39	3.23 ± 0.54	1.39 ± 0.43	5 ± 2
28	7.1 ± 0.3	5.7 ± 0.6	5.5 ± 0.4	3.2 ± 0.6	1.96 ± 0.34	3.86 ± 0.35	1.42 ± 0.34	13 ± 2

7.5.3 Mapped Communities

The mapped communities were based around those defined by the statistical approaches described above, but with certain modifications dictated largely by practicalities in the field of distinguishing these communties. In some cases the communties described above intergraded in the field; these could sometimes be mapped showing an indistinct boundary, but in other cases the communities were found to intergrade on a scale too small to effectively map. The following communities were therefore combined for the purposes of mapping:

- Group 12 *Filipendula ulmaria-Vicia cracca* and Group 9 *Phalaris arundinacea-Potentilla anserina* were combined as **Tall Herb community**. While occurring in different clusters, these communities had numerous species in common, and the development of this community is likely to depend on the level of grazing present.
- Group 22 *Molinia caerulea-Carex panicea* and Group 23 *Carex nigra-Leontodon autumnalis* were similarly combined into a ***Carex* fen community**.
- Group 11 *Polygonum amphibium-Mentha aquatica* and Group 2 *Polygonum amphibium-Eleocharis palustris* were combined to provide a ***Polygonum***

***amphibium* community**. Variation in *Polygonum amphibium* communities was noted in the field (and incorporated into GIS), but intergradation coupled with difficulty of access to these communities presented problems for mapping them individually in the field.

- The Group 16 *Equisetum fluviatile* community was subsumed into the Group 27 *Carex nigra-Equisetum fluviatile* community and were combined as it appeared to merely reperesent an extreme form that was connected by intermediates.

The following communities were not mapped:

- Group 25 *Carex nigra-Carex viridula* community was represented by 9 relevees from only two turloughs; these were patchy communties and the areas of individual patches was generally less than the minumum area mapped.
- Group 24 *Potamogeton natans-Glyceria fluitans* community was not mapped. This community occurred in open water; while open water was always mapped, we cannot be certain that all open water contained the *Potamogeton natans-Glyceria fluitans* community. We therefore prefer to use the term Open Water.

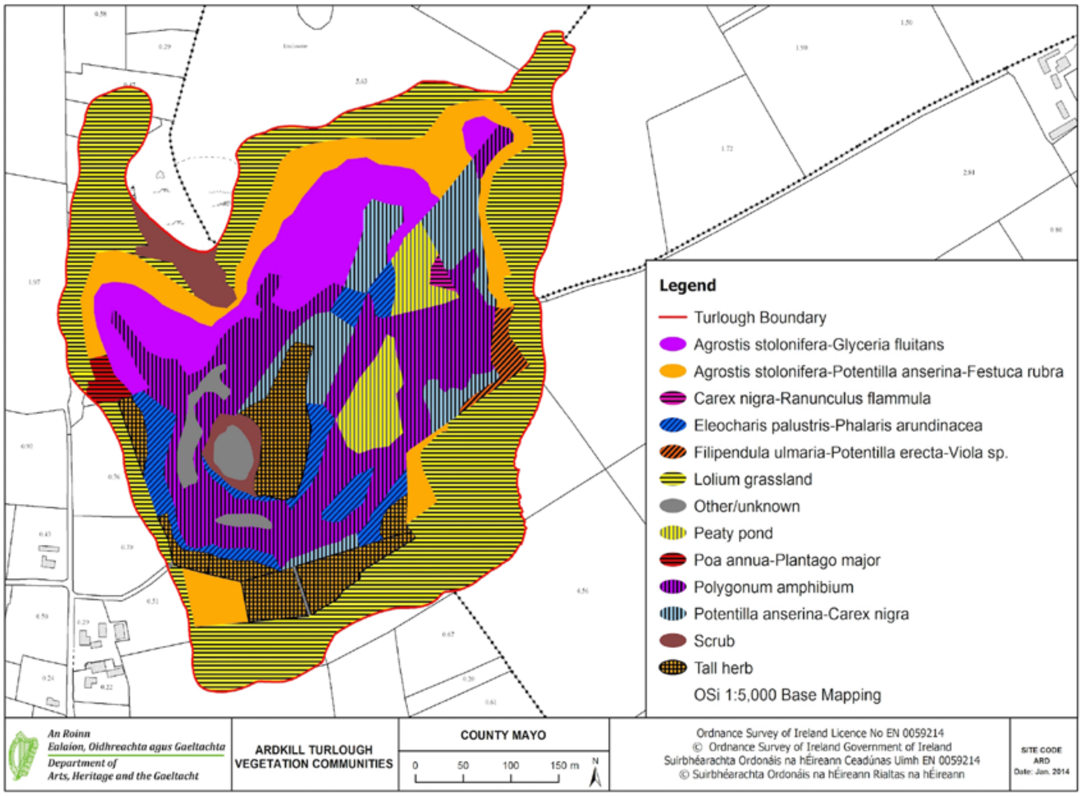
A guide to mapping the communities was developed and this is provided in Appendix 7.1. The area of all communities mapped in each turough is given in Table 7.62, followed by the maps of the vegetation of each turlough arranged alphabetically (Figures 7.8 – 7.29); where available, digitised versions of the maps from Goodwillie (1992) are provided for comparison.

Table 7.62. Areas and numbers of mapped communities in the study turloughs

Mapped Community Name	*Total Sites*	*Total Area (Ha)*	*Mean Ellenberg fert*	*Ardkill*	*Ballinderreen*	*Blackrock*	*Brierfield*	*Caherglassan*	*Caranavoodaun*	*Carrowreagh*	*Coolcam*	*Croaghill*	*Garryland*	*Kilglassan*	*Knockaunroe*
Agrostis stolonifera-Glyceria fluitans	**14**	**22.64**	5.54	2.32	0.21	0.21	0.55				0.34	1.02		0.88	0.06
A. stolonifera-P. anserina-F. rubra	**8**	**27.69**	4.71		1.73	0.78					0.10		11.27	3.61	
A. stolonifera-Ranunculus repens	**21**	**47.94**	5.14	2.37	3.07	5.69	3.68	1.96	0.22	9.17	1.40	1.92		2.75	0.21
Carex nigra-Carex panicea	**14**	**42.53**	3.52		3.04		4.49		0.57	4.25	0.68	2.67	0.51	6.17	2.05
Carex nigra-Equisetum fluviatile	**8**	**8.04**	4.02	0.84								0.06		0.41	0.20
Carex nigra-Ranunculus flammula	**11**	**39.05**	3.93	0.05		0.72	22.80			2.63	0.63	3.23		2.07	
Eleocharis acicularis	**5**	**10.36**	5.81			0.08		1.52					0.40		
Eleocharis palustris-P. arundinacea	**10**	**14.20**	5.15	1.08	0.04		2.38		0.34		2.27	0.85			
Eleocharis palustris-R. flammula	**9**	**108.52**	4.62		18.06				13.52		9.61				19.22
F. ulmaria-P. erecta-Viola sp.	**11**	**40.89**	3.96	0.21		3.24		6.30			0.69		2.07	2.16	0.15
Flooded Pavement	**8**	**35.57**	3.24		2.90			0.52	0.95						16.03
Limestone grassland	**9**	**16.81**	3.28		3.23			0.41	2.24		0.12				1.44
Lolium grassland	**21**	**99.82**	5.50	7.56	7.14	15.87	0.28	6.21	1.50	4.77	1.70	2.89		4.18	13.03
Molinia caerulea-Carex panicea	**10**	**58.97**	2.67		2.11				7.77		1.56				11.24
Open water	**16**	**49.24**	4.22					10.46	0.16	0.01	13.55	0.67		0.07	0.37
Other/unknown	**22**	**35.78**		0.46	0.96	2.12	3.48	0.97	0.28	0.75	1.49	0.76	3.59	0.46	5.46
Polygonum amphibium	**13**	**62.51**	5.29	4.03			6.91		0.05		18.99	11.81		8.21	0.63
Poa annua-Plantago major	**6**	**10.32**	6.40	0.14		3.43		0.16		0.05					
Potentilla anserina-Carex nigra	**12**	**68.70**	4.71	1.47	3.79		10.84			5.18	1.97	8.16		14.38	
Potentilla anserina-P. reptans	**8**	**47.32**	5.17			24.14		16.25	0.15	0.78		0.33			
Reedbed	**6**	**37.15**	4.82												4.61
Schoenus nigricans fen	**7**	**24.33**	2.21		17.93				0.14						0.30
Tall herb	**11**	**21.07**	5.10	1.74	0.20		3.78			1.50	0.60	4.01			
Woodland/scrub	**20**	**62.87**		0.58	3.96	4.08	0.13	18.57	6.12		0.01		2.48	0.20	5.97
Total Communities				**13**	**15**	**11**	**11**	**11**	**14**	**10**	**17**	**13**	**6**	**13**	**16**
Total Area (Ha)				**22.84**	**68.37**	**60.36**	**59.31**	**63.32**	**34.03**	**29.09**	**55.70**	**38.38**	**20.31**	**45.54**	**80.98**

Table 7.62 (cont)

Mapped Community Name	*Lisduff*	*Lough Aleenaun*	*Lough Coy*	*Lough Gealain*	*Rathnalull*	*Roo West*	*Skealoghan*	*Termon*	*Tullaghnaf*	*Turloughmore*
Agrostis stolonifera-Glyceria fluitans	0.07	7.48						1.41	0.24	
A. stolonifera-P. anserina-F. rubra			4.12			1.38				
A. stolonifera-Ranunculus repens	1.39	0.33	0.61		2.14	2.04	0.60	0.84	0.04	10.66
Carex nigra-Carex panicea	4.01				0.84	3.66	4.62		1.45	
Carex nigra-Equisetum fluviatile							1.02		0.63	
Carex nigra-Ranunculus flammula				0.23			2.72			
Eleocharis acicularis			2.55							
Eleocharis palustris-P. arundinacea	0.84						0.17			
Eleocharis palustris-R. flammula	20.22			3.41		11.60		8.27		
F. ulmaria-P. erecta-Viola sp.			4.38		17.51					
Flooded Pavement		0.04		6.56		5.33				
Limestone grassland				1.37		2.84	1.88			0.19
Lolium grassland	2.99	1.50	2.19		6.44	2.38	3.43	1.33	1.37	19.94
Molinia caerulea-Carex panicea	19.56			4.52		3.69	1.86		3.99	
Open water		0.02	8.00	8.11	0.01	1.00	0.08	2.16	0.35	
Other/unknown	0.77	1.03	0.74	4.83	0.38	4.86	0.60	1.04	0.30	0.83
Polygonum amphibium	0.30						0.82	1.03	0.40	
Poa annua-Plantago major										1.17
Potentilla anserina-Carex nigra	3.04						13.57	0.14		
Potentilla anserina-P. reptans			0.18		0.31					
Reedbed				0.41			1.08	21.65	4.57	
Schoenus nigricans fen				2.37		0.37			0.99	
Tall herb	0.36			0.20	1.83					
Woodland/scrub	0.35	3.85	2.68	4.79	0.03	3.32	0.70	3.72	0.76	1.35
Total Communities	**12**	**7**	**9**	**11**	**9**	**12**	**14**	**10**	**12**	**6**
Total Area (Ha)	**53.91**	**14.26**	**25.45**	**36.81**	**29.50**	**42.47**	**33.16**	**41.58**	**15.09**	**34.13**



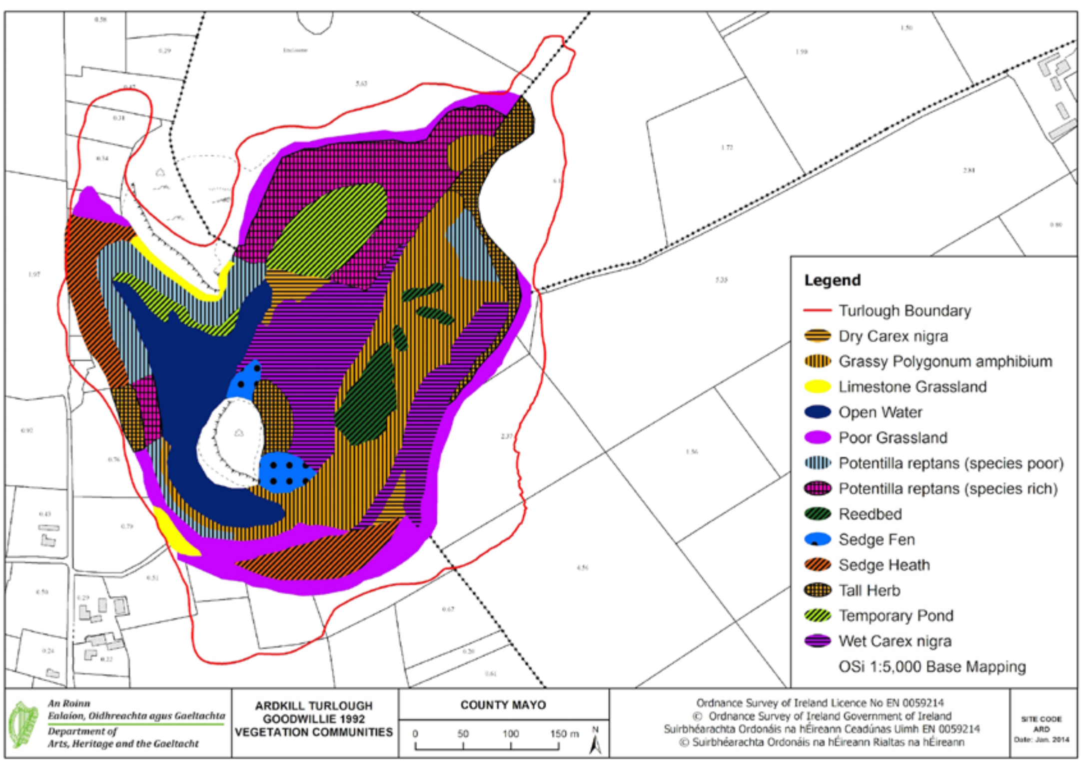
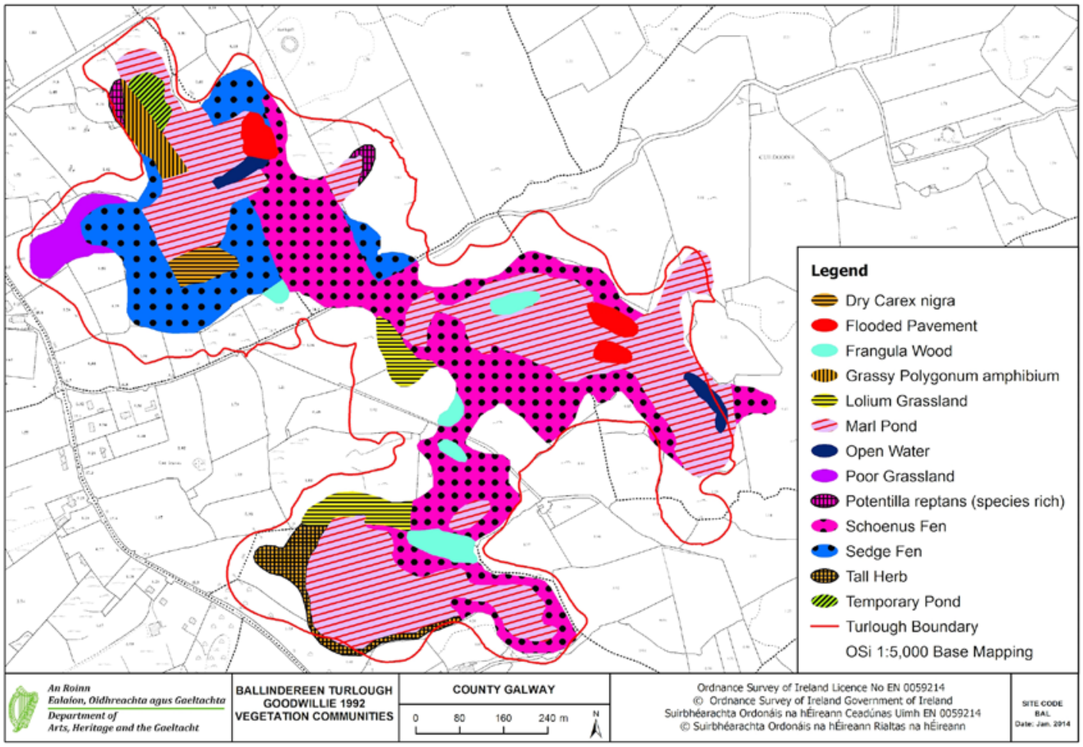


Figure 7.8 Ardkill. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



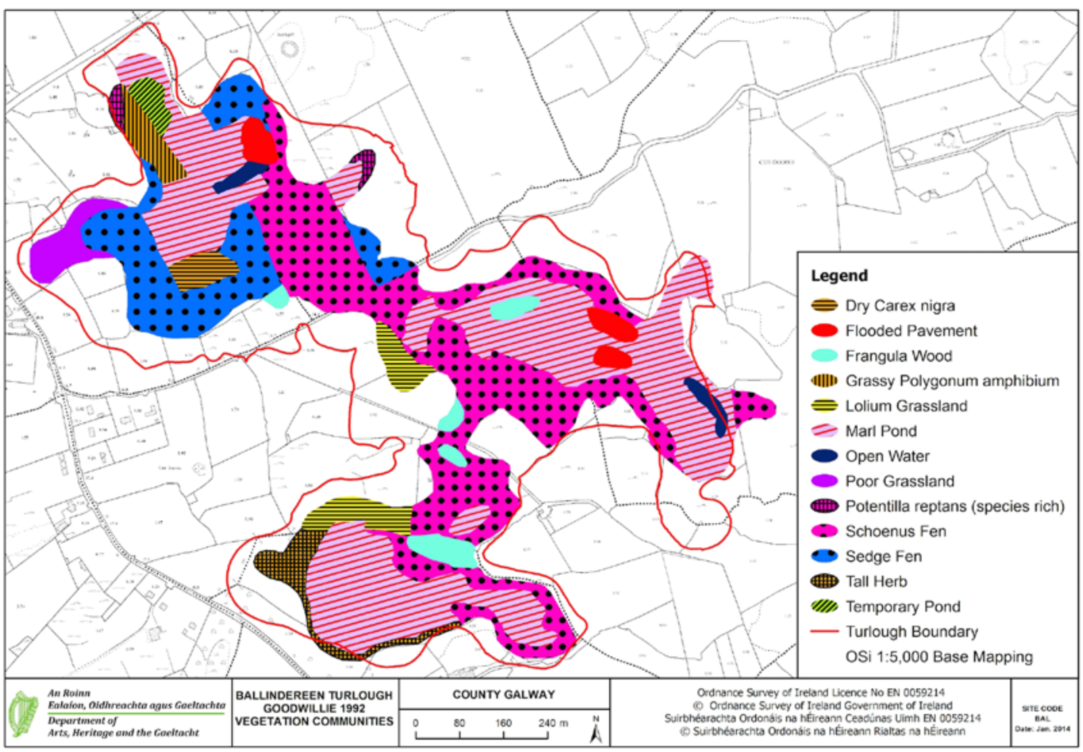
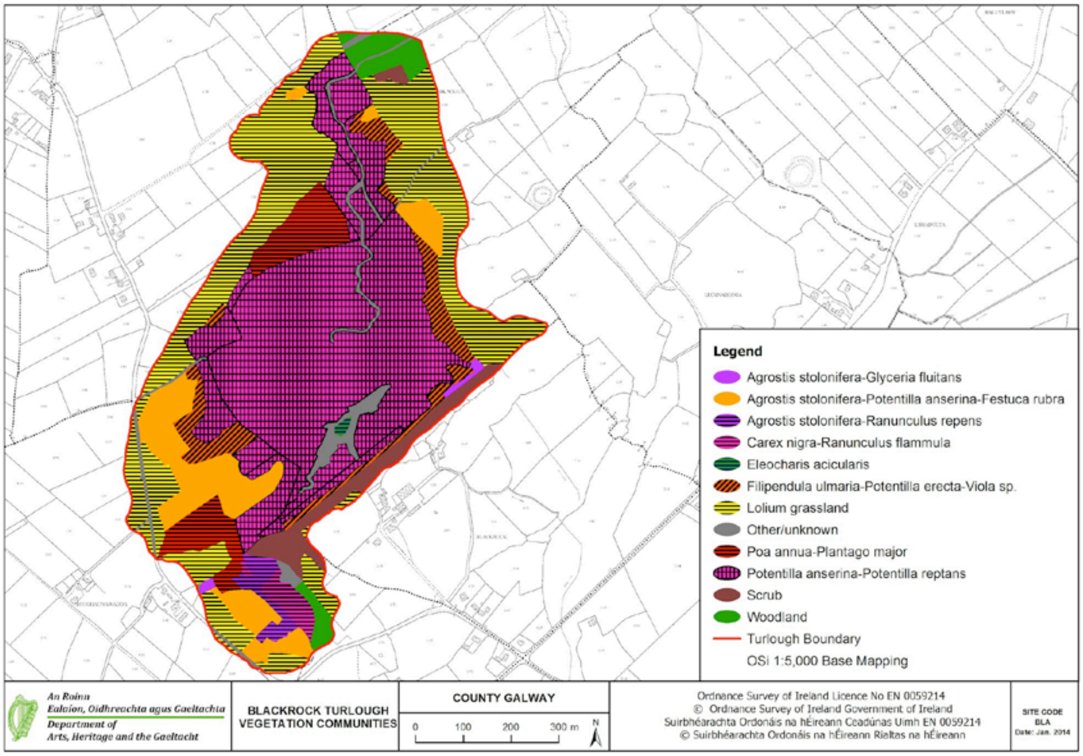


Figure 7.9 Ballindereen. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



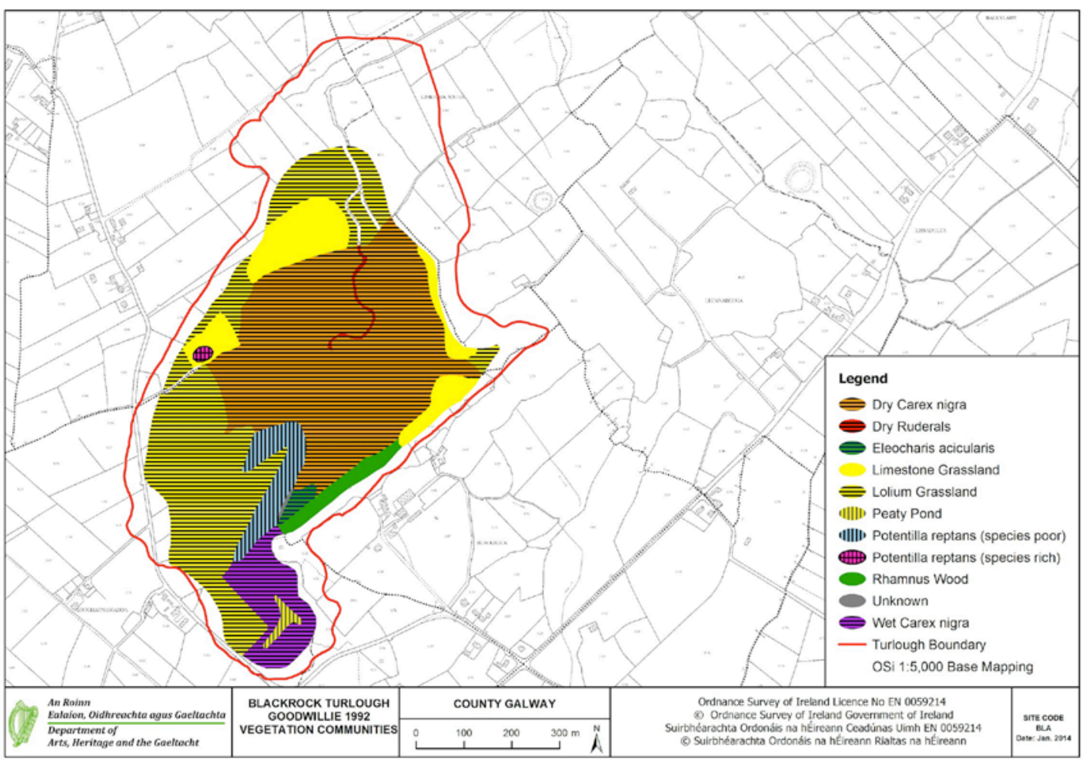


Figure 7.10 Blackrock. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).

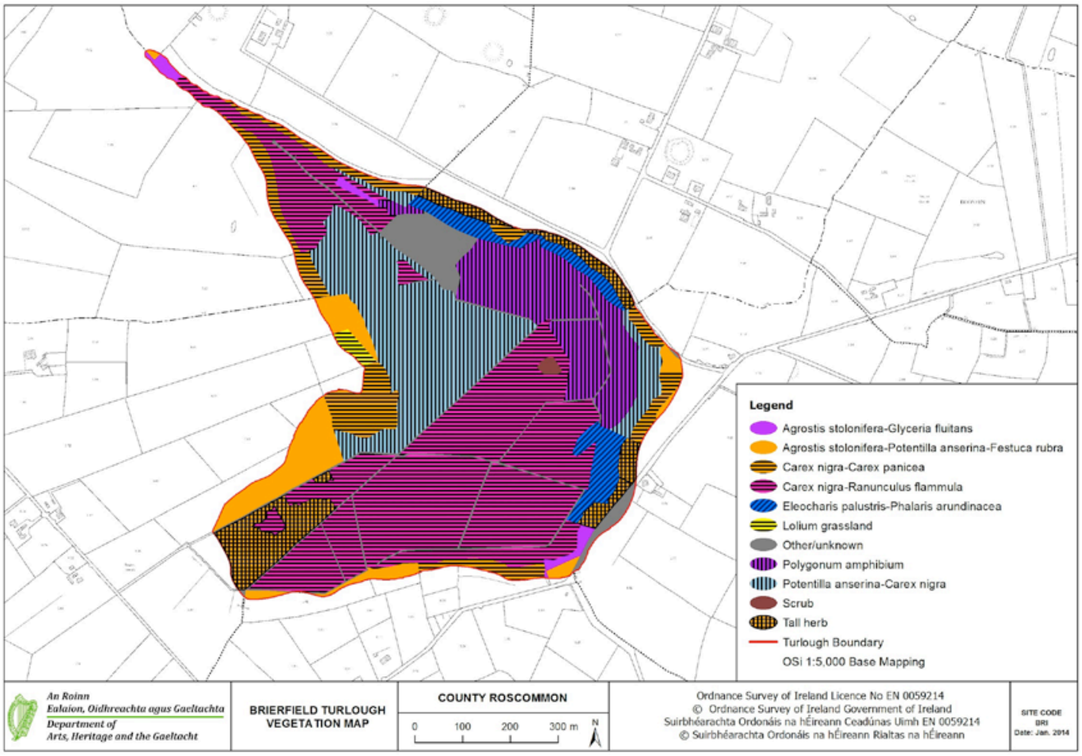
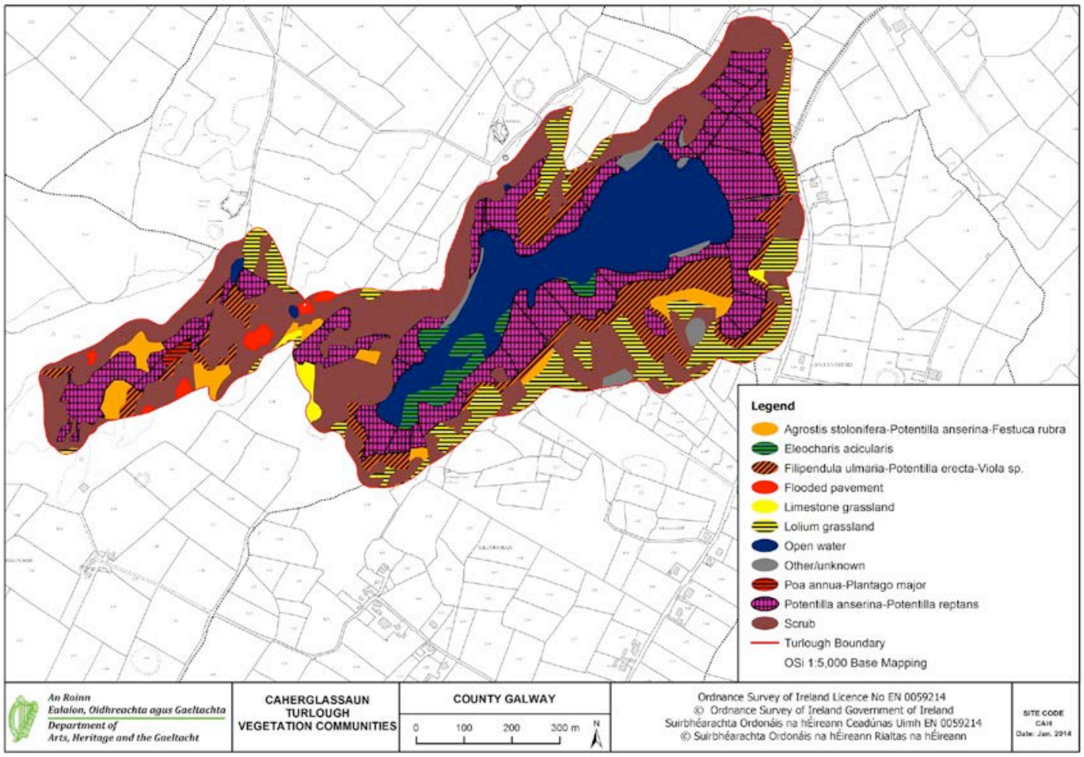


Figure 7.11 Brierfield. The figure shows vegetation mapped by TCD, a digitised version of the communities mapped by Goodwillie (1992) is not available.



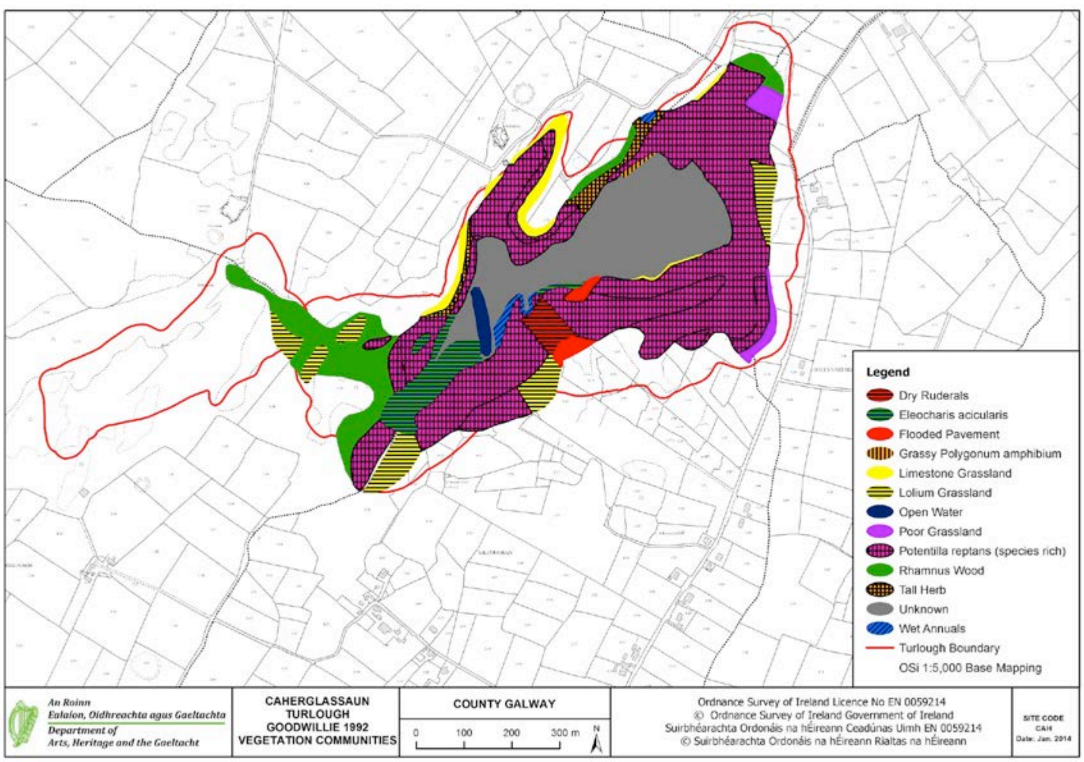
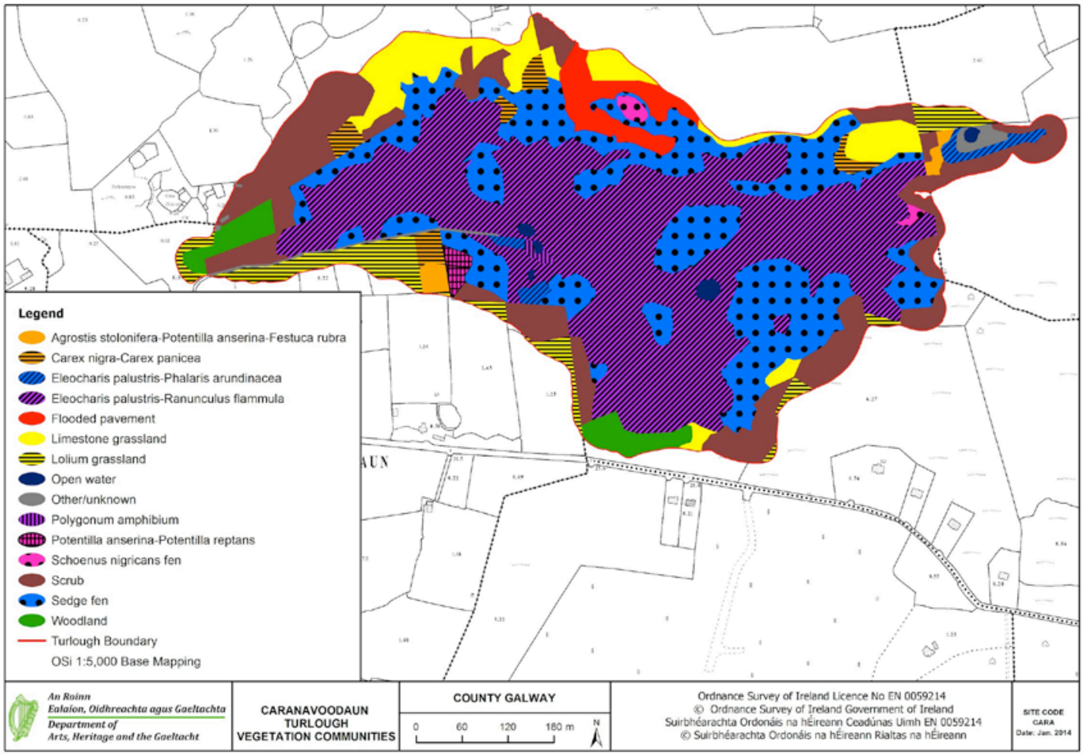


Figure 7.12 Caherglassan. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



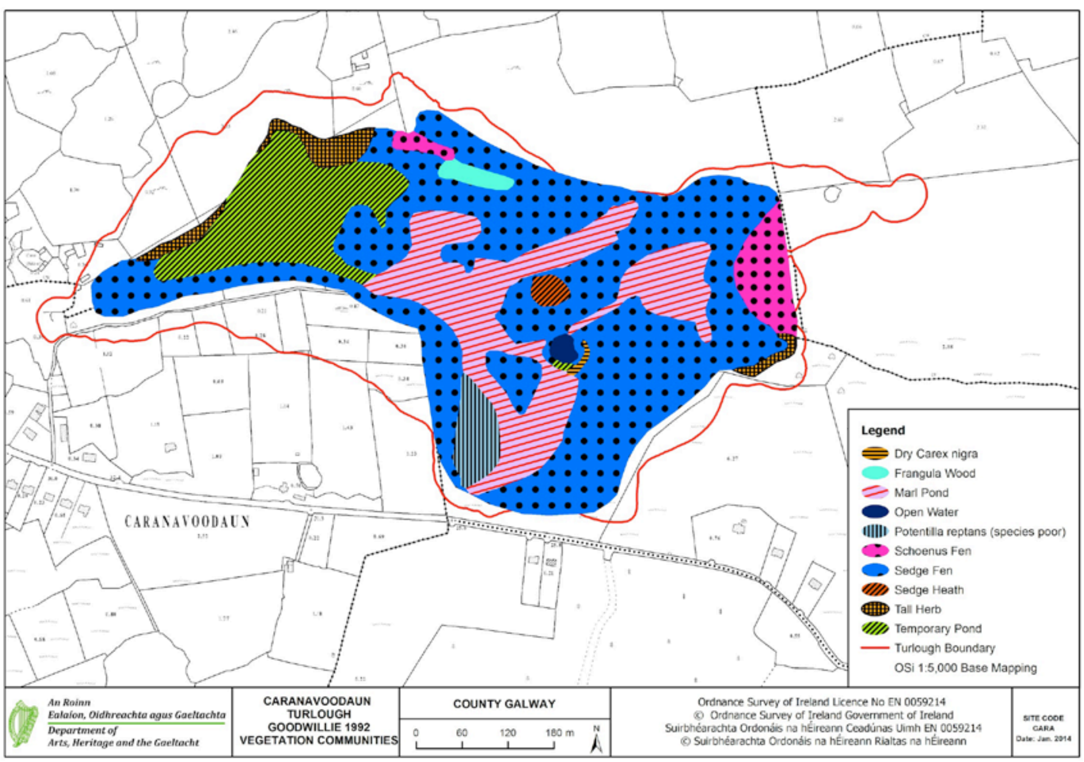
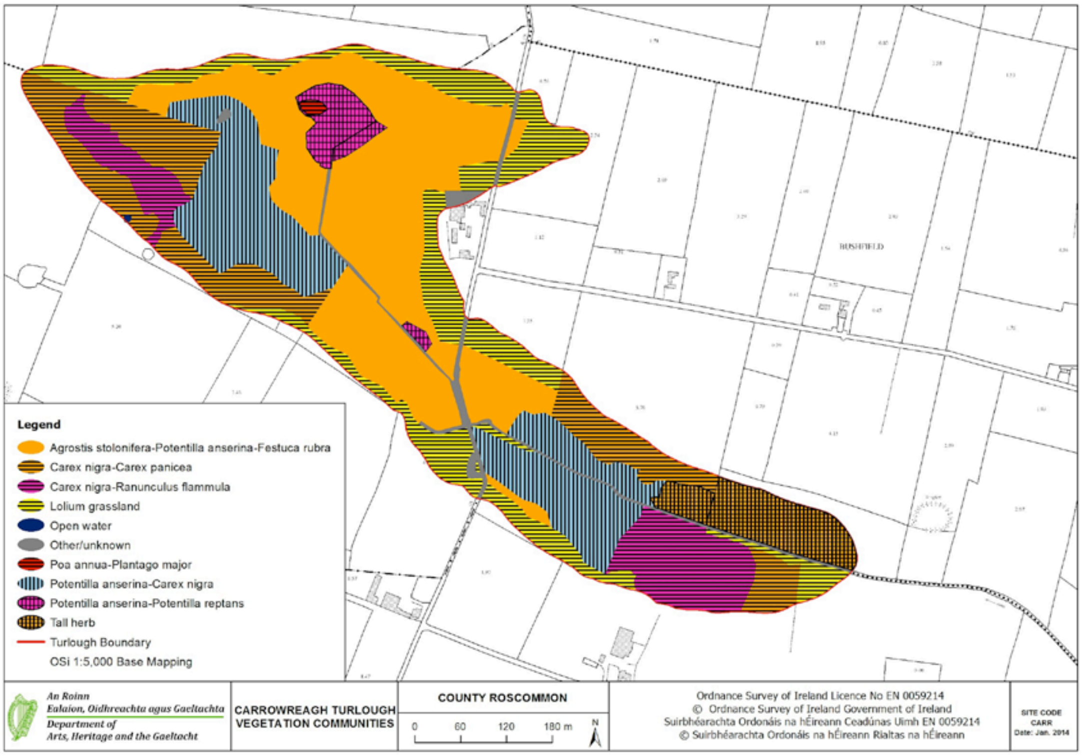


Figure 7.13 Caranavoodaun. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



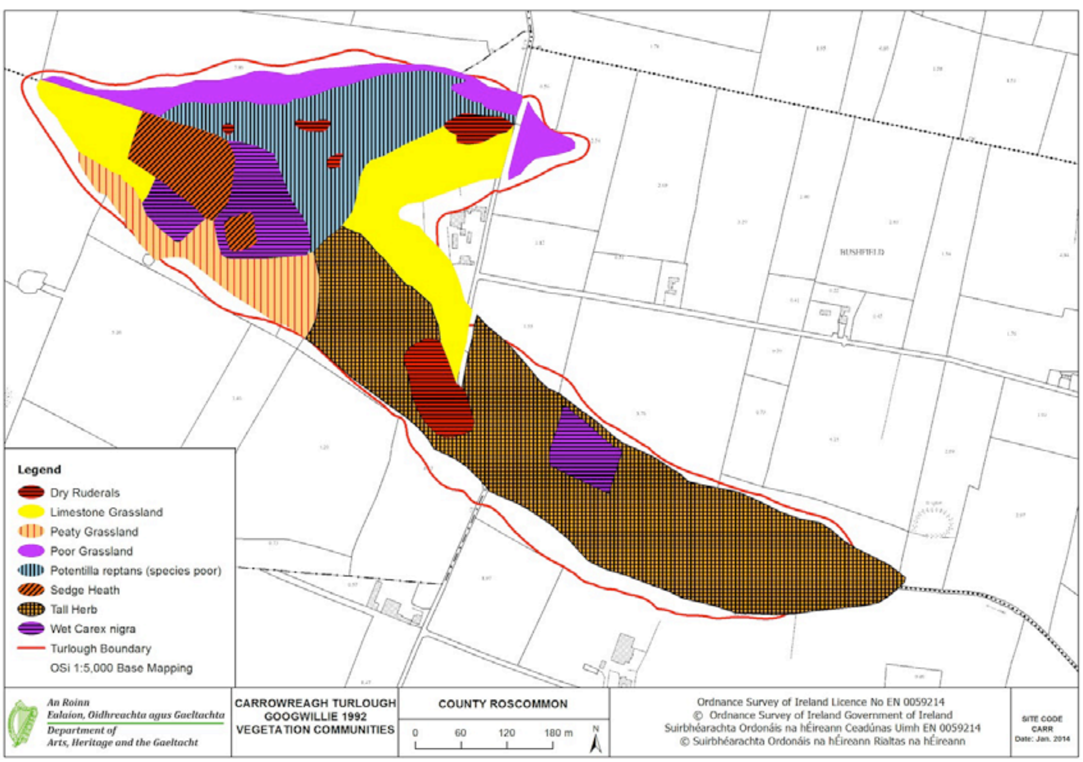
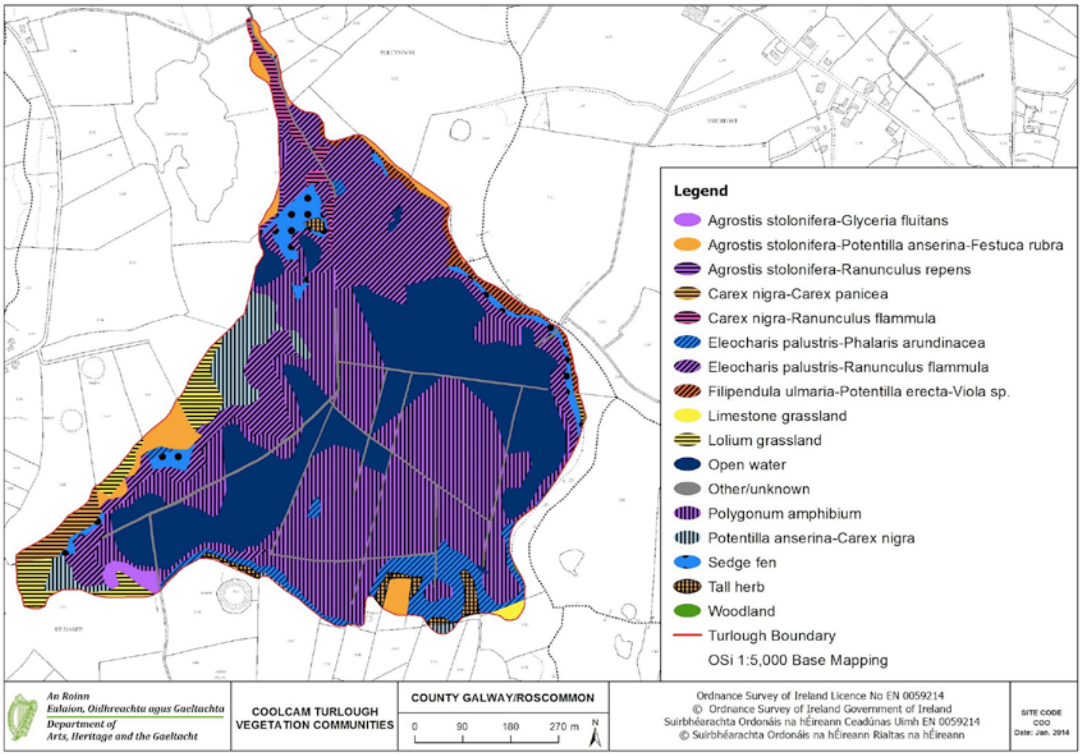


Figure 7.14 Carrowreagh. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



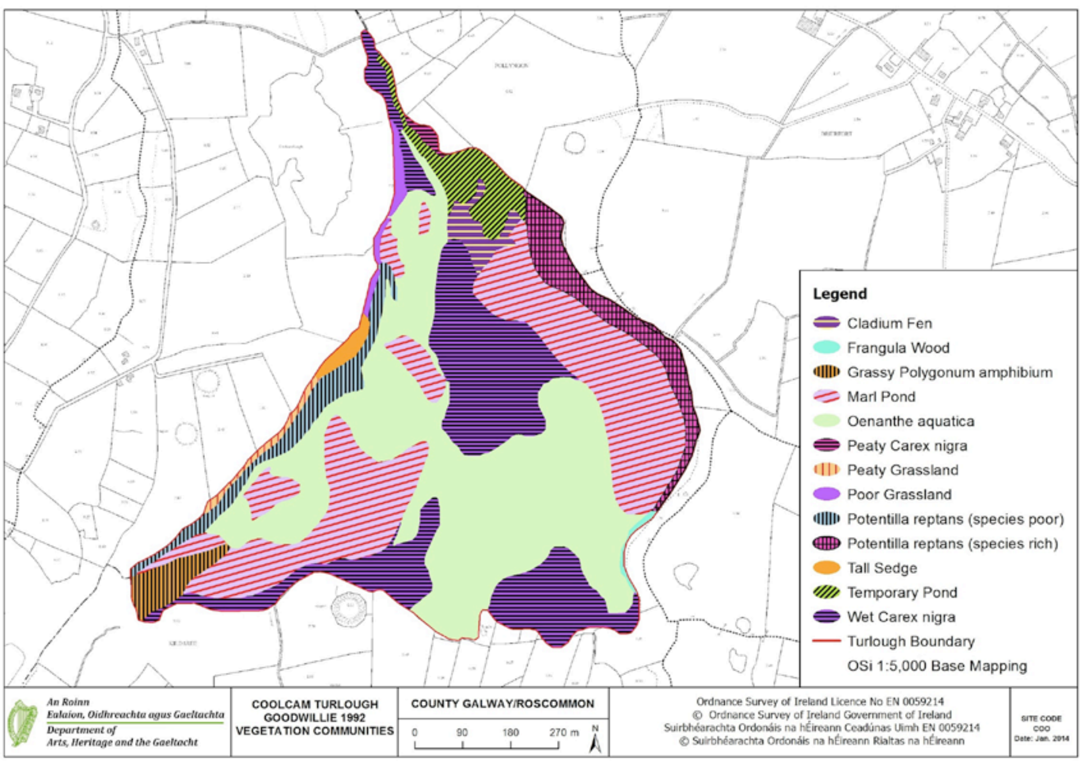
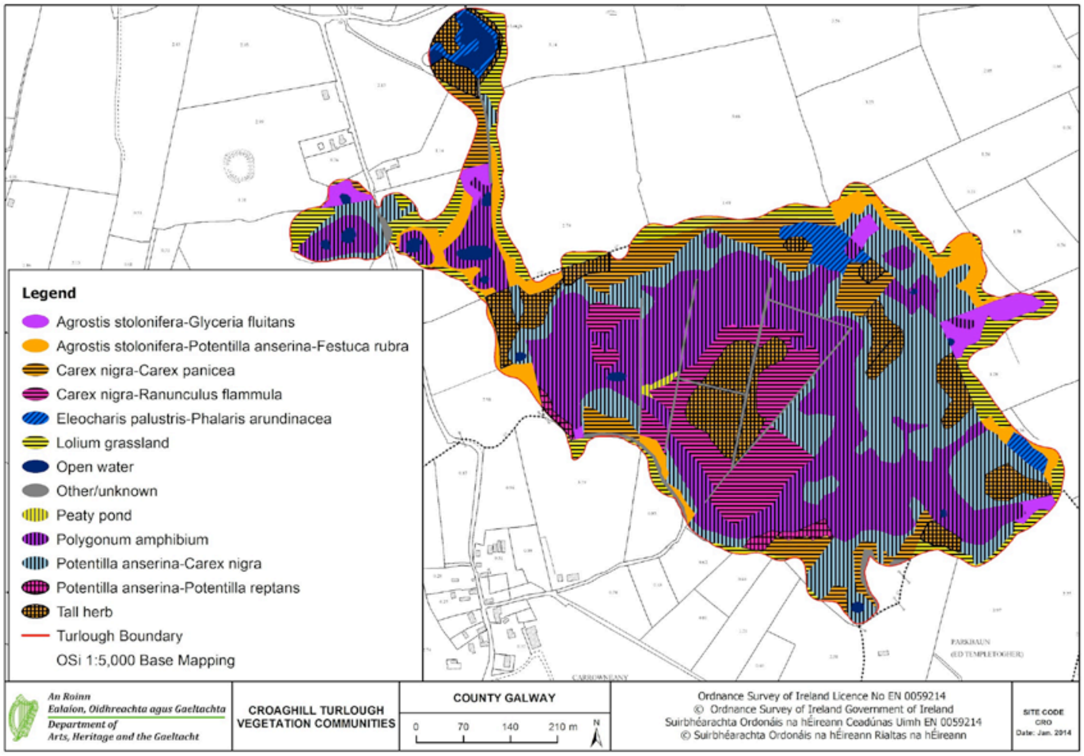


Figure 7.15 Coolcam. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



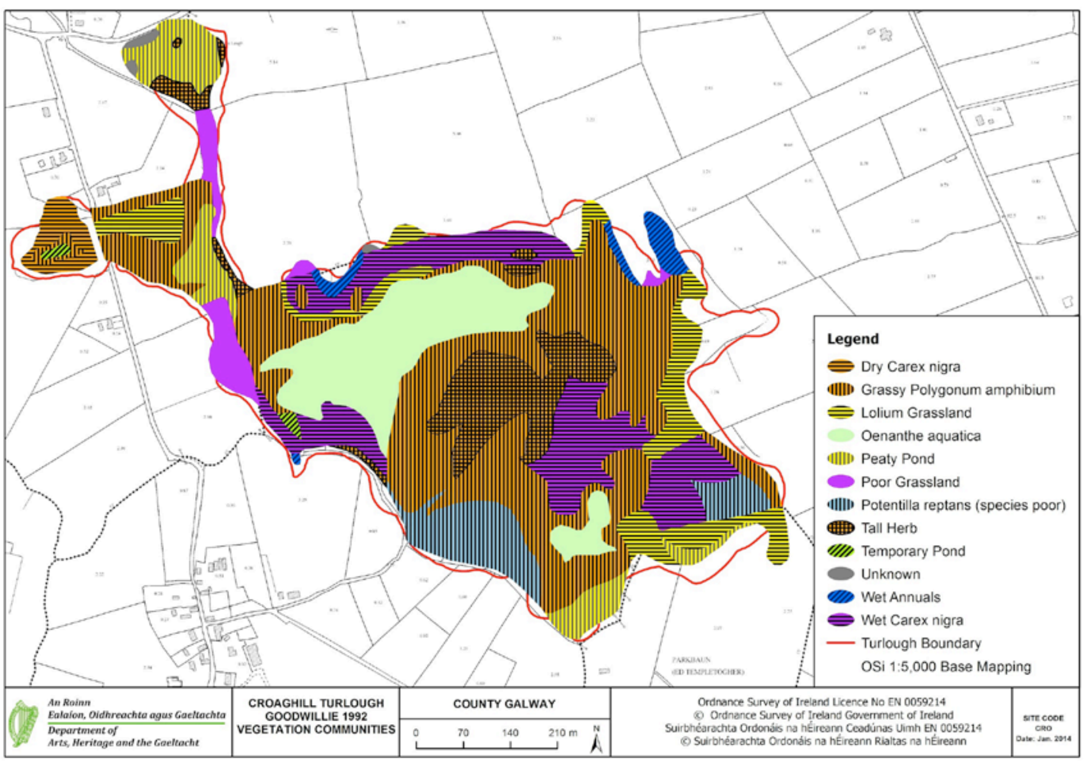
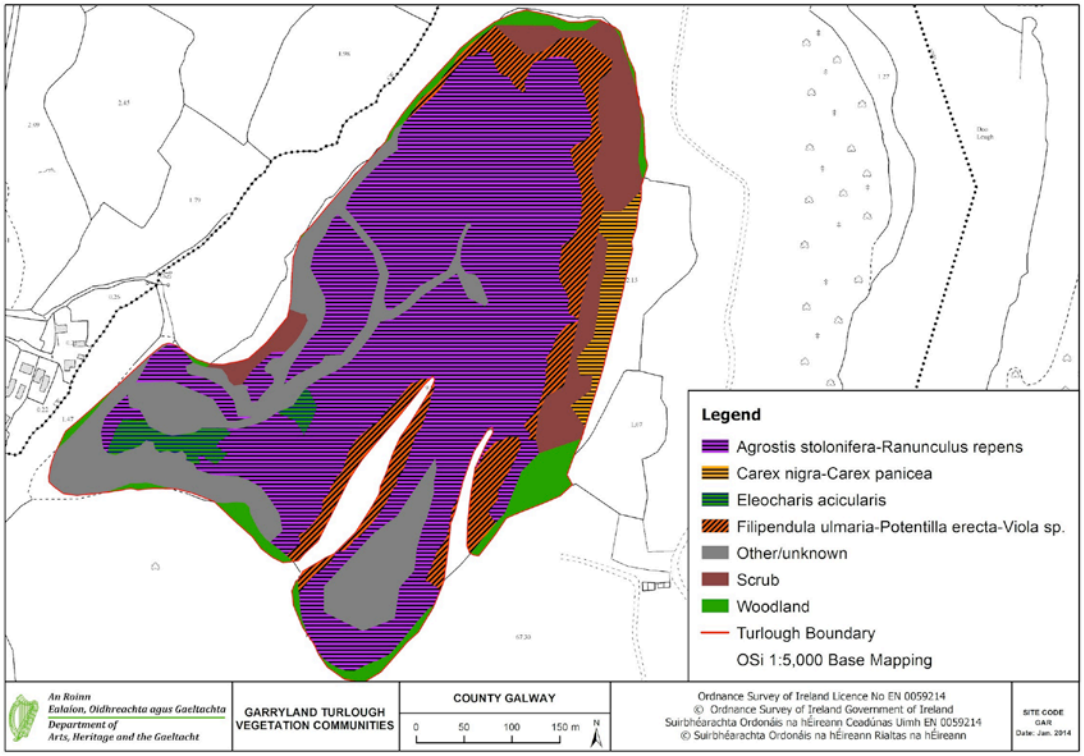


Figure 7.16 Croaghill. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



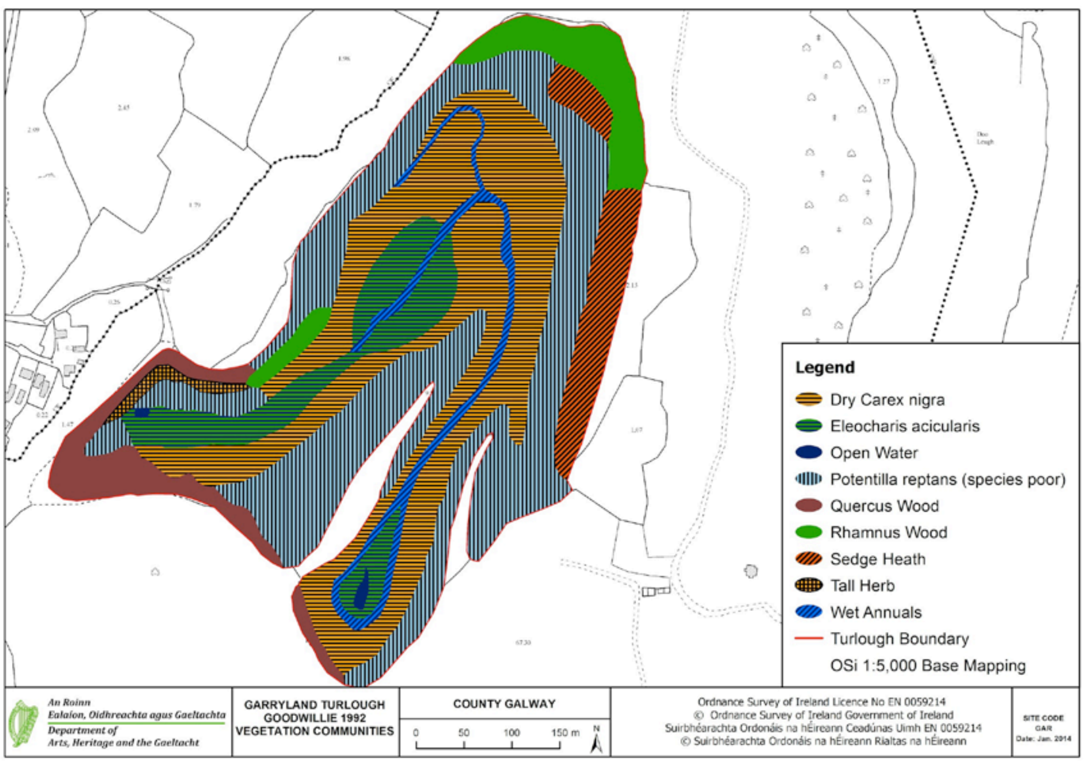
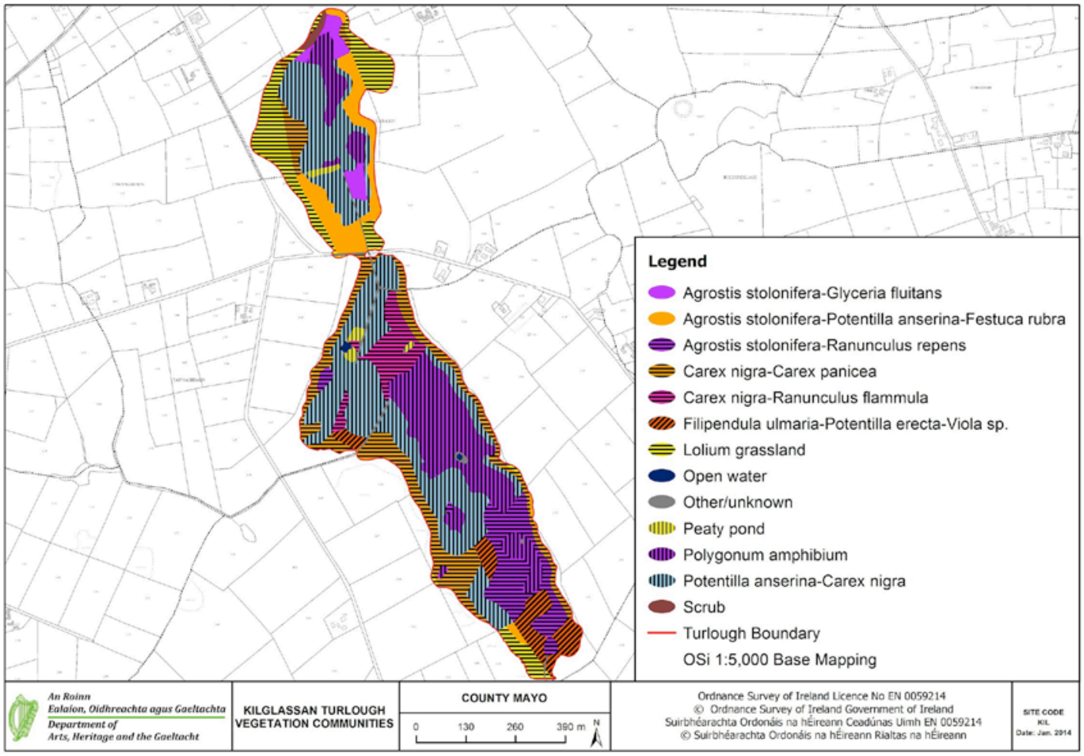


Figure 7.17 Garryland. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



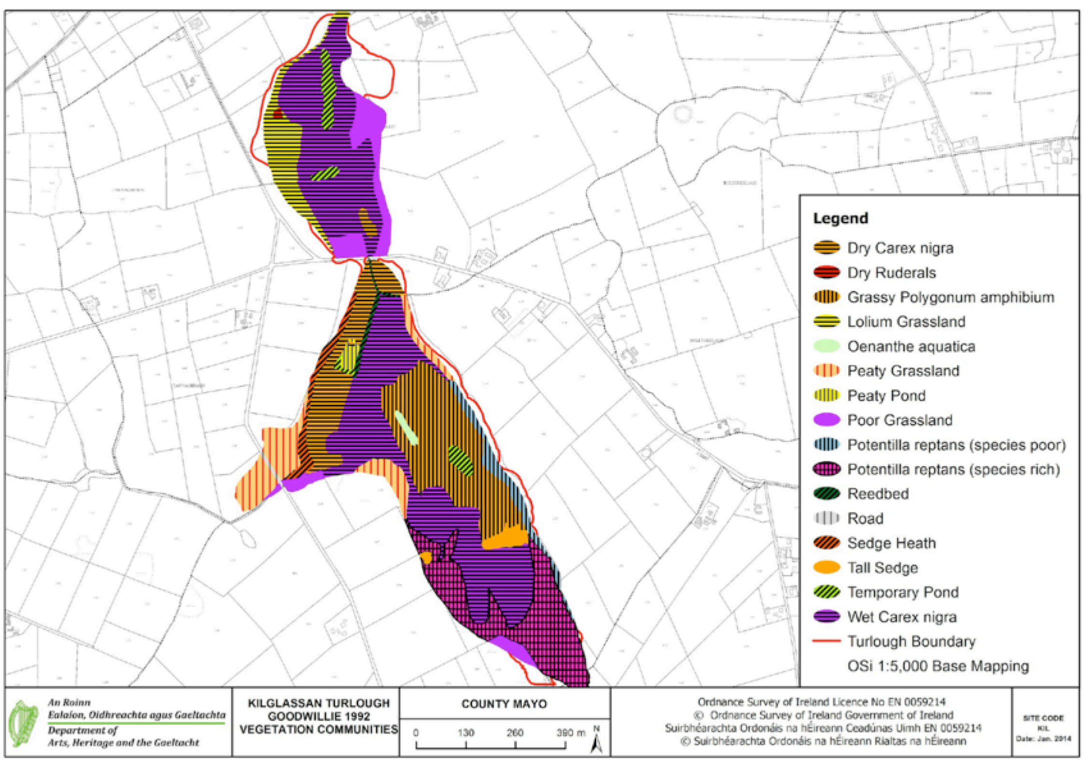


Figure 7.18 Kilglassan. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).

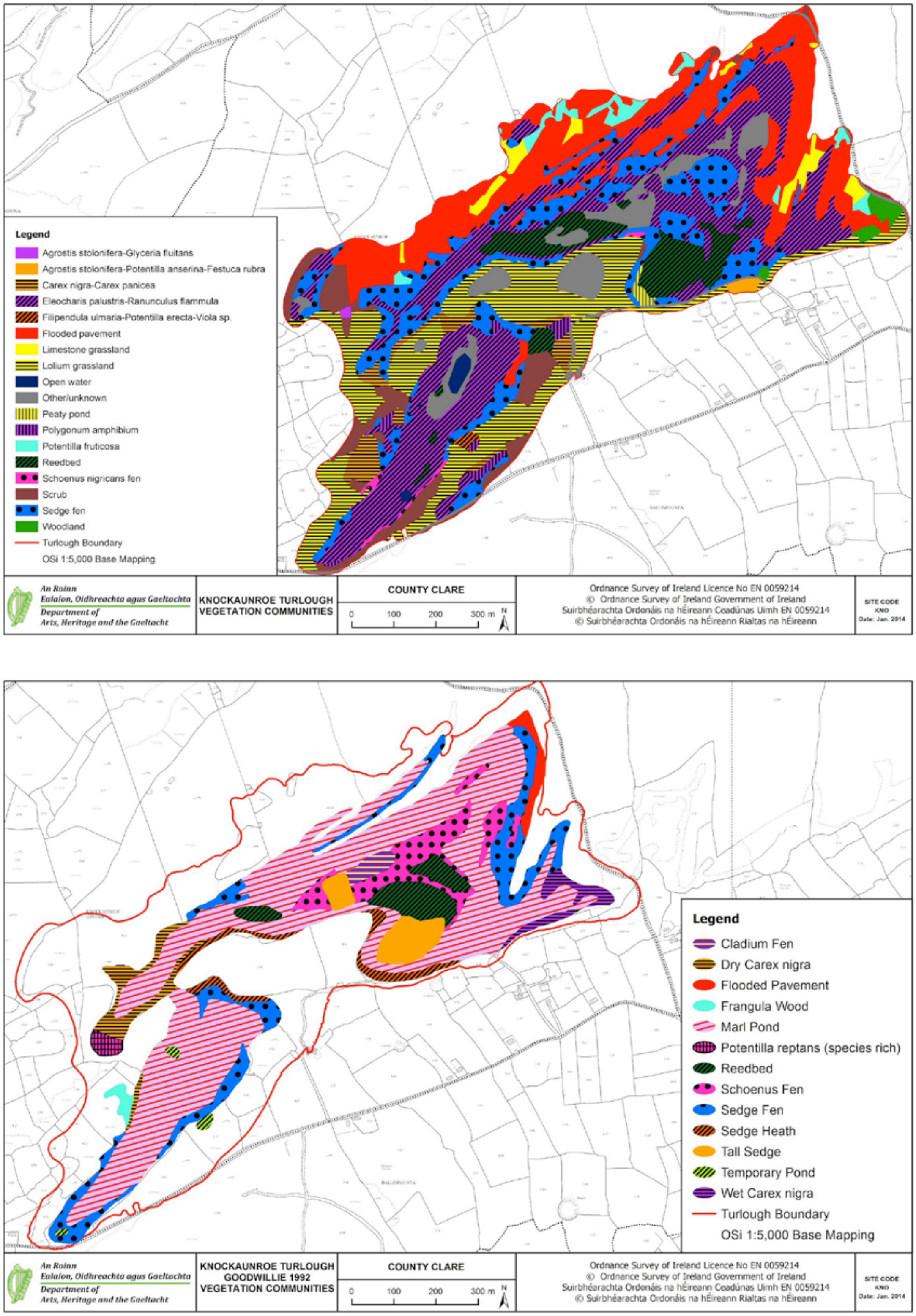
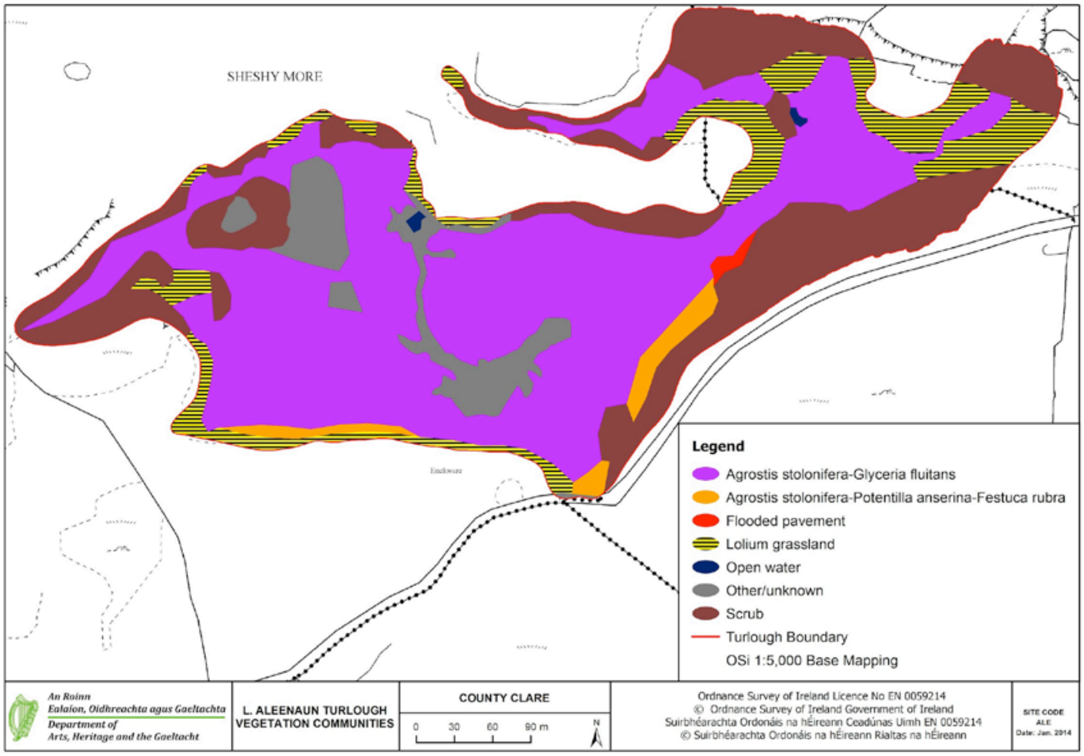


Figure 7.19 Knockaunroe. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



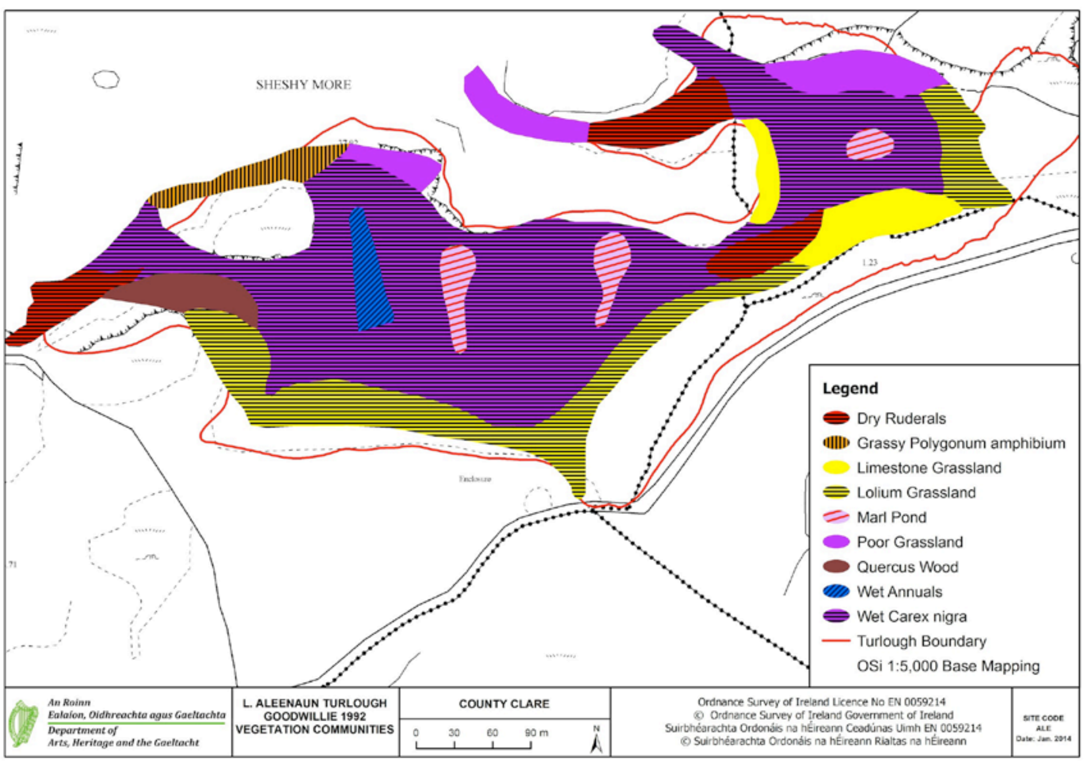


Figure 7.20 Lough Aleenaun. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).

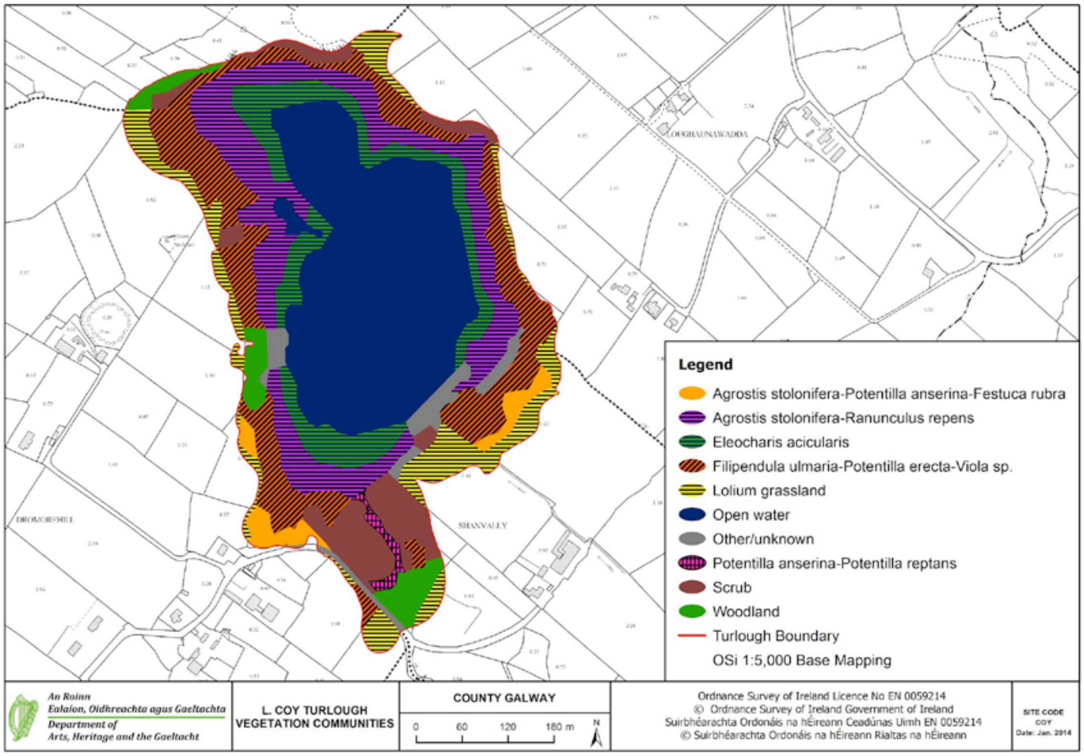


Figure 7.21 Lough Coy. The figure shows vegetation mapped by TCD, Lough Coy was not mapped by Goodwillie (1992).

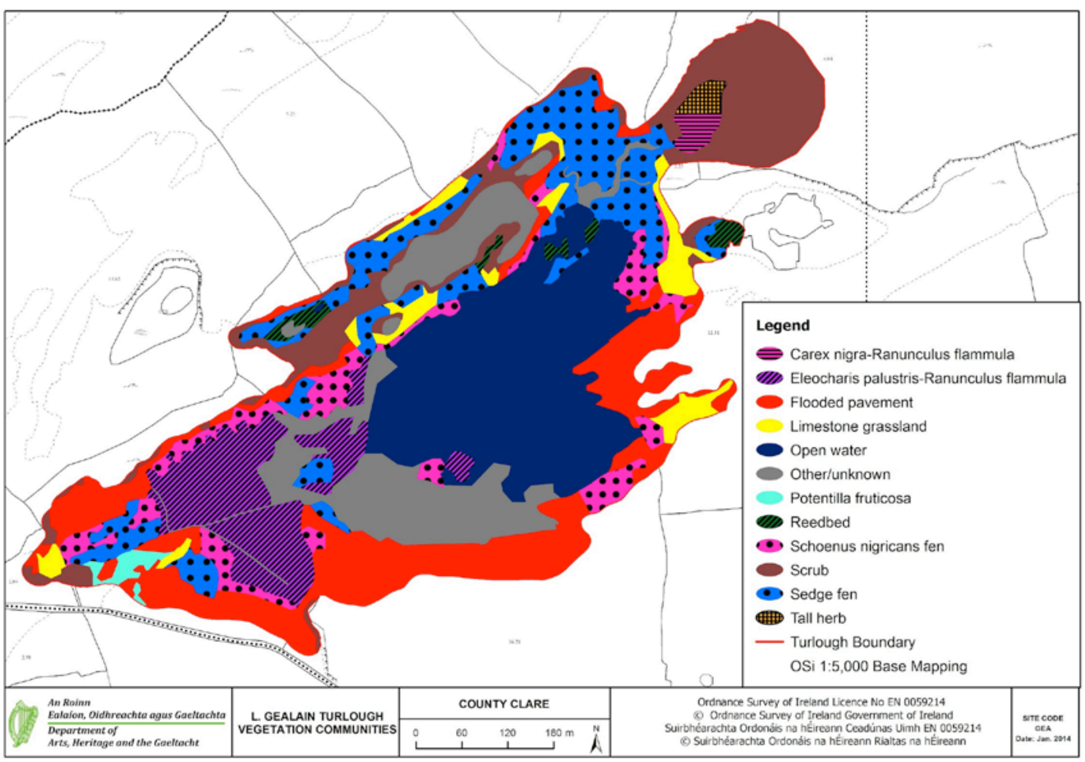
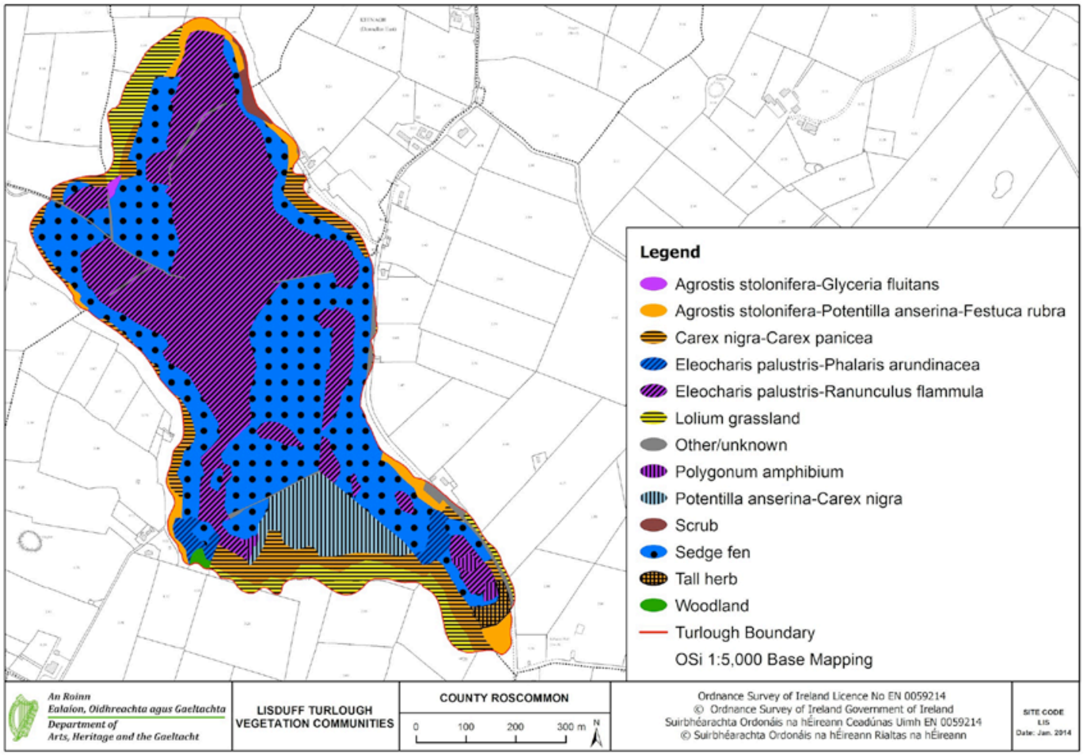


Figure 7.22 Lough Gealain. The figure shows vegetation mapped by TCD, Lough Gealain was not mapped by Goodwillie (1992).



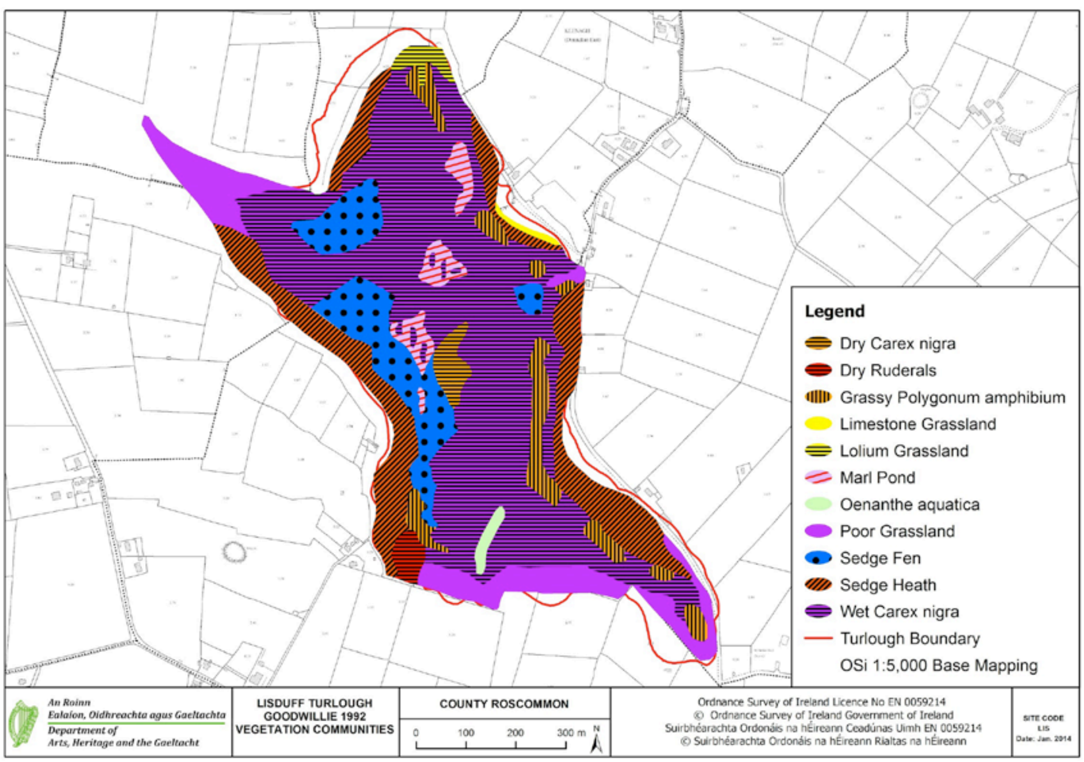
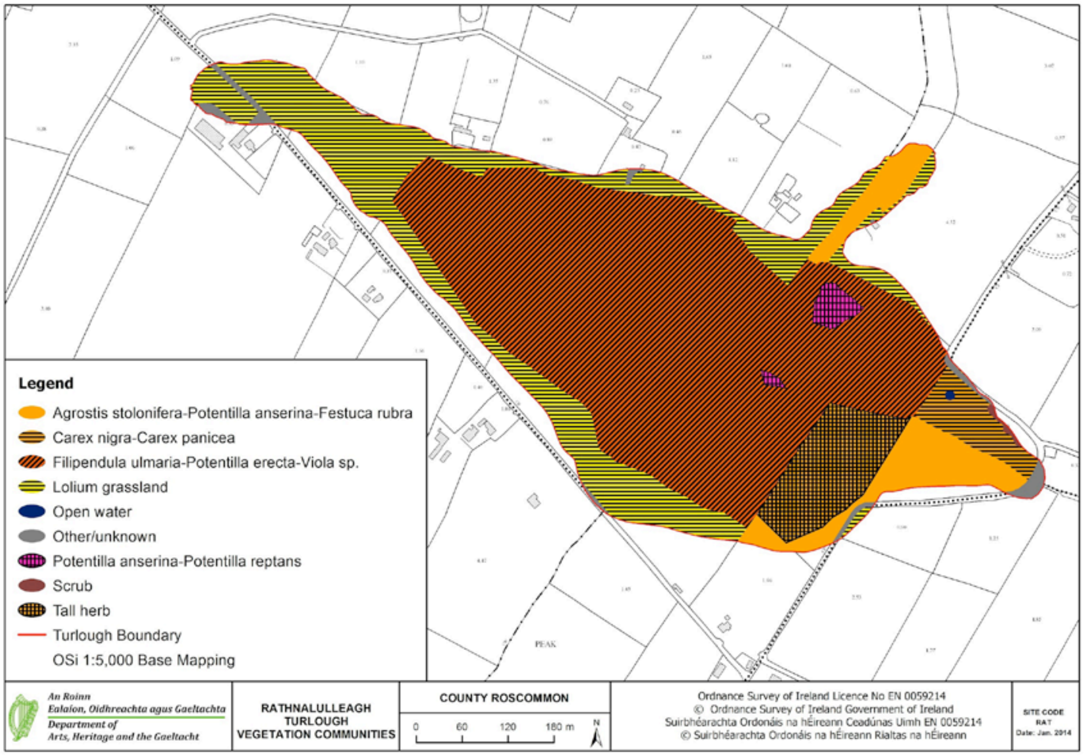


Figure 7.23 Lisduff. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



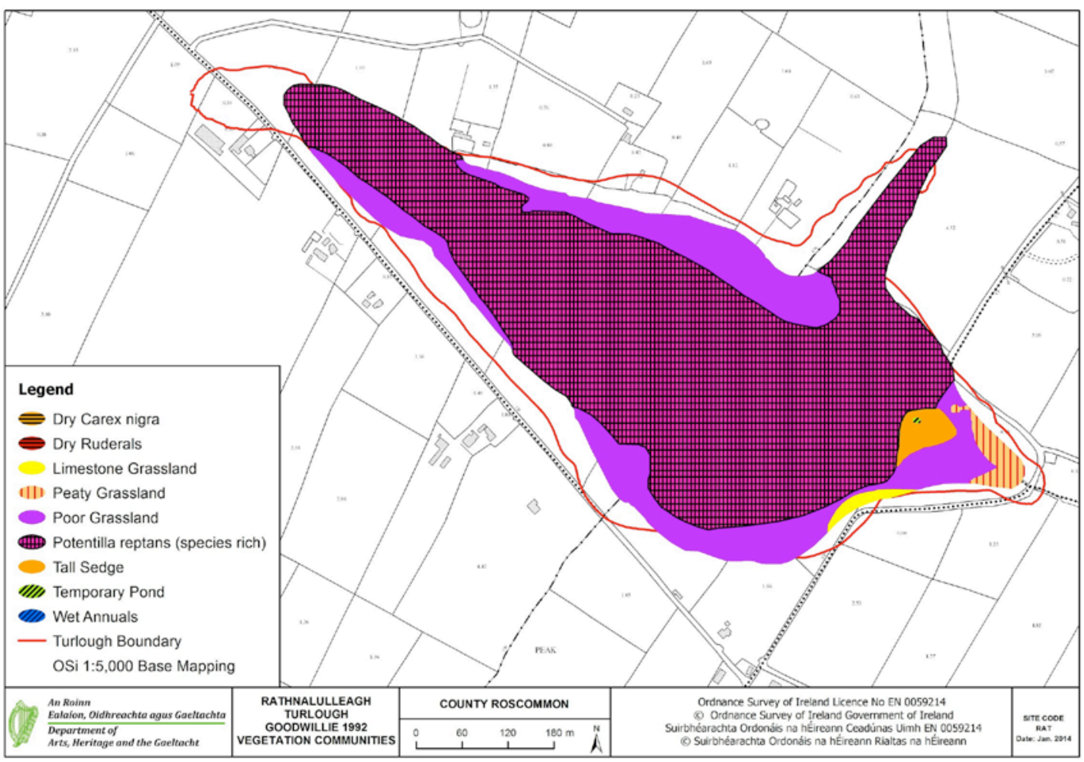


Figure 7.24 Rathnalulleagh. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).

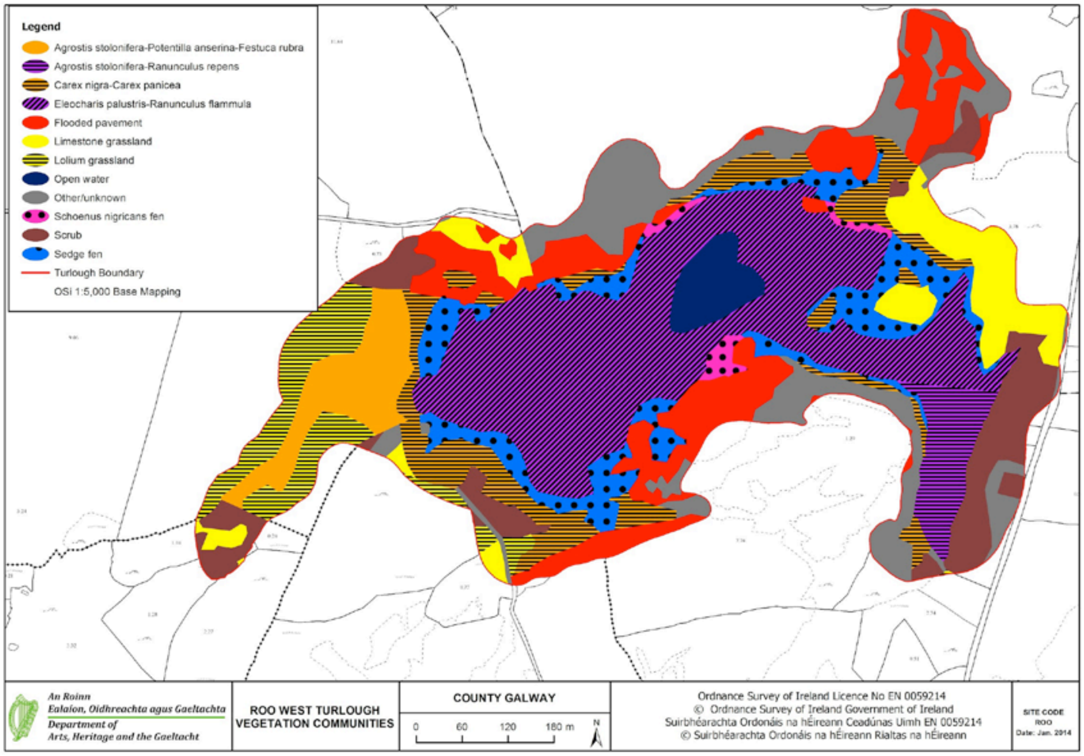
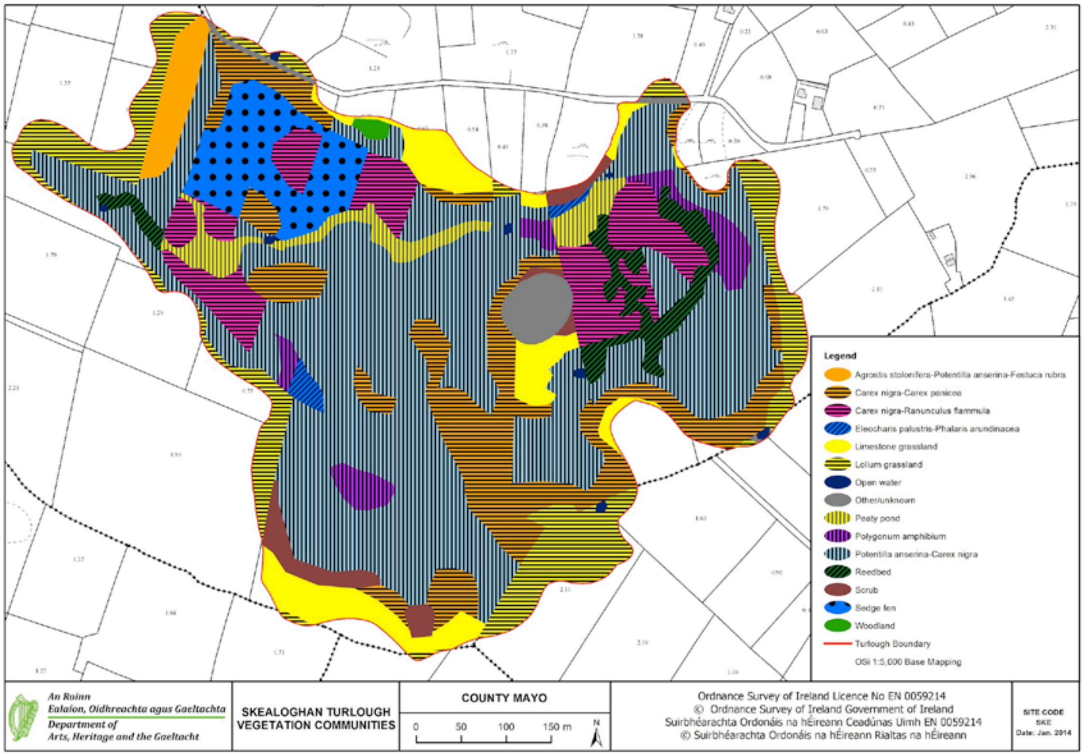


Figure 7.25 Roo West. The figure shows vegetation mapped by TCD, Roo West was not mapped by Goodwillie (1992).



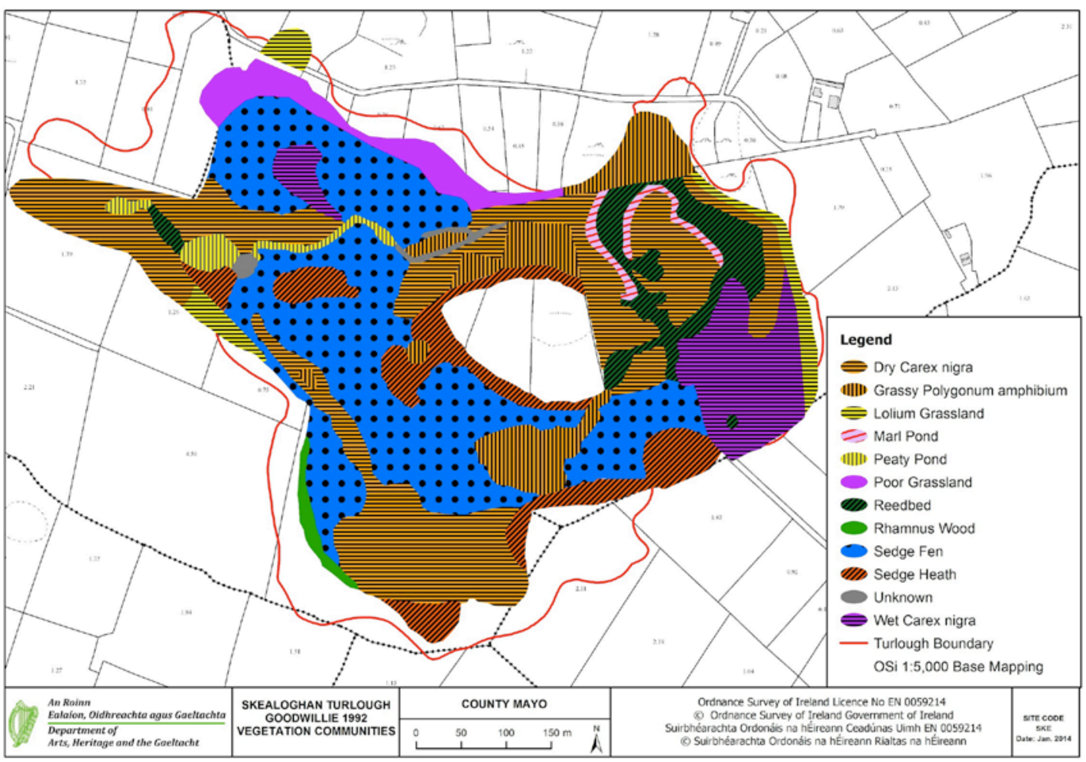
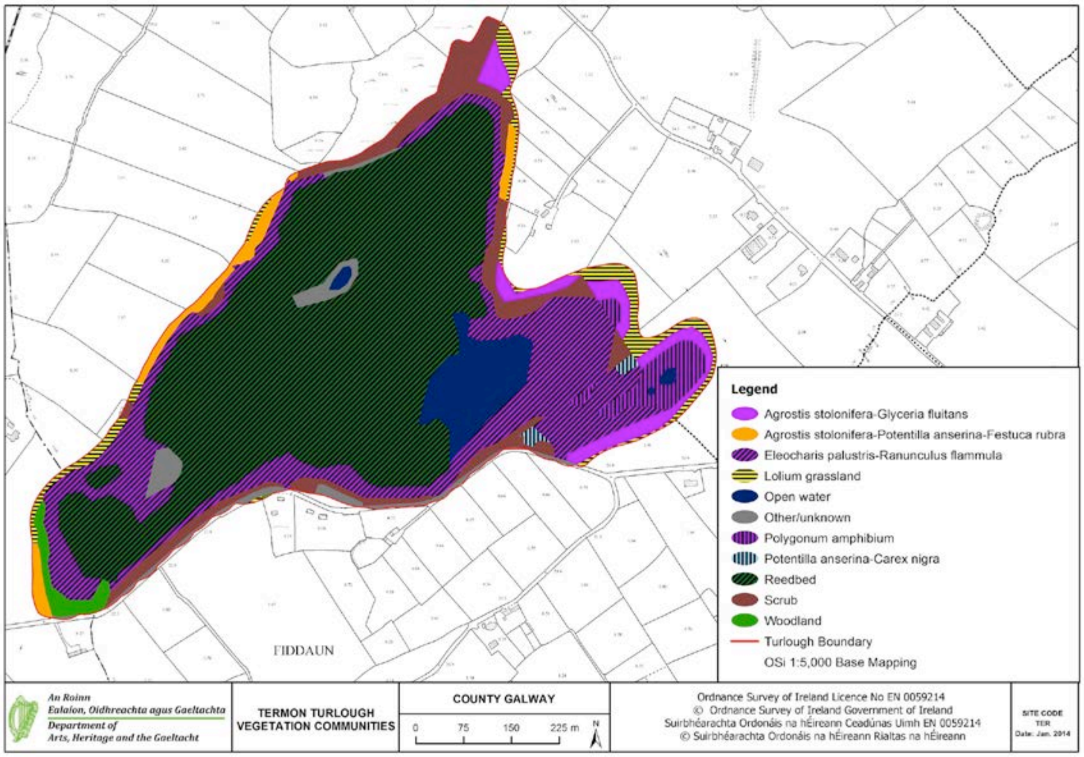


Figure 7.26 Skealoghan. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).



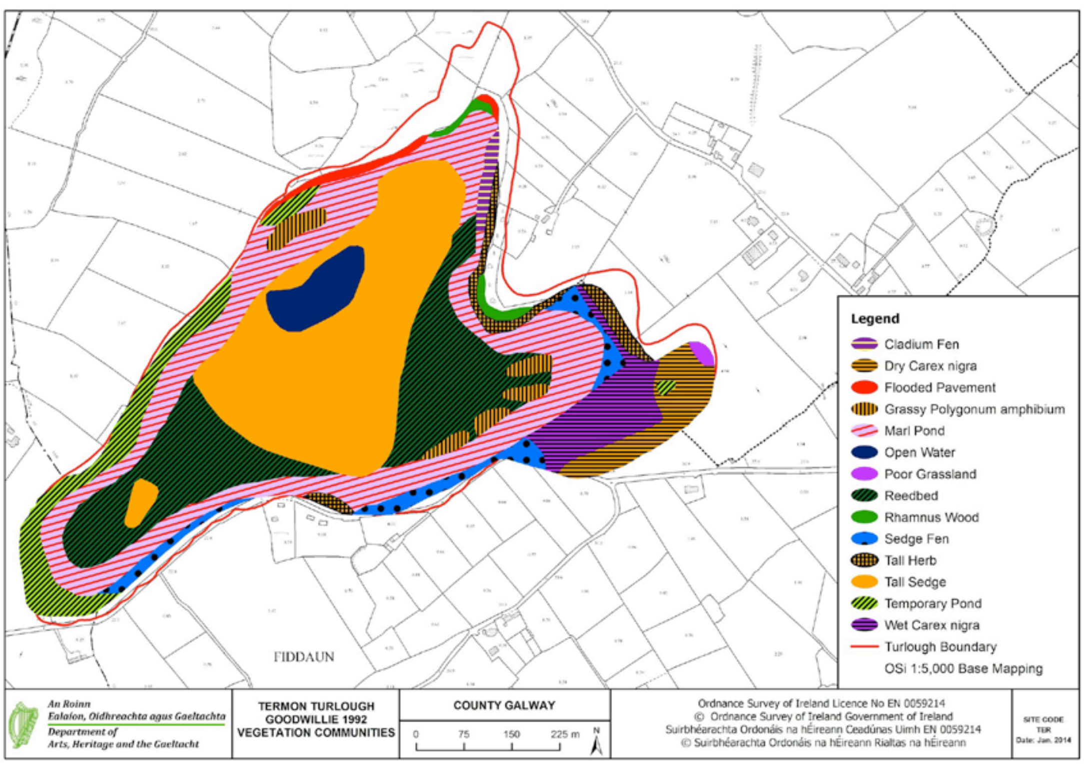


Figure 7.27 Termon. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).

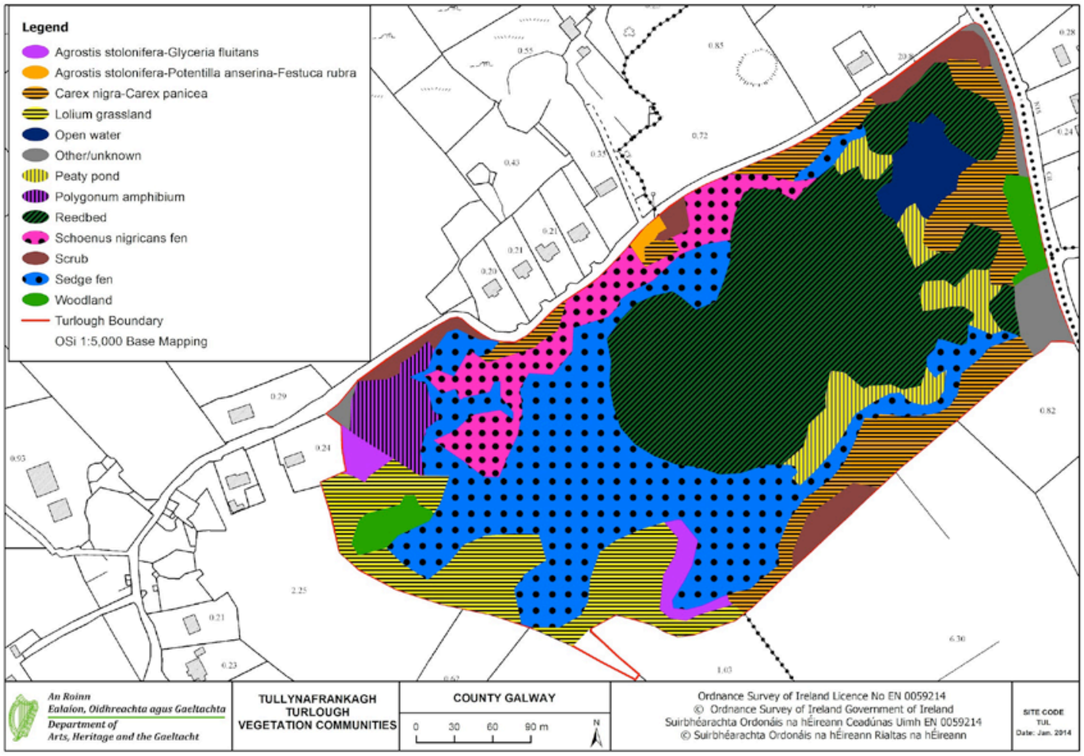
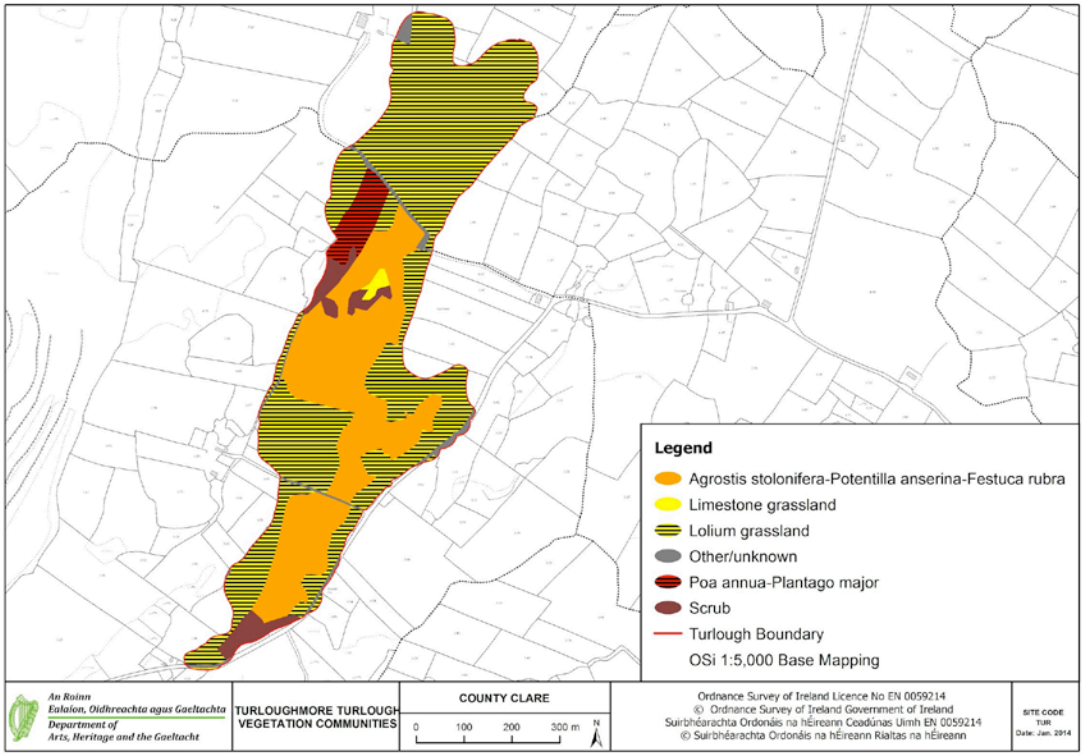


Figure 7.28 Tullynafrankagh. The figure shows vegetation mapped by TCD, Tullynafrankagh was not mapped by Goodwillie (1992).



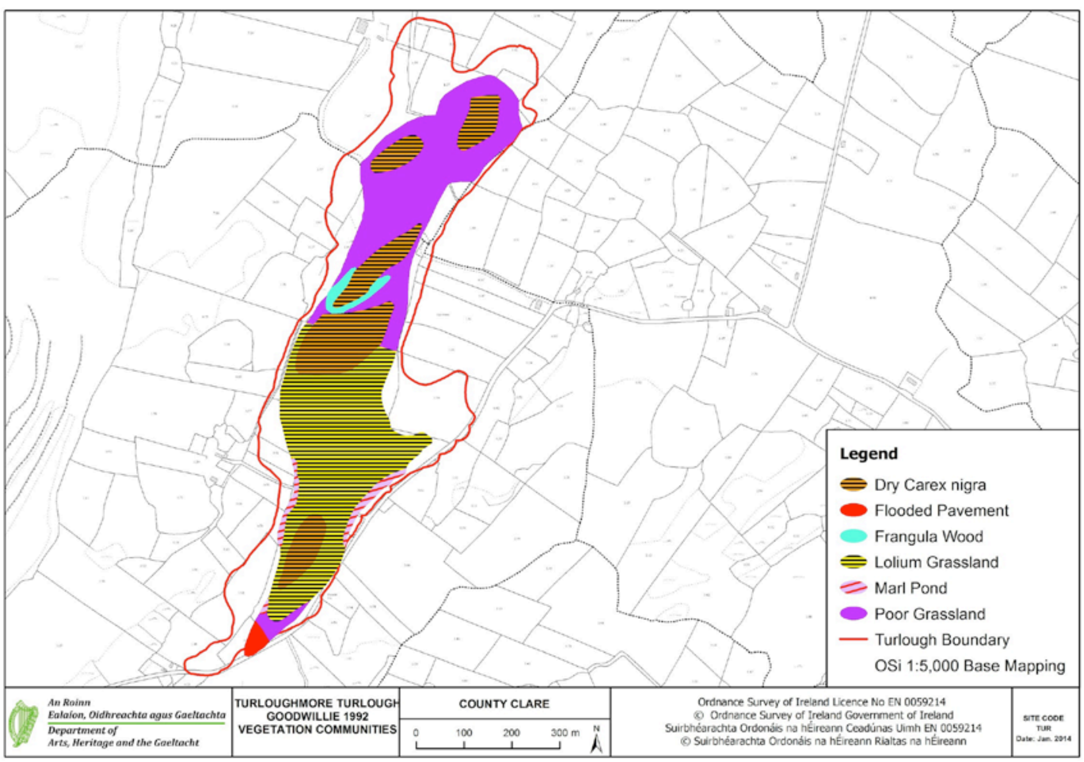


Figure 7.29 Turloughmore. Upper figure shows vegetation mapped by TCD, lower figure is a digitised version of the communities mapped by Goodwillie (1992).

7.5.4 Environmental Drivers of Turlough Vegetation

For the sake of brevity, names of the vegetation communities have been abbreviated (Table 7.63), these abbreviations will be used when referencing vegetation groups in this section.

Table 7.63. Abbreviations used in this section when referring to vegetation communities

Cluster	*Group*	*Name*	*Abbreviation*
1	1	*Poa annua-Plantago major* community	*PoaPlan*
2	2	*Polygonum amphibium-Eleocharis palustris* community	*PersEleo*
3	3	*Agrostis stolonifera-Ranunculus repens* community	*AgroRanu*
3	4	*Agrostis stolonifera-Potentilla anserina-Festuca rubra* community	*AgroPote*
4	5	Limestone Grassland	LimeGras
5	6	*Eleocharis palustris-Ranunculus flammula* community	*EleoRanu*
2	7	*Eleocharis palustris-Phalaris arundinacea* community	*EleoPhal*
6	8	*Carex nigra-Carex panicea* community	*CareCpan*
3	9	*Phalaris arundinacea-Potentilla anserina* community	*PhalPote*
7	10	*Lolium perenne-Trifolium repens* community	*LoliTrif*
5	11	*Polygonum amphibium-Mentha aquatica* community	*PersMent*
6	12	*Filipendula ulmaria-Vicia cracca* community	*FiliVici*
3	13	*Potentilla anserina-Carex nigra* community	*PoteCare*
5	14	Reedbed	Reedbed
7	15	*Lolium perenne-Trifolium repens-Agrostis stolonifera* community	*LoliAgro*
2	16	*Equisetum fluviatile-Menyanthes trifoliata* community	*EquiMeny*
2	17	*Carex nigra-Ranunculus flammula* community	*CareRanu*
2	18	*Agrostis stolonifera-Glyceria fluitans* community	*AgroGlyc*
3	19	*Potentilla anserina-Potentilla reptans* community	*PotePote*
3	20	*Filipendula ulmaria-Potentilla erecta-Viola* sp. community	*FiliPote*
4	21	*Schoenus nigricans* fen	*Schoenus*
8	22	*Molinia caerulea-Carex panicea* community	*MoliCare*
6	23	*Carex nigra-Leontodon autumnalis* community	*CareScor*
5	24	*Potamogeton natans-Glyceria fluitans* community	*PotaGlyc*
8	25	*Carex nigra-Carex viridula* community	*CareCvir*
1	26	*Eleocharis acicularis* community	*Eleoacic*
2	27	*Carex nigra-Equisetum fluviatile* community	*CareEqui*
4	28	Flooded Pavement	FldPavmt

In this section, environmental variables are summarised and presented graphically in the form of boxplots, to show the median, interquartile range and the smallest and largest values for each group. Outliers are indicated by a circle on the graphs, while extreme outliers are shown by an asterisk.

Investigation into differences between group medians was carried out using Mann-Whitney U tests. With 28 different groups, pairwise testing and subsequent adjustment for multiple comparisons results in an unwieldy table with an extremely low threshold for significance; *post-hoc* testing was, therefore, carried out on clusters (the eight broader groups defined in section 7.5.) rather than each individual vegetation community.

7.5.4.1 Hydrology

Frequency

Frequency of flooding at 0 cm, 10 cm, 25 cm and 50 cm (height of flooding above the substrate, for duration of ≥ 48 hours) was analysed and is presented in Table 7.64 and Figure 7.30. A Kruskal-Wallis test was carried out to test for differences between group medians which indicated that there were significant differences between the medians of at least two groups for each of the soil chemistry variables. *Post-hoc* Mann-Whitney U tests were therefore carried out to determine which clusters differed from each other (Table 7.65).

Note: the frequency of inundation for some of the quadrats increases as the level of flooding examined increases – this is due to fluctuating water levels above the level being examined – i.e. a flooding event which reaches at or above 10 cm can reach 50 cm a number of times before receding below 10 cm again.

There was a large amount of variation in the frequency of flooding for some of the communities, in particular those of Clusters 2 and 3. There were a number of outliers, especially in Lough Aleenaun (denoted by the code ALE), which is the 'flashiest' turlough of the study, it responds rapidly to rainfall events, filling and emptying frequently. At 50 cm, the outliers were mostly relevés from Lisduff and Knockaunroe.

For many of the communities, the range of frequencies of inundation events decreased as the depth of inundation increased (Table 7.64). Group 1 *PoaPlan* is a striking example of this; at 0cm the frequency of flooding ranged from 2 to 21 flood events, while when only flooding to a depth of 50 cm is considered, the range contracted to 2 to 9 events (Table 7.64, Figure 7.30). Cluster 7, which contains Group 10 *LoliTrif* and Group 15 *LoliAgro*, also experienced a wide range of flooding frequencies at 0 cm, 10 cm and 25 cm depth, but this was much reduced at 50 cm. These communities occur around the edge of turloughs, and it seems they can experience frequent, but shallow, flooding. The frequency of flood events to 5 0cm or deeper does not differ significantly between many of the clusters (Table 7.65); at this depth of flooding, only 3 pairs of clusters show significant differences.

Table 7.64. Mean, median and range for frequency of flooding (number of events of duration > 48 hrs) at 0 cm, 10 cm, 25 cm and 50 cm above substrate surface.

		Frequency (0 cm)		*Frequency (10 cm)*		*Frequency (25 cm)*		*Frequency (50 cm)*	
		Mean	*Median (range)*	*Mean*	*Median (range)*	*Mean*	*Median (range)*	*Mean*	*Median (range)*
1	*PoaPlan*	8	6 (2-21)	7	6 (1-21)	8	6 (1-25)	4	4 (2-9)
2	*PersEleo*	4	3 (1-20)	4	3 (1-22)	4	3 (1-24)	5	4 (2-25)
3	*AgroRanu*	4	3 (2-9)	4	3 (2-9)	4	3 (2-9)	4	4 (0-9)
4	*AgroPote*	6	5 (2-18)	6	5 (2-18)	6	5 (2-16)	4	3 (0-25)
5	LimeGras	4	4 (1-12)	4	4 (0-12)	4	4 (0-11)	3	3 (0-12)
6	*EleoRanu*	4	4 (1-9)	5	4 (3-16)	4	3 (3-8)	6	4 (2-12)
7	*EleoPhal*	3	3 (2-5)	3	3 (2-4)	3	3 (2-5)	5	5 (2-9)
8	*CareCpan*	3	3 (1-6)	3	3 (1-6)	3	3 (0-5)	3	4 (0-7)
9	*PhalPote*	3	3 (2-5)	3	3 (1-5)	3	3 (1-5)	4	3 (2-8)
10	*LoliTrif*	6	3 (1-18)	5	3 (1-19)	5	3 (0-16)	3	3 (0-7)
11	*PersMent*	6	4 (1-17)	7	4 (3-17)	7	3 (3-18)	3	3 (1-6)
12	*FiliVici*	3	3 (1-4)	2	2 (1-4)	2	2 (0-4)	3	3 (1-9)
13	*PoteCare*	6	5 (1-14)	6	5 (1-12)	6	5 (1-12)	4	4 (0-11)
14	Reedbed	3	3 (1-9)	4	3 (1-8)	3	3 (1-6)	9	5 (1-21)
15	*LoliAgro*	7	3 (1-21)	7	3 (1-21)	6	4 (1-18)	3	3 (1-7)
16	*EquiMeny*	3	4 (1-4)	3	4 (2-5)	3	3 (1-5)	4	3 (1-8)
17	*CareRanu*	4	3 (1-9)	4	3 (2-9)	4	3 (3-9)	6	4 (0-25)
18	*AgroGlyc*	7	4 (1-19)	7	5 (2-19)	6	5 (2-18)	4	4 (0-9)
19	*PotePote*	7	7 (3-11)	7	7 (3-11)	7	7 (4-11)	4	4 (0-13)
20	*FiliPote*	7	7 (5-9)	7	7 (5-9)	7	7 (5-9)	6	7 (0-9)
21	*Schoenus*	4	4 (3-6)	5	5 (3-6)	4	4 (4-5)	4	4 (3-6)
22	*MoliCare*	4	4 (3-9)	4	4 (3-9)	4	4 (3-8)	5	3 (0-27)
23	*CareScor*	5	4 (3-8)	5	4 (3-8)	5	4 (3-8)	3	3 (0-4)
24	*PotaGlyc*	3	3 (1-5)	3	3 (2-5)	6	5 (3-10)	4	3 (1-10)
25	*CareCvir*	5	4 (2-9)	4	4 (2-6)	4	5 (2-5)	3	3 (1-5)
26	*Eleoacic*	7	7 (6-9)	7	7 (5-9)	7	7 (5-9)	4	4 (3-5)
27	*CareEqui*	6	5 (1-11)	6	5 (1-9)	6	5 (4-8)	4	4 (3-5)
28	FldPavmt	5	5 (3-8)	5	4 (3-9)	5	5 (4-8)	4	3 (2-6)

Table 7.65 *Post-hoc* Mann-Whitney U tests for differences between medians of clusters for frequency of flooding at 0 cm, 10 cm, 25 cm and 50 cm.

Frequency of flooding to 0 cm.							
	1	2	3	4	5	6	7
2	**0.000**						
3	**0.001**	**0.000**					
4	**0.000**	0.004	0.225				
5	**0.000**	0.872	**0.002**	0.065			
6	**0.000**	**0.000**	**0.000**	**0.000**	0.015		
7	0.172	0.771	0.540	0.915	0.441	0.027	
8	**0.000**	0.007	0.219	0.809	0.070	**0.000**	0.027

Frequency of flooding to 10 cm.							
	1	2	3	4	5	6	7
2	**0.000**						
3	**0.002**	**0.000**					
4	**0.000**	0.032	0.166				
5	**0.001**	0.668	0.089	0.254			
6	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**		
7	0.146	0.971	0.409	0.785	0.450	0.018	
8	**0.000**	0.120	0.096	0.382	0.367	**0.000**	0.018

Frequency of flooding to 25 cm.							
	1	2	3	4	5	6	7
2	**0.000**						
3	**0.002**	**0.000**					
4	**0.000**	0.033	0.094				
5	**0.001**	0.850	0.035	0.183			
6	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**		
7	0.141	0.567	0.274	0.756	0.452	0.066	
8	**0.000**	0.086	0.076	0.567	0.187	**0.000**	0.066

Frequency of flooding to 50 cm.							
	1	2	3	4	5	6	7
2	0.294						
3	0.956	0.022					
4	0.011	**0.000**	0.005				
5	0.665	0.677	0.269	0.003			
6	0.060	**0.000**	0.023	0.600	0.009		
7	0.014	**0.000**	0.016	0.826	0.005	0.527	
8	0.126	0.009	0.139	0.254	0.080	0.575	0.527

Figures in bold are significant ($p \leq 0.05$) after correction for multiple comparisons using the Dunn-Šidák method.

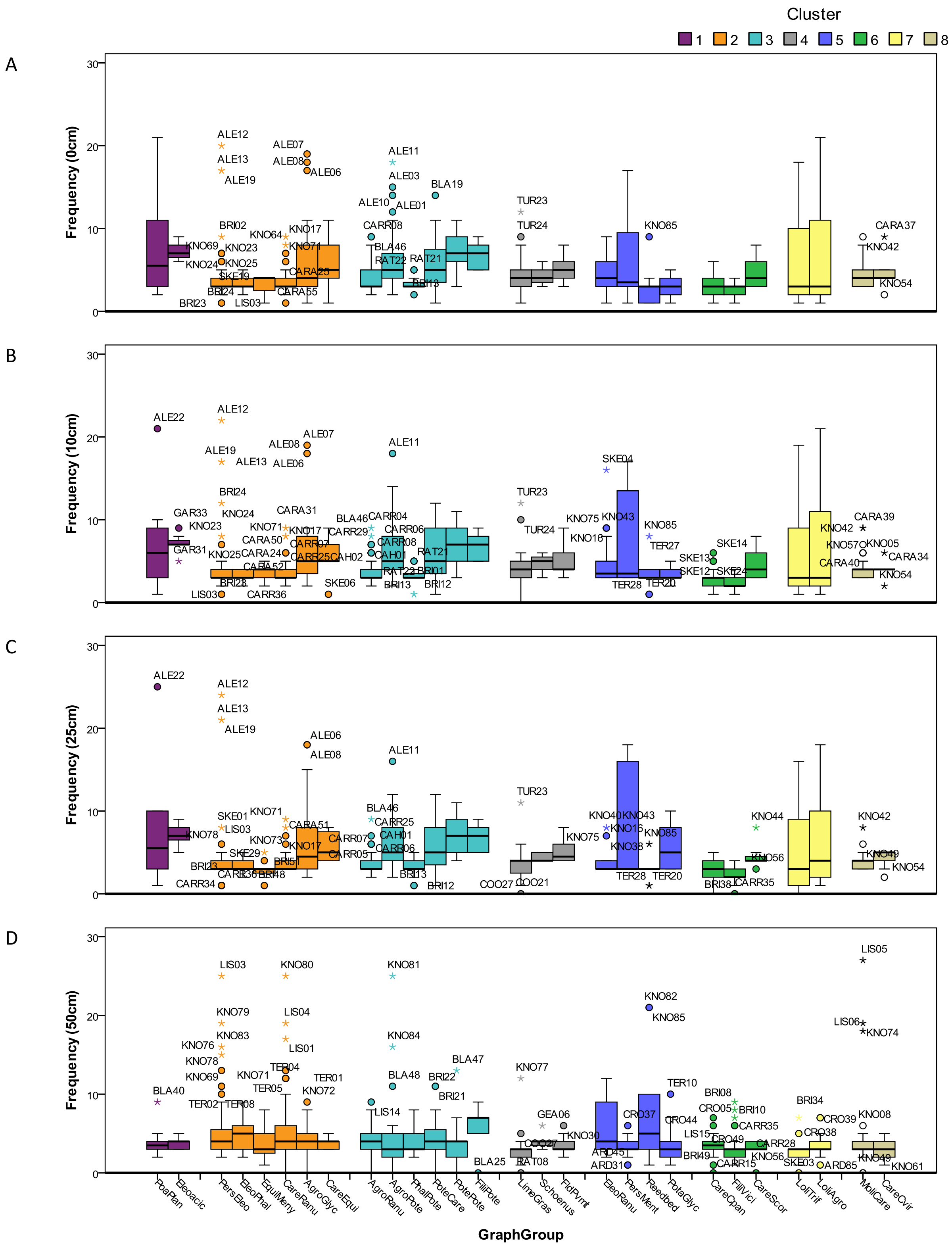


Figure 7.30 (A-D) Boxplots showing the median, interquartile range and highest and lowest values for frequency of flooding at 0 cm, 10 cm, 25 cm and 50 cm for each of the 28 groups. Groups are colour-coded and divided into clusters as shown in the legend.

Duration of flooding

Summary statistics for the combined duration of flooding for 2007 and 2008 for each of the vegetation communities are presented in Table 7.66 and presented graphically in Figure

7.31. A Kruskal-Wallis test was carried out to test for differences between the medians of the groups, and results indicated that there was a highly significant difference between the medians of at least two groups. *Post-hoc* Mann-Whitney U tests were carried out to determine any statistically significant differences between the medians of clusters (Table 7.67).

A number of communities exhibit a wide range of duration of flooding, for example Group 18 *AgroGlyc* had the greatest range, from 120 days to 547 days (Table 7.66).

The two *Lolium* grassland communities (Group 10 *LoliTrif* and Group 15 *LoliAgro*) had the shortest mean duration of flooding at 0cm, at just 107.3 days and 188.0 days. Group 12 *FiliVici* also had a very short mean duration of flooding, at 193.8 days. At the opposite end of the flooding gradient lie Group 14 Reedbed and Group 24 *PotaGlyc*, with mean duration of flooding of 602.5 days and 640.8 days respectively.

Within each cluster, the median durations of flooding for all groups were similar (Figure 7.31), although there were some exceptions. In Cluster 1, the median duration of flooding for Group 26 *Eleoacic* was greater than the median duration of flooding for Group 1 *PoaPlan* for all levels of flooding. Group 26 *Eleoacic*, however, was only recorded in relevés from one turlough, and so has a lesser range of duration than might be expected if it were recorded in a number of turloughs. However, this is a community which occurs on the fringes of permanent water, on a wet, muddy substrate, and so duration of flooding may well be comparable for this community across different turloughs. Cluster 2 has six different vegetation communities, and the medians for these were similar, with the exception of Group 27 *CareEqui*, for which the median was consistently higher at all levels of flooding. In Cluster 6, the median duration of flooding for Group 23 *CareScor* is consistently higher than the other two communities in that cluster.

Cluster 5 contains the four vegetation communities with the highest median duration of flooding. Only Group 27 *CareEqui* reached a comparable duration of flooding. Group 24 *PotaGlyc* had the highest median duration of flooding at 0cm, 10cm, and 25 cm, but at 50cm Group 11 *PersMent* was highest.

Cluster 7 contained the two *Lolium perenne* grasslands, and of these, Group 10 *LoliTrif* had the lowest median duration of flooding at each level. Group 15 *LoliAgro* and Group 12 *FiliVici* had comparable medians at all levels of flooding. While the median duration of flooding for these communities was similar, when the frequency of flooding is examined (Figure 7.30), the *Lolium* grasslands experienced a much greater range of frequency of flooding events than Group 12 *FiliVici.*

In general, clusters 2 and 3 have the greatest numbers of outliers for duration of flooding at all levels of inundation (Figure 7.29 A-D), but especially at 0 cm, 10 cm, and 25 cm. These clusters are comprised of communities with high proportions of amphibious and water-dependent species, such as Group 2 *PersEleo*, and occur in the middle of the duration gradient; these communities might, therefore, be expected to tolerate fluctuations in water level and varying lengths of inundation. These clusters also experience the widest range of frequency of flooding events, with a large number of outliers (Figure 7.30 A-D). The ranges of duration of flooding for some of the other clusters are much tighter, with fewer outliers (Figure 7.31 A-D). This is especially evident at duration of flooding to 50 cm (Figure 7.31 D), where the interquartile ranges are much smaller than at other depths of flooding, and there are few outliers.

Table 7.66. Mean, median and range of duration of flooding for each of the 28 vegetation communities.

		Duration 0 cm (days)		Duration 10 cm (days)		Duration 25 cm (days)		Duration 50 cm (days)	
		Mean	Median (range)	Mean	Median (range)	Mean	Median (range)	Mean	Median (range)
1	*PoaPlan*	311.7	309.2 (133.0-471.0)	302.1	302.4 (99.0-453.0)	291.2	293.3 (84.0-428.0)	267.0	276.1 (7.0-385.0)
2	*PersEleo*	449.4	464.2 (94.0-731.0)	433.8	451.0 (90.0-731.0)	408.4	410.0 (87.0-731.0)	373.0	388.0 (73.0-731.0)
3	*AgroRanu*	309.6	306.0 (123.0-467.0)	309.2	298.0 (110.0-511.3)	292.3	284.8 (91.0-511.3)	246.1	257.0 (11.0-414.8)
4	*AgroPote*	292.3	321.0 (90.0-446.0)	296.9	317.0 (81.0-473.3)	285.6	303.0 (33.0-463.4)	257.5	290.0 (0.0-410.0)
5	LimeGras	278.8	322.4 (11.0-499.0)	254.4	289.0 (0.0-457.0)	223.2	255.0 (0.0-407.0)	173.3	157.0 (0.0-387.0)
6	*EleoRanu*	559.5	564.0 (345.0-731.0)	531.0	542.0 (329.0-729.0)	484.4	508.0 (288.0-599.0)	421.3	419.5 (234.0-554.0)
7	*EleoPhal*	447.6	464.2 (280.0-525.0)	434.1	446.2 (267.0-515.0)	410.8	423.8 (250.0-508.0)	365.1	393.5 (214.0-490.0)
8	*CareCpan*	235.9	265.7 (85.0-414.0)	217.6	255.3 (41.0-401.0)	188.2	202.5 (0.0-389.0)	132.3	106.0 (0.0-365.0)
9	*PhalPote*	379.9	406.4 (114.0-537.0)	369.2	400.3 (98.0-527.0)	353.7	391.8 (87.0-515.0)	324.9	354.0 (32.0-501.0)
10	*LoliTrif*	107.3	93.0 (10.0-223.0)	96.8	82.0 (7.0-214.0)	75.7	64.0 (0.0-195.0)	58.0	34.0 (0.0-158.0)
11	*PersMent*	553.1	542.9 (315.0-731.0)	531.4	531.5 (297.0-668.0)	511.5	522.2 (273.0-638.0)	487.5	510.7 (208.0-615.0)
12	*FiliVici*	193.8	190.0 (20.0-381.0)	180.8	183.0 (13.0-359.0)	160.3	141.0 (0.0-330.0)	127.7	98.7 (0.0-284.0)
13	*PoteCare*	402.4	419.0 (111.0-731.0)	395.1	417.0 (95.0-731.0)	380.3	399.0 (78.0-731.0)	348.7	389.0 (45.0-546.0)
14	Reedbed	602.5	594.0 (403.0-731.0)	583.4	564.0 (394.0-731.0)	552.9	520.3 (387.0-731.0)	484.6	481.0 (360.0-623.0)
15	*LoliAgro*	188.0	204.0 (26.0-337.0)	175.6	188.0 (21.0-320.0)	156.9	158.0 (12.0-293.0)	123.1	109.0 (0.0-252.0)
16	*EquiMeny*	436.8	479.0 (189.0-731.0)	402.3	460.0 (142.0-555.0)	366.4	414.0 (98.0-507.0)	307.4	313.0 (77.0-468.6)
17	*CareRanu*	479.9	466.0 (331.0-731.0)	449.3	423.0 (314.0-711.0)	406.3	401.0 (274.0-660.0)	352.7	359.0 (214.0-485.0)
18	*AgroGlyc*	385.4	372.5 (135.0-731.0)	358.1	359.5 (120.0-547.0)	332.8	348.5 (102.0-521.0)	298.8	317.0 (82.0-494.0)
19	*PotePote*	357.6	371.0 (271.0-400.0)	355.2	370.0 (269.0-397.0)	351.5	368.0 (261.0-392.0)	345.6	362.0 (255.0-388.0)
20	*FiliPote*	306.8	317.0 (234.0-353.0)	304.2	314.0 (228.0-352.0)	299.5	307.0 (219.0-346.0)	292.9	301.0 (211.0-341.0)
21	*Schoenus*	305.4	312.0 (202.8-394.4)	287.1	286.0 (165.3-386.3)	257.9	270.0 (102.4-373.1)	214.3	248.0 (64.9-349.8)
22	*MoliCare*	422.3	413.0 (277.0-629.0)	399.2	394.0 (258.0-592.0)	371.0	379.0 (225.0-530.0)	318.7	333.0 (108.0-414.0)
23	*CareScor*	438.2	394.0 (364.0-585.0)	419.7	389.0 (355.0-548.0)	387.9	375.0 (342.0-471.0)	350.7	353.0 (286.0-399.0)
24	*PotaGlyc*	640.8	685.0 (391.0-731.0)	611.3	655.0 (371.0-727.0)	537.5	536.0 (337.0-668.0)	443.0	457.0 (293.0-493.0)
25	*CareCvir*	411.9	481.0 (71.0-536.0)	392.9	468.0 (64.0-481.0)	358.1	421.0 (46.0-457.0)	297.8	360.0 (7.0-385.0)
26	*Eleoacic*	449.9	466.5 (311.0-498.0)	441.8	455.0 (305.0-491.0)	428.3	438.0 (297.0-477.0)	411.7	424.5 (288.0-450.0)
27	*CareEqui*	543.6	556.0 (299.0-731.0)	526.1	543.0 (294.0-731.0)	478.7	508.0 (287.0-545.0)	428.1	453.0 (265.0-495.0)
28	FldPavmt	390.3	359.0 (288.0-640.0)	370.7	350.5 (274.0-603.0)	344.8	328.5 (262.0-546.0)	305.9	277.5 (238.0-418.0)

Table 7.67. Mann-Whitney U test results for duration of flooding for 8 clusters.

Duration of flooding to 0 cm.							
	1	2	3	4	5	6	7
2	0.013						
3	0.005	**0.000**					
4	0.009	**0.000**	0.524				
5	**0.000**	**0.000**	**0.000**	**0.000**			
6	**0.000**	**0.000**	**0.000**	0.007	**0.000**		
7	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	
8	0.506	0.037	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Duration of flooding to 10 cm.							
	1	2	3	4	5	6	7
2	0.046						
3	0.017	**0.000**					
4	**0.002**	**0.000**	0.079				
5	**0.000**	**0.000**	**0.000**	**0.000**			
6	**0.000**	**0.000**	**0.000**	0.010	**0.000**		
7	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	
8	0.910	0.027	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Duration of flooding to 25 cm.							
	1	2	3	4	5	6	7
2	0.221						
3	0.015	**0.000**					
4	**0.000**	**0.000**	0.006				
5	**0.000**	**0.000**	**0.000**	**0.000**			
6	**0.000**	**0.000**	**0.000**	0.020	**0.000**		
7	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	
8	0.365	0.013	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Duration of flooding to 50 cm.							
	1	2	3	4	5	6	7
2	0.912						
3	**0.002**	**0.000**					
4	**0.000**	**0.000**	**0.000**				
5	**0.000**	**0.000**	**0.000**	**0.000**			
6	**0.000**	**0.000**	**0.000**	0.038	**0.000**		
7	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.039	
8	0.024	0.004	0.059	**0.000**	**0.000**	**0.000**	**0.000**

Figures in bold are significant ($p \leq 0.05$) after correction for multiple comparisons using the Dunn-Šidák method.

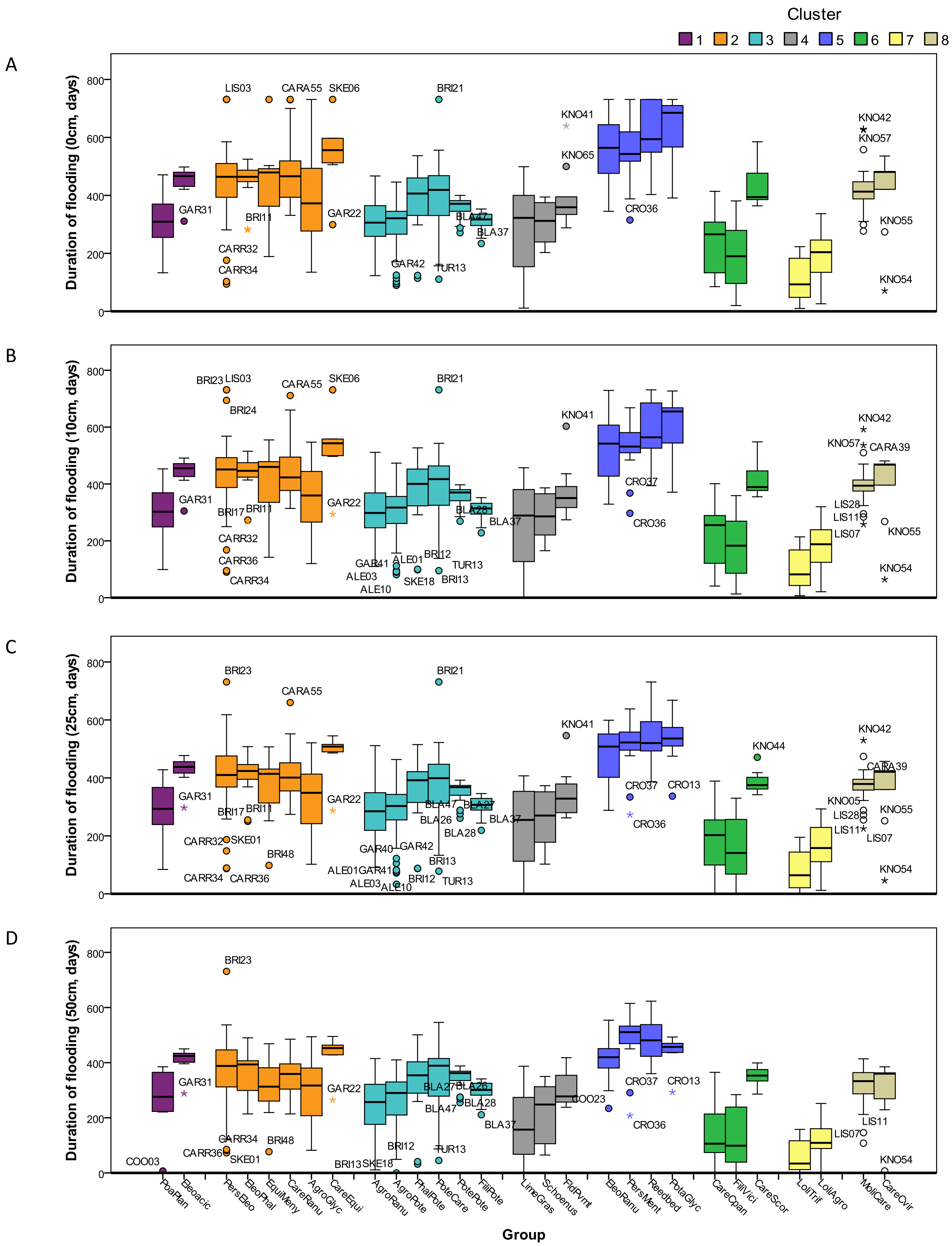


Figure 7.31 (A-D) Boxplots showing the median, interquartile range and highest and lowest values for duration of flooding to 0 cm, 10 cm, 25 cm and 50 cm for each of the 28 groups. Groups are colour-coded and divided into clusters as shown in the legend.

There was a large amount of inter-annual variation in duration of flooding (Figure 7.32), as has been reported in other studies on turloughs. In this study, the mean duration over two years was taken to be representative of the hydrological regime, as in other studies (for example Moran *et al.*, 2008, used the mean duration of flooding over three years). Duration of flooding was always greater in 2008 than 2007, but for some clusters there was relatively little difference (Clusters 6 and 7) while the difference was greater for others (Clusters 4, 8 and 9).

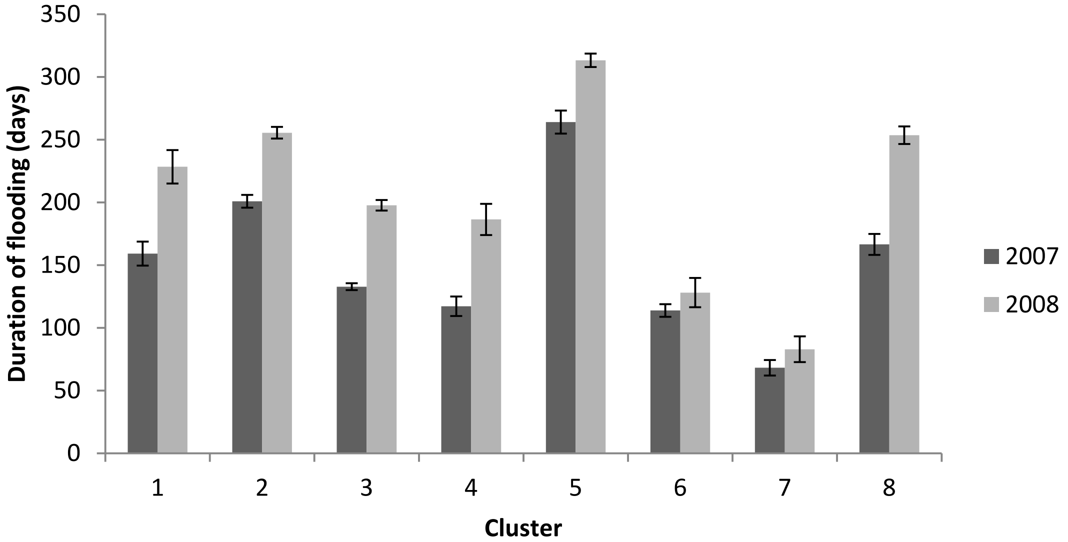


Figure 7.32 Mean duration of inundation to 0 cm (± standard error) for 2007 and 2008.

Length of longest dry period

This variable is the length of the longest continuous dry period for each relevé over the entire recording period (3 years), presented as a percentage. This extends beyond the time period for the rest of the hydrological data, but was chosen to examine the extremes of hydrological regime to which the vegetation communities may be subjected. Results are presented in Table 7.68 and Figure 7.33. A Kruskal-Wallis test indicated that there were significant differences between the medians of at least two of the groups. *Post-hoc* Mann-Whitney U tests were carried out on the cluster medians (Table 7.70). Group 8 *CareCpan* had the longest mean continuous dry period, at 72.8% of the recorded time, but relevés in this community experienced a wide range of longest dry period, from 11.9% to 84.8%. Group 14 Reedbed, Group 24 *PotaGlyc* and Group 26 *Eleoacic* were the communities with the shortest mean length of continuous dry period (6.2% to 9%; Table 7.69). In general, the interquartile ranges for each of the communities were quite small (Figure 7.31 A), although there were also a large number of outliers, mainly from Coolcam, Carrowreagh, Brierfield, Garryland and Rathnalulleagh.

Start of longest wet period and longest dry period

The start of the longest wet period and longest dry periods were presented as Julian days (Table 7.69, Figure 7.31). Table 7.68 shows the range of Julian days which correspond to each calendar month. Most communities experienced a range of starting dates for longest wet period. A Kruskal-Wallis test indicated that there were significant differences between the medians of at least two of the groups. *Post-hoc* Mann-Whitney U tests were carried out on the cluster medians (Table 7.70). Group 27 *CareEqui* had the earliest median start date for longest wet period, at 214 (early August). Group 10 *LoliTrif* and Group 15 *LoliAgro* had the latest median start date for longest wet period, at 337 and 348 (December) respectively. Cluster 7 (Group 10 *LoliTrif* and Group 15 *LoliAgro*) also had the earliest median start date for longest dry period, at 75 and 82 Julian days (March). Group 26 *Eleoacic* had the latest median start date for longest dry period, at 246 Julian days (September).

Table 7.68. Relationship between Julian days and months.

Julian day	*Month*
1-31	January
32-59	February
60-90	March
91-120	April
121-151	May
152-181	June
182-212	July
213-243	August
244-273	September
274-304	October
305-334	November
335-365	December

Maximum depth

Summary statistics for maximum depth of inundation for each of the 28 vegetation communities are presented in Table 7.69 and Figure 7.31. A Kruskal-Wallis test indicated that there were significant differences between the medians of at least two of the groups. *Post-hoc* Mann-Whitney U tests were carried out on the cluster medians (Table 7.70).

The communities with the greatest median maximum depth were Group 26 *Eleoacic*, Group 19 *PotePote* and Group 20 *FiliPote* (Table 7.69, Figure 7.31). These groups were all found in Garryland and Blackrock turloughs, which are two of the deepest turloughs. Apart from a single outlier, a very narrow range of maximum depths were associated with Group 26 *Eleoacic*; these relevés were all recorded from Garryland turlough, at similar elevations within the turlough. Group 19 *PotePote* was associated with the greatest median maximum depth (10.68m).

The communities with the lowest median maximum depth were Group 8 *CareCpan*, Group 10 *LoliTrif*, and Group 12 *FiliVici*, all of which had median maximum depths of less than one metre.

Table 7.69. Summary statistics for length of longest dry period (%), start of longest wet and dry periods (Julian days) and maximum depth of flooding for each of the vegetation communities.

		Length of longest dry period		Start of longest wet period (Julian days)		Start of longest dry period (Julian days)		Maximum depth (m)	
		Mean	Median (range)	Mean	Median (range)	Mean	Median (range)	Mean	Median (range)
1	*PoaPlan*	26.3	26.1 (6.1-48.3)	296	329 (8-362)	108	111 (75-159)	3.35	3.11 (0.28-6.72)
2	*PersEleo*	24.9	21.5 (0-52.6)	282	292 (221-345)	151	161 (0-274)	2.68	2.74 (0.58-4.67)
3	*AgroRanu*	28.5	24.4 (9.9-51.4)	310	325 (0-352)	116	109 (51-307)	2.87	2.27 (0.41-6.94)
4	*AgroPote*	22.7	23.6 (8.3-50)	290	322 (6-362)	90	85 (56-248)	4.61	4.44 (0.50-10.23)
5	LimeGras	30.1	24.4 (6.1-90.2)	253	284 (7-362)	113	103 (24-352)	1.42	1.55 (0.05-3.10)
6	*EleoRanu*	14.7	9.2 (0-27.8)	246	229 (173-348)	170	194 (0-266)	2.74	2.58 (1.18-5.20)
7	*EleoPhal*	19.9	21.9 (11.7-26.5)	322	323 (307-342)	182	181 (136-222)	2.64	2.38 (1.08-4.28)
8	*CareCpan*	72.8	31 (11.9-84.8)	278	327 (8-350)	98	105 (34-149)	1.05	0.96 (0.02-2.92)
9	*PhalPote*	27.1	25.2 (9.1-52)	277	323 (6-335)	143	153 (45-223)	2.86	3.07 (0.28-4.95)
10	*LoliTrif*	41.4	37.9 (27.1-84.1)	226	337 (8-362)	95	75 (13-351)	0.99	0.93 (0.02-2.48)
11	*PersMent*	11.7	13.4 (0-25)	297	309 (226-320)	150	163 (0-273)	4.33	4.80 (0.98-6.21)
12	*FiliVici*	46.5	36 (21.3-90.5)	234	334 (2-364)	101	102 (34-144)	1.18	0.95 (0.04-2.54)
13	*PoteCare*	20.1	10.3 (0-34.6)	259	225 (7-362)	131	100 (0-258)	5.14	3.70 (0.64-13.33)
14	Reedbed	9	11.8 (0-22.4)	266	245 (215-309)	119	136 (0-218)	2.91	2.85 (2.12-5.11)
15	*LoliAgro*	37	27.7 (15.4-90.2)	282	348 (6-362)	101	82 (37-352)	1.36	1.30 (0.01-2.64)
16	*EquiMeny*	24.9	16.4 (0-46.3)	312	326 (228-364)	161	182 (0-253)	1.77	1.77 (0.44-4.29)
17	*CareRanu*	23.8	14.8 (0-23.9)	253	237 (170-344)	160	160 (0-257)	1.93	1.90 (1.04-3.41)
18	*AgroGlyc*	28.9	23.4 (0-31.2)	283	315 (213-342)	125	109 (0-273)	2.87	2.28 (1.05-10.57)
19	*PotePote*	15.5	13.4 (9.6-27.1)	305	319 (224-322)	114	94 (76-242)	10.23	10.68 (7.19-12.67)
20	*FiliPote*	18.9	15.7 (13.8-27.8)	321	321 (320-322)	81	81 (74-86)	8.56	8.61 (6.17-10.56)
21	*Schoenus*	26.4	24.6 (23.4-30.7)	204	228 (0-362)	95	95 (82-108)	1.84	2.00 (1.07-2.49)
22	*MoliCare*	49.4	12 (3.9-27.6)	238	228 (213-323)	122	117 (96-241)	2.26	2.28 (0.66-3.42)
23	*CareScor*	17.7	22.7 (4.3-23.6)	240	227 (216-283)	114	108 (101-135)	2.82	2.75 (2.40-3.30)
24	*PotaGlyc*	6.2	3.1 (0-21.1)	239	266 (170-283)	150	192 (0-237)	2.25	2.35 (1.35-2.56)
25	*CareCvir*	15.4	8.6 (8.3-52.5)	252	228 (227-344)	122	138 (54-140)	1.80	2.00 (0.54-2.10)
26	*Eleoacic*	9.9	8.4 (8.1-24.2)	231	222 (222-323)	208	246 (88-247)	9.40	9.74 (6.10-10.12)
27	*CareEqui*	25.4	6.9 (0-24.5)	235	214 (186-324)	157	130 (0-266)	6.19	5.88 (2.05-10.59)
28	FldPavmt	20.1	23.8 (3.7-24.7)	276	284 (213-326)	121	100 (94-273)	2.49	2.34 (1.92-3.45)

Table 7.70. Mann-Whitney U test results for lengths of longest dry period, start of longest wet and dry periods and maximum quadrat depth for 8 clusters.

Length of longest dry period.							
	1	2	3	4	5	6	7
2	0.886						
3	0.006	**0.000**					
4	0.003	**0.000**	0.127				
5	0.005	**0.000**	**0.000**	**0.000**			
6	**0.000**	**0.000**	**0.000**	**0.001**	**0.000**		
7	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.162	
8	0.538	0.974	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Start of longest wet period (Julian days).							
	1	2	3	4	5	6	7
2	0.197						
3	0.020	**0.000**					
4	0.306	0.647	0.018				
5	0.951	0.019	**0.000**	0.377			
6	0.110	0.023	0.523	0.094	0.004		
7	0.034	**0.000**	**0.002**	0.003	**0.000**	0.020	
8	0.620	**0.000**	**0.000**	0.006	0.013	**0.001**	**0.001**

Start of longest dry period (Julian days).							
	1	2	3	4	5	6	7
2	0.883						
3	**0.002**	**0.000**					
4	0.009	**0.000**	0.796				
5	0.951	0.221	**0.000**	**0.000**			
6	0.004	**0.000**	0.912	0.762	**0.000**		
7	**0.000**	**0.000**	**0.000**	0.003	**0.000**	0.004	
8	0.270	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.000**

Maximum depth.							
	1	2	3	4	5	6	7
2	**0.000**						
3	0.016	**0.000**					
4	**0.000**	**0.000**	**0.000**				
5	**0.000**	**0.000**	0.005	**0.000**			
6	**0.000**	**0.000**	**0.000**	0.010	**0.000**		
7	**0.000**	**0.000**	**0.000**	0.004	**0.000**	0.688	
8	**0.000**	0.647	**0.000**	0.003	**0.000**	**0.000**	**0.000**

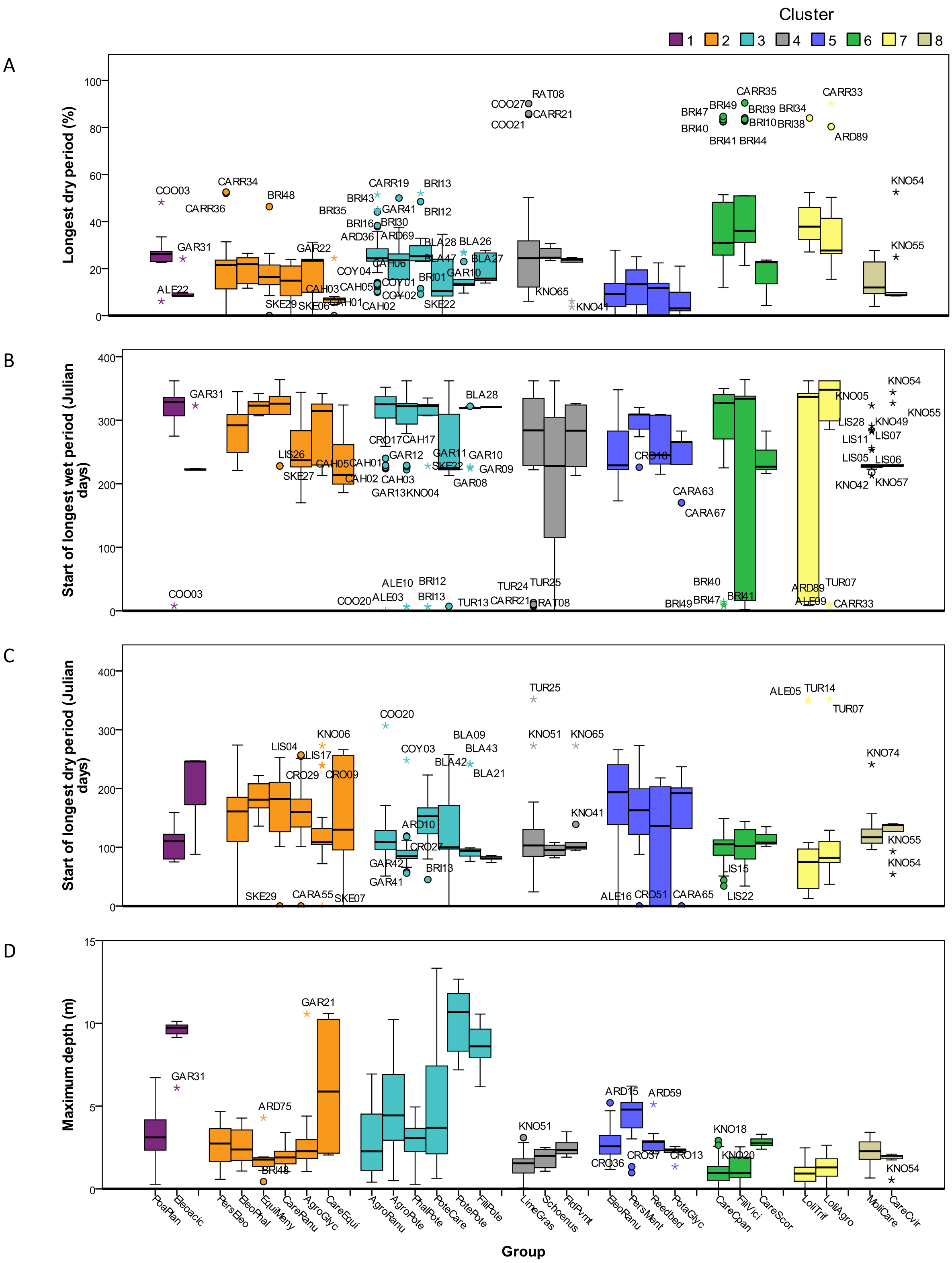


Figure 7.33 (A-D). Boxplots showing the median, interquartile range and highest and lowest values for the length of the longest dry period, and the beginning of the longest dry and wet periods and maximum depth of inundation for each of the 28 groups. Groups are colour-coded and divided into clusters as shown in the legend.

7.5.4.2 Soils

Soil chemistry

Soil chemistry data for each turlough are presented in Table 7.71; these are the means of the soil chemistry of the upper middle and lower zones within the turlough (see *Chapter 6: Soils and Landuse* for further details). Summary statistics for each of the variables for each vegetation community are shown in Table 7.73, Figure 7.34 and Figure 7.35. A Kruskal-Wallis test was carried out to test for differences between group medians, which indicated that there are significant differences between the medians of at least two groups, for each of the soil chemistry variables. Mann-Whitney U tests were then carried out to test for significant differences in median values between clusters (Table 7.74).

Lough Aleenaun had the highest mean total phosphorus (1594 mg kg^{-1}; Table 7.71), while Coolcam had the lowest (245 mg kg^{-1}). These two turloughs can be seen as outliers on the boxplot of soil total phosphorus for each vegetation community (Figure 7.34 A). Group 14 Reedbed had the lowest median total phosphorus, at 475.5 mg kg^{-1}, while Group 19 *PotePote* and Group 20 *FiliPote* had the highest median total phosphorus, at 1123.0 mg kg^{-1}.

Mean soil total nitrogen ranged from 4,983 mg kg^{-1} (Coolcam turlough) to 24,233 mg kg^{-1} for Knockaunroe and 22,383 mg kg^{-1} for Skealoghan (Table 7.71). Knockaunroe and Skealoghan can be seen as outliers towards the top of the nitrogen gradient on the boxplot of soil total nitrogen for each vegetation community (Figure 7.34 B), while relevés from Coolcam are evident outliers towards the bottom of the gradient. Group 19 *PotePote* and Group 20 *FiliPote* have the lowest total nitrogen (7050 mg kg^{-1}; Table 7.73, Figure 7.34 B), while Group 22 *MoliCare*, Group 23 *CareScor* and Group 28 FldPavmt had the highest median total nitrogen (24233 mg kg^{-1}).

Mean soil pH ranged from 5.9 for Garryland to 8.3 for Termon (Table 7.71). Group 26 *Eleoacic* and Group 27 *CareEqui* were associated with a low median pH (5.9; Table 7.73, Figure 7.34 C), while the community with the highest median pH was Group 14 Reedbed (8.3).

There was a wide range of mean soil organic matter, ranging from 10.2% in Coolcam to 69.1% in Knockaunroe (Table 7.71). Group 19 *PotePote* and Group 20 *FiliPote* had the lowest median organic matter content (14.6; Table 7.73, Figure 7.35 A), while Group 22 *MoliCare*, Group 23 *CareScor* and Group 28 FldPavmt had the highest organic matter content (69.1). Mean soil inorganic matter content ranges from 25.7% in Knockaunroe to 85.0% in Coolcam (Table 7.71). Group 22 *MoliCare*, Group 23 *CareScor* and Group 29 FldPavmt all had the lowest median inorganic matter content (25.7%; Table 7.73, Figure 7.35B), while Group 19 *PotePote* and Group 20 *FiliVici* had the highest (80.4%).

Mean soil $CaCO_3$ ranged from 2.5% dry weight in Turloughmore to almost half of the dry weight of the soil (42.5%) in Lisduff (Table 7.71). Group 4 *AgroPote*, Group 19 *PotePote* and Group 20 *FiliPote* all had low median $CaCO_3$ content (5.0% dry weight; Tbale 7.73, Figure 7.35 C), while Group 14 Reedbed had the highest (42.4% dry weight).

Table 7.71. Soil nutrient variables (mean and standard deviation) for each of the 22 turloughs.

Turlough	*Abbreviation*	*Total phosphorus (mg kg^{-1})*		*Total nitrogen (mg kg^{-1})*		*pH*		*Organic matter (% dry weight)*		*Inorganic matter (% dry weight)*		*$CaCO_3$ (% dry weight)*	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Lough Aleenaun	ALE	1594	670	12077	5042	7.6	0.5	24.1	9.8	38.2	25.8	37.7	30.3
Ardkill	ARD	844	121	15400	4042	7.8	0.3	36.2	10.3	31.0	4.4	32.8	12.3
Ballindereen	BAL	761	137	9708	1231	8.0	0.2	21.5	4.3	39.9	11.4	38.6	14.5
Blackrock	BLA	1123	618	7050	1388	6.6	0.2	14.6	2.6	80.4	3.1	5.0	0.7
Brierfield	BRI	939	237	19458	10574	7.2	0.9	44.6	23.9	35.8	29.1	19.6	22.5
Caherglassan	CAH	1016	449	6263	884	6.4	0.7	13.8	1.7	81.8	2.3	4.4	1.7
Caranavoodaun	CARA	814	365	15893	7540	8.0	0.2	38.0	18.5	27.5	16.2	34.6	31.4
Carrowreagh	CARR	1056	304	11783	5105	6.1	0.4	27.4	13.0	66.6	19.7	6.0	8.2
Coolcam	COO	245	36	4983	1191	7.8	0.6	10.2	3.3	85.0	4.4	4.8	4.7
Lough Coy	COY	1163	402	7069	2234	6.6	0.6	14.5	4.6	81.5	5.6	4.0	1.1
Croaghill	CRO	896	391	15883	11881	6.8	0.8	41.6	27.8	54.6	28.8	3.8	2.4
Garryland	GAR	920	270	9756	3379	5.9	0.6	22.6	8.4	71.6	8.6	5.8	0.4
Lough Gealain	GEA	578	220	21917	8630	7.5	0.8	38.1	18.3	41.9	23.6	20.0	28.4
Kilglassan	KIL	1226	495	17450	4918	7.4	0.5	34.0	10.4	44.5	8.0	21.5	11.9
Knockaunroe	KNO	1080	410	24233	9468	7.1	0.6	69.1	15.5	25.7	13.4	5.2	2.5
Lisduff	LIS	432	187	9234	2204	8.0	0.2	23.7	5.6	33.8	31.1	42.5	26.9
Rathnalulleagh	RAT	713	352	7958	3572	6.2	0.6	18.4	6.8	78.0	8.3	3.5	1.5
Roo West	ROO	716	193	14000	2945	7.2	0.7	29.1	10.5	55.1	19.4	15.8	21.0
Skealoghan	SKE	1059	288	22383	10719	7.0	0.7	53.4	25.4	39.9	26.2	6.7	6.2
Termon	TER	476	165	8217	2785	8.3	0.1	23.0	5.1	34.6	27.8	42.4	26.3
Tullynafrankagh	TUL	616	222	10050	4917	7.9	0.2	29.7	12.8	26.6	10.3	43.7	10.3
Turloughmore	TUR	915	328	8233	1725	6.6	0.5	18.8	2.6	78.7	2.8	2.5	0.4

Table 7.72. Summary statistics for soil chemistry variables.

		Total phosphorus (mg kg^{-1})		Total nitrogen (mg kg^{-1})		pH		Organic matter (% dry weight)		Inorganic matter (% dry weight)		$CaCO_3$ (% dry weight)	
		Mean	Median (range)	Mean	Median (range)	Mean	Median (range)	Mean	Median (range)	Mean	Median (range)	Mean	Median (range)
1	*PoaPlan*	964.9	985.6 (244.7-1594.3)	10673	11783 (4983-15400)	6.9	6.6 (6.1-7.8)	24.1	25.8 (10.2-36.2)	62.3	66.6 (31.0-85.0)	13.6	6.0 (2.5-37.7)
2	*PersEleo*	902.5	895.6 (244.7-1594.3)	16590	15400 (4983-24233)	7.4	7.2 (6.1-8.3)	41.6	36.2 (10.2-69.1)	38.0	33.8 (25.7-85.0)	20.4	19.6 (3.8-42.5)
3	*AgroRanu*	899.6	919.9 (244.7-1163.4)	12027	11783 (4983-22383)	6.9	6.8 (5.9-8.3)	28.5	27.4 (10.2-53.4)	59.1	66.6 (31.0-85.0)	12.5	5.8 (3.5-42.5)
4	*AgroPote*	1071.6	1080.3 (713-1594.3)	10230	7958 (6263-24233)	6.6	6.6 (5.9-7.8)	23.9	18.4 (13.8-69.1)	68.3	78.7 (25.7-81.8)	7.9	5.0 (2.5-37.7)
5	LimeGras	842.3	814.3 (244.7-1080.3)	15774	15893 (4983-24233)	7.4	7.8 (6.1-8.0)	38.9	38.0 (10.2-69.1)	41.5	27.5 (25.7-85.0)	19.5	20.0 (2.5-34.6)
6	*EleoRanu*	774.9	869.8 (244.7-1080.3)	15992	15642 (4983-24233)	7.5	7.4 (6.8-8.3)	43.1	38.9 (10.2-69.1)	38.2	33.8 (25.7-85.0)	18.7	5.2 (3.8-42.5)
7	*EleoPhal*	894.4	939.2 (844.1-939.2)	17549	19458 (15400-19458)	7.5	7.2 (7.2-7.8)	40.6	44.6 (36.2-44.6)	33.5	35.8 (31.0-35.8)	25.9	19.6 (19.6-32.8)
8	*CareCpan*	891.6	939.2 (244.7-1080.3)	15865	15883 (4983-24233)	7.0	7.0 (6.1-8.0)	38.8	41.6 (10.2-69.1)	46.3	39.9 (25.7-85.0)	14.9	6.7 (3.8-42.5)
9	*PhalPote*	859.0	844.1 (713.0-1059.3)	15667	15400 (7958-22383)	7.4	7.8 (6.2-7.8)	36.6	36.2 (18.4-53.4)	38.3	31.0 (31.0-78.0)	25.1	32.8 (3.5-32.8)
10	*LoliTrif*	1063.0	939.2 (713.0-1594.3)	12081	11783 (7958-22383)	6.9	6.6 (6.1-7.8)	27.1	24.1 (18.4-53.4)	57.5	66.6 (31.0-78.7)	15.4	6 (2.5-37.7)
11	*PersMent*	1091.4	895.6 (844.1-1594.3)	14482	15400 (12077-15883)	7.5	7.6 (6.8-7.8)	33.8	36.2 (24.1-41.6)	39.1	38.2 (31.0-54.6)	27.1	32.8 (3.8-37.7)
12	*FiliVici*	819.1	844.1 (244.7-1056.2)	13923	15400 (4983-19458)	7.2	7.2 (6.1-8.0)	32.7	36.2 (10.2-44.6)	48.6	35.8 (27.5-85.0)	18.7	19.6 (3.5-34.6)
13	*PoteCare*	931.9	919.9 (244.7-1163.4)	10312	9756 (4983)	6.7	6.6 (5.9-8.0)	23.8	22.6 (10.2-44.6)	65.5	71.6 (31.0-85.0)	10.7	5.8 (2.5-42.5)
14	Reedbed	650.9	475.5 (475.5-1080.3)	12574	8217 (8217-24233)	8.0	8.3 (7.1-8.3)	34.7	23.0 (23.0-69.1)	32.3	34.6 (25.7-34.6)	33.1	42.4 (5.2-42.4)
15	*LoliAgro*	916.5	915.0 (244.7-1594.3)	11022	8233 (4983-15883)	7.0	6.6 (6.1-7.8)	25.6	18.8 (10.2-41.6)	60.9	78.0 (31.0-85.0)	13.6	3.8 (2.5-37.7)
16	EquiMeny	906.3	939.2 (432.1-1059.3)	18692	19458 (9234-22383)	7.3	7.2 (7.0-8.0)	43.5	44.6 (23.7-53.4)	35.9	35.8 (31.0-39.9)	20.6	19.6 (6.7-42.5)
17	CareRanu	708.4	814.3 (244.7-1080.3)	14207	15883 (4983-24233)	7.7	8.0 (6.8-8.3)	36.5	38.0 (10.2-69.1)	40.6	33.8 (25.7-85.0)	22.9	34.6 (3.8-42.5)
18	AgroGlyc	1020.4	1056.2 (432.1-1594.3)	14859	12077 (7958-24233)	6.8	6.9 (5.9-8.0)	36.2	27.4 (18.4-69.1)	51.2	47.3 (25.7-78.0)	12.6	6.0 (3.5-42.5)
19	PotePote	1090.5	1123.0 (919.9-1123.0)	7483	7050 (7050-9756)	6.5	6.6 (5.9-6.6)	15.9	14.6 (14.6-22.6)	79.0	80.4 (71.6-80.4)	5.1	5.0 (5-5.8.0)
20	FiliPote	1123.0	1123.0 (1123)	7050	7050 (7050)	6.6	6.6 (6.6)	14.6	14.6 (14.6-14.6)	80.4	80.4 (80.4)	5.0	5.0 (5.0)
21	Schoenus	721.3	577.7 (577.7-1080.3)	22579	21917 (21917-24233)	7.4	7.5 (7.1-7.5)	47.0	38.1 (38.1-69.1)	37.3	41.9 (25.7-41.9)	15.7	20.0 (5.2-20.0)
22	MoliCare	901.5	1080.3 (432.1-1080.3)	19433	24233 (9234-24233)	7.5	7.1 (7.1-8.0)	52.8	69.1 (23.7-69.1)	27.5	25.7 (25.7-33.8)	19.7	5.2 (5.2-42.5)
23	CareScor	1080.3	1080.3 (1080.3)	24233	24233 (24233)	7.1	7.1 (7.1)	69.1	69.1 (69.1)	25.7	25.7 (25.7)	5.2	5.2 (5.2)
24	PotaGlyc	794.7	814.3 (475.5-895.6)	15038	15893 (8217-15893)	7.8	8.0 (6.8-8.3)	37.1	38.0 (23.0-41.6)	34.3	27.5 (27.5-54.6)	28.6	34.6 (3.8-42.4)
25	CareCvir	873.4	814.3 (814.3-1080.3)	17747	15893 (15893-24233)	7.8	8.0 (7.1-8.0)	44.9	38.0 (38.0-69.1)	27.1	27.5 (27.5)	28	34.6 (5.2-34.6)
26	Eleoacic	919.9	919.9 (919.9)	9756	9756 (9756)	5.9	5.9 (5.9)	22.6	22.6 (22.6-22.6)	71.6	71.6 (71.6)	5.8	5.8 (5.8)
27	CareEqui	800.4	919.9 (432.1-1059.3)	11411	9756 (9234-22383)	6.7	5.9 (5.9-8.0)	27.3	22.6 (22.6-53.4)	56.3	71.6 (33.8-71.6)	16.4	5.8 (5.8-42.5)
28	FldPavmt	1080.3	1080.3 (1080.3)	24233	24233 (24233)	7.1	7.1 (7.1)	69.1	69.1 (69.1)	25.7	25.7 (25.7)	5.2	5.2 (5.2)

Table 7.73. *Post-hoc* Mann-Whitney U tests for differences between clusters for soil variables.

Total phosphorus (mg kg^{-1})	1	2	3	4	5	6	7
2	0.186						
3	0.184	**0.000**					
4	0.173	0.698	**0.000**				
5	0.021	0.640	**0.000**	0.577			
6	0.625	0.299	**0.000**	0.728	0.230		
7	0.093	0.235	0.033	0.258	0.032	0.815	
8	0.561	0.309	**0.002**	0.416	0.520	0.607	0.618

Total nitrogen (mg kg^{-1})	1	2	3	4	5	6	7
2	**0.000**						
3	0.432	**0.000**					
4	**0.000**	**0.000**	**0.000**				
5	**0.002**	0.354	**0.000**	**0.000**			
6	**0.000**	0.938	**0.000**	0.003	0.520		
7	0.597	**0.000**	0.026	**0.000**	0.004	**0.000**	
8	**0.000**	**0.000**	**0.000**	0.358	**0.000**	**0.000**	**0.000**

pH	1	2	3	4	5	6	7
2	**0.000**						
3	**0.000**	**0.000**					
4	**0.000**	0.585	**0.000**				
5	**0.000**	0.052	**0.000**	0.038			
6	**0.000**	**0.001**	**0.000**	0.025	**0.000**		
7	**0.000**	**0.000**	0.082	**0.001**	**0.000**	0.146	
8	**0.000**	0.097	**0.000**	0.026	0.968	**0.000**	**0.000**

Organic matter (% dry weight)	1	2	3	4	5	6	7
2	**0.000**						
3	0.493	**0.000**					
4	**0.000**	0.023	**0.000**				
5	**0.000**	0.436	**0.000**	0.021			
6	**0.000**	0.683	**0.000**	0.079	0.314		
7	0.768	**0.000**	0.044	**0.000**	**0.000**	**0.000**	
8	**0.000**	**0.000**	**0.000**	0.358	**0.000**	0.003	**0.000**

Inorganic matter (% dry weight)	1	2	3	4	5	6	7
2	**0.000**						
3	0.404	**0.000**					
4	**0.000**	0.020	**0.000**				
5	**0.000**	0.065	**0.000**	0.083			
6	**0.000**	0.181	**0.000**	**0.002**	0.012		
7	0.630	**0.000**	0.031	**0.000**	**0.000**	**0.000**	
8	**0.000**	**0.000**	**0.000**	0.017	**0.000**	**0.000**	**0.000**

$CaCO_3$ (% dry weight)	1	2	3	4	5	6	7
2	0.006						
3	0.098	**0.000**					
4	0.635	0.085	**0.000**				
5	0.031	0.284	**0.000**	0.018			
6	0.172	0.008	**0.002**	0.545	0.004		
7	0.630	**0.000**	0.239	0.050	**0.000**	0.045	
8	0.216	0.485	**0.000**	0.039	0.968	0.016	**0.001**

Figures in bold are significant ($p \leq 0.05$) after correction for multiple comparisons using the Dunn-Šidák method.

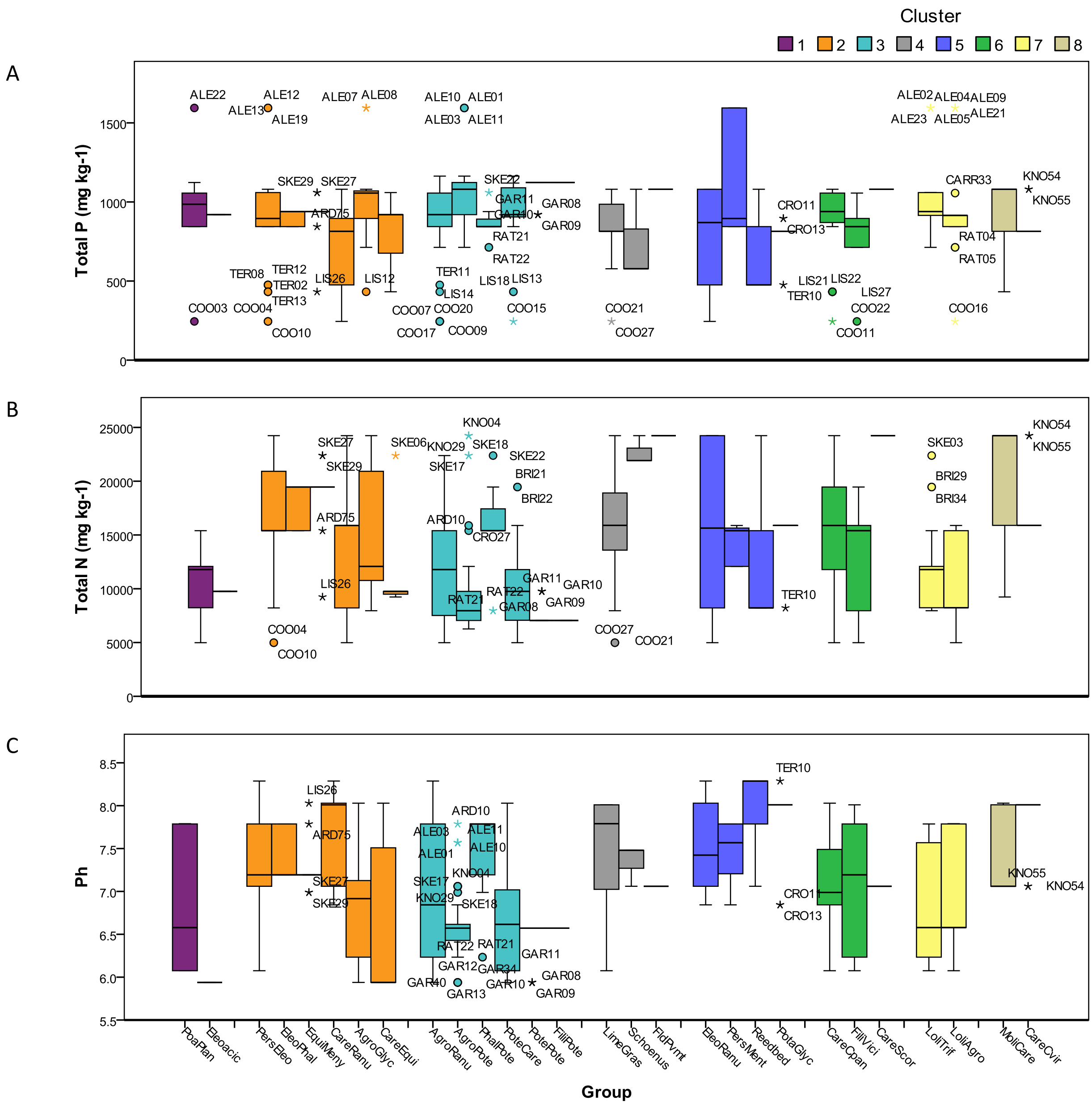


Figure 7.34 (A-C) Boxplots showing the median, interquartile range and highest and lowest values for total phosphorus, total nitrogen and pH (soil chemistry) for each of the 28 groups. Groups are colour-coded and divided into clusters as shown in the legend.

Soil types

A total of 13 soil types were found to be associated with the relevés recorded in this study (Table 7.75). For each vegetation community, the number of relevés occurring in each soil type (as mapped) were calculated (Table 7.76). For ease of interpretation, each specific soil type was assigned to one of the general soil types, these are shown in Figure 7.36.

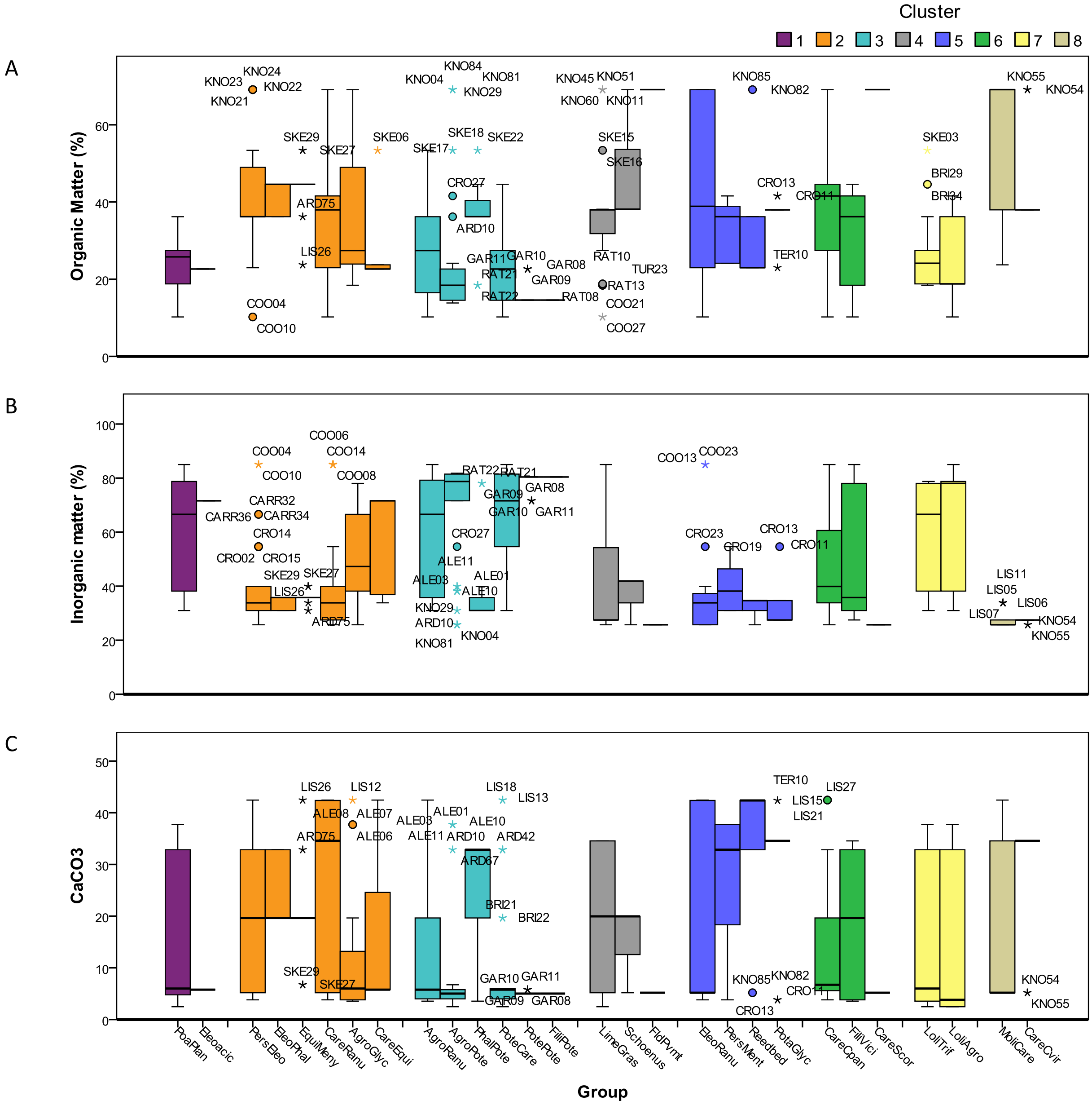


Figure 7.35 (A-C) Boxplots showing the median, interquartile range and highest and lowest values for soil organic matter, inorganic matter and $CaCO_3$ content for each of the 28 groups. Groups are colour-coded and divided into clusters as shown in the legend.

Four vegetation communities were recorded only on one general soil type. Group 28 FldPavmt and Group 23 *CareScor* were recorded only on Alluvium, Group 26 *Eleoacic* was recorded only on PDM, and Group 20 *FiliPote* was only recorded on WDM. Twelve communities occurred on two soil types; of these, 10 were recorded on both Alluvium and PDO (Figure 7.36), while Group 27 *CareEqui* was recorded on both PDM and PDO, and Group 19 *PotePote* was recorded on both PDM and WDM. The remainder of the vegetation communities occurred on a variety of soil types, suggesting that these communities are not restricted by soil type.

Table 7.74. General (in bold) and specific soil types found in the 22 turloughs in this study.

Soil type	*Code*	*Characteristics*
Well-drained mineral (WDM)		
Very shallow well drained mineral	BminVSW	Soil depth <25cm; well drained mineral soils derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Shallow well drained mineral	BminSW	Soil depth 25-76cm well drained mineral soils; derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Poorly-drained mineral (PDM)		
Very shallow poorly drained mineral	BminVSP	Soil depth < 25 cm; poorly drained mineral soils derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Shallow poorly drained mineral	BminSP	Soil depth 25-76cm; poorly drained mineral soils derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Deep poorly drained mineral	BminDP	Soil depth >76cm; poorly drained mineral soils derived principally from calcareous parent materials. Generally have medium textures (sandy loam, loam, sandy clay loam) with semi-fibrous organic material.
Shallow poorly drained mineral soils with peaty topsoil	BminSPPT	Soil depth 25-76cm; poorly drained mineral soils derived principally from calcareous parent materials. Distinct peaty topsoil present with organic texture and dark (10 YR 3/1, 3/2, 3/3, 2/1or 2/2) colouration. Lower horizons generally have silty clay, clay loam textures with semi-fibrous organic material.
Well drained organic (WDO)		
Very shallow well drained organic	BorgVSW	Soil depth <25cm; well drained organic soils derived principally from calcareous parent materials. Generally have organic or loamy textures with fibrous organic material.
Poorly drained organic (PDO)		
Very shallow poorly drained organic	BorgVSP	Soil depth <25cm; poorly drained organic soils derived principally from calcareous parent materials. Generally have organic or loamy textures with fibrous organic material. M/SM not significant.
Fen Peat	FenPt	Soil depth >30cm; poorly drained organic soils derived principally from calcareous parent materials. Generally have organic or organic silty clay textures with fibrous organic material. Dark (10 YR 3/1, 3/2, 3/3, 2/1or 2/2) or Dusky red (10 R 3/2, 3/3or 3/4) colouration. 0-20% marl or shell marl may or may not be present.
Alluviums		
Peat-marl	Pt-MRL	Mid-point of the continuum from marl to peat and has a characteristic calcium carbonate content of 55-70% and an organic matter content of 10-25% (Coxon, 1986). Dark (10 YR 3/1, 3/2, 3/3, 2/1, 2/2) or greyish brown (10 YR 5/2) soil matrix with abundant flecks of snail shell marl and/or marl deposition. Profile generally undifferentiated into horizons. Depths range from very shallow to deep.
Marl with peaty topsoil	AlluvMRLPT	Profile generally has two distinct horizons consisting of peaty topsoil with organic texture and dark (10 YR 3/1, 3/2, 3/3, 2/1, 2/2) colouration and a grey (10 YR 5/1, 6/1, 7/1 or 8/1) marl horizon with of clay, silty clay or silty clay loam texture. Distinct mottling is often present.
Marl alluvium	AlluvMRL	Generally grey (10 YR 5/1) or greyish brown (10 YR 5/2), very shallow or shallow, often stony soils. Abundant marl and/or shell marl evident. Semi-fibrous organic matter. Deeper lacustrine type soils
Mineral alluvium	AlluvMIN	Generally dark, very shallow, often stony soils with silty textures and semi-fibrous organic material. Marl and/or shell marl often common but not abundant.

Table 7.75. Number of relevés belonging to each community occurring in each soil type (descriptions are presented in Table 7.74).

		Alluvium				PDM				PDO		WDM		WDO
		AlluvMIN	AlluvMRL	AlluvMRLPT	Pt-MRL	BminDP	BminSP	BminSPPT	BminVSP	BorgVSP	FenPt	BminSW	BminVSW	BorgVSW
1	*PoaPlan*	1					4		1	2			1	1
2	*PersEleo*	2	4	8	8		3			19	18			1
3	*AgroRanu*	4	1	5		1	22		14	12	18	1	1	
4	*AgroPote*				2		14		12	7		2	10	2
5	LimeGras				3		2	2	1	5	8	2		12
6	*EleoRanu*	3	6		10					3	6			
7	*EleoPhal*			9						4	4			
8	*CareCpan*	1		5	1		6		1	3	14			1
9	*PhalPote*			3			2			10	1			
10	*LoliTrif*			2			3		2	5	1	3		1
11	*PersMent*			4						8	4			
12	*FiliVici*	1		4		1	5			9	2	2		1
13	*PoteCare*	1		2		1	8		12	1	6			
14	Reedbed		6		2					1				
15	*LoliAgro*	1					9			7		2		1
16	*EquiMeny*			7							4			
17	*CareRanu*	8	9	1	8					2	31			
18	*AgroGlyc*			1	2		7			3	7			
19	*PotePote*						11		3			4	7	
20	*FiliPote*											2	11	
21	*Schoenus*				2					5				
22	*MoliCare*				16					2	15			
23	*CareScor*				7									
24	*PotaGlyc*		1								8			
25	*CareCvir*				2						7			
26	*Eleoacic*					8			4					
27	*CareEqui*					4					3			
28	FldPavmt				10									

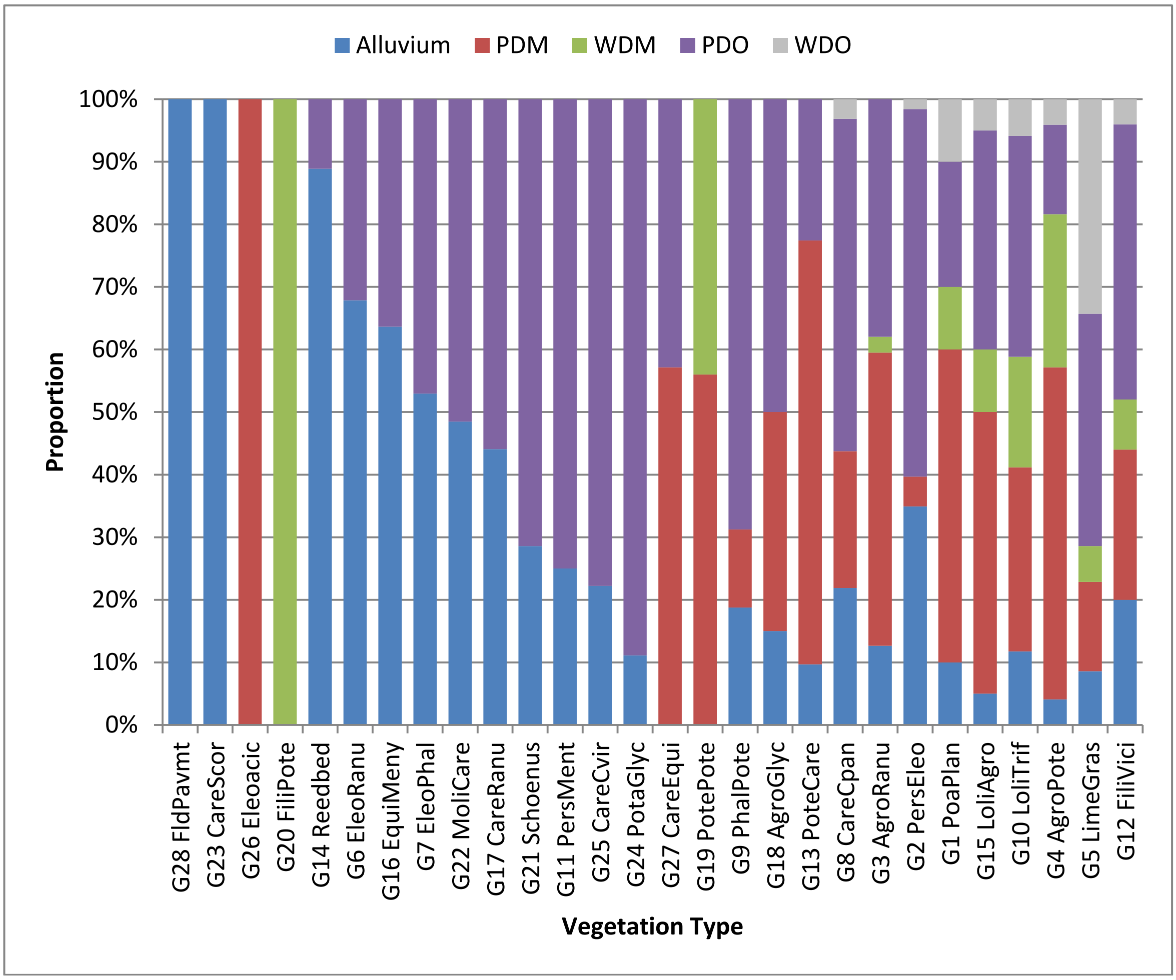


Figure 7.36 Stacked bar chart showing the proportions of each general soil type for each vegetation community. See Table 7.74 for explanation of the codes used.

7.5.4.3 Water Chemistry

Water chemistry results for each turlough are presented in Table 7.77. Water chemistry results were summarised for each vegetation community and are presented in Table 7.78, and displayed graphically in Figure 7.37 and Figure 7.38. A Kruskal-Wallis test was conducted on the data to test for differences between group medians indicated that there were significant differences between the medians of at least two groups for each of the water chemistry variables. *Post-hoc* Mann-Whitney U tests were carried out to determine which clusters differed (Table 7.79).

Nutrient Concentrations and Turloughs

There was considerable variation in nutrient levels between turloughs; mean values for the sampling period (October 2006 to June 2007) are presented in Table 7.77. Mean TP ranged from 4.0 to 82.1 μg l^{-1}. Four turloughs had mean TP values of < 12 μg l^{-1}, indicating oligotrophic status (see Table 7.8 in Methods section for threshold values), twelve had mean TP values indicating they were mesotrophic, while six had mean TP levels making them eutrophic. Mean MRP also spanned a large range of values, from 42.1 μg l^{-1} in Ardkill to 0.71 μg l^{-1} in Knockaunroe. Caranavoodaun and Tullynafrankagh had the highest mean TN, at 2.3 and 2.1 mg l^{-1}, while Knockaunroe had the lowest (0.55 mg l^{-1}). Mean nitrate concentrations showed a similar pattern to TN; Caranavoodaun, Tullynafrankagh and

Lisduff had the highest levels (1.49 – 1.86 mg l^{-1}). Knockaunroe was among the turloughs with the lowest mean MRP values, at 0.3 mg l^{-1}, but Brierfield had the lowest, at 0.1 mg l^{-1}. Mean alkalinity values ranged from 112.3 mg l^{-1} in Brierfield to 236.4 mg l^{-1} in Rathnalulleagh. There was relatively little temporal variation in alkalinity; standard deviations were low. Unsurprisingly, mean calcium concentrations varied in a similar fashion to mean alkalinity. As with alkalinity, Brierfield was the turlough with the lowest mean calcium concentration (44.41 mg l^{-1}), while Rathnalulleagh had the highest mean concentration (99.17 mg l^{-1}).

Nutrient Concentrations and Vegetation Communities

Many of the vegetation communities were associated with a wide range of median TP values (Figure 7.37 A). While some of the vegetation communities occurred in turloughs with a range of TP concentrations (e.g. Group 2 *PersEleo*), others seemed to occur in turloughs with a lower concentration (e.g. Group 5 *LimeGras*, Group 21 *Schoenus*). Group 21 *Schoenus*, Group 22 *MoliCare*, Group 23 *CareScor* and Group 28 FldPavmt had the lowest median TP concentrations. Group 9 *PhalPote* had by far the highest median TP concentration, at 82.12 µg l^{-1}. Ardkill was the turlough with the highest mean TP (Table 7.77), and at 82.1 µg l^{-1} this was almost 30 µg l^{-1} higher than the next highest mean, in Blackrock. There was also significant temporal variation in the TP concentrations found in Ardkill, as evidenced by the large standard deviation. There are a large number of positive outliers present in Figure 7.37 A and B; most of these are quadrats that were recorded in Ardkill, suggesting higher TP at Ardkill than were usual for the plant communities found there.

Table 7.76. Mean and standard deviations of water chemistry variables for each of the 22 turloughs.

Turlough	*Abbreviation*	*TP (µg l^{-1})*		*MRP (µg l^{-1})*		*TN (mg l^{-1})*		*Nitrate (mg l^{-1})*		*Alk (mg l^{-1} $CaCO_3$)*		*Calcium (mg l^{-1})*		*OECD trophic status based on TP**
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	
Lough Aleenaun	**ALE**	30.7	13.8	9.1	6.3	1.3	0.3	1.0	0.3	160.2	25.2	67.1	11.8	Mesotrophic
Ardkill	**ARD**	82.1	32.6	42.1	26.6	1.7	1.0	1.3	1.0	220.2	25.0	90.9	15.6	Eutrophic
Ballindereen	**BAL**	12.4	8.5	1.1	0.4	0.7	0.4	0.2	0.2	183.6	20.2	71.9	7.4	Mesotrophic
Blackrock	**BLA**	52.4	15.7	27.3	9.5	1.7	0.3	1.2	0.4	166.9	58.4	71.0	28.6	Eutrophic
Brierfield	**BRI**	19.8	9.5	1.9	0.8	0.6	0.2	0.1	0.1	210.2	25.9	85.3	15.7	Mesotrophic
Caherglassan	**CAH**	43.2	12.1	18.8	6.9	1.2	0.2	0.7	0.2	112.4	28.1	44.4	7.0	Eutrophic
Caranavoodaun	**CARA**	11.0	3.8	1.5	0.7	2.3	1.4	1.9	1.4	217.1	30.0	87.4	16.9	Mesotrophic
Carrowreagh	**CARR**	42.8	7.7	8.2	7.5	0.9	0.5	0.4	0.4	218.8	14.7	92.5	8.4	Eutrophic
Coolcam	**COO**	34.0	21.3	3.7	4.1	1.3	0.7	0.9	0.6	214.0	29.0	87.1	17.7	Mesotrophic
Lough Coy	**COY**	43.4	15.9	20.6	9.9	1.4	0.3	1.0	0.3	142.7	26.1	56.5	8.4	Eutrophic
Croaghill	**CRO**	25.0	16.6	3.5	2.3	1.2	0.7	0.7	0.7	220.2	21.3	90.7	13.5	Mesotrophic
Garryland	**GAR**	24.6	6.8	10.9	3.8	1.1	0.4	0.6	0.2	122.1	23.5	47.9	7.5	Mesotrophic
Lough Gealain	**GEA**	4.0	1.2	0.8	0.4	0.6	0.2	0.4	0.1	134.9	4.9	55.4	3.9	Oligotrophic
Kilglassan	**KIL**	27.2	11.6	4.6	3.6	1.5	1.0	1.1	1.0	216.2	39.4	91.9	17.7	Mesotrophic
Knockaunroe	**KNO**	4.2	1.8	0.7	0.4	0.6	0.2	0.3	0.2	138.5	3.1	56.5	3.3	Oligotrophic
Lisduff	**LIS**	7.4	2.0	1.5	0.5	1.9	0.8	1.8	0.8	227.8	43.8	96.0	23.4	Oligotrophic
Rathnalulleagh	**RAT**	44.6	22.0	3.4	1.9	1.3	0.5	0.7	0.5	236.4	38.9	99.2	16.4	Eutrophic
Roo West	**ROO**	9.8	4.1	1.1	0.5	0.6	0.3	0.3	0.2	141.0	26.3	58.6	11.2	Eutrophic
Skealoghan	**SKE**	20.4	6.2	5.8	5.9	0.9	0.7	0.5	0.7	197.8	26.6	79.2	14.8	Mesotrophic
Termon	**TER**	19.5	10.9	3.3	1.8	0.6	0.4	0.3	0.4	167.5	19.1	68.0	6.9	Mesotrophic
Tullynafrankagh	**TUL**	33.0	17.9	3.3	1.9	2.1	1.2	1.5	1.3	233.8	22.2	91.5	15.9	Mesotrophic
Turloughmore	**TUR**	15.0	7.9	2.3	1.1	0.6	0.3	0.3	0.3	225.6	30.7	88.3	13.9	Mesotrophic

* as presented in Cunha Pereira et al. (2010).

Table 7.77. Mean, median and range of water chemistry variables for each of the 28 vegetation communities.

		TP (µg l^{-1})		*MRP (µg l^{-1})*		*TN (mg l^{-1})*		*Nitrate (mg l^{-1})*		*Alkalinity (mg l^{-1} $CaCO_3$)*		*Calcium (mg l^{-1})*	
		Mean	*Median (range)*	*Mean*	*Median (range)*	*Mean*	*Median (range)*	*Mean*	*Median (range)*	*Mean*	*Median (range)*	*Mean*	*Median (range)*
1	*PoaPlan*	44.9	42.8 (19.5-82.1)	15.6	8.2 (3.3-42.1)	1.17	1.08 (0.63-1.74)	0.74	0.64 (0.33-1.25)	197.3	216.4 (160.2-220.2)	82.1	89.0 (67.1-92.5)
2	*PersEleo*	36.7	25.0 (4.2-82.1)	14.4	3.5 (0.7-42.1)	1.13	1.17 (0.55-1.9)	0.73	0.7 (0.06-1.75)	200.6	220.2 (138.5-227.8)	82.2	88.3 (56.5-96.0)
3	*AgroRanu*	44.0	42.8 (7.4-82.1)	15.7	8.2 (1.5-42.1)	1.24	1.22 (0.57-1.9)	0.75	0.7 (0.06-1.75)	195.1	218.8 (112.4-236.4)	80.2	90.7 (44.4-99.2)
4	*AgroPote*	36.3	43.2 (4.2-82.1)	15.0	18.8 (0.7-42.1)	1.23	1.25 (0.55-1.74)	0.80	0.69 (0.30-1.25)	155.7	160.2 (112.4-236.4)	63.7	67.1 (44.4-99.2)
5	LimeGras	18.0	11.0 (4.04-82.1)	3.4	1.5 (0.7-42.1)	1.52	1.27 (0.55-2.3)	1.12	0.92 (0.30-1.86)	197.5	217.1 (134.9-236.4)	80.3	87.4 (55.4-99.2)
6	*EleoRanu*	20.9	15.0 (4.2-82.1)	6.4	2.3 (0.7-42.1)	0.94	0.62 (0.55-1.9)	0.61	0.30 (0.28-1.75)	190.4	214.0 (138.5-227.8)	77.2	87.1 (56.5-96.0)
7	*EleoPhal*	49.2	19.8 (19.84-82.1)	20.8	1.9 (1.9-42.1)	1.12	0.57 (0.57-1.74)	0.62	0.06 (0.06-1.25)	214.9	210.2 (210.2-220.2)	87.9	85.3 (85.3-90.9)
8	*CareCpan*	29.5	22.7 (4.2-82.1)	7.9	3.63 (0.7-42.1)	1.09	0.92 (0.55-1.9)	0.66	0.50 (0.06-1.75)	210.4	218.8 (138.5-227.8)	86.9	90.7 (56.5-96.0)
9	*PhalPote*	61.9	82.1 (19.84-82.1)	27.5	42.1 (1.9-42.1)	1.41	1.74 (0.57-1.74)	0.91	1.25 (0.06-1.25)	218.9	220.2 (197.8-236.4)	90.1	90.9 (79.2-99.2)
10	*LoliTrif*	33.1	30.7 (19.5-82.1)	7.5	3.4 (1.9-42.1)	0.99	0.92 (0.57-1.74)	0.58	0.50 (0.06-1.25)	193.8	197.8 (160.2-236.4)	80.2	79.2 (67.1-99.2)
11	*PersMent*	51.8	30.7 (25.0-82.1)	22.1	9.1 (3.5-42.1)	1.44	1.25 (1.17-1.74)	1.04	1.01 (0.7-1.25)	201.4	220.2 (160.2-220.2)	83.4	90.7 (67.1-90.9)
12	*FiliVici*	49.7	44.6 (11.0-82.1)	17.2	3.5 (1.5-42.1)	1.31	1.25 (0.57-2.3)	0.80	0.7 (0.06-1.86)	221.6	220.2 (210.2-236.4)	91.5	90.9 (85.3-99.2)
13	*PoteCare*	35.5	25.0 (7.4-82.1)	14.1	10.7 (1.5-42.1)	1.22	1.17 (0.57-1.9)	0.78	0.7 (0.06-1.75)	169.8	166.9 (112.4-227.8)	69.0	68.0 (44.4-96.0)
14	Reedbed	20.1	15.0 (4.2-82.1)	6.4	2.3 (0.7-42.1)	0.73	0.62 (0.55-1.74)	0.39	0.28 (0.28-1.25)	205.6	225.6 (138.5-225.6)	81.5	88.3 (56.5-90.9)
15	*LoliAgro*	40.2	30.7 (19.5-82.1)	13.4	3.5 (3.3-42.1)	1.11	1.17 (0.63-1.74)	0.71	0.66 (0.33-1.25)	195.6	214.0 (160.2-236.4)	80.6	87.1 (67.1-99.2)
16	*EquiMeny*	30.4	19.8 (7.4-82.1)	10.9	1.9 (1.5-42.1)	1.07	0.92 (0.57-1.9)	0.61	0.50 (0.06-1.75)	202.6	210.2 (166.9-227.8)	83.1	85.3 (71.0-96.0)
17	*CareRanu*	15.6	11.0 (4.2-34.0)	2.3	1.5 (0.7-5.79)	1.33	1.17 (0.55-2.3)	0.98	0.7 (0.06-1.86)	206.1	217.1 (138.5-227.8)	83.4	87.4 (56.5-96.0)
18	*AgroGlyc*	27.5	25.0 (4.2-44.6)	5.3	4.7 (0.7-10.7)	1.06	1.13 (0.55-1.9)	0.64	0.62 (0.06-1.75)	196.9	214.5 (122.1-236.4)	81.4	88.0 (47.9-99.2)
19	*PotePote*	48.0	52.4 (24.6-52.4)	24.7	27.3 (10.7-27.3)	1.62	1.72 (1.08-1.72)	1.11	1.21 (0.57-1.21)	159.8	166.9 (122.1-166.9)	67.3	71.0 (47.9-71.0)
20	*FiliPote*	52.4	52.4 (52.4)	27.3	27.3 (27.3)	1.72	1.72 (1.72)	1.21	1.21 (1.21)	166.9	166.9 (166.9)	71.0	71.0 (71.0)
21	*Schoenus*	4.1	4.0 (4.04-4.2)	0.7	0.75 (0.7-0.75)	0.58	0.59 (0.55-0.59)	0.34	0.35 (0.3-0.35)	135.9	134.9 (134.9-138.5)	55.7	55.4 (55.4-56.5)
22	*MoliCare*	6.7	4.2 (4.2-11.0)	1.1	0.7 (0.7-1.5)	1.28	0.55 (0.55-2.3)	0.99	0.30 (0.3-1.86)	175.8	138.5 (138.5-227.8)	71.8	56.5 (56.5-96.0)
23	*CareScor*	4.2	4.2 (4.2)	0.7	0.7 (0.7)	0.55	0.55 (0.55)	0.30	0.30 (0.3)	138.5	138.5 (138.5)	56.5	56.5 (56.5)
24	*PotaGlyc*	14.6	11.0 (11.0-25.0)	2.1	1.5 (1.5-3.5)	1.86	2.3 (0.62-2.3)	1.43	1.86 (0.28-1.86)	218.7	217.1 (217.1-225.6)	88.2	87.4 (87.4-90.7)
25	*CareCvir*	9.5	11.0 (4.2-11.0)	1.4	1.5 (0.7-1.5)	1.91	2.3 (0.55-2.3)	1.51	1.86 (0.3-1.86)	199.6	217.1 (138.5-217.1)	80.5	87.4 (56.5-87.4)
26	*Eleoacic*	24.6	24.6 (24.6)	10.9	10.7 (10.7)	1.08	1.08 (1.08)	0.57	0.57 (0.57)	122.1	122.1 (122.1)	47.9	47.9 (47.9)
27	*CareEqui*	19.1	24.6 (7.4-24.6)	7.5	10.7 (1.5-10.7)	1.29	1.08 (0.92-1.9)	0.90	0.57 (0.5-1.75)	163.1	122.1 (122.1-227.8)	66.1	47.9 (47.9-96.0)
28	FldPavmt	4.2	4.2 (4.2)	0.7	0.7 (0.7)	0.55	0.55 (0.55)	0.30	0.30 (0.30)	138.5	138.5 (138.5)	56.5	56.5 (56.5)

Table 7.78. Mann-Whitney U tests for water chemistry variables.

TP (µg l^{-1})							
	1	2	3	4	5	6	7
2	0.019						
3	0.003	**0.000**					
4	**0.000**	**0.000**	**0.000**				
5	0.027	0.436	**0.000**	**0.000**			
6	0.698	0.067	**0.000**	**0.000**	0.048		
7	0.950	0.009	0.006	**0.000**	**0.001**	0.709	
8	**0.000**	**0.000**	**0.000**	0.302	**0.000**	**0.000**	**0.000**

MRP (µg l^{-1})							
	1	2	3	4	5	6	7
2	**0.000**						
3	0.254	**0.000**					
4	**0.000**	**0.000**	**0.000**				
5	**0.000**	0.763	**0.000**	**0.000**			
6	**0.000**	0.532	**0.000**	**0.000**	0.455		
7	**0.001**	0.009	**0.000**	**0.000**	0.012	0.173	
8	**0.000**	**0.000**	**0.000**	0.046	**0.000**	**0.000**	**0.000**

Nitrate (mg l^{-1})							
	1	2	3	4	5	6	7
2	0.890						
3	0.007	0.054					
4	0.310	0.436	0.051				
5	0.870	0.793	0.257	0.303			
6	0.742	0.363	0.007	0.516	0.403		
7	0.792	0.718	0.009	0.754	0.946	0.864	
8	0.794	0.014	0.264	0.897	0.016	0.030	0.445

TN (mg l^{-1})							
	1	2	3	4	5	6	7
2	0.873						
3	0.006	0.014					
4	0.264	0.394	0.023				
5	0.886	0.832	0.053	0.595			
6	0.780	0.354	0.005	0.810	0.644		
7	0.761	0.874	0.005	0.325	0.699	0.804	
8	0.749	0.658	0.572	0.897	0.515	0.392	0.710

Alkalinity (mg l^{-1} $CaCO_3$)							
	1	2	3	4	5	6	7
2	**0.000**						
3	0.018	**0.000**					
4	0.015	**0.000**	0.257				
5	**0.000**	0.343	**0.000**	**0.000**			
6	**0.000**	0.320	**0.000**	**0.000**	0.876		
7	**0.000**	0.331	0.005	0.003	0.402	0.114	
8	0.010	0.005	0.481	0.350	**0.002**	**0.001**	0.011

Calcium (mg l^{-1})							
	1	2	3	4	5	6	7
2	**0.000**						
3	0.026	**0.000**					
4	0.017	**0.000**	0.599				
5	**0.002**	0.886	0.023	**0.000**			
6	**0.000**	0.023	**0.000**	**0.000**	0.018		
7	**0.002**	0.766	0.113	0.003	0.490	0.119	
8	0.010	0.005	0.757	0.350	**0.002**	**0.001**	0.011

Figures in bold are significant ($p \leq 0.05$) after correction for multiple comparisons using the Dunn-Šidák method.

When Mann-Whitney U-tests were carried out to gauge the statistical significance of differences between median TP concentrations for clusters, clusters 4 and 8 were not significantly different from each other, but were significantly different from every other cluster. These are clusters which contain vegetation communities associated with lower nutrient levels, such as Group 21 *Schoenus*, while the vegetation communities in the other clusters are composed of species which are associated with higher levels of soil nutrients. Cluster 1 was significantly different from clusters 4 and 8, but no others. Cluster 2 was significantly different from Clusters 3, 4 and 8, but no others.

A similar pattern was evident with MRP. Many communities occurred in turloughs with wide ranges of MRP concentrations, but as described above, some communities seemed to be restricted to turloughs with high MRP concentrations while others occurred in turloughs with low concentrations. Group 21 *Schoenus*, Group 22 *MoliCare*, Group 23 *CareScor* and Group 28 FldPavmt had the lowest concentrations, while Group 9 *PhalPote* had the highest (Figure 7.37 B).

Many of the positive outliers for TP and MRP were from Ardkill turlough (Figure 7.37). Ardkill had by far the highest mean TP and MRP of all turloughs sampled (Table 7.77). This suggests that there is some nutrient input to the turlough, either via overland flow from surrounding farmland or via the recharge water from the catchment.

Knockaunroe had the lowest mean total nitrogen concentration Table 7.77, and there were a number of outliers from this turlough (Figure 7.37 C). Group 28 FldPavmt, Group 6 *EleoRanu*, Group 14 Reedbed and Group 23 *CareScor* all had very low median total nitrogen concentration (Figure 7.37 C). Some communities had very low total phosphorus concentrations, but high total nitrogen concentrations, i.e. Group 5 LimeGras and Group 25 *CareCvir*.

It is interesting to note that total nitrogen concentration across communities seemed to be less variable than total phosphorus concentration; most communities occurred in turloughs with a wide range of total nitrogen concentration in turlough waters, with a few exceptions. This may suggest that total phosphorus concentrations in turlough waters are a stronger driver of turlough plant communities than total nitrogen.

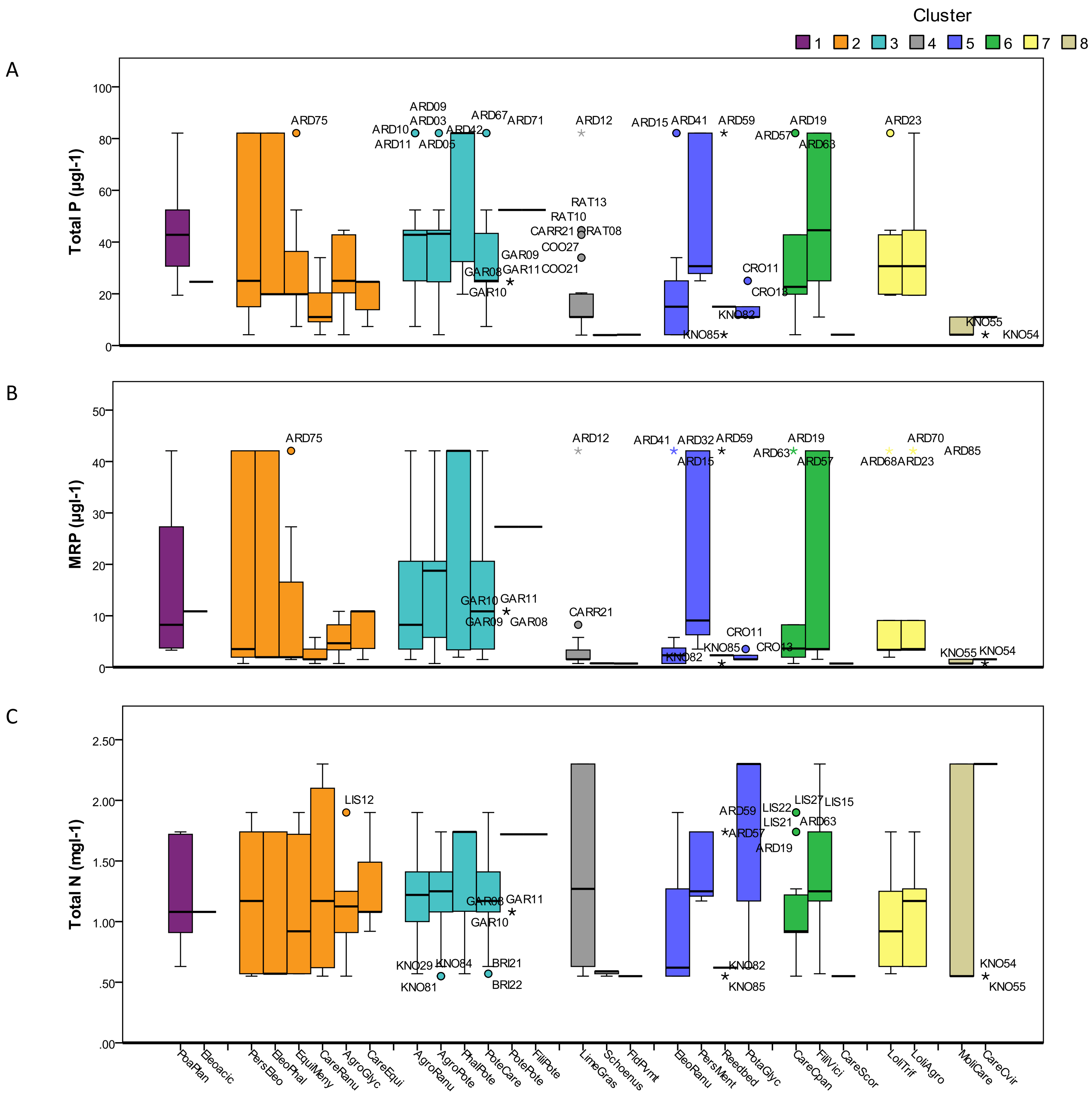


Figure 7.37 (A-C) Boxplots showing the median, interquartile range and highest and lowest values for total phosphorus, molybdate reactive phosphorus and total nitrogen (water chemistry) for each of the 28 groups. Groups are colour-coded and divided into clusters as shown in the legend.

There was a wide range of median nitrate concentrations associated with turlough vegetation communities (Table 7.78, Figure 7.38 A). The pattern of nitrate concentrations for each vegetation community closely resembled that of TN concentrations (Figure 7.38 C). As with TN, Ardkill and Lisduff feature in the outliers seen in the boxplots. While the turlough values for these were at the higher end of the range (Table 7.77), neither was the highest value recorded for TN or nitrate in any turlough. This might indicate that these communities are at the edge of their range when they occur in Ardkill and Lisduff, or alternatively that the mean water TN and nitrate concentrations are not highly associated with specific vegetation types.

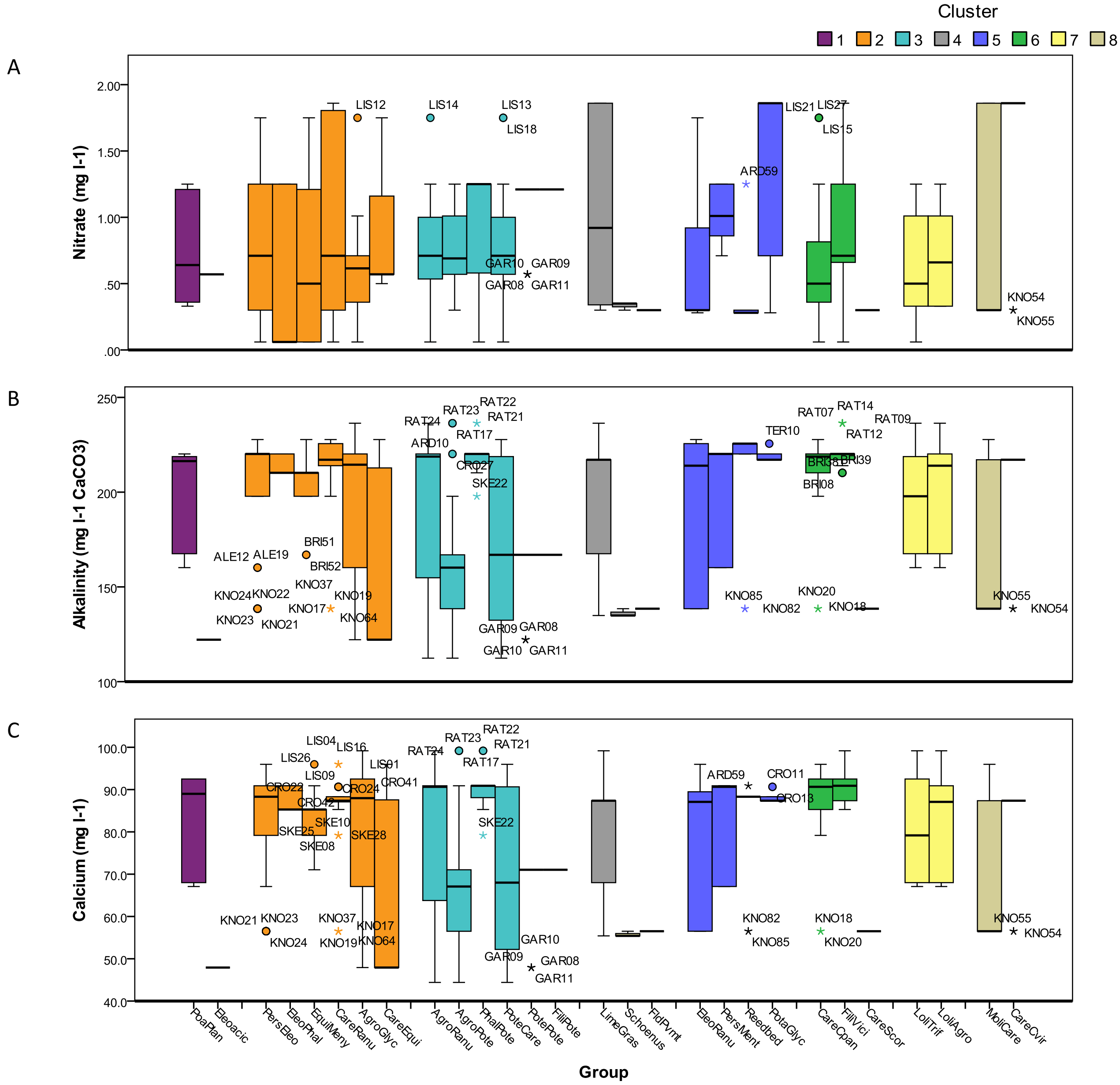


Figure 7.38 (A-C) Boxplots showing the median, interquartile range and highest and lowest values for nitrate, alkalinity and calcium (water chemistry) for each of the 28 groups. Groups are colour-coded and divided into clusters as shown in the legend.

A number of vegetation communities were associated with turlough water with low alkalinity, i.e. Group 21 *Schoenus*, Group 23 *CareScor*, Group 26 *Eleoacic*, Group 27 *CareEqui* and Group 28 FldPavmt all had low median alkalinity (Figure 7.38 B). Group 2 *PersEleo*, Group 9 *PhalPote*, Group 11 *PersMent* and Group 12 *FiliVici* are all communities which seem to be associated with a high level of alkalinity; all of these groups had a high median alkalinity (220.2).

The distribution of calcium concentration followed a pattern similar to that of alkalinity – Group 21 *Schoenus*, Group 23 *CareScor*, Group 26 *Eleoacic*, Group 27 *CareEqui* and Group 28 FldPavmt all had low median concentrations of calcium (47.9 – 56.5; Table 7.78, Gigure 7.38 C). Group 3 *AgroRanu*, Group 8 *CareCpan*, Group 9 *PhalPote*, Group 11 *PersMent* and Group 12 *FiliVici* all had high median alkalinity concentrations (90.7 – 90.9; Table 7.78, Figure 7.38 C).

There were a number of outliers in the boxplots for Alkalinity and Calcium (Figure 7.38 B & C). At the upper end of the range these were mainly relevés recorded in Rathnalulleagh and Lisduff, both of which were among the most highly alkaline and had the highest mean calcium concentrations (Table 7.77). Outliers occurring towards the lower end of the range were quadrats from Knockaunroe and Garryland.

7.5.4.4 Management

The numbers of grazed and ungrazed relevés in each vegetation type were calculated, and are presented in Table 7.81. The proportion of grazed:ungrazed relevés is presented in Figure 7.39. Four vegetation types were only recorded in relevés from ungrazed land-parcels; these were Group 14 Reedbed, Group 21 *Schoenus*, Group 23 *CareScor* and Group 28 FldPavmt. Six vegetation communities were recorded only in grazed land-parcels; these were Group 1 *PoaPlan*, Group 10 *LoliTrif*, Group 19 *PotePote*, Group 20 *FiliPote*, Group 24 *PotaGlyc*, and Group 26 *Eleoacic*. The remaining vegetation types were found in both grazed and ungrazed land-parcels, although some, such as Group 7 *EleoPhal* and Group 9 *PhalPote* were found mostly in ungrazed land-parcels, while Group 3 *AgroRanu*, Group 4 *AgroPote* and Group 15 *LoliAgro* were found mostly in grazed land-parcels.

Table 7.79. Number of relevés in each vegetation type occurring in grazed and ungrazed land-parcels.

Community		*Grazed*	*Ungrazed*	*Total*
1	*PoaPlan*	10	0	10
2	*PersEleo*	38	25	63
3	*AgroRanu*	71	8	79
4	*AgroPote*	45	4	49
5	LimeGras	28	7	35
6	*EleoRanu*	10	18	28
7	*EleoPhal*	1	16	17
8	*CareCpan*	19	13	32
9	*PhalPote*	3	13	16
10	*LoliTrif*	17	0	17
11	*PersMent*	8	8	16
12	*FiliVici*	12	13	25
13	*PoteCare*	25	6	31
14	Reedbed	0	9	9
15	*LoliAgro*	20	1	21
16	*EquiMeny*	7	4	11
17	*CareRanu*	29	30	59
18	*AgroGlyc*	16	4	20
19	*PotePote*	25	0	25
20	*FiliPote*	13	0	13
21	*Schoenus*	0	7	7
22	*MoliCare*	11	22	33
23	*CareScor*	0	7	7
24	*PotaGlyc*	9	0	9
25	*CareCvir*	7	2	9
26	*Eleoacic*	12	0	12
27	*CareEqui*	6	1	7
28	FldPavmt	0	10	10

Group 12 *FiliVici* - of the 25 relevés recorded in this vegetation type that were retained in this analysis, a 'low' level of grazing was recorded for 6 of these, so that even though c. 50% of the relevés occurred in 'grazed' land-parcels, grazing was not evident in the majority of them.

7.5.4.5 Derived Variables

Summary statistics and boxplots for Ellenberg values, Grime's C-S-R values and species richness for each of the 28 vegetation types are presented in Table 7.80, Table 7.81, Figure 7.40 and Figure 7.41. (These variables were briefly mentioned in the description of vegetation communites, but are presented here again to facilitate comparison with the other variables, and are described in greater detail). A Kruskal-Wallis test was carried out to test for differences between the medians of the clusters. This gave Chi-square values of 330.16 - 542.37, with p-values of 0.000, indicating that there was a highly significant difference between the medians of at least two clusters. *Post-hoc* Mann-Whitney U tests for differences between the medians of clusters are presented in Table 7.82 and Table 7.83.

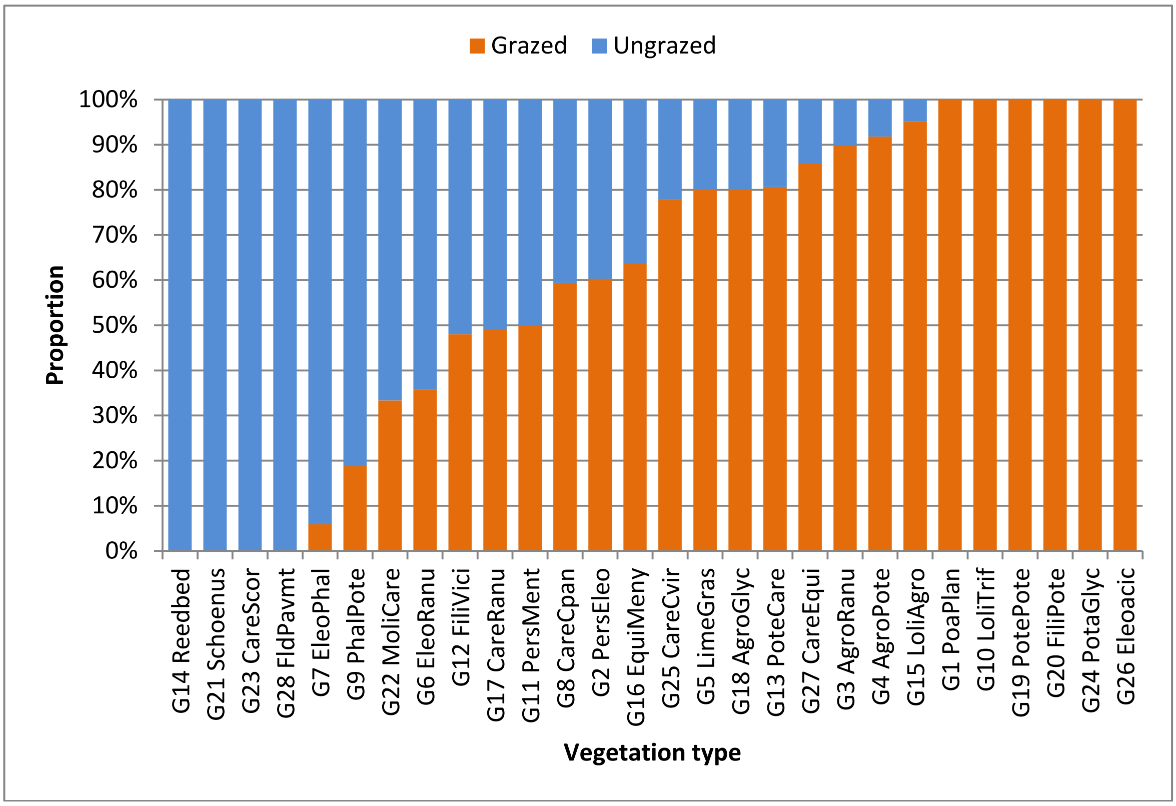


Figure 7.39 Stacked bar chart showing the proportion of relevés for each vegetation community occurring in grazed or ungrazed land-parcels.

Table 7.80. Mean, median and range of Ellenberg Wetness, Fertility and pH values for each community.

Community		*Wetness*		*Fertility*		*pH*	
		Mean	*Median (range)*	*Mean*	*Median (range)*	*Mean*	*Median (range)*
1	*PoaPlan*	6.0	6.0 (5.2-6.7)	6.4	6.4 (6.0-6.9)	6.3	6.3 (6.1-6.7)
2	*PersEleo*	8.2	8.1 (6.4-9.7)	5.2	5.3 (3.8-6.9)	6.2	6.3 (5.0-6.8)
3	*AgroRanu*	6.7	6.6 (5.5-8.0)	5.1	5.2 (3.7-6.7)	6.1	6.1 (5.3-6.9)
4	*AgroPote*	6.2	6.1 (5.5-7.4)	4.7	4.6 (3.5-6.0)	6.0	6.0 (5.1-6.7)
5	LimeGras	6.0	6.0 (4.8-6.9)	3.3	3.1 (2.2-4.9)	5.4	5.5 (4.2-6.3)
6	*EleoRanu*	9.4	9.6 (7.6-10.0)	4.6	4.3 (3.1-6.7)	6.1	6.0 (5.4-6.7)
7	*EleoPhal*	8.6	8.5 (8.0-9.5)	5.1	4.8 (3.8-6.9)	6.1	6.2 (5.1-7.0)
8	*CareCpan*	7.3	7.2 (6.2-8.2)	3.5	3.5 (2.4-4.5)	5.2	5.3 (4.3-5.9)
9	*PhalPote*	7.3	7.5 (6.2-8.7)	5.9	6.0 (5.2-6.7)	6.7	6.8 (6.2-7.0)
10	*LoliTrif*	5.5	5.5 (5.2-6.1)	5.1	5.0 (4.5-5.7)	6.0	6.0 (5.8-6.3)
11	*PersMent*	9.2	9.1 (8.4-10.0)	5.7	5.7 (4.7-6.1)	6.3	6.4 (6.0-6.7)
12	*FiliVici*	6.7	6.7 (5.8-7.2)	4.6	4.7 (3.9-5.2)	5.9	5.9 (5.1-6.5)
13	*PoteCare*	7.4	7.5 (5.6-8.2)	4.7	4.9 (2.8-6.3)	5.9	5.9 (4.6-6.9)
14	Reedbed	9.4	9.3 (8.3-10.0)	4.8	4.7 (3.7-6.0)	6.3	6 (5.7-7.4)
15	*LoliAgro*	5.9	5.9 (5.1-7.1)	5.8	5.9 (5.1-6.4)	6.4	6.4 (5.9-6.8)
16	*EquiMeny*	9.2	9.4 (8.1-10.0)	4.4	4.7 (3.1-6.0)	5.5	5.7 (4.0-6.5)
17	*CareRanu*	8.0	8.1 (7.0-9.4)	3.9	3.9 (2.5-5.6)	5.6	5.7 (4.5-6.6)
18	*AgroGlyc*	8.6	8.8 (6.8-9.8)	5.5	5.8 (4.0-6.7)	6.1	6.2 (5.0-6.7)
19	*PotePote*	6.1	6.0 (5.2-6.8)	5.2	5.2 (4.3-6.0)	6.5	6.6 (5.9-7.0)
20	*FiliPote*	6.2	6.2 (5.5-7.0)	4.0	3.9 (3.2-4.8)	5.9	6.0 (5.2-6.2)
21	*Schoenus*	6.9	7.1 (6-7.3)	2.3	2.4 (2.0-2.7)	4.5	4.7 (3.1-5.5)
22	*MoliCare*	7.8	7.7 (6.3-8.7)	2.7	2.6 (2.0-4.0)	5.1	5.2 (3.7-6.2)
23	*CareScor*	6.7	6.6 (5.9-7.4)	4.5	4.3 (3.9-5.5)	6.1	6.1 (5.8-6.6)
24	*PotaGlyc*	10.3	10.0 (10.0-11.0)	4.2	4.2 (4.0-4.9)	6.0	6.0 (6)
25	*CareCvir*	8.3	8.4 (7.9-8.5)	2.1	2.1 (2.0-2.4)	5.6	5.8 (4.4-6.6)
26	*Eleoacic*	7.3	6.9 (6.3-9.0)	5.8	6.0 (5.0-6.4)	6.4	6.4 (6.1-6.8)
27	*CareEqui*	9.3	9.7 (8.1-10.0)	3.4	3.7 (2.2-4.7)	4.9	5.0 (4.1-5.9)
28	FldPavmt	5.7	5.7 (4.9-6.5)	3.2	3.2 (2.5-4.5)	5.5	5.4 (5.1-6.4)

Wetness

Communities had a wide range of mean Ellenberg Wetness values. Group 10 *LoliTrif*, Group 15 *LoliAgro*, and Group 28 FldPavmt had the lowest median values for Wetness (5.5-5.9; Table 7.82, Figure 7.40 A). These are all communities which occur around the fringes of the turlough basin, and so they would be expected to experience relatively little flooding. Group 6 *EleoRanu*, Group 24 *PotaGlyc* and Group 27 *CareEqui* had the highest median values for Wetness (9.6-10). These are communities which generally occur towards the bottom of the turlough basin, and would be expected to experience more flooding than communities at higher levels. Group 2 *PersEleo* and Group 18 *AgroGlyc* had the largest ranges of values, with quadrats in these communities ranging from a mean Ellenberg Wetness value of 6.4 to 9.7 and 6.8 to 9.8 respectively.

Fertility

There was a wide range of mean Ellenberg Fertility values, from 2.1 to 6.4 (Table 7.82). Group 21 *Schoenus*, Group 22 *MoliCare* and Group 25 *CareCvir* had the lowest median Ellenberg Fertility values (2.1-2.6; Table 7.82, Figure 7.40 B). The highest median values for Fertility were for Group 1 *PoaPlan*, Group 9 *PhalPote* and Group 26 *Eleoacic* (6.0-6.4).

While some communities contained species with a wide range of Ellenberg Fertility values, for example Group 13 *PoteCare*, others had quadrats containing species with a tighter range of values. Group 26 *Eleoacic*, Group 15 *LoliAgro*, Group 9 *PhalPote* and Group 1 *PoaPlan* were all communities with high mean Fertility values and low ranges, suggesting that these communities occur in areas with relatively high nutrient loading. Group 22 *MoliCare*, Group 8 *CareCpan*, Group 28 FldPavmt, Group 21 *Schoenus* and Group 25 *CareCvir* all had low mean Ellenberg Fertility values, and low ranges of values, which suggest that these more sedge-dominated communities occur in more oligotrophic areas.

pH

The lowest median pH values were for Group 21 *Schoenus*, Group 22 *MoliCare* and Group 27 *CareEqui* (4.7-5.2; Table 7.82, Figure 7.40 C). Group 9 *PhalPote*, Group 11 *PersMent*, Group 15 *LoliAgro*, Group19 *PotePote* and Group 27 *Eleoacic* all had the highest median pH values (6.6-6.8). Mean Ellenberg pH values were generally basic to very acidic, which is surprising given the karstic bedrock on which turloughs occur.

Species richness

Group 14 Reedbed, Group 24 *PotaGlyc* and Group 27 *CareEqui* had the lowest median number of species (3-5; Table 7.83, Figure 7.41 A). Group 4 *AgroPote*, Group 5 LimeGras and Group 8 *CareCpan* had the highest median number of species (15-18).

Grime's C-S-R values

The communities with the lowest medians for Grime's C value are Group 1 *PoaPlan*, Group 5 LimeGras, Group 25 *CareCvir* and Group 28 FldPavmt (1.86-2.07; Table 7.83, Figure 7.41 B). Group 7 *EleoPhal*, Group 9 *PhalPote* and Group 24 *PotaGlyc* have the highest median Grime's C values (3.53-3.89).

Group 1 *PoaPlan*, Group 11 *PersMent*, Group 18 *AgroGlyc* and Group 26 *Eleoacic* have the lowest median Grime's S values (1.25-1.38; Table 7.83, Figure 7.41 C), suggesting that these communities occur in sites with relatively high fertility. Group 5 LimeGras, Group 22 *MoliCare,* Group 25 *CareCvir* and Group 28 FldPavmt have the highest median Grime's S values (3.65-3.91); these are communities with high proportions of 'stress-tolerators'.

The communities with the lowest median Grime's R values are Group 24 *PotaGlyc*, Group 25 *CareCvir*, Group 27 *CareEqui* and Group 28 FldPavmt (1.16-1.30; Table 7.83, Figure 7.41 D). Group 1 *PoaPlan*, Group 10 *LoliTrif*, Group 15 *LoliAgro* and Group 26 *Eleoacic* have the highest median Grime's R values (3.04-3.95).

Table 7.81. Mean, median and range for number of species and Grime's C-S-R values for each group.

Community		No. of species		C		S		R	
		Mean	Median (range)	Mean	Median (range)	Mean	Median (range)	Mean	Median (range)
1	*PoaPlan*	10	10 (6-15)	2.09	2.04 (1.41-2.71)	1.38	1.34 (1.04-1.77)	3.88	3.95 (3.29-4.53)
2	*PersEleo*	10	11 (5-19)	2.98	2.99 (2.10-3.98)	1.8	1.88 (1.00-2.69)	2.69	2.73 (1.73-3.83)
3	*AgroRanu*	14	14 (9-21)	2.98	2.88 (2.54-3.97)	2.06	2.03 (1.29-2.96)	2.58	2.68 (1.62-3.40)
4	*AgroPote*	14	15 (7-20)	2.66	2.69 (1.79-3.13)	2.39	2.33 (1.70-3.55)	2.69	2.72 (1.95-3.39)
5	LimeGras	18	18 (10-24)	2.12	2.07 (1.27-2.95)	3.6	3.65 (2.72-4.59)	1.98	2.00 (1.19-2.73)
6	*EleoRanu*	8	8 (3-14)	3.07	3.08 (2.69-3.39)	1.99	2.20 (1.10-2.70)	2.53	2.63 (1.47-3.31)
7	*EleoPhal*	8	8 (3-12)	3.59	3.53 (2.62-4.96)	2.11	2.31 (1.04-3.09)	1.65	1.61 (1.02-2.60)
8	*CareCpan*	15	15 (10-23)	2.66	2.69 (2.07-3.29)	2.95	2.78 (2.16-3.89)	1.92	1.94 (1.15-2.55)
9	*PhalPote*	7	7 (4-9)	3.80	3.86 (3.16-4.44)	1.78	1.75 (1.28-2.38)	1.81	1.76 (1.12-2.77)
10	*LoliTrif*	15	14 (10-21)	2.85	2.84 (2.61-3.12)	2.25	2.18 (1.88-2.77)	2.99	3.06 (2.46-3.18)
11	*PersMent*	6	6 (3-10)	3.24	3.22 (2.90-3.73)	1.24	1.25 (1.00-1.54)	2.64	2.69 (1.74-3.00)
12	*FiliVici*	13	13 (6-18)	3.17	3.16 (2.63-3.62)	2.5	2.47 (2.04-3.03)	2.05	2.07 (1.51-2.62)
13	*PoteCare*	7	7 (3-11)	2.81	2.90 (2.19-3.57)	2.38	2.49 (1.25-3.55)	2.23	2.19 (1.01-3.10)
14	Reedbed	5	5 (4-8)	3.34	3.37 (3.02-4.00)	2.23	2.28 (1.50-2.92)	1.98	2.20 (1.10-2.62)
15	*LoliAgro*	10	10 (6-21)	3.03	2.96 (2.71-3.67)	1.63	1.62 (1.20-2.09)	2.92	3.04 (1.87-3.21)
16	*EquiMeny*	8	8 (3-12)	2.72	2.64 (2.30-3.49)	2.73	2.72 (1.58-3.70)	1.8	1.75 (1.00-2.43)
17	*CareRanu*	12	12 (8-17)	2.82	2.87 (1.87-3.48)	2.55	2.46 (1.82-4.01)	2.25	2.26 (1.40-2.98)
18	*AgroGlyc*	8	8 (2-16)	2.99	3.00 (2.01-3.43)	1.56	1.38 (1.00-2.87)	2.69	2.66 (1.93-3.87)
19	*PotePote*	10	11 (4-14)	2.83	2.83 (2.31-3.05)	2.07	2.04 (1.77-2.59)	2.88	2.86 (2.49-3.21)
20	*FiliPote*	13	14 (8-16)	2.74	2.75 (2.45-3.2)	2.56	2.48 (2.09-3.14)	2.4	2.41 (1.73-3.04)
21	*Schoenus*	13	13 (8-17)	2.35	2.38 (2.02-2.74)	3.54	3.57 (3.26-3.89)	1.34	1.41 (1.13-1.58)
22	*MoliCare*	11	12 (6-20)	2.10	2.13 (1.22-2.77)	3.64	3.63 (2.71-4.71)	1.56	1.52 (1.04-2.45)
23	*CareScor*	12	12 (8-16)	2.79	2.66 (2.26-3.52)	2.55	2.80 (1.84-2.92)	1.91	1.98 (1.35-2.24)
24	*PotaGlyc*	4	3 (1-9)	3.87	3.89 (3.44-4.00)	1.91	1.92 (1.63-2.05)	1.25	1.22 (1.00-2.16)
25	*CareCvir*	6	6 (5-10)	2.08	2.00 (1.79-2.54)	3.8	3.91 (3.25-4.14)	1.23	1.16 (1.00-1.62)
26	*Eleoacic*	10	10 (5-15)	2.44	2.38 (1.31-3.74)	1.28	1.25 (1.00-1.74)	3.36	3.34 (1.52-4.68)
27	*CareEqui*	5	4 (3-9)	2.60	2.78 (2.08-3.00)	3.23	3.06 (2.52-3.91)	1.39	1.24 (1.00-2.00)
28	FldPavmt	13	14 (8-15)	1.96	1.86 (1.51-2.66)	3.86	3.86 (3.30-4.40)	1.42	1.30 (1.07-2.13)

Table 7.82. *Post-hoc* Mann-Whitney U tests for differences between the medians of clusters for Ellenberg Wetness, Fertility and pH values.

Wetness							
	1	**2**	**3**	**4**	**5**	**6**	**7**
2	**0.000**						
3	0.868	**0.000**					
4	0.041	**0.000**	**0.000**				
5	**0.000**	**0.000**	**0.000**	**0.000**			
6	0.032	**0.000**	**0.000**	**0.000**	**0.000**		
7	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	
8	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Fertility							
	1	**2**	**3**	**4**	**5**	**6**	**7**
2	**0.000**						
3	**0.000**	**0.001**					
4	**0.000**	**0.000**	**0.000**				
5	**0.000**	0.102	0.675	**0.000**			
6	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**		
7	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	
8	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

pH							
	1	**2**	**3**	**4**	**5**	**6**	**7**
2	**0.000**						
3	0.005	**0.000**					
4	**0.000**	**0.000**	**0.000**				
5	**0.001**	0.003	0.945	**0.000**			
6	**0.000**	**0.000**	**0.000**	0.055	**0.000**		
7	0.010	0.002	0.419	**0.000**	0.343	**0.000**	
8	**0.000**	**0.000**	**0.000**	0.510	**0.000**	0.020	**0.000**

Table 7.83. *Post-hoc* Mann-Whitney U tests for differences between the medians of clusters for Species Richness and Grime's C-S-R values.

Species Richness							
	1	**2**	**3**	**4**	**5**	**6**	**7**
2	0.562						
3	0.012	**0.000**					
4	**0.000**	**0.000**	**0.000**				
5	**0.000**	**0.000**	**0.000**	**0.000**			
6	**0.000**	**0.000**	**0.001**	**0.001**	**0.000**		
7	0.049	0.040	0.897	**0.000**	**0.000**	0.011	
8	0.789	0.895	0.006	**0.000**	**0.000**	**0.000**	0.064

C							
	1	**2**	**3**	**4**	**5**	**6**	**7**
2	**0.000**						
3	**0.000**	0.015					
4	0.276	**0.000**	**0.000**				
5	**0.000**	**0.000**	**0.000**	**0.000**			
6	**0.000**	0.413	0.966	**0.000**	**0.000**		
7	**0.000**	0.575	0.128	**0.000**	**0.000**	0.436	
8	0.258	**0.000**	**0.000**	0.964	**0.000**	**0.000**	**0.000**

S							
	1	**2**	**3**	**4**	**5**	**6**	**7**
2	**0.000**						
3	**0.000**	0.223					
4	**0.000**	**0.000**	**0.000**				
5	**0.000**	**0.000**	**0.000**	**0.000**			
6	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**		
7	**0.000**	0.014	**0.000**	**0.000**	0.156	**0.000**	
8	**0.000**	**0.000**	**0.000**	0.765	**0.000**	**0.000**	**0.000**

R							
	1	**2**	**3**	**4**	**5**	**6**	**7**
2	**0.000**						
3	**0.000**	**0.000**					
4	**0.000**	**0.000**	**0.000**				
5	**0.000**	0.951	0.016	**0.000**			
6	**0.000**	**0.000**	**0.000**	0.015	**0.000**		
7	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	
8	**0.000**	**0.000**	**0.000**	0.004	**0.000**	**0.000**	**0.000**

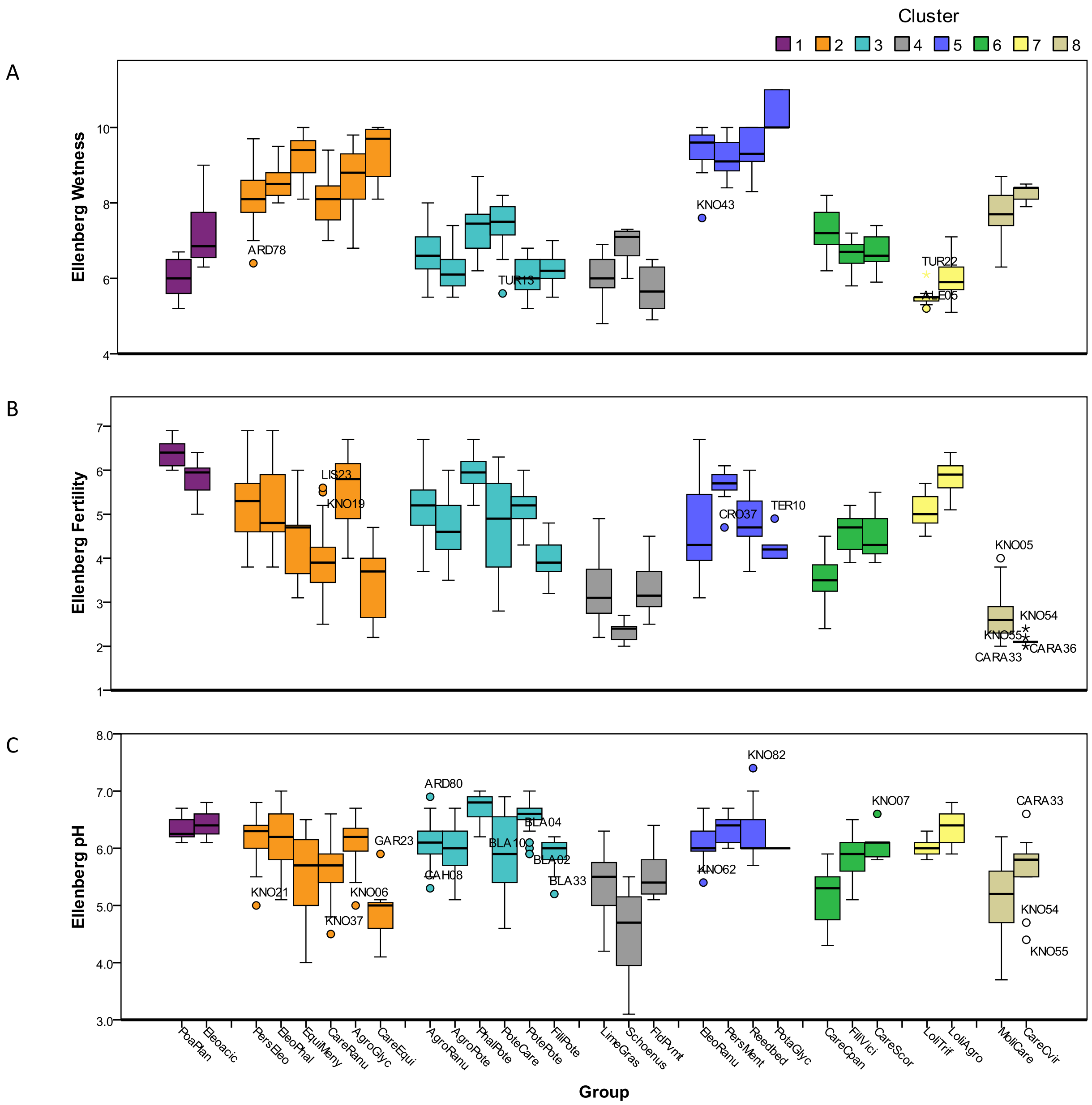


Figure 7.40 (A-C) Boxplots showing the median, interquartile range and highest and lowest values for Ellenberg Wetness, Fertility and pH values for each of the 28 groups. Groups are colour-coded and divided into clusters as shown in the legend.

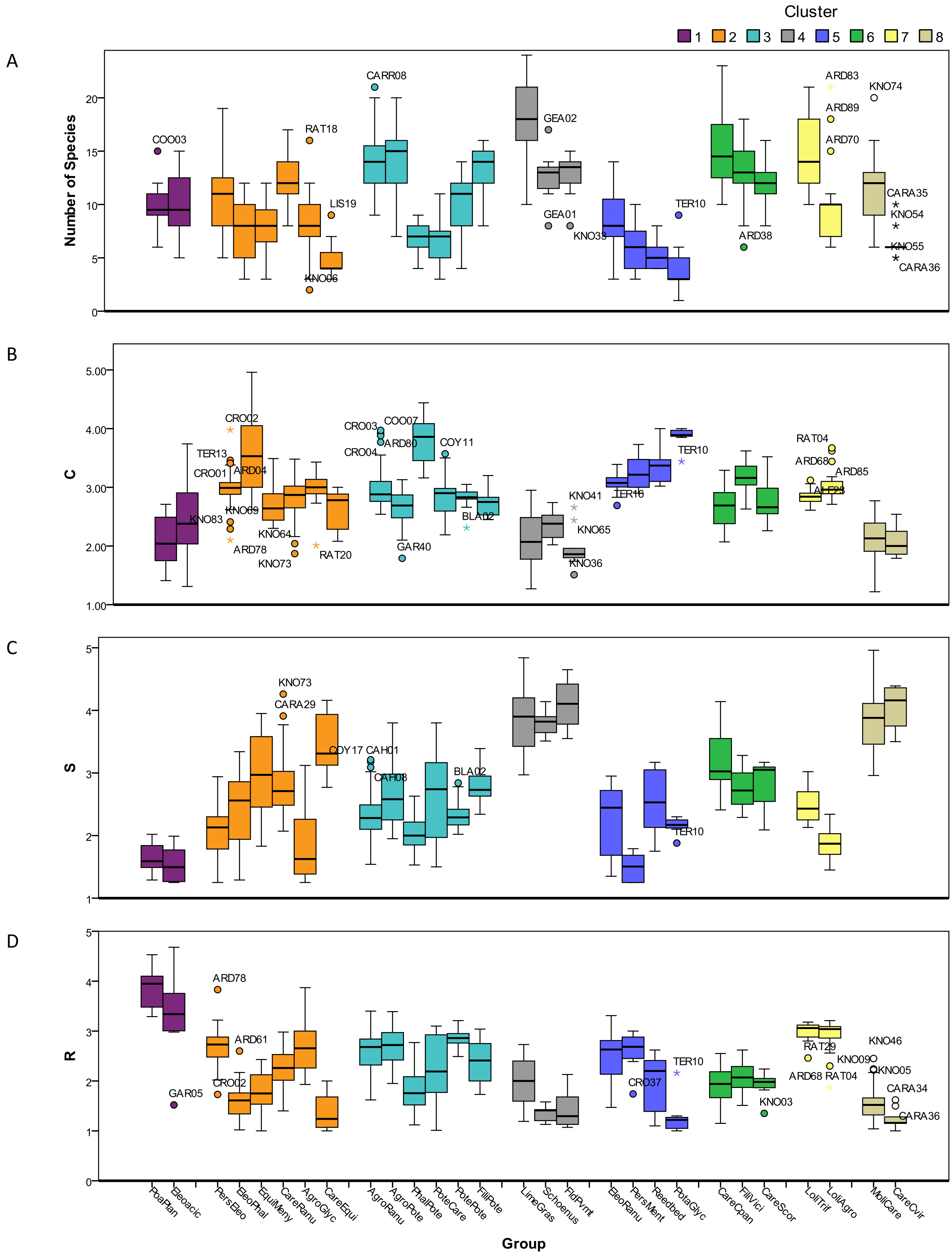


Figure 7.41 (A-D) Boxplots showing the median, interquartile range and highest and lowest values for number of species and Grime's C-S-R values for each of the 28 groups. Groups are colour-coded and divided into clusters as shown in the legend.

7.5.4.6 Multicollinearity

The measured and derived environmental variables were tested for multicollinearity in order to allow further analyses of the data. Since there were so many variables, initial testing was done for each category to rule out variables which were highly correlated within the same category, before testing the remainder. Variables which had correlation values of ≥ 0.800 were considered very highly correlated, and one of the variables was removed before proceeding.

Hydrological variables

For duration, all levels of inundation were highly correlated (Table 7.84). Frequency 0cm was highly correlated with Frequency 10cm, but not with Frequency 25cm or Frequency 50cm, while Frequency 10cm was highly correlated with Frequency 25cm. Maximum quadrat depth was moderately correlated with all duration and frequency variables (0.442-0.660) except for Frequency 50cm.

Duration 0cm was retained; other levels of inundation were discarded. Frequency 0cm and 50cm were retained, other levels were discarded. The length of the longest dry period (LongDry) was highly significantly negatively correlated with Dur0cm and Dur10cm, and so was not retained. All other hydrological variables were retained.

Table 7.84. Spearman's rank correlation coefficients for hydrological variables.

	DryDate	*Dur0cm*	*Dur10cm*	*Dur25cm*	*Dur50cm*	*Freq0cm*	*Freq10cm*	*Freq25cm*	*Freq50cm*	*LongDry*
Dur0cm	**0.604**									
Dur10cm	**0.571**	**0.986**								
Dur25cm	**0.550**	**0.970**	**0.993**							
Dur50cm	**0.525**	**0.936**	**0.952**	**0.973**						
Freq0cm	-0.032	0.096	0.101	0.113	**0.145**					
Freq10cm	-0.083	**0.199**	0.209	**0.214**	**0.240**	**0.843**				
Freq25cm	-0.127	**0.201**	0.220	**0.229**	**0.244**	**0.766**	**0.835**			
Freq50cm	0.116	**0.163**	0.141	0.132	0.126	0.000	0.026	0.012		
LongDry	**-0.354**	**-0.821**	**-0.810**	**-0.795**	**-0.769**	**-0.266**	**-0.357**	**-0.333**	-0.121	
WetDate	**-0.251**	**-0.435**	**-0.428**	**-0.415**	**-0.386**	-0.080	-0.110	-0.110	-0.104	**0.531**
MDQuad	.073	**.442**	**.499**	**.564**	**.660**	**.497**	**.536**	**.538**	-.022	**-.435**

Figures in bold are significant to p=0.05 when corrected for multiple comparisons using the Dunn-Šidák correction. Correlations ≥ 0.800 are highlighted in grey.

Soil variables

Organic matter and soil total nitrogen were very highly correlated (Table 7.87). Based on this, organic matter was removed before proceeding, as total nitrogen is more widely used in the literature.

Table 7.87. Spearman's rank correlation coefficients for soil variables.

	Soil TP	Soil TN	Soil pH	OM	INORG
Soil TN	**.214**				
Soil pH	**-.494**	**.247**			
OM	**.195**	**.985**	**.259**		
INORG	**.120**	**-.732**	**-.535**	**-.726**	
$CACO_3$	**-.272**	**.251**	**.729**	**.235**	**-.513**

Figures in bold are significant to p=0.05 when corrected for multiple comparisons using the Dunn-Šidák correction. Correlations ≥ 0.800 are highlighted in grey.

Water chemistry

Total phosphorus and MRP were very highly correlated (Table 7.88). Nitrate was very highly correlated with total nitrogen, and calcium was very highly correlated with alkalinity, as was expected.

Total phosphorus, total nitrogen and alkalinity were retained while MRP, nitrate, and calcium were removed; the former are much more widely used in the literature than the latter, and this will allow comparison with other studies.

Tabe 7.88. Spearman's rank correlation coefficients for water chemistry variables.

	TP	MRP	TN	Nitrate	Ca
MRP	**0.936**				
TN	**0.505**	**0.482**			
Nitrate	**0.444**	**0.442**	**0.973**		
Ca	**0.374**	**0.176**	**0.463**	**0.388**	
Alkalinity	**0.324**	**0.142**	**0.459**	**0.365**	**0.957**

Figures in bold are significant to p=0.05 when corrected for multiple comparisons using the Dunn-Šidák correction. Correlations ≥ 0.800 are highlighted in grey.

Derived variables

Mean Ellenberg pH value was highly significantly correlated with mean Ellenberg Fertility value (Table 7.89). Fertility was also highly negatively correlated with Grime's S value. On this basis, Ellenberg pH and Grime's S values were removed before proceeding.

Spearman's rank correlation coefficients were then calculated for the remaining variables (Table 7.90). None of these remaining variables were highly (≥ 0.800) correlated; all were therefore retained for further analyses.

Table 7.89 Spearman's rank correlation coefficients for derived variables.

	Wetness	pH	Fertility	C	S	R
pH	**-.061**					
Fertility	-.048	**.839**				
C	**.348**	**.505**	**.525**			
S	-.077	**-.710**	**-.831**	**-.551**		
R	**-.270**	**.552**	**.657**	**.095**	**-.609**	
Number of species	**-.467**	**-.227**	**-.195**	**-.295**	**.328**	.117

Figures in bold are significant to p=0.05 when corrected for multiple comparisons using the Dunn-Šidák correction. Correlations ≥ 0.800 are highlighted in grey.

Dur0cm was highly significantly correlated with DryDate and Wetness (0.604, 0.672), moderately correlated with MDQuad (0.442), and moderately negatively correlated with WetDate (-0.435). Wetness was also positively correlated with DryDate (0.479), and moderately negatively correlated with species richness (-0.409). Freq0cm was moderately negatively correlated with Alkalinity (-0.435), and positively correlated with MDQuad and SoilTP (0.497, 0.458).

Ellenberg Fertility was correlated with Grime's R value and WaterTP (0.657, 0.489).

INORG was negatively correlated with $CaCO_3$ and SoilTN (-0.513, -0.732) and positively correlated with, Grime's R value and WaterTP (0.647, 0.405, 0.501). SoilTN was also moderately negatively correlated with WaterTP (-0.499).

Table 7.90 Spearman's rank correlation coefficients for the retained variables from all categories.

	Alkalinity	*C*	*CACO3*	*DryDate*	*Dur0cm*	*Fertility*	*Freq0cm*	*Freq50cm*	*INORG*	*MDQuad*	*No.Specis*	*R*	*SoilTN*	*SoilTP*	*WaterTN*	*WaterTP*	*WetDate*
C	**0.369**																
$CACO_3$	**0.313**	0.067															
DryDate	**0.280**	**0.216**	**0.311**														
Dur0cm	0.038	**0.156**	**0.330**	**0.604**													
Fertility	**0.192**	0.525	-0.057	0.031	-0.049												
Freq0cm	**-0.435**	**-0.194**	**-0.180**	-0.032	0.096	0.070											
Freq50cm	0.035	0.050	-0.019	0.116	**0.163**	-0.022	0.000										
INORG	-0.053	0.091	**-0.513**	**-0.279**	**-0.317**	**0.295**	**0.223**	0.094									
MDQuad	**-0.372**	-0.005	-0.101	0.073	**0.442**	**0.223**	**0.497**	-0.022	**0.161**								
No.Species	0.008	**-0.295**	-0.078	**-0.220**	**-0.317**	**-0.195**	-0.041	-0.025	0.084	**-0.247**							
R	0.050	0.095	-0.132	-0.105	**-0.155**	**0.657**	**0.194**	0.027	**0.405**	**0.178**	0.117						
SoilTN	**-0.136**	-0.056	**0.251**	**0.188**	**0.248**	**-0.221**	-0.116	0.035	**-0.732**	**-0.223**	0.037	**-0.335**					
SoilTP	**-0.652**	**-0.165**	**-0.272**	**-0.315**	-0.1	0.076	**0.458**	0.020	0.120	**0.396**	0.101	**0.162**	**0.214**				
WaterTN	**0.459**	0.095	**0.346**	**0.155**	0.117	0.085	0.001	**-0.194**	0.105	0.123	-0.021	0.046	**-0.346**	**-0.381**			
WaterTP	**0.324**	**0.314**	-0.111	-0.006	**-0.197**	**0.489**	-0.047	**-0.197**	**0.501**	**0.283**	0.035	**0.338**	**-0.499**	0.034	**0.505**		
WetDate	**0.282**	**0.144**	-0.056	**-0.251**	**-0.435**	**0.282**	-0.080	-0.104	**0.259**	-0.097	**0.196**	**0.215**	**-0.194**	-0.025	**0.139**	**0.453**	
Wetness	**0.211**	**0.348**	**0.320**	**0.479**	**0.672**	-0.048	**-0.162**	**0.198**	**-0.274**	0.050	**-0.467**	**-0.270**	**0.309**	**-0.191**	0.009	**-0.174**	**-0.247**

Figures in bold are correlations with $p<0.001$. Correlations ≥ 0.400 are highlighted in grey.

7.5.4.7 Relationships Between Measured and Derived Variables

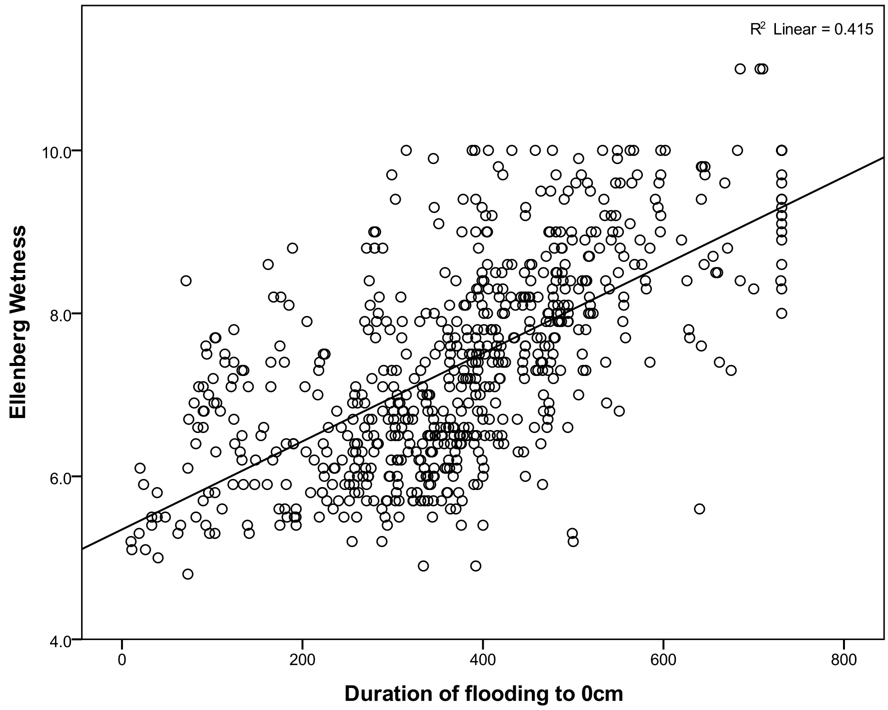
Ellenberg values have been used in the literature as indicators for environmental conditions (e.g. Hawkes *et al.*, 1997). In this study, Spearman rank correlations infer relationships between Ellenberg values and Water TP and Dur0cm (Table 7.90). In order to further explore these relationships, scatterplots and regression equations were used.

Ellenberg Wetness

A strong positive relationship was evident between duration of flooding to 0cm and Ellenberg Wetness (Figure 7.42 A). The regression equation is Ellenberg Wetness = (0.005 x Ellenberg Wetness) + 5.348; F = 474.781, $p<0.001$; R^2 = 41.5%.

There was a much weaker relationship between duration of flooding to 50cm and Ellenberg Wetness (Figure 7.42 B). Regression equation: Ellenberg Wetness = (0.005 x Ellenberg Wetness) + 5.909; F = 263.539, $p<0.001$; R^2 = 28.3%.

A



B

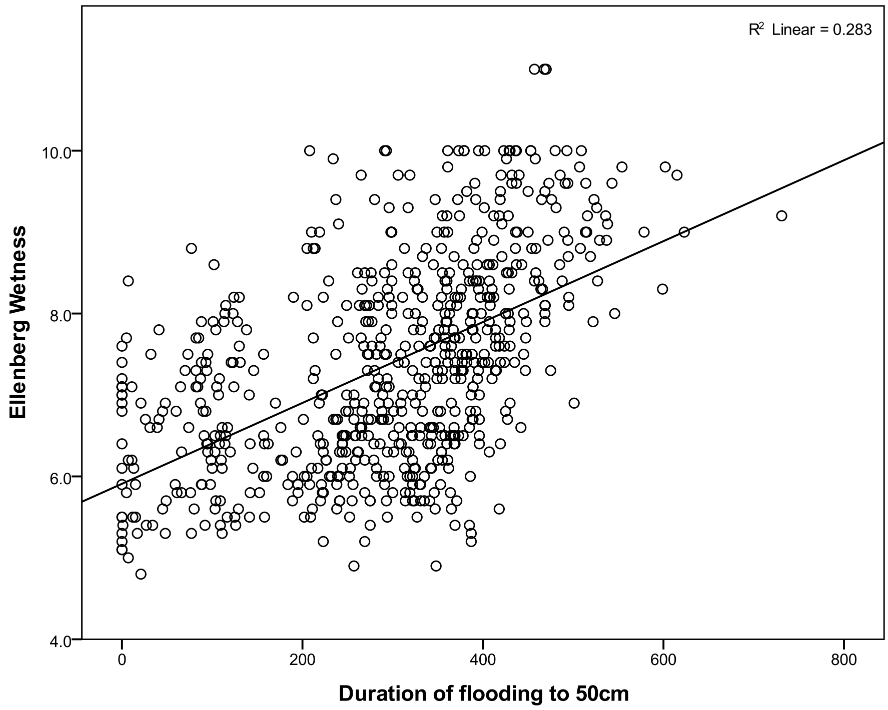


Figure 7.42 Scatterplots of Ellenberg Wetness values and duration of flooding.

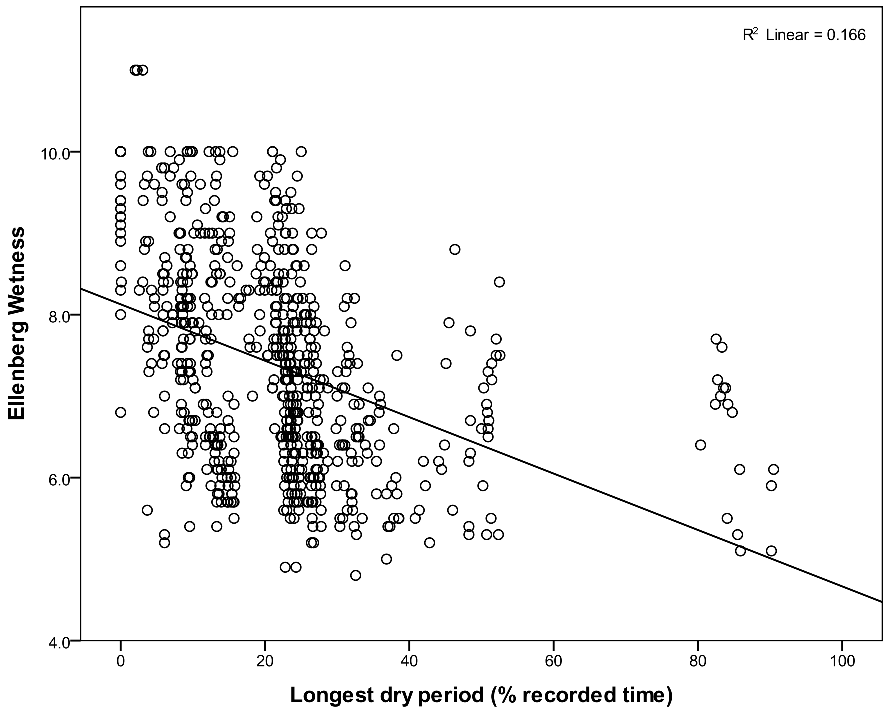


Figure 7.43 Scatterplot showing the relationship between Ellenberg Wetness value and the longest dry period.

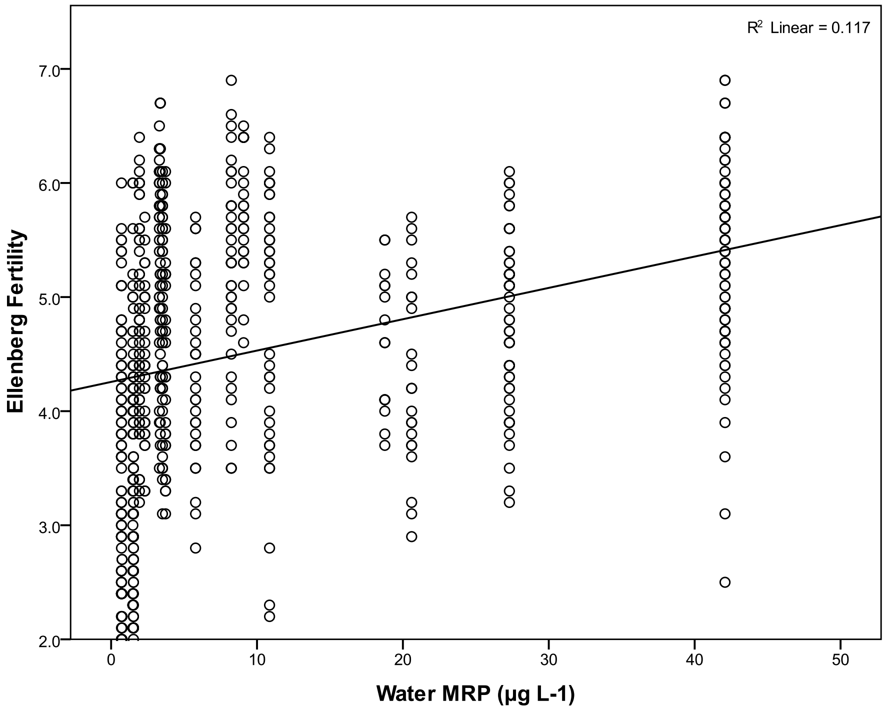
Ellenberg pH

Ellenberg pH showed no relationship with either water pH or soil pH.

Ellenberg Fertility

There was no relationship between Ellenberg Fertility and water TN or nitrate. There was a slight positive relationship between Ellenberg Fertility values and Water MRP and Water TP (Figure 7.44). There was a very weak positive relationship between Ellenberg fertility and soil TP, and a weak neagtive relationship with soil TN (Figure 7.45).

A



B

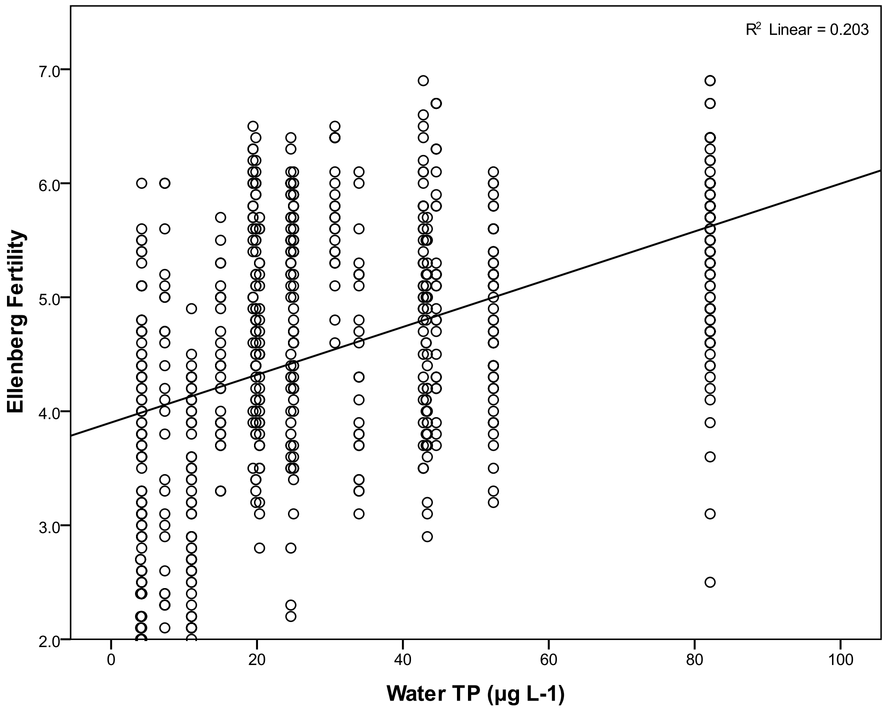


Figure 7.44 Scatterplots showing the relationships between Ellenberg Fertility values and water MRP and TP.

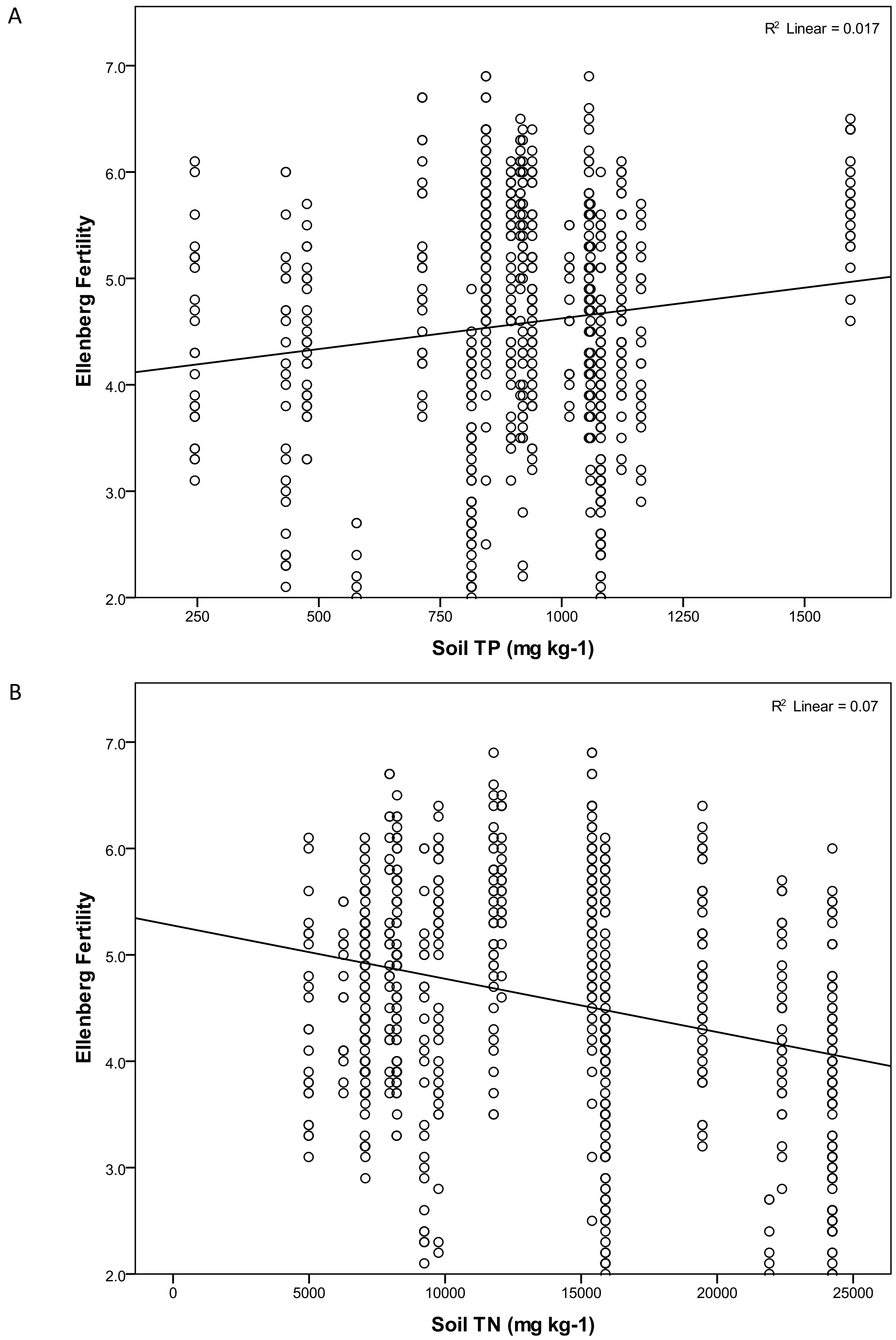


Figure 7.45 Scatterplots showing the relationships between Ellenberg Fertility values and soil TP and TN.

7.5.4.8 Relationships Between All Variables and Vegetation types

An ordination of the species abundance in quadrats was carried out on this reduced dataset using Non-Metric Multidimensional Scaling (NMS) as per 7.5.1. A 3-dimensional solution was chosen for the ordination by PC-ORD, with a final stress of 21.3. This is a high stress value, but given the large dataset, acceptable (McCune & Grace, 2002). The probability of finding a similar final stress by chance, with 250 randomised runs, was calculated using a Monte Carlo test as 0.004. A plot of stress vs. iteration number was used to assess stability; a final instability of 0.00032 was calculated after 500 iterations. Environmental data were added to the second matrix and overlayed on the ordination as a biplot; the threshold for displaying environmental variables as a biplot was $r^2 > 0.200$. The major correlation vectors were visually aligned with Axes 2 and 3 by rotating the axes until the biplots were aligned with the ordination axes, both to improve ease of interpretation (McCune and Grace, 2002) and to allow comparison with the ordination diagrams presented in Section 7.5.1.2. This is a type of rigid rotation which does not change the geometry of the points in ordination space or the cumulative variance represented by the axes, but does affect the correlation of variables with the ordination axes and the variance represented by an individual axis (McCune and Grace, 2002); correlations and variance were calculated after rotation. Ordination diagrams are presented in Figure 7.46. Axis 2 explained the largest amount of variation, (r^2 = 0.301), Axis 3 the next largest amount (r^2 = 0.197), while Axis 1 explained the least (r^2 = 0.139). The cumulative amount of variance represented by all three axes was 63.7% (r^2 = 0.637). This ordination corresponds well with that carried out for the full data set (Vegetation Description section, above). When Figure 7.46 C is compared with Figure 7.4 the scatter of clusters is broadly similar.

The mean Ellenberg Wetness score was highly negatively correlated with Axis 2 (r^2 = -0.863, $p \leq 0.001$). Duration of flooding was also highly negatively correlated with this axis (r^2 = -0.643, $p \leq 0.001$). This indicates that the clusters towards the negative end of Axis 2 are associated with a longer duration of flooding, and contain species with a higher Ellenberg value for wetness, than those on the positive end of the axis. As can be seen in Figure 7.46 C, Clusters 5 and 2, both of which contain very water-dependent communities, are located towards the negative end of Axis 2. Conversely, Clusters 4 and 7, which contain vegetation communities associated with drier habitats, occur on the opposite end of Axis 2. Species richness is positively correlated with Axis 2 (r^2 = 0.589, $p \leq 0.001$), which indicates that communities that experience least inundation have a greater number of species.

Axis 3 was highly negatively correlated with the mean Ellenberg value for Fertility (r^2 = -0.831, $p \leq 0.001$), as well as Grime's R value (r^2 = -0.713, $p \leq 0.001$). Grime's S value was also positively correlated with Axis 3 (r^2 = 0.793, $p \leq 0.001$). This suggests that communities occurring towards the negative end of Axis 3 are those that contain a high proportion of species which occur on relatively fertile soil, and which may contain a high number of ruderal species. Cluster 1, which occurs on the negative end of Axis 3, consists of two communities which have a large number of ruderal species (the *Poa annua-Plantago major* community and the *Eleocharis acicularis* community). At the opposite end of the fertility gradient is Cluster 8, which contains sedge-dominated communities, characterised by 'Stress-tolerator' species which can tolerate low levels of soil nutrients.

Maximum quadrat depth and frequency of flooding did not have a sufficiently high Tau value to be displayed on the ordination diagrams when the biplot was overlaid, and indeed these variables were only weakly correlated with the ordination axes (Table 7.91). This suggests that duration of flooding rather than frequency or maximum depth of flooding is the strongest hydrological driver of vegetation, although these may have interactions or effects which are not seen through this type of analysis.

It should be noted here that the vectors on the ordination diagrams indicate the strength of the relationship between the axes and the variables using Kendall's tau, while the values presented in Table 7.91 are the correlations between the axes and the variables using Spearman's rank correlation coefficients. Ordination diagrams displaying the vectors obtained from Kendall's tau are commonly published in the literature (for example Perrin *et al.*, 2006), Spearman's rank correlation coefficients are more appropriate for non-parametric data, and so these are also presented here.

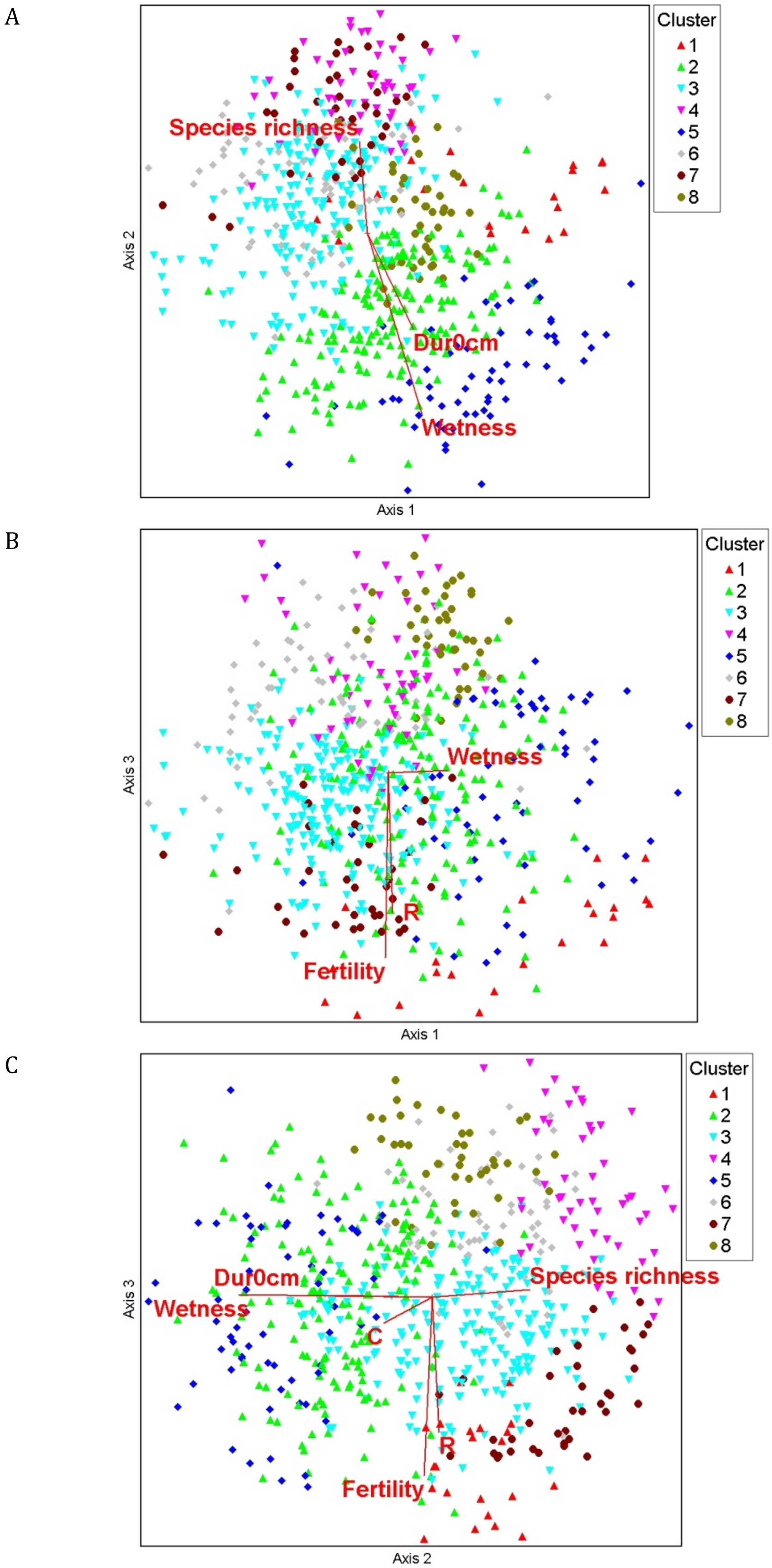


Figure 7.46. Non-metric Multidimensional Scaling ordination showing the 8 vegetation clusters derived by cluster analysis and a biplot showing duration of flooding, Ellenberg and Grime's indicator values, and species richness (r^2 values of axes: 1 = 0.139, 2 = 0.301, 3 = 0.197, total = 0.637).

Table 7.91. Statistically significant Spearman's rank correlation coefficients between the ordination axes and the measured or derived environmental variables

	Axis1	*Axis2*	*Axis3*
C	**-0.175**	**-0.449**	**-0.342**
$CaCO_3$	**0.200**	**-0.215**	**0.173**
DryDate	**0.226**	**-0.485**	0.063
Dur0cm	**0.438**	**-0.643**	0.099
Fertility	**-0.135**	**-0.157**	**-0.831**
Freq0cm	0.089	**0.170**	**-0.163**
Freq50cm	0.113	**-0.169**	0.013
INORG	**-0.266**	**0.154**	**-0.368**
MDQuad	0.052	**-0.128**	**-0.248**
Species richness	**-0.184**	**0.589**	**0.180**
R	0.108	**0.161**	**-0.713**
SoilTN	**0.188**	**-0.137**	**0.319**
SoilTP	-0.072	**0.191**	**-0.144**
WaterTN	-0.100	-0.024	-0.077
WaterTP	**-0.394**	0.003	**-0.463**
WetDate	**-0.319**	**0.173**	**-0.221**
Wetness	**0.457**	**-0.863**	**0.127**

Figures in bold are significant to p<0.05, corrected for multiple comparisons with Dunn-Šidák correction

A multi-response permutation procedure (MRPP) was carried out on the species abundance matrix to confirm that there was clear separation between the vegetation communities. A high chance-corrected within-group agreement (A = 0.733), and a highly significant effect of 'group' ($P < 10^8$) were found. The test statistic, T, was large and negative (-149.3), indicating good separation between groups. A describes within-group homogeneity; the highest possible value is 1, when all items are identical within groups. If within-group heterogeneity is as expected by chance, then A = 0 (McCune & Grace, 2002). An A > 0.3 is described by McCune and Grace as 'fairly high'. The results of MRPP therefore support the separation of relevés into groups, and confirm that this reduced dataset still contains well-defined groups. The Mantel test yielded a small r (0.074), but was statistically significant (p = 0.001).

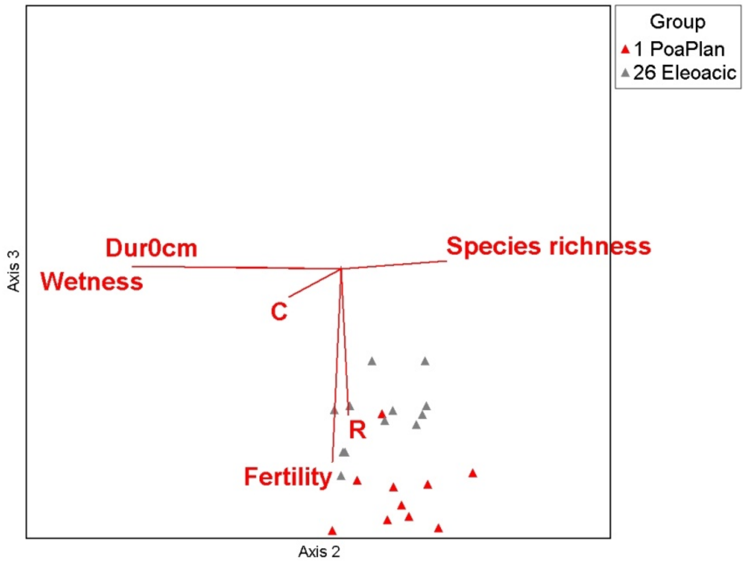
In order to visualise the position of the 28 different vegetation communities in the ordination diagrams, each cluster was graphed individually (Figure 7.47 to Figure 7.49). Axes 2 and 3 are shown, as these represent the greatest amount of variation (48.9%).

Cluster 1 is shown in Figure 7.47 A, and occurs at the top of the Fertility, and R gradient. This cluster consists of two vegetation communities, Group 1 *PoaPlan* and Group 26 *Eleoacic*. Both of these communities are characterised by a high proportion of ruderal species, as indicated by the correlation vector for Grime's R value. They also both have a high mean Ellenberg Fertility value. Group 26, *Eleoacic* occurs on wet mud near to standing water, and is higher up the Wetness/Duration gradient, while Group 1, *PoaPlan* occurs on heavily poached soils which experience less inundation.

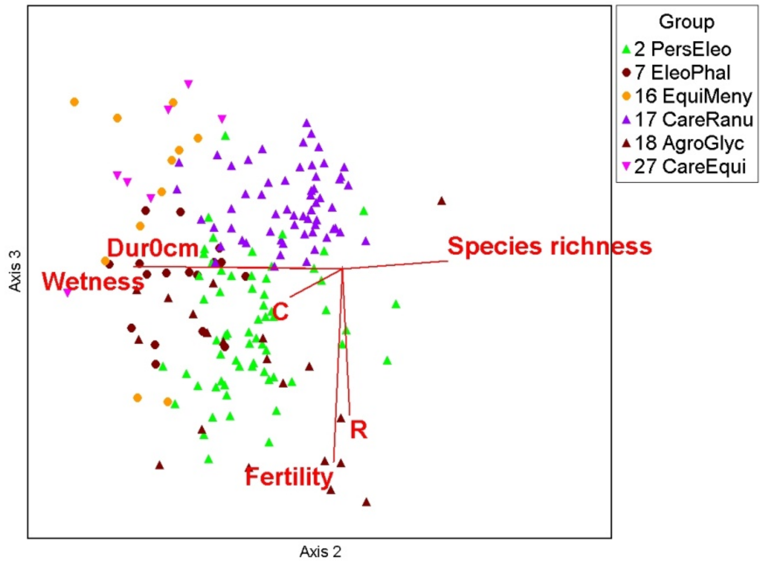
Figure 7.47 B shows the position of the vegetation communities in Cluster 2 in the ordination space. These communities all occur towards the wetter end of the Wetness/Duration gradient, but are well spread out along the Fertility gradient. They all occur towards the bottom of the Species Richness gradient, indicating relatively low species diversity. Group 2 *PersEleo* and Group 18 *AgroGlyc* both occur towards the negative end of Axis 3, i.e. at the top of the Fertility gradient, indicating that these communities have a high proportion of species which flourish on relatively fertile soils. Group 7 *EleoPhal*, Group 17 *CareRanu* and Group 27 *CareEqui* all occur towards the top of the Wetness/Duration gradient, indicating that these communities are composed of species which tolerate or require a relatively long duration of inundation. These communities are also aligned at the bottom of the Fertility gradient, which suggests there is a high proportion of stress-tolerator species in these groups. Group 16 *EquiMeny* occurs towards the top of the Wetness/Duration gradient, indicating the requirement for relatively long duration of flooding, but relevés from this group are plotted all along the Fertility gradient, which suggests that nutrient availability is not a driver for this community.

Cluster 3 is represented in Figure 7.47 C, and although they occur throughout the Wetness gradient, there is a trend for these communities to occur towards the positive end of Axis 2, suggesting they occur in areas with a shorter duration of flooding. They also seem to be concentrated towards the upper end of the Fertility gradient, suggesting that these communities occur in areas of high fertility. Group 4 *AgroPote* and Group 20 *FiliPote* occur towards the top end of the Species Richness gradient, which indicates that these communities have a high level of species richness, while also occurring in areas with a shorter duration of flooding. Group 9 *PhalPote* and Group 13 *PoteCare*, on the other hand, occur towards the opposite end of this gradient, which suggests these communities require a longer duration of inundation, and that they have a lower species richness.

A – Cluster 1



B – Cluster 2



C – Cluster 3

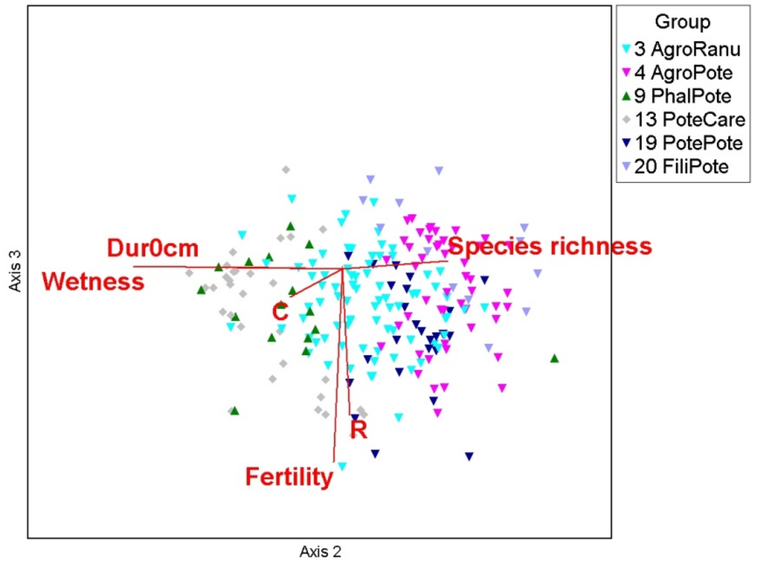
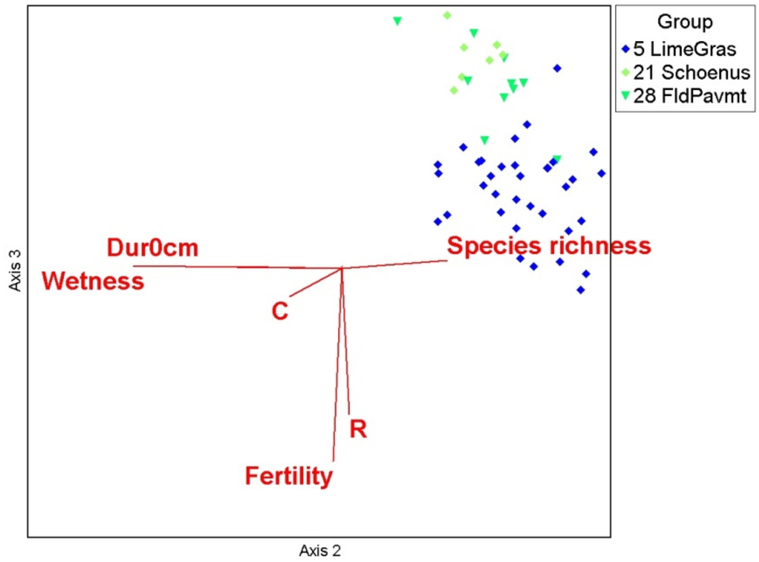


Figure 7.47 (A-C) Non-metric Multidimensional Scaling ordination of Axes 2 and 3 (r^2 = 0.498) showing the vegetation communities in clusters 1 to 3, with a biplot showing duration of flooding, Ellenberg and Grime's indicator values, and species richness (r^2 values of axes: , 2 = 0.301 = 0.197).

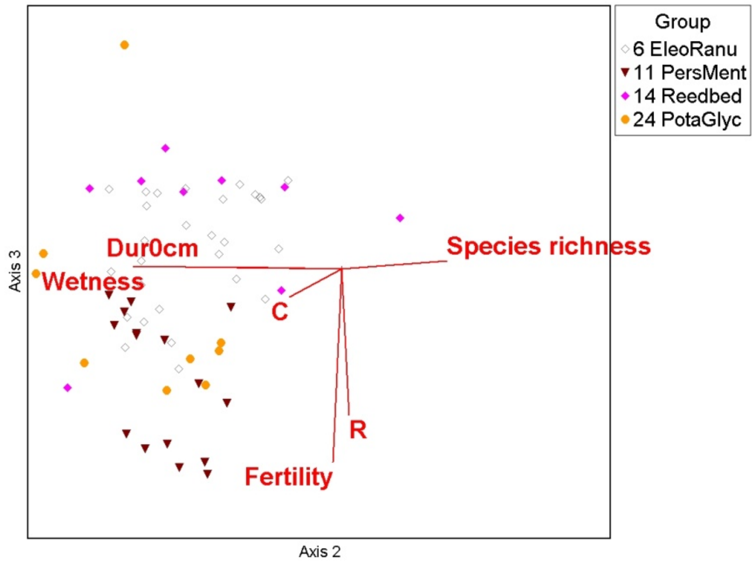
The location of Cluster 4 on the ordination diagram can be seen in Figure 7.48 A. The communities in this cluster all occur at the positive ends of axes 2 and 3, indicating that these communities occur in areas that experience a short duration of flooding, have a high proportion of stress-tolerator species (as suggested by the low Fertility), a high number of species, and occur in areas with relatively low fertility. The communities in this cluster are Group 5 LimeGras, Group 21 *Schoenus* and Group 28 FldPavmt. There is some separation of these communities along the Fertility gradient; the position of Group 5 LimeGras suggests that this community occurs in areas of higher fertility than the others.

Cluster 5 is shown in Figure 7.48 B. This cluster consists of 4 of the more water-dependent communities in this study: Group 6 *EleoRanu*, Group 11 *PersMent*, Group 14 Reedbed, and Group 24 *PotaGlyc*. These communities all occur towards the negative end of Axis 2, which is correlated with a greater duration of duration of flooding. *PersMent* and *PotaGlyc* occur towards top of the Fertility gradient, suggesting these communities occur on more fertile soils, while *EleoRanu* and Reedbed have lower mean Ellenberg Fertility values, and lower mean Grime's R value.

A – Cluster 4



B – Cluster 5



C – Cluster 6

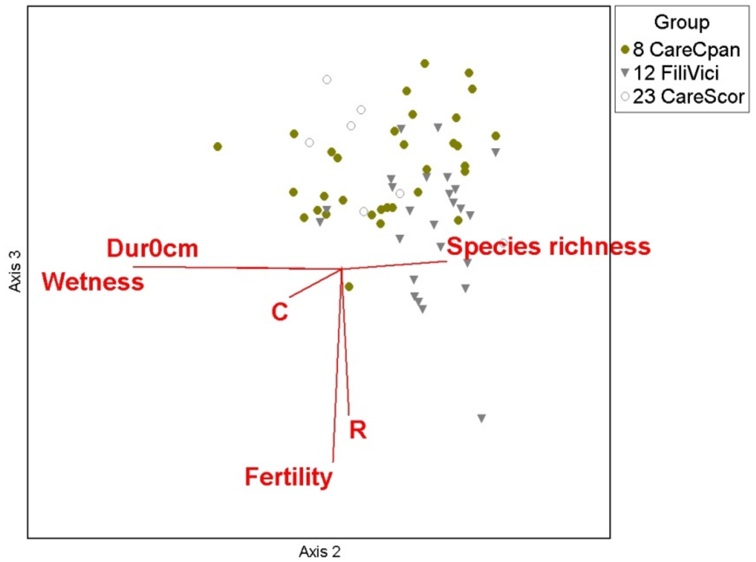


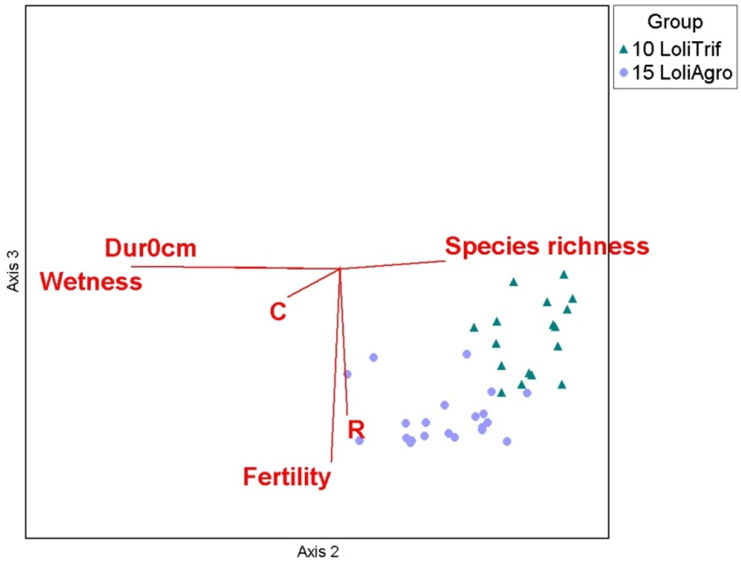
Figure 7.48 (A-C) Non-metric Multidimensional Scaling ordination of Axes 2 and 3 (r^2 = 0.498) showing the vegetation communities in clusters 4 to 6, with a biplot showing duration of flooding, Ellenberg and Grime's indicator values, and species richness (r^2 values of axes: , 2 = 0.301 = 0.197).

In Figure 7.48 C, Cluster 6 is shown. This cluster contains three vegetation communities: Group 8 *CareCpan*, Group 12 *FiliVici*, and Group 23 *CareScor*. As in Cluster 4, these communities all occur towards the positive end of both axes, indicating they experience shorter periods of inundation, and occur in areas with a lower nutrient status. Of the three communities, *FiliVici* occurs along a greater range of Fertility values.

Cluster 7 is represented in Figure 7.49 A. This cluster is composed of two vegetation communities: Group 10 *LoliTrif*, and Group 15 *LoliAgro*. These communities are similar floristically, although *LoliAgro* has a higher proportion of ruderal species. Their position on the ordination diagram indicates that these communities are well-drained and occur on relatively fertile soils. They also occur towards the top of the species richness gradient. Group 15 *LoliAgro* is associated with higher Ellenberg Fertility values, and occurs more towards the middle of the duration gradient, while Group 10 *LoliTrif* has shorter flooding duration and higher species richness.

Figure 7.49 B shows the location of Cluster 8 in the ordination space. This cluster consists of two vegetation communities: Group 22 *MoliCare* and Group 25 *CareCvir*. These communities are characterised by species with a high stress tolerance – *Molinia caerulea*, for example, usually occurs in vegetation types with low productivity (Grime *et al.*, 1988). Their position at the bottom of the Fertility gradient indicates that these communities occur in areas with low nutrient availability. They are plotted in the middle of the Wetness/Duration gradient, indicating they experience moderate inundation, and have an intermediate level of species richness. There is some separation of these two communities, with the position of Group 25 *CareCvir* on the Fertility gradient suggesting that this community occurs in less fertile areas than Group 22 *MoliCare*. Group 25 *CareCvir* also experiences longer duration of inundation than Group 25 *CareCvir*, as indicated by position on the duration gradient.

A – Cluster 7



B – Cluster 8

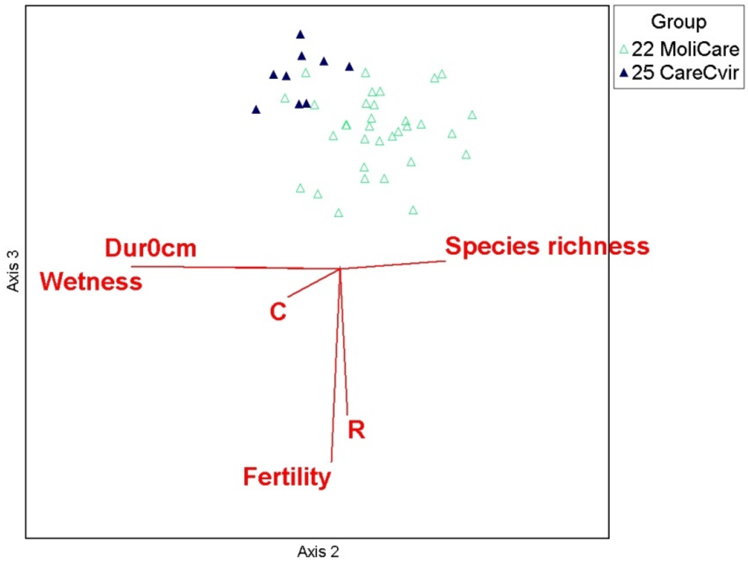


Figure 7.49 (A-B) Non-metric Multidimensional Scaling ordination of Axes 2 and 3 (r^2 = 0.498) showing the vegetation communities in clusters 7 to 8, with a biplot showing duration of flooding, Ellenberg and Grime's indicator values, and species richness (r^2 values of axes: 1 = 0.139, 2 = 0.301 = 0.197, total = 0.637)

A Discriminant Analysis was carried out on the quantitative environmental variables, with Vegetation Group as the grouping variable, in order to ascertain which environmental variables were most important in distinguishing between the vegetation groups. MDQuad and WaterTP were log transformed to improve normality prior to analysis.

A Box's M test was carried out to test the null hypothesis that the covariance matrices do not differ between groups. This test was significant, indicating that the null hypothesis should be rejected. However, a significant result is not regarded as too important where sample sizes are large, and non-normality can also affect the result (Leech *et al*., 2005). Tests of equality of group means showed that all variables were significantly different across groups.

Eigenvalues, percentage of variance explained, cumulative variance and canonical correlations associated with the discriminant analysis for the first eight discriminant functions are presented in Table 7.92. The canonical correlation provides an indication of overall model fit. Function 1 has a canonical correlation of 0.839. Each progressive function explains less of the variation. These results suggest that the first four discriminant functions are most important; the cumulative amount of variation explained by these four functions is 88.2%.

Table 7.92 Eigenvalues, variance explained, and canonical correlations from the stepwise discriminant analysis.

Function	*Eigenvalue*	*% of Variance*	*Cumulative %*	*Canonical Correlation*
1	2.381	41.3	41.3	0.839
2	1.353	23.5	64.8	0.758
3	.923	16.0	80.8	0.693
4	.429	7.4	88.2	0.548
5	.297	5.2	93.4	0.478
6	.220	3.8	97.2	0.424
7	.095	1.7	98.9	0.295
8	.066	1.1	100.0	0.249

Table 7.93 presents the standardised canonical discriminant function coefficients from the discriminant analysis. These values are the weightings added to each variable to maximise the differences between groups for each function. MDQuad and Dur0cm carry the highest weightings for the first two functions. Water TN and ROCK_CVR are heavily weighted in functions 3 and 4. Table 7.94 gives a different view of the results, in the correlations for the structure matrix. Structure matrix correlations are often used instead of standardised canonical discriminant function coefficients as they are considered to be more accurate (Burns & Burns, 2008). These values indicate how important each of the variables is in each of the functions. MDQuad, Dur0cm, WaterTP and WaterTN were the most important variables in the first four functions.

Table 7.93. Standardised canonical discriminant function coefficients from the Discriminant Analysis.

	Function 1	*Function 2*	*Function 3*	*Function 4*
MDQuad	1.072	.438	-.227	.207
Dur0cm	-.606	.783	.532	-.064
WaterTN	.056	-.227	-.865	.597
WaterTP	-.163	-.182	.840	-.577
Alkalinity	.245	.081	.535	.576
SoilTP	.206	-.242	.578	.122
SoilTN	-.175	.090	-.641	-.105
ROCK_CVR	-.018	.106	-.212	-.587

MDQuad and SoilTN were the most important variables in Function 1, with structure matrix correlations of 0.794 and -0.366. Dur0cm was the most important variable in Function 2, with a structure matrix correlation of 0.898, while MDQuad was also important (0.547). WaterTP was the most important variable in Function 3 (0.573), while WaterTN was the most important in Function 4 (0.593). Variables which also contributed but were not as important were ROCK_CVR, Alkalinity, SoilTP and SoilTN.

Table 7.94. Structure matrix correlation coefficients from Discriminant Analysis.

	Function 1	*Function 2*	*Function 3*	*Function 4*
MDQuad	.794	.547	.030	-.064
Dur0cm	-.228	.898	.134	.177
WaterTP	.226	-.189	.573	-.044
WaterTN	.108	-.007	-.038	.593
ROCK_CVR	.036	.077	-.196	-.592
Alkalinity	-.272	-.170	.364	.519
SoilTP	.215	-.082	.028	-.267
SoilTN	-.366	.072	-.263	-.301

Table 7.95 presents the classification results from the discriminant analysis, i.e. the percentage of relevés which were placed in the correct group based only on the environmental variables in the analysis. This table is read from left to right, so that for Group 1 *PoaPlan*, no relevés were correctly classified based only on the environmental variables; 50% of the relevés were placed in Group 3 *AgroRanu* instead, and so on. Discriminant analysis placed 31.2% of the relevés in the correct group.

Some groups were very well classified based only on the environmental variables in the analysis, while others were completely misclassified. For Group 1 *PoaPlan*, it is not surprising that classification based solely on environmental variables was not successful; this community is composed primarily of ruderal species and occurs on heavily poached ground, which could not be predicted with the variables in the analysis.

Groups which were well-classified on the basis of only the quantitative environmental variables were Group 9 *PhalPote*, Group 14 Reedbed, Group 19 *PotePote*, Group 21 *Schoenus*, Group 24 *PotaGlyc*, Group 25 *CareCvir* and Group 26 *Eleoacic*. These were the groups for which > 60% of relevés were assigned to the correct vegetation group by Discriminant Analysis.

None of the relevés from Group 1 *PoaPlan*, Group 7 *EleoPhal*, Group 16 *EquiMeny*, Group 18 *AgroGlyc* and Group 27 *CareEqui* were correctly assigned by Discriminant Analysis. This suggests that the measured environmental variables associated with these communities do not differ enough from those associated with other communities to distinguish between them.

In some cases, relevés from similar communities were incorrectly classified. For example, Group 19 *PotePote* and Group 20 *FiliPote* are floristically quite similar, but occur at different elevations within the same turlough. 46.2% of relevés in Group 20 *FiliPote* were assigned to Group 19 *PotePote*, and 16% of relevés in Group 19 *PotePote* were assigned to Group 20 *FiliPote*.

45.5% of relevés from Group 16 *EquiMeny* were mis-classified into Group 2 *PersEleo*, while 41.2% of relevés from Group 7 *EleoPhal* were mis-classified into Group 2 *PersEleo*. This suggests that the environmental variables included here are very similar for these groups, and that there is another explanation (i.e. due to variables not used in this analysis) for the floristic differences between them.

Table 7.95 Number of relevés correctly classified by discriminant analysis using only quantitative environmental variables. Figures in bold are those which were correctly classified by discriminant analysis.

G	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1			50.0	10.0					10.0		10.0	10.0	10.0															
2		**23.8**	1.6					4.8	27.0	3.2	4.8			7.9			6.3					17.5	1.6	1.6				
3		5.1	**22.8**	26.6	1.3			19.0	12.7	1.3		5.1	2.5				3.8											
4		2.0	14.3	**40.8**				4.1		6.1		2.0							4.1	14.3		8.2				4.1		
5			2.9		**8.6**			5.7		5.7		14.3			5.7							17.1	2.9		37.1			
6		10.7				**28.6**			7.1					25.0			10.7					17.9						
7		41.2						11.8	47.1																			
8		6.3	12.5		9.4			**40.6**	6.3	12.5		3.1					3.1					3.1						3.1
9		12.5	12.5					12.5	**62.5**																			
10			17.6					17.6		**41.2**		17.6			5.9													
11		12.5				12.5	6.3	6.3	31.3		**31.3**																	
12		4.0	16.0		4.0			24.0	16.0	4.0		**32.0**																
13		6.5	16.1	19.4				3.2	6.5				**9.7**	3.2	3.2		9.7		3.2							19.4		
14						11.1			11.1					**66.7**								11.1						
15		4.8	28.6					4.8		14.3		33.3			**9.5**								4.8					
16		45.5				9.1		27.3	9.1								9.1											
17		16.9				5.1								8.5			**32.2**					11.9		15.3	10.2			
18		20.0	30.0			5.0		5.0		15.0							5.0					10.0	5.0			5.0		
19																			**68.0**	16.0						16.0		
20				7.7															46.2	**46.2**								
21																					**71.4**	14.3						14.3
22					9.1	6.1											6.1					**45.5**		3.0	27.3			3.0
23						14.3																28.6	**42.9**					14.3
24		22.2												11.1										**66.7**				
25					11.1																	11.1			**77.8**			
26				8.3																						**91.7**		
27				14.3		14.3											28.6									42.9		
28						10.0																50.0	20.0					**20.0**

The top ten BIO-ENV results are presented in Table 7.96. The Spearman's rank correlation coefficient was maximised at two combinations of either four or five variables. The combination of variables which explained most variation was Dur0cm, WaterTP, DryDate and whether the relevé occurred in a grazed or ungrazed land-parcel. The addition of Freq0cm did not improve the correlation.

Table 7.96. BIO-ENV results showing top ten combinations of variables (see **Table 7.97** for variable names).

Number of Variables	*Spearman's rank correlation*	*Variables*
4	0.307	1,4,9,12
5	0.307	1,4,6,9,12
3	0.305	1,9,12
3	0.303	1,4,9
4	0.303	1,5,9,12
6	0.302	1,4,6,9,11,12
5	0.300	1,4,9,11,12
6	0.299	1,4,5,6,9,12
4	0.298	1,4,6,9
5	0.296	1,4,9,12,18

Table 7.97. Variables included in BIO-ENV analysis (variables in bold are those that were found to be important in BIO-ENV analysis).

Variable number	*Variable name*
1	**Dur0cm**
2	Group
3	Alkalinity
4	**WaterTP**
5	**WaterTN**
6	**Freq0cm**
7	Freq50cm
8	MDQuad
9	**DryDate**
10	WetDate
11	**Soil Type**
12	**Grazed/Ungrazed**
13	Turlough
14	SoilTP
15	SoilTN
16	INORG
17	CACO3
18	**BARE_GRND**
19	ROCK_CVR
20	DUNG_CVR
21	GrazInten
22	PoachScale

7.5.5 Summary of Important Drivers of Turlough Vegetation

The important environmental variables affecting turlough vegetation, as identified through NMS, Discriminant Analysis and BIO-ENV are summarised and presented in Table 7.98.

Table 7.98. Summary of important environmental variables (means are presented here) affecting turlough vegetation communities, as determined by NMS, Discriminant Analysis and BIO-ENV.

Community		***Duration***	***MDQuad***	***Water TP***	***Water TN***	***DryDate***	***Freq0cm***	***Grazing***	***Soil Type***
1	*PoaPlan*	311.7	3.35	44.9	1.3	108	8	Grazed	Alluvium, PDM, PDO, WDM, WDO
2	*PersEleo*	449.4	2.68	36.7	1.7	151	4	Mixed	Alluvium, PDM, PDO, WDO
3	*AgroRanu*	309.6	2.87	44.0	0.7	116	4	Mixed, mostly grazed	Alluvium, PDM, PDO, WDM
4	*AgroPote*	292.3	4.61	36.3	1.7	90	6	Mixed, mostly grazed	Alluvium
5	LimeGras	278.8	1.42	18.0	0.6	113	4	Mixed, mostly grazed	Alluvium
6	*EleoRanu*	559.5	2.74	20.9	1.2	170	4	Mixed	Alluvium, PDO
7	*EleoPhal*	447.6	2.64	49.2	2.3	182	3	Mixed, mostly ungrazed	Alluvium, PDO
8	*CareCpan*	235.9	1.05	29.5	0.9	98	3	Mixed	Alluvium, PDM, PDO, WDO
9	*PhalPote*	379.9	2.86	61.9	1.3	143	3	Mixed, mostly ungrazed	Alluvium, PDM, PDO
10	*LoliTrif*	107.3	0.99	33.1	1.4	95	6	Grazed	Alluvium, PDM, PDO, WDM, WDO
11	*PersMent*	553.1	4.33	51.8	1.2	150	6	Mixed	Alluvium, PDO
12	*FiliVici*	193.8	1.18	49.7	1.1	101	3	Mixed	Alluvium, PDM, PDO, WDM, WDO
13	*PoteCare*	402.4	5.14	35.5	0.6	131	6	Mixed, mostly grazed	Alluvium, PDM, PDO
14	Reedbed	602.5	2.91	20.1	1.5	119	3	Ungrazed	Alluvium, PDO
15	*LoliAgro*	188.0	1.36	40.2	0.6	101	7	Mostly grazed	Alluvium, PDM, PDO, WDM, WDO
16	*EquiMeny*	436.8	1.77	30.4	1.9	161	3	Mixed	Alluvium, PDO
17	*CareRanu*	479.9	1.93	15.6	1.3	160	4	Mixed	Alluvium, PDO
18	*AgroGlyc*	385.4	2.87	27.5	0.6	125	7	Mixed, mostly grazed	Alluvium, PDM, PDO
19	*PotePote*	357.6	10.23	48.0	0.9	114	7	Grazed	PDM, WDM
20	*FiliPote*	306.8	8.56	52.4	0.6	81	7	Grazed	WDM
21	*Schoenus*	305.4	1.84	4.1	2.1	95	4	Ungrazed	Alluvium, PDO
22	*MoliCare*	422.3	2.26	6.7	0.6	122	4	Mixed	Alluvium, PDO
23	*CareScor*	438.2	2.82	4.2	1.3	114	5	Ungrazed	Alluvium
24	*PotaGlyc*	640.8	2.25	14.6	1.7	150	3	Grazed	Alluvium, PDO
25	*CareCvir*	411.9	1.80	9.5	0.7	122	5	Mixed, mostly grazed	Alluvium, PDO
26	*Eleoacic*	449.9	9.40	24.6	1.7	208	7	Grazed	PDM
27	*CareEqui*	543.6	6.19	19.1	0.6	157	6	Mixed, mostly grazed	PDM, PDO
28	FldPavmt	390.3	2.49	4.2	1.2	121	5	Ungrazed	Alluvium

7.5.1 Species Distribution in Relation to Flooding Duration and Water TP

The trends in species cover/abundance (Domin scale) were generally obscured by the frequent absences of species in many relevees, this was true for even widespread species. An example is given in Figure 7.50 of one of the most widespread turlough species, *Potentilla anserina*. Though some trends can be seen, they are not necessarily very obvious, and trends were often far less obvious in less-common species. For this reason it was decided to develop flooding duration and TP categories, and examine species frequency in these. This gives less precise but more readily interpretable results. Full results of frequencies in each duration/TP category combination are given in Appendix 7.2, summarized results are given in Table 7.98 where cells are colour coded to indicate frequency class within each duration/TP category. Some combinations of flooding and TP had relatively few relevees (see Table 7.98, indicated by blue shading for number of relevees), the frequency classes for these combinations are less reliable and indicators for these combinations may require further investgation.

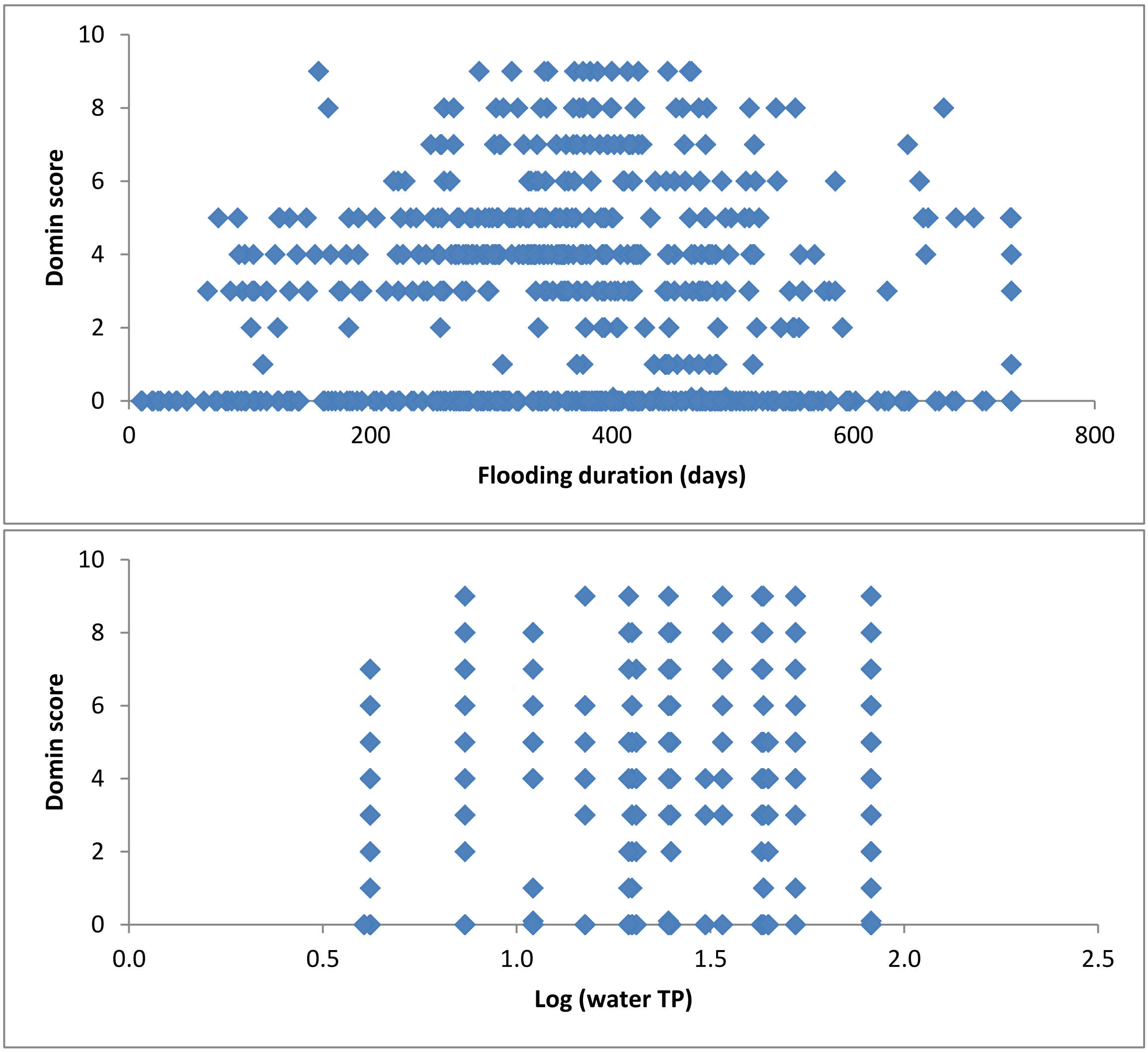


Figure 7.50 Cover-abundance of *Potentilla anserina*, a common turlough species, in relation to duration of flooding (days) over three years, and log of total phosphorus in the water column.

Table 7.98. Summarised frequencies of species in relation to categories of flooding duration and water TP (log transformed); frequency classes are colour coded (see footnote) with darker shading indicating a higher frequency class. Only species that showed reasonably consistent frequencies above 20% are shown; for all species and the calculated frequency values, see Appendix 7.2.

Flood duration category	**VS**					**S**					**M**					**L**					**VL**				
Log Water TP category	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**
No. of relevees	*1*	*3*	*21*	*37*	*3*	*9*	*5*	*30*	*49*	*34*	*56*	*23*	*26*	*101*	*60*	*16*	*31*	*37*	*38*	*38*	*9*	*20*	*15*	*7*	*1*
Common and widespread species																									
Agrostis stolonifera	100-80%	40-20%	80-60%	80-60%	80-60%	40-20%	80-60%	80-60%	100-80%	80-60%	80-60%	60-40%	80-60%	80-60%	80-60%	80-60%	60-40%	80-60%	80-60%	60-40%	80-60%	60-40%	60-40%		
Carex nigra	100-80%	80-60%	40-20%	40-20%		60-40%	80-60%	60-40%	60-40%	40-20%	60-40%	40-20%	80-60%	60-40%	60-40%	40-20%	60-40%	40-20%	40-20%	40-20%	40-20%	40-20%			
Galium palustre		40-20%	40-20%	40-20%	40-20%	40-20%		60-40%	60-40%		60-40%		60-40%	60-40%	60-40%	80-60%	60-40%	60-40%	40-20%	60-40%	40-20%				
Mentha aquatica	100-80%								40-20%		60-40%	40-20%	60-40%	60-40%		80-60%	60-40%	60-40%	40-20%	60-40%	80-60%	80-60%	80-60%	80-60%	100-80%
Potentilla anserina		40-20%		60-40%	40-20%		60-40%	60-40%	80-60%	80-60%	60-40%	40-20%	80-60%	80-60%	100-80%	60-40%	60-40%	60-40%	60-40%	80-60%		60-40%	40-20%		
Ranunculus repens			40-20%	60-40%	40-20%		60-40%	60-40%	80-60%	60-40%	40-20%	40-20%	80-60%	80-60%	60-40%	40-20%		40-20%	40-20%	60-40%		40-20%			
Long Duration, low TP																									
Baldellia ranunculoides																					40-20%	40-20%	40-20%		
Carex elata																					40-20%				
Littorella uniflora																					60-40%	40-20%			
Veronica beccabunga																40-20%									
Medium-long duration, low TP																									
Juncus articulatus											40-20%		40-20%				60-40%				80-60%	60-40%			
Ranunculus flammula							40-20%				40-20%	40-20%	40-20%			40-20%	80-60%	40-20%	40-20%		80-60%	80-60%	60-40%		
Teucrium scordium																60-40%									
Short-medium duration, low TP																									
Carex hostiana	100-80%	80-60%				40-20%	40-20%				40-20%	60-40%				60-40%	40-20%								
Cirsium dissectum	100-80%	40-20%									40-20%	40-20%													
Molinia caerulea	100-80%	100-80%	40-20%	40-20%		80-60%	80-60%				60-40%	80-60%	40-20%			40-20%	60-40%								
Plantago maritima							60-40%					40-20%													
Potentilla erecta		80-60%	40-20%	40-20%	40-20%	60-40%	100-80%		40-20%	40-20%	40-20%	60-40%	40-20%		40-20%	40-20%									
Succisa pratensis		80-60%	40-20%			80-60%	100-80%				40-20%	60-40%				40-20%									

Frequency classes	(darkest)	:100-80%		:80-60%		:60-40%		:40-20%	(white)	:<20%

Flood duration category	VS					S					M					L					VL				
Log Water TP category	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**
No. of relevees	*1*	*3*	*21*	*37*	*3*	*9*	*5*	*30*	*49*	*34*	*56*	*23*	*26*	*101*	*60*	*16*	*31*	*37*	*38*	*38*	*9*	*20*	*15*	*7*	*1*
Short duration, low TP																									
Briza media																									
Danthonia decumbens																									
Festuca ovina																									
Parnassia palustris																									
Potentilla fruticosa																									
Prunus spinosa																									
Schoenus nigricans																									
Short-medium duration, medium-low TP																									
Carex flacca																									
Carex panicea																									
Short-medium duration, medium-high TP																									
Bellis perennis																									
Cardamine pratensis																									
Carex hirta																									
Filipendula ulmaria																									
Rumex crispus																									
Trifolium repens																									
Long duration, high TP																									
Oenanthe aquatica																									
Polygonum amphibium																									
Rorippa amphibia																									
Veronica catenata																									
Short-medium duration, high TP																									
Cerastium fontanum																									
Cirsium vulgare																									
Plantago major																									
Rumex acetosa																									

Flood duration category	VS					S					M					L					VL				
Log Water TP category	VL	ML	M	MH	VH	VL	ML	M	MH	VH	VL	ML	M	MH	VH	VL	ML	M	MH	VH	VL	ML	M	MH	VH
No. of relevees	*1*	*3*	*21*	*37*	*3*	*9*	*5*	*30*	*49*	*34*	*56*	*23*	*26*	*101*	*60*	*16*	*31*	*37*	*38*	*38*	*9*	*20*	*15*	*7*	*1*
Short duration, high TP																									
Alopecurus geniculatus																									
Carex disticha																									
Deschampsia cespitosa																									
Iris pseudacorus																									
Phleum pratense																									
Long duration, wide TP																									
Eleocharis palustris																									
Equisetum fluviatile																									
Glyceria fluitans																									
Short-medium duration, wide TP																									
Lotus corniculatus																									
Short duration, wide TP																									
Festuca arundinacea																									
Festuca rubra																									
Galium verum																									
Holcus lanatus																									
Juncus acutiflorus																									
Lolium perenne																									
Plantago lanceolata																									
Prunella vulgaris																									
Ranunculus acris																									
Senecio aquaticus																									
Taraxacum officinale ag.																									
Trifolium pratense																									
Vicia cracca																									

Flood duration category	VS					S					M					L					VL				
Log Water TP category	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**	**VL**	**ML**	**M**	**MH**	**VH**
No. of relevees	*1*	*3*	*21*	*37*	*3*	*9*	*5*	*30*	*49*	*34*	*56*	*23*	*26*	*101*	*60*	*16*	*31*	*37*	*38*	*38*	*9*	*20*	*15*	*7*	*1*
Wide duration, low TP																									
Carex viridula agg.																									
Medium/wide duration, medium TP																									
Hydrocotyle vulgaris																									
Phalaris arundinacea																									
Leontodon autumnalis																									
Wide duration high TP																									
Myosotis scorpioides																									

Six species showed high frequencies in a wide range of flood duration and water TP categories: *Agrostis stolonifera, Carex nigra, Galium palustre, Mentha aquatica, Potentilla anserina* and *Ranunculus repens*, all are widespread and familiar turlough species. Their high frequency tends to obscure their distribution patterns in relation to flooding and nutrient status, and they are unlikely therefore to be useful ecological indicators. *Galium palustre* and *P. anserina* are less frequent at very long duration flooding and *R. repens* also declines in frequency somewhat at long duration flooding; *M. aquatica* on the other hand increases in frequency in very long duration flooding.

Four species were more or less restricted to long duration flooding at low to very low TP: *Baldellia ranunculoides*, *Carex elata*, *Littorella uniflora* and *Veronica beccabunga*. Many of these occur at relatively low frequency classes, perhaps indicating a lack of dominance of species at long duration/low TP combinations (cf. long duration/high TP, below). Of these *B. ranunculoides* and *L. uniflora* are amphibious species, able to persist submerged for very long periods; *L. uniflora* appears to be the best ecological indicator for long duration flooding in oligotrophic turloughs.

Juncus articulatus and *Ranunculus flammula* show increasing frequency with duration of flooding in low TP. *R. flammula* also occurs in shorter duration flooding, and in medium TP, though at lower frequencies; it is a key component of the *Eleocharis palustris* – *Ranunculus flammula* community which is characteristic of the deeper ones of oligotrophic truloughs, as noted above. The nationally scarce *Teucrium scordium* also is largely restricted to long flood duration parts of oligotrophic truloughs.

Several species are characteristic of short to medium duration flooding in turloughs with very to low TP; these include *Carex hostiana, Cirsium dissectum, Molinia caerulea, Potentilla erecta* and *Succisa pratensis*. *Plantago maritima* also falls into this group, and is particularly interesting as it is normally considered a coastal species; it is however fairly frequent in damp seepages in the Burren and occurs around the upper zones of oligotrophic turloughs. It occurs mainly in rather bare areas such as the flooded pavement communities, it may well be outcompeted in the shortest flood duration locations (where it is absent) by *Lolium perenne* communities and/or Limestone Grassland community. Most of these species appear to have a moderate capacity to tolerate waterlogging.

Several species are restricted to the upper zones of the most oligotrophic turloughs, which experience low TP and short to very short duration flooding. Many are species of nutrient poor grasslands, notably *Briza media*, *Danthonia decumbens* and *Festuca ovina*. However, the wetland species *Parnassia palustris* and *Schoenus nigricans* also have their highest frequency in this zone. The shrub *Prunus spinosa* is also of note here, and especially noteworthy is the scarce shrub *Potentilla fruticosa*. The latter species typically forms a shrub zone just below the upper flooding zones in the more oligotrophic turloughs of the Burren.

The two sedges *Carex flacca* and *Carex panicea* are most frequent is short to medium duration flooding and low to medium TP. Together with *C. hostiana* (at consistently lower TP) and *C. nigra* (wide ecological range), these sedges are important components of several communities restricted to lower nutrient status locations.

In contrast, *Carex hirta* is typical of short to medium duration flooding with medium to high levels of TP. The forbs *Bellis perennis, Cardamine pratensis, Filpendula ulmaria, Rumex crispus* and *Trifolium repens* are also more frequent in these higher nutrient turloughs, where they appear to replace the sedges that are more frequent in lower nutrient turloughs.

The lower zones of eutrophic truloughs, where long duration flooding occurs with high to very high TP, are dominated by the *Oenanthe aquatica* and particularly *Polygonum* *amphibium*, which reach very high frequencies. *Veronica catenata*, at relatively lower frequencies, and *Rorippa amphibia* are also restricted to these zones. *P. amphibium* in particular appears to be dominant in long flood duration zones of eutrophic turloughs, as already noted in the dominance of the *Polygonum amphibium* communities in these situations, and appears to replace communities dominated by *Ranunculus flammula* and associates such as *Littorella uniflora* and *Baldellia ranunculoides* (see above).

Cerastium fontanum, *Cirsium vulgare*, *Plantago major* and *Rumex acetosa* are most frequent in short to medium duration flooding and high TP. *P. major* may be associated with disturbance from grazing animals in these situations, the other species tend to be more frequent at shorter duration flooding and are note noted for being waterlogging tolerant. *Alopecurus geniculatus, Carex disticha, Deschampsia caespitosa, Iris pseudacorus* and *Phleum pratense* are most frequent in similar situations, but occur at much lower frequencies at longer duration flooding.

Eleocharis paulstris, *Equisetum fluviatile* and *Glyceria fluitans* have highest frequencies at longer duration flooding, though over a wide range of TP. *Lotus corniculatus* occurs in the short to medium duration flooding zones in moderate or high frequencies again over a wide range of TP values. There are also a number of species that have their highest frequencies in short duration flooding but over a wide range of TP; perhaps the best indicators here are *Festuca rubra, Lolium perenne, Prunella vulgaris, Ranunculus acris* (medium TP) and *Senecio aquaticus*.

Carex viridula agg. occurs in low TP but over a wide range of flooding durations, while *Myosotis scorpiodes* occurs over a wide range of flooding but only at high to very high TP. *Hydrocotyle vulgaris, Phalaris arundinacea* and *Leontodon autumnalis* tend to occur over medium to wide duration flooding and medium TP, though patterns here are complex.

7.5.2 Species Cover/Abundance in Relation to Flooding along Transects at Blackrock and Caranavoodaun

7.5.2.1 Transect Descriptions

The Blackrock A transect consisted of 48 contiguous quadrats, the elevation varied from 12.68 to 20.35 m asl. A total of 26 vascular plants were recorded, along with *Cinclidotus fontainalis* and other bryophytes (pooled); species richness in each quadrat varied from 3 to 17 (mean = 9.13). The Blackrock B transect consisted of 56 contiguous quadrats, the elevation varied from 13.24 to 20.22 m asl. A total of 38 vascular plants were recorded, along with *Cinclidotus fontainalis* and other bryophytes; species richness in each quadrat varied from 4 to 23 (mean = 12.13).

The Caranavoodaun A transect consisted of 30 contiguous quadrats, the elevation varied from 22.56 to 24.30 m asl. A total of 68 vascular plants were recorded, along with *Cinclidotus fontainalis* and other bryophytes and pooled charophytes; species richness in each quadrat varied from 9 to 34 (mean = 16.53). The Caranavoodaun B transect consisted of 33 contiguous quadrats, the elevation varied from 22.35 to 24.49 m asl. A total of 66 vascular plants were recorded, along with pooled bryophytes and pooled charophytes (*Cinclidotus fontainalis* was absent); species richness in each quadrat varied from 6 to 28 (mean = 13.53).

7.5.2.2 Patterns of Duration and Frequency of Flooding

At Blackrock, the duration of flooding very closely correlated with elevation, with lower elevations within the turlough being flooded for longer durations, as expected (Figure 7.51). There was a greater duration of flooding in 2007 than 2008 at all elevations. The frequency of flooding events was greater at the lower elevations, least at the intermediate elevations, and then somewhat higher again at the upper elevations (Figure 7.51). In 2007 the lowest and uppermost elevations had similar frequencies of flooding, whereas in 2008 the lower elevations had a greater frequency than the uppermost, in both transects.

At Caranavoodaun there was also a greater duration of flooding in 2007 compared to 2008, but this was only apparent in the lowest elevations (Figure 7.51). Again, the duration of flooding was greatest at the lowest elevations of the turlough, and the duration decreased with decreasing elevation. The relationships between duration of flooding and elevation were less linear in Caranavoodaun than in Blackrock, and the duration-elevation profiles were slightly different in the two years. Flooding frequency showed a different relationship to elevation at Caranavoodaun compared to Blackrock, and it also differed between the two years though was similar in each of the two transects. In 2008 there was a general decrease in the frequency of flooding events from the lower elevations of the turlough to the upper (Figure 7.51); however, in 2007 while the lowest frequency of flooding still occurred in the upper elevations of the turlough, the frequency was greatest at mid to lower elevation, but reduced at the lowest elevations. There were fewer distinct flooding events in Caranavoodaun compared to Blackrock (Table 7.99), this probably reflects the deeper basin with more flashy flooding at Blackrock. This complex pattern of frequency and elevation probably reflects the differing annual profiles of flooding duration and elevation in the two years, and different numbers of flooding events.

In summary, while there is a predictable and reasonably linear relationship between duration of flooding and elevation (Table 7.100), frequency of flooding events shows a complex relationship to elevation, likely depending on different patterns of flooding (discharge/recharge rates, effect of topography, groundwater supply) in different turloughs.

Table 7.99. The duration and frequency of flooding for each transect over the two recording years at Blackrock and Caranavoodaun turloughs

	Year	*Blackrock A*	*Blackrock B*	*Caranavoodaun A*	*Caranavoodaun B*
Max duration (days)	2008	254	249	270	271
Min duration (days)	2008	147	153	14	5
Max duration (days)	2007	178	163	191	218
Min duration (days)	2007	75	75	3	0
Max frequency	2008	6	6	4	4
Min frequency	2008	3	3	1	1
Max frequency	2007	10	8	4	4
Min frequency	2007	2	3	1	0

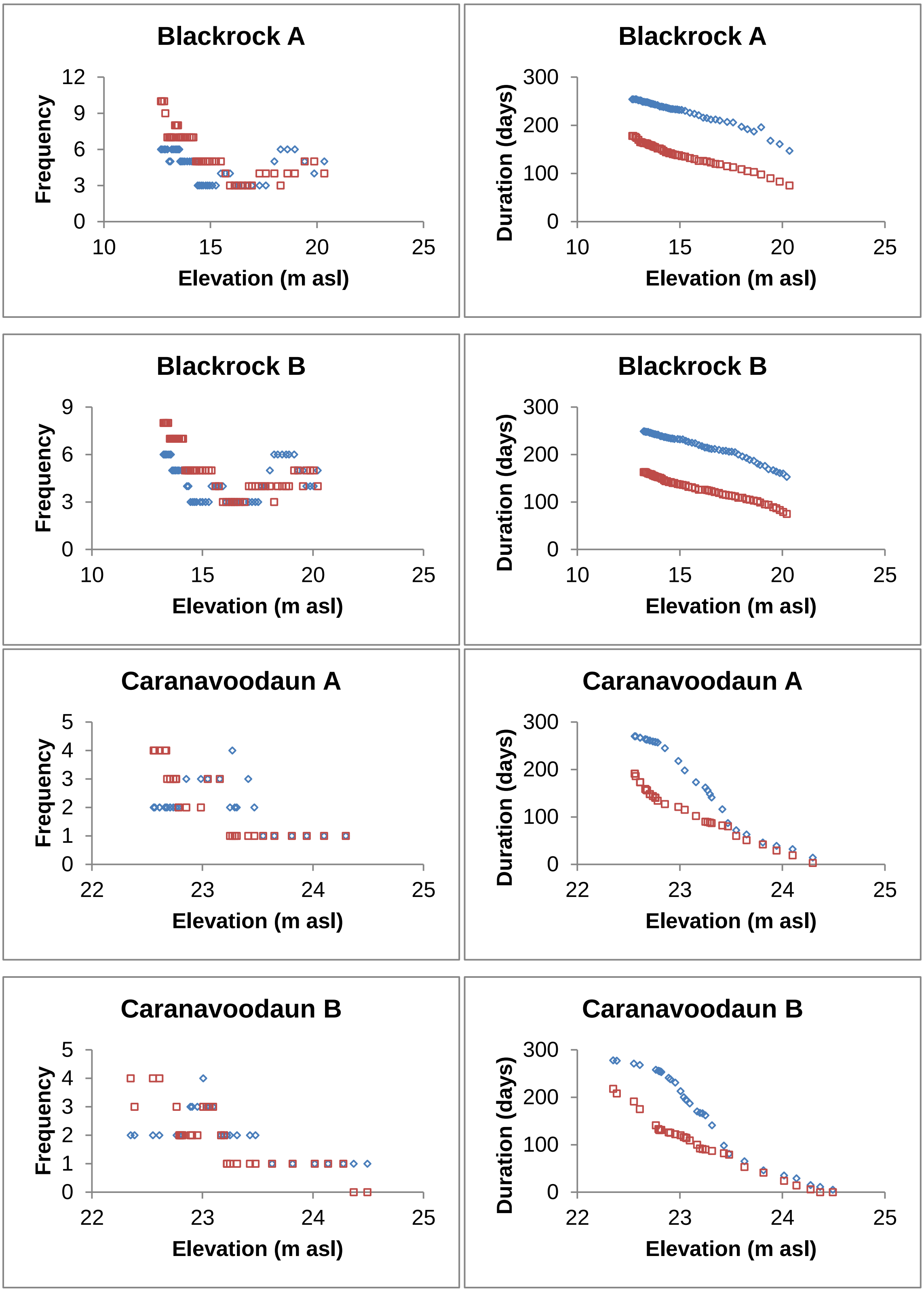


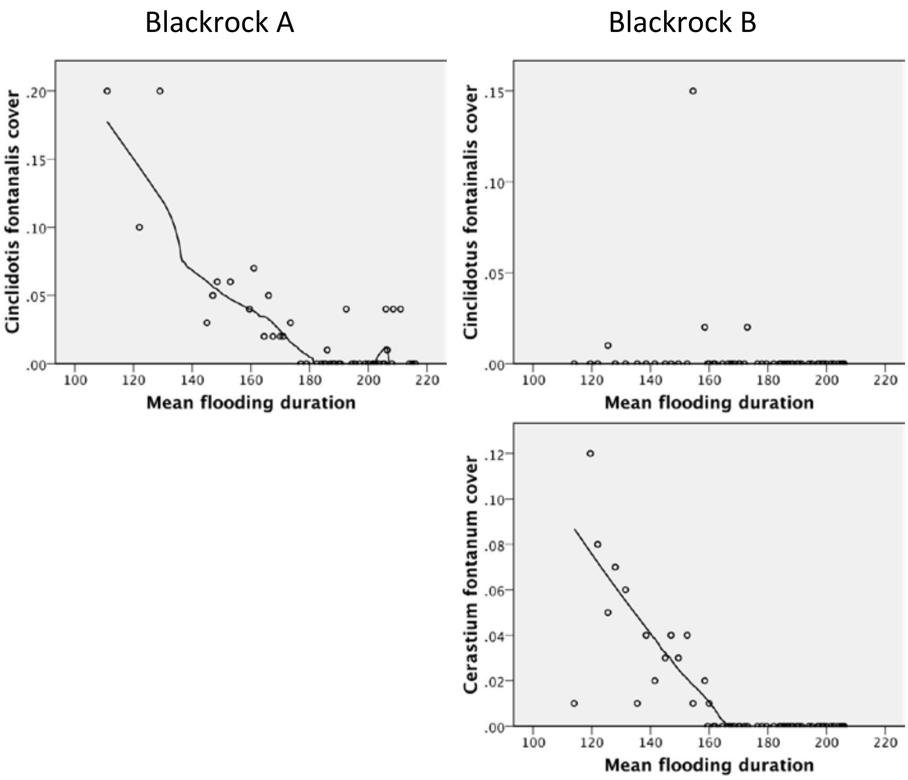
Figure 7.51 Frequency (number of times the location flooded) and total duration of flooding in 2007 (blue diamonds) and 2008 (red squares) for vegetation transects (A and B) at Blackrock and Caranavoodaun turloughs.

Table 7.100. Pearson product-moment correlations between elevation and mean (for 2007 and 2008) frequency and duration of flooding along two vegetation transects at Blackrock and Caranavoodaun turloughs.

	Blackrock		*Caranavoodaun*	
	Elevation A	*Elevation B*	*Elevation A*	*Elevation B*
Frequency	-0.630	-0.463	-0.879	-0.808
Duration	-0.993	-0.995	-0.993	-0.989

7.5.2.3 Plant Distribution in Relation to Flooding

There was a general trend of plant species richness at first increasing slightly and then decreasing markedly deeper into the turlough in each transect and at both of the turloughs. Vegetation changes over the flooding/elevation gradient have been described by O'Rourke (2010) and will not be considered here. Figures 7.52 to 7.59 show different types of species cover relationships with duration of flooding at Blackrock and Caranavoodaun.



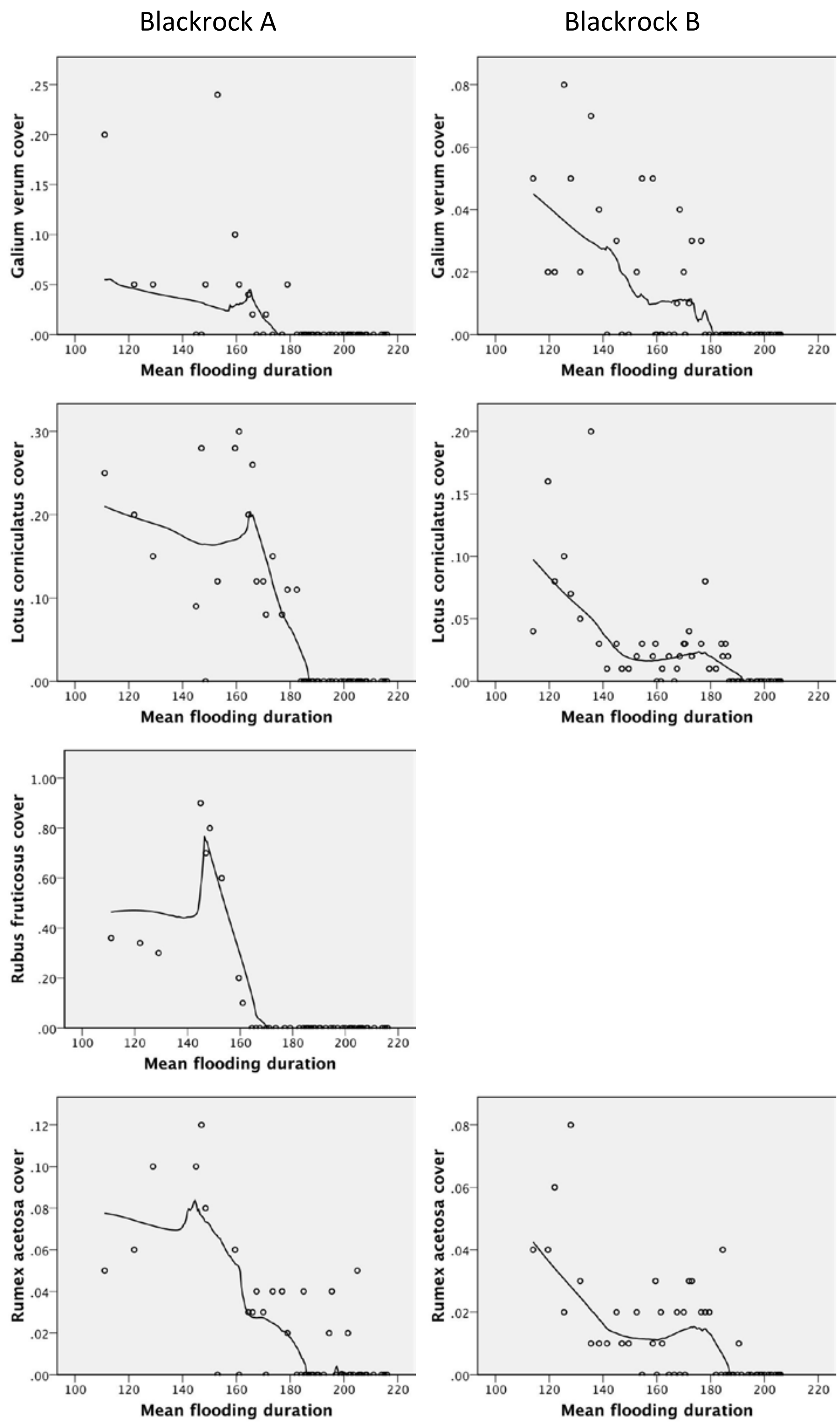
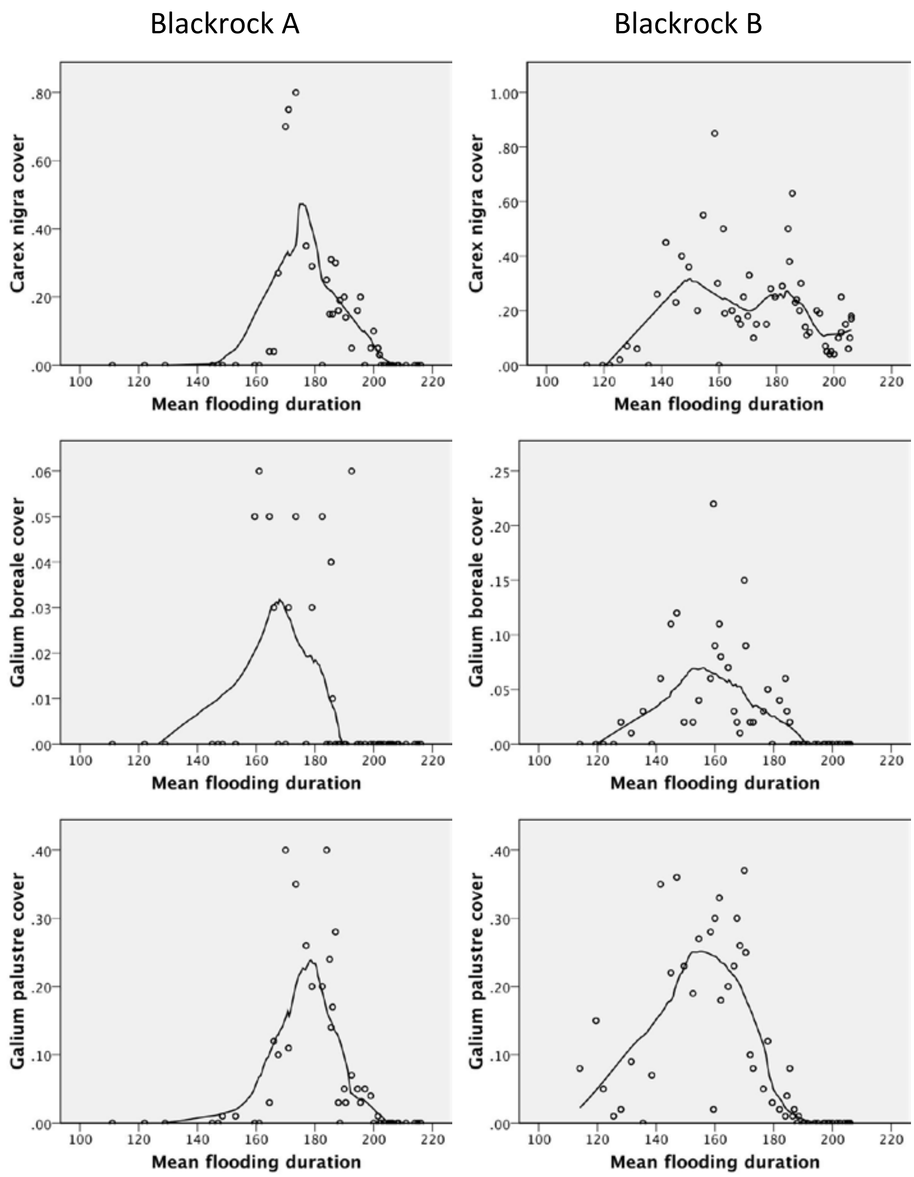


Figure 7.52 Species showing higher cover-abundance values at shorter to intermediate duration of flooding at Blackrock A and B transects. Cover was measured as a proportion of total sample area, and mean flooding duration is the mean number of days annually flooded to the substrate surface during 2007/8. The trend lines are fitted by Lowess smoothing. Blanks indicate that the species was absent from a particular transect, or had very few occurrences and no clear trend.

Species with higher cover-abundance values at low flooding duration at Blackrock are shown in Figure 7.52. The distribution of *Lotus corniculatus* and *Rumex acetosa* in relation to flooding duration are typical: relatively high cover values at low duration flooding, lower cover at intermediate duration flooding, and both species absent from quadrats experiencing long duration flooding. Note also that the trends for both species are different in the two transects – each has relatively lower cover at intermediate flooding in transect B as compared to transect A. Some species show a relatively strong response profile in one transect, and almost no pattern in the other; for example, *Cinclidotus fontainaliodes* shows a fairly linear decrease in cover with increasing duration of flooding in transect A, but no discernable pattern (and low cover) in transect B.



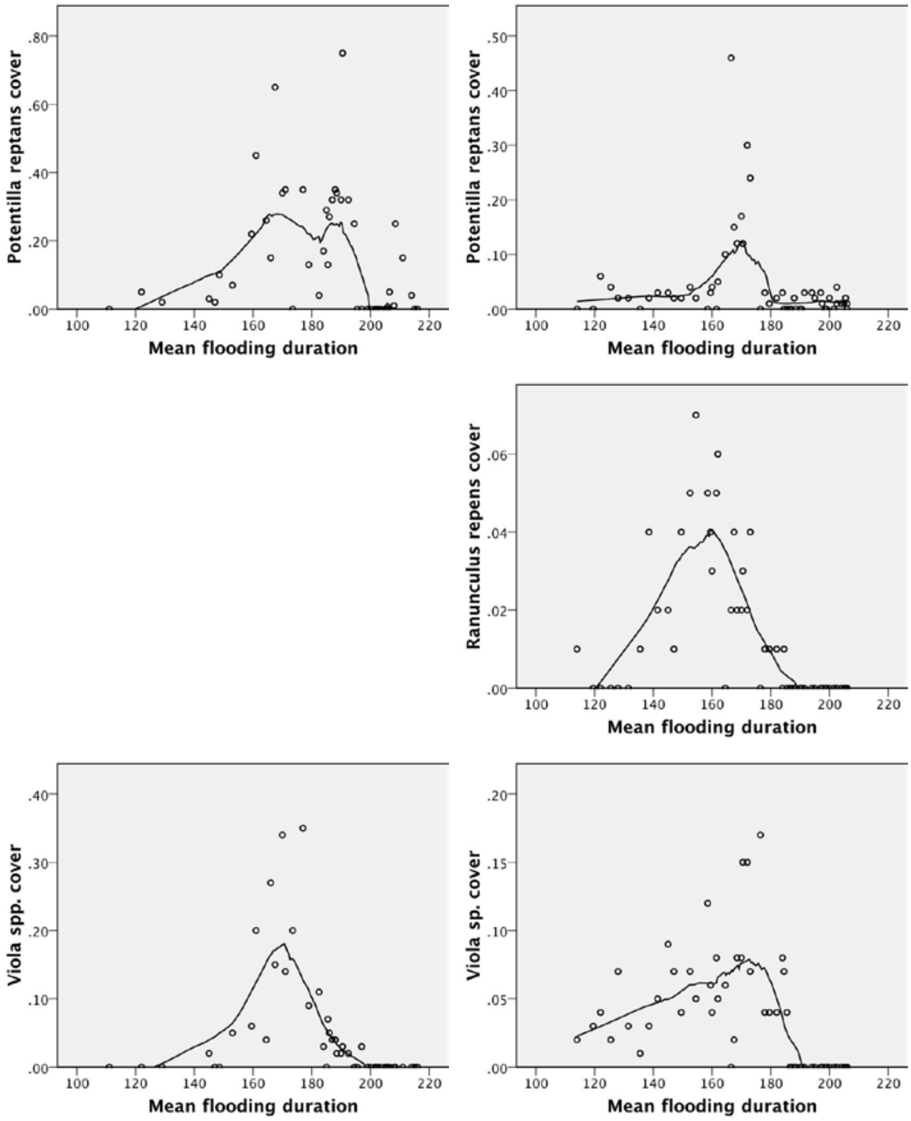


Figure 7.53 Species showing higher cover-abundance values at intermediate flooding duration at Blackrock A and B transects. Cover was measured as a proportion of total sample area, and mean flooding duration is the mean number of days flooded annually to the substrate surface during 2007/8. The trend lines are fitted by Lowess smoothing. Blanks indicate that the species was absent from a particular transect, or had very few occurrences and no clear trend.

Species showing high cover-abundance values at intermediate flooding durations are shown in figure 7.53. These species are typically absent at both very short and very long flooding durations while their cover-abundance is greatest at intermediate duration flooding. The responses of *Carex nigra* and *Galium palustre* are typical, although *C. nigra* also occurred at low cover values at long duration flooding in transect B, and *G. palustre* showed the opposite in its low occurrence at low flooding duration in transect B.

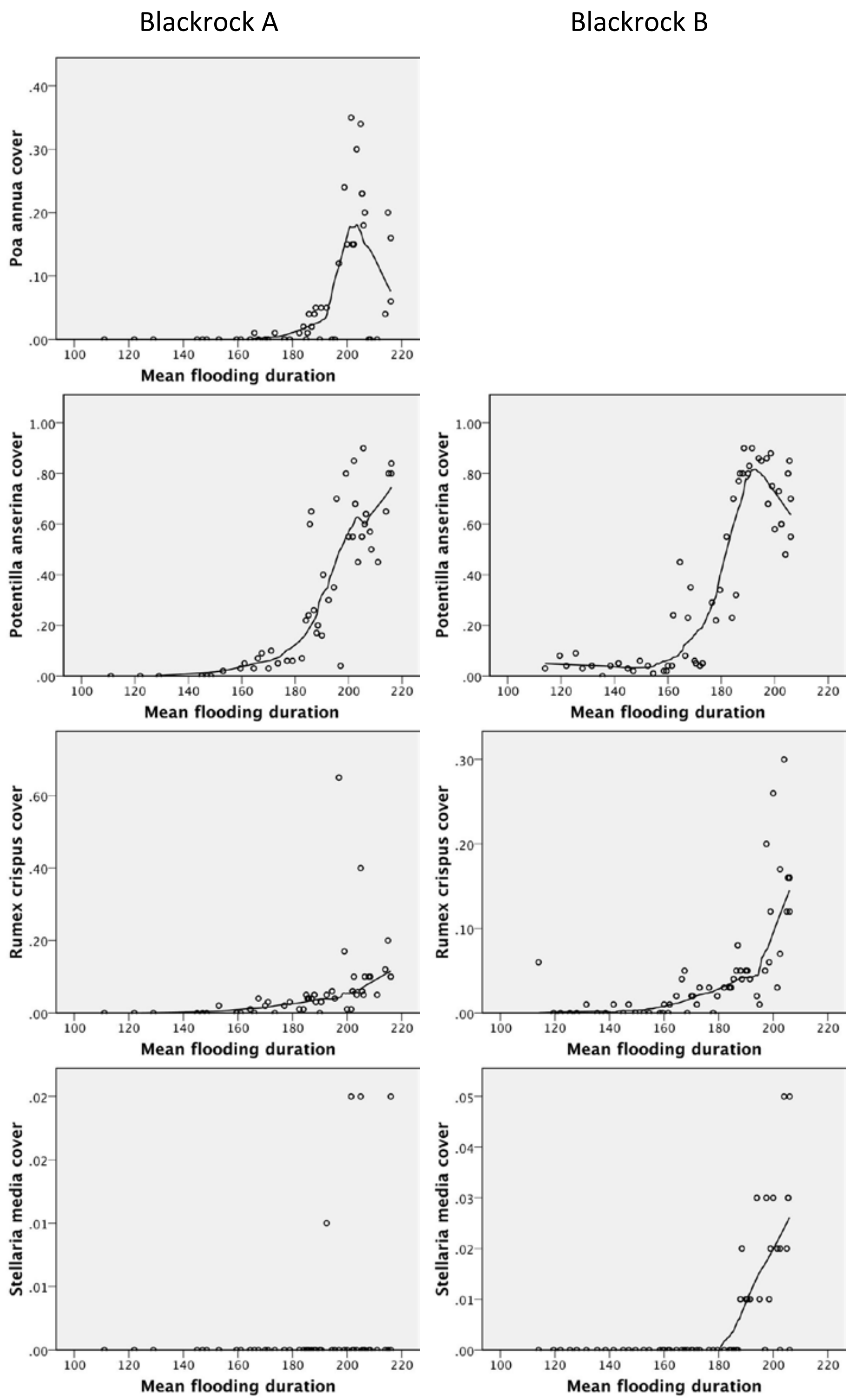


Figure 7.54 Species showing higher cover-abundance values at long flooding duration at Blackrock A and B transects. Cover was measured as a proportion of total sample area, and mean flooding duration is the mean number of days annually flooded to the substrate surface during 2007/8. The trend lines are fitted by Lowess smoothing. Blanks indicate that the species was absent from a particular transect, or had very few occurrences and no clear trend.

Species with high cover-abundance values in long duration flooding are shown in figure 7.54. These species are absent from short flooding duration quadrats, are either absent or with low cover values at intermediate flooding durations, and have their highest cover values where the duration of flooding is long. A typical response to flooding duration of this sort is demonstrated by *Potentilla anserina* in both transects, where cover values gradually increase from very low values at low duration flooding, then cover rapidly and consistently increases as the duration of flooding becomes long (above ~180 days per annum); at the very longest durations of flooding there is a tendency in this species for cover to decline, particularly in transect B. More extreme versions of this long duration response are shown by the annuals *Poa annua* (transect A) and *Stellaria media* (transect B), these species occupy bare ground in the deepest part of the turlough once the floodwater has receded; they therefore tolerate the prolonged flooding period as dormant seed, but are likely to be outcompeted by perennial swards at shorter flooding durations.

Caranavoodaun:

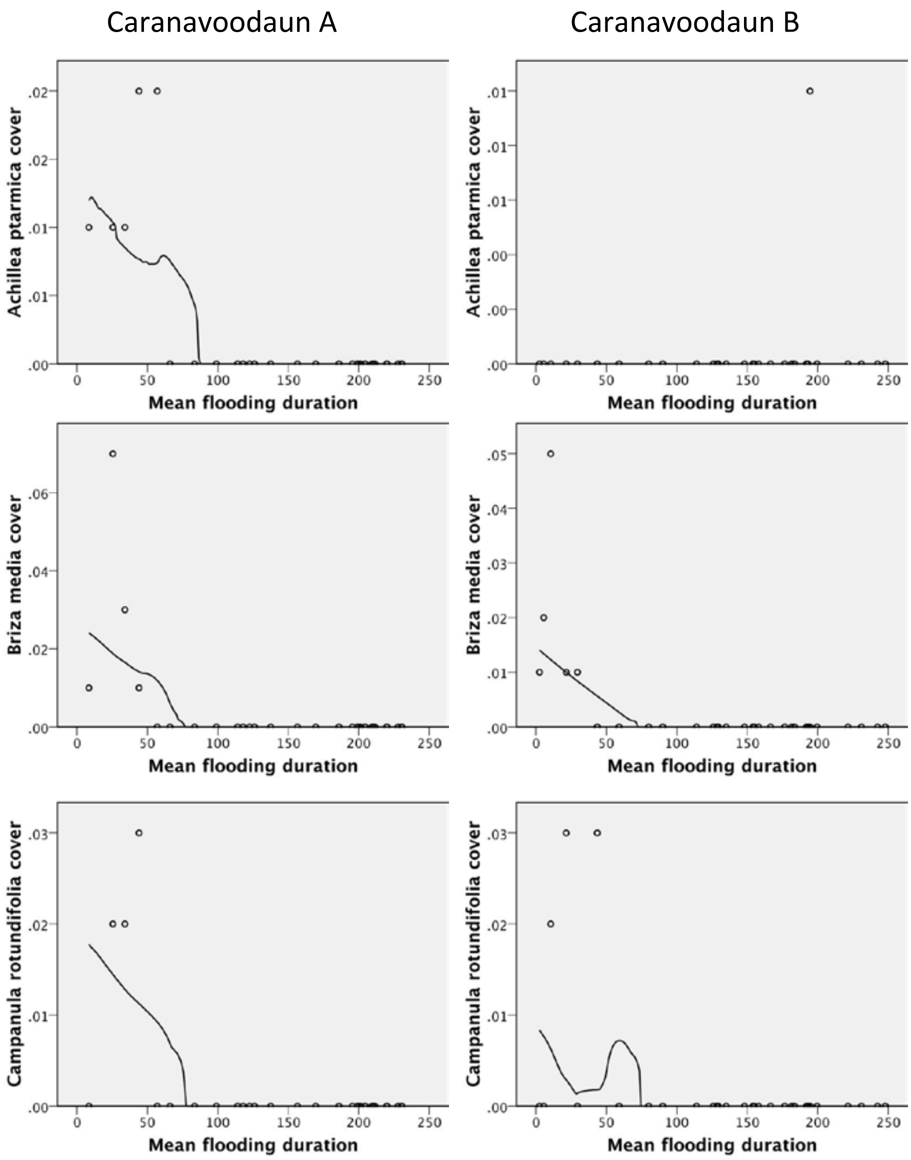
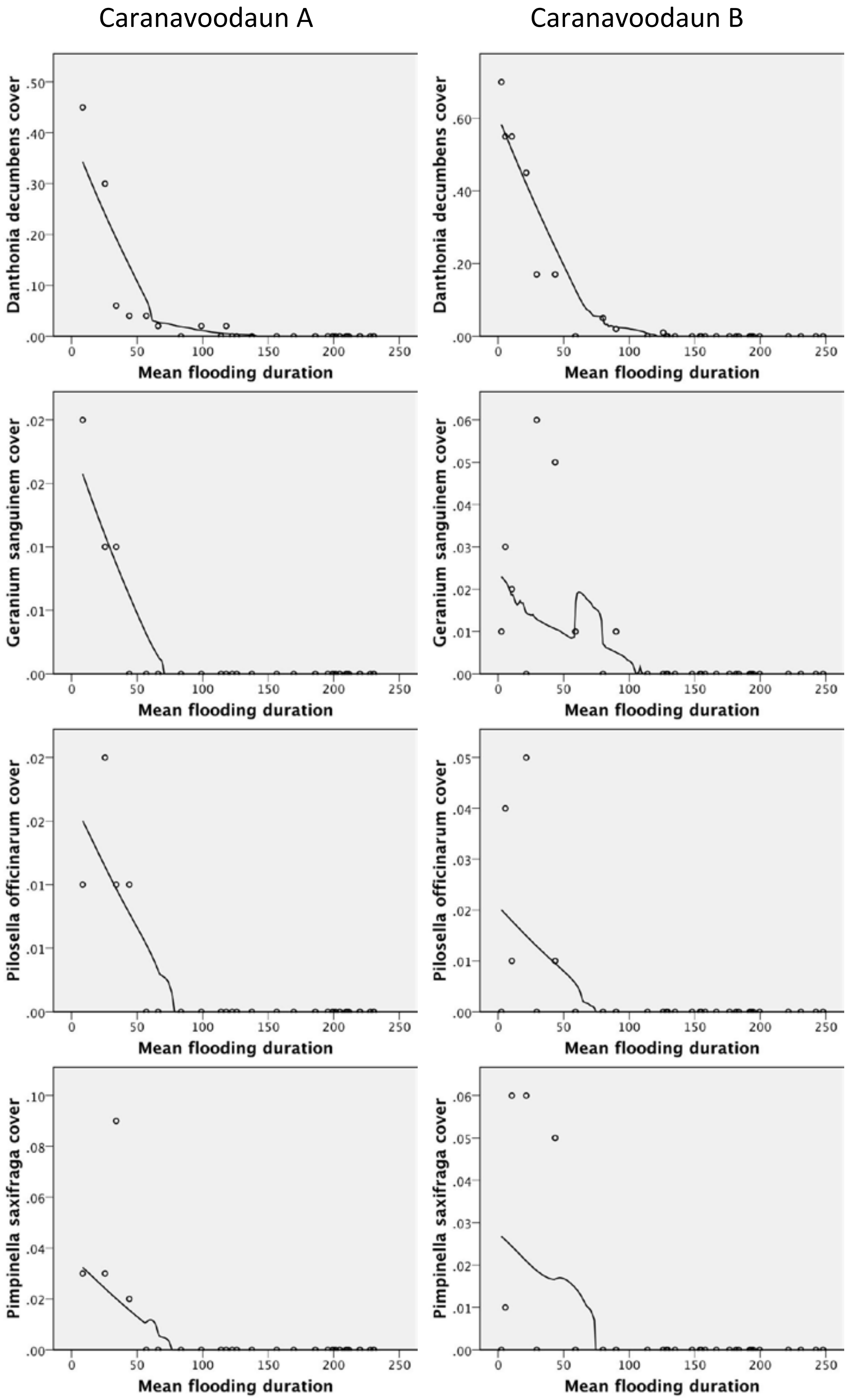


Figure 7.55 For legend see next page



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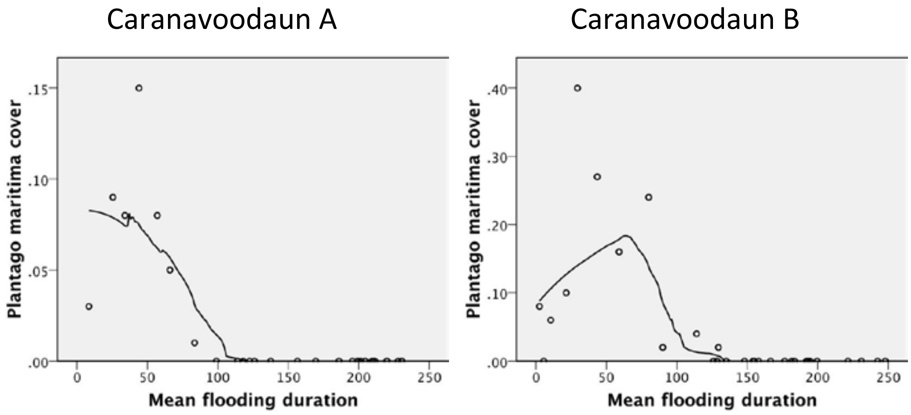
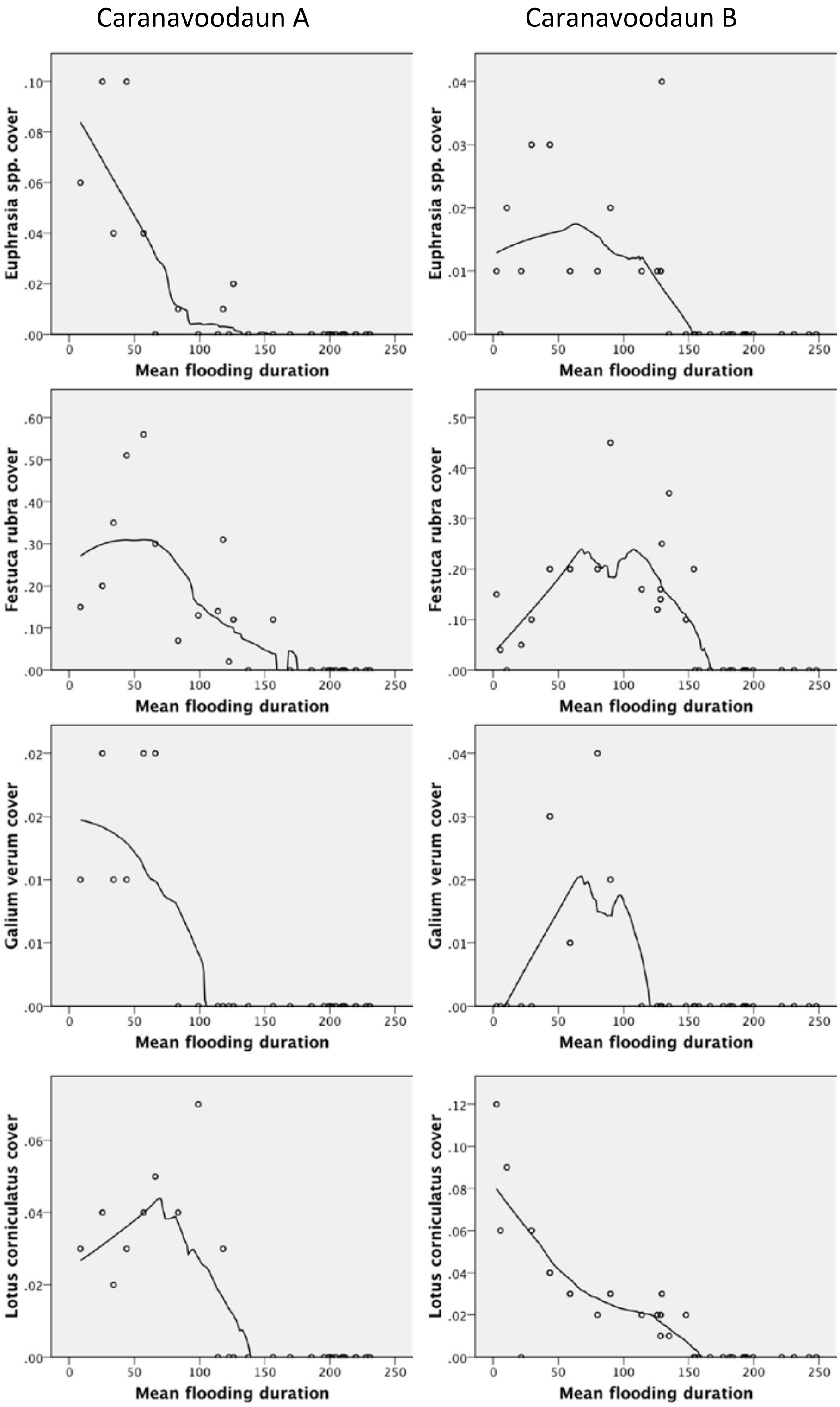


Figure 7.55. Species showing higher cover-abundance values at short duration flooding at Caranavoodaun A and B transects. Cover was measured as a proportion of total sample area, and mean flooding duration is the mean number of days annually flooded to the substrate surface during 2007/8. The trend lines are fitted by Lowess smoothing. Blanks indicate that the species was absent from a particular transect, or had very few occurrences and no clear trend.

Species restricted to short duration flooding at Caranavoodaun are shown in figure 7.55. These are typically species of well-drained limestone grassland, whose cover-abundance rapidly declines when the duration of flooding increases beyond the shortest duration. *Danthonia decumbens* illustrates this response type very well in both transects, its cover abundance declines rapidly with increasing duration of flooding and it is more or less absent from the transects when flooding lasts longer than 100 days per annum. The one exception in this group is *Plantago maritima*, usually thought of as a halophytic species, but which is also common in damp, nutrient-poor limestone grassland in the Burren; it is surprising that it does not occur further into the flooding profile, although there is some suggestion of lower cover at the very shortest flooding durations.

Species showing highest cover-abundance values at low to intermediate duration flooding at Caranavoodaun are shown in figure 7.56. Some species show a gradual decline in cover abundance with increased duration of flooding from short to medium, and are absent from longer duration flooding; good examples are *Lotus corniculatus* in transect B and *Euphrasia* spp. in transect A. Other species show a peak in cover-abundance at low to intermediate duration flooding, such as *Potentilla erecta* in transect A and *Succisa pratensis* in transect B.

The only species showing consistently high cover-abundance at lower duration flooding in both turloughs are *Galium verum* and *Lotus corniculatus*. As noted previously from examination of all relevee data, these two species are frequent in a wide range of water TP; other species which are restricted in this response type to either Blackrock or Caranavoodaun are likely illustrating the differential distributions in relation to TP noted earlier.



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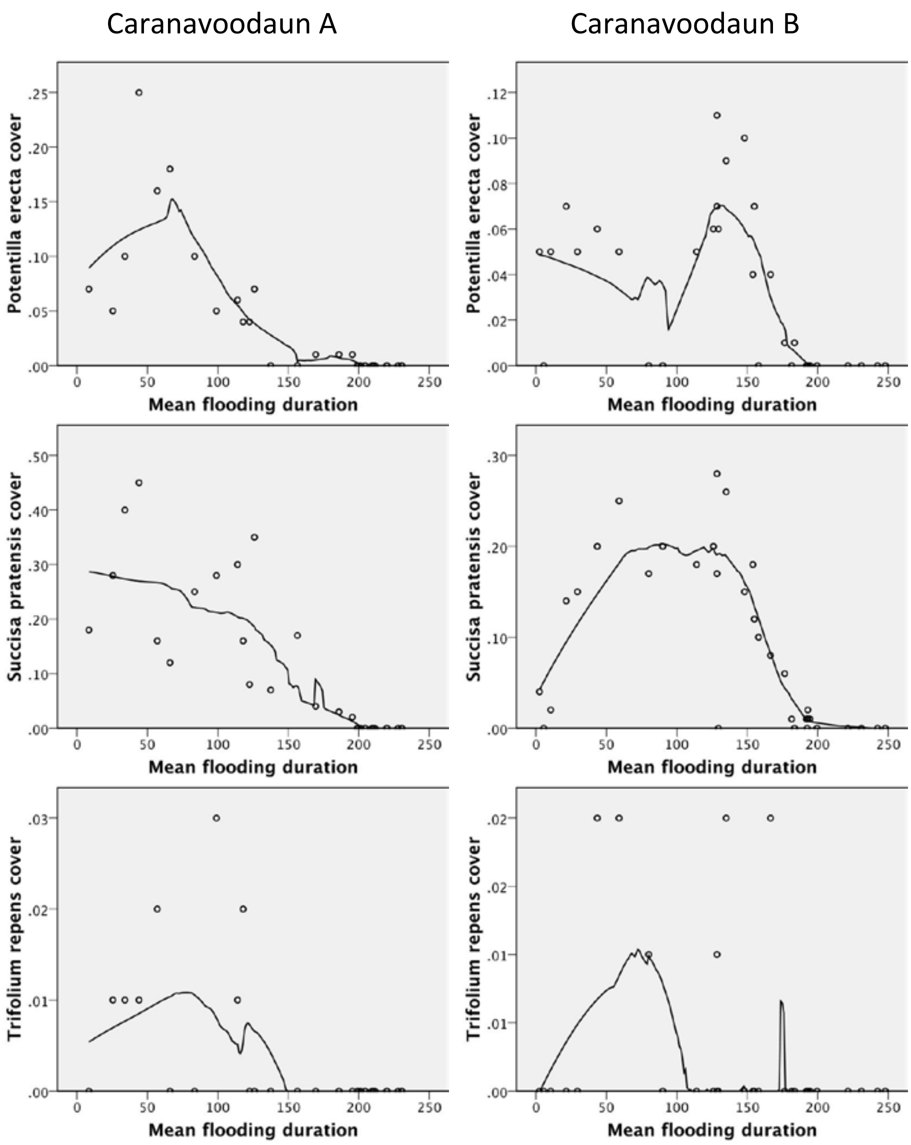


Figure 7.56 Species showing higher cover-abundance values at short to intermediate flooding duration at Caranavoodaun A and B transects. Cover was measured as a proportion of total sample area, and mean flooding duration is the mean number of days annually flooded to the substrate surface during 2007/8. The trend lines are fitted by Lowess smoothing. Blanks indicate that the species was absent from a particular transect, or had very few occurrences and no clear trend.

Molinia caerulea and *Schoenus nigricans* generally showed maximum cover-abundance at intermediate flooding durations of around 150 days (Figure 7.57), though *Molinia* shows greater scatter. Neither species occurred in the Blackrock transects.

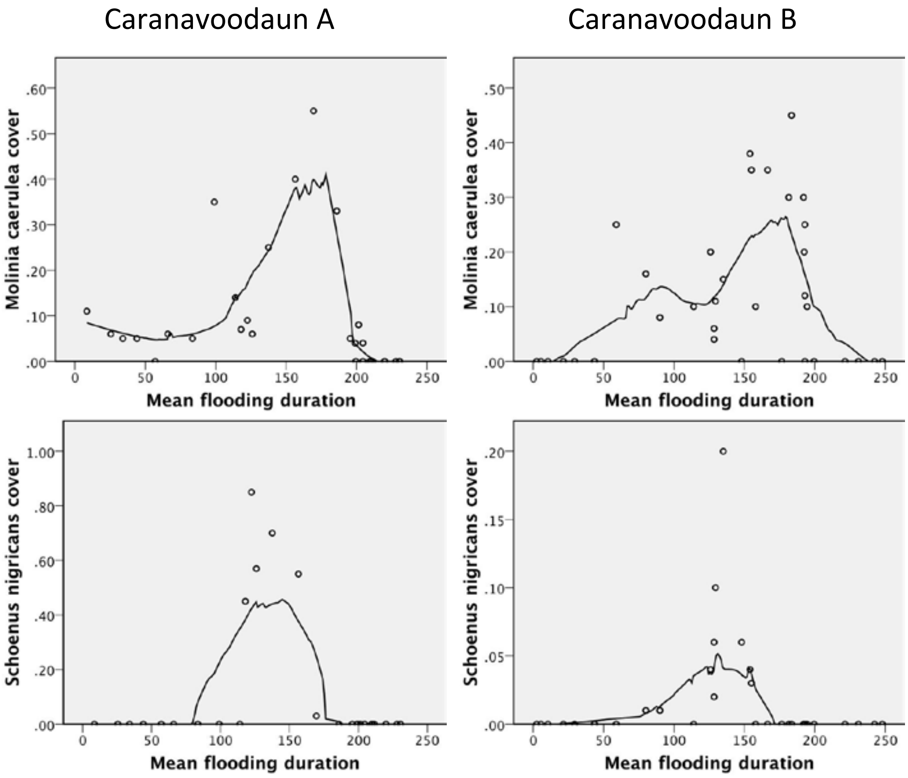


Figure 7.57 Species showing higher cover-abundance values at intermediate flooding duration at Caranavoodaun A and B transects. Cover was measured as a proportion of total sample area, and mean flooding duration is the mean number of days annually flooded to the substrate surface during 2007/8. The trend lines are fitted by Lowess smoothing. Blanks indicate that the species was absent from a particular transect, or had very few occurrences and no clear trend.

Carex hostiana and *Hydrocotyle vulgaris* both show maximum cover-abundance at medium to long duration flooding (Figure 7.58), with a peak at a duration of around 200 days. Typically these species are absent or present in very low cover at both very short and very long duration flooding, although C. hostiana tends to have higher cover at lower duration flooding while the reverse is true for Hydrocotyle which also occurs at very long duration flooding.

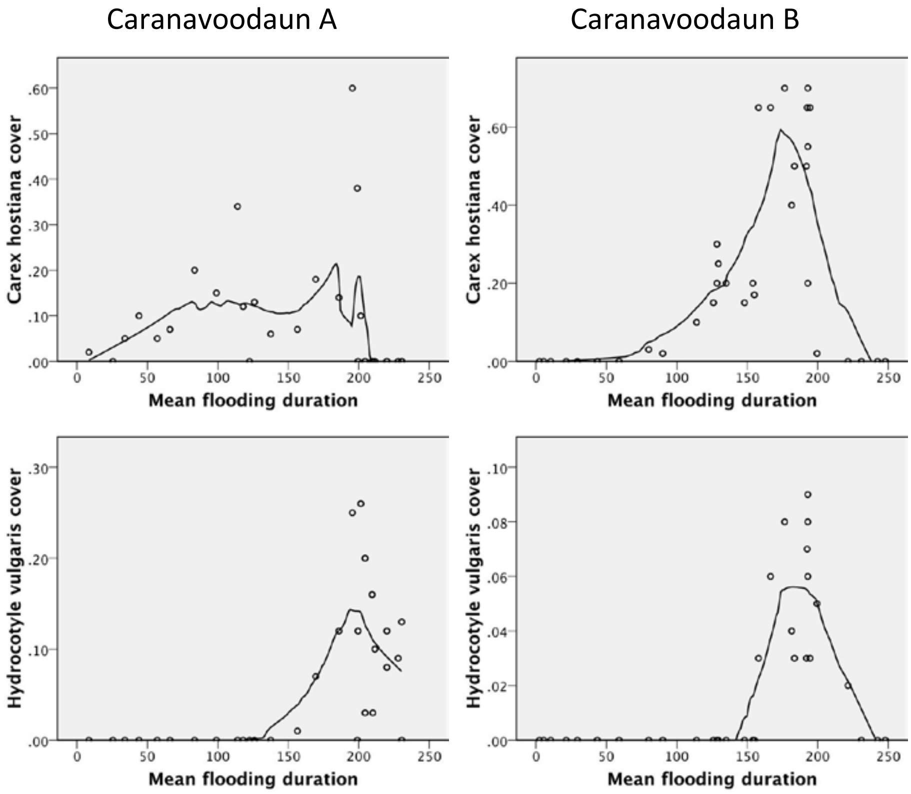


Figure 7.58 Species showing higher cover-abundance values at intermediate to long flooding duration at Caranavoodaun A and B transects. Cover is measured as a proportion of total sample area, and mean flooding duration is the mean number of days flooded to the substrate surface during 2007/8. The trend lines are fitted by Lowess smoothing. Blanks indicate that the species was absent from a particular transect, or had very few occurrences and no clear trend.

Species which show maximum cover at long to very long duration flooding are shown in Figure 7.59. The relationship is well illustrated by *Ranunculus flammula*, which is absent where flooding duration is less than 170 days, but then increases rapidly as the duration of flooding increases beyond 200 days. Again this group of species is very different from those found at long duration flooding in Blackrock; many of the Caranavoodaun species typical of long and very long duration flooding are also restricted to low and very low TP turloughs, as shown in analyses of the relevee data from all turloughs. The data from these two transects therefore broadly agrees with data from the complete vegetation data set – many species show a differential relationship to either short or long duration flooding dependent on the nutrient status (water TP), while relatively few species (e.g. *Lotus corniculatus*, *Galium palustre*) show similar trends in both nutrient-poor Caranavoodaun and nutrient-rich Blackrock.

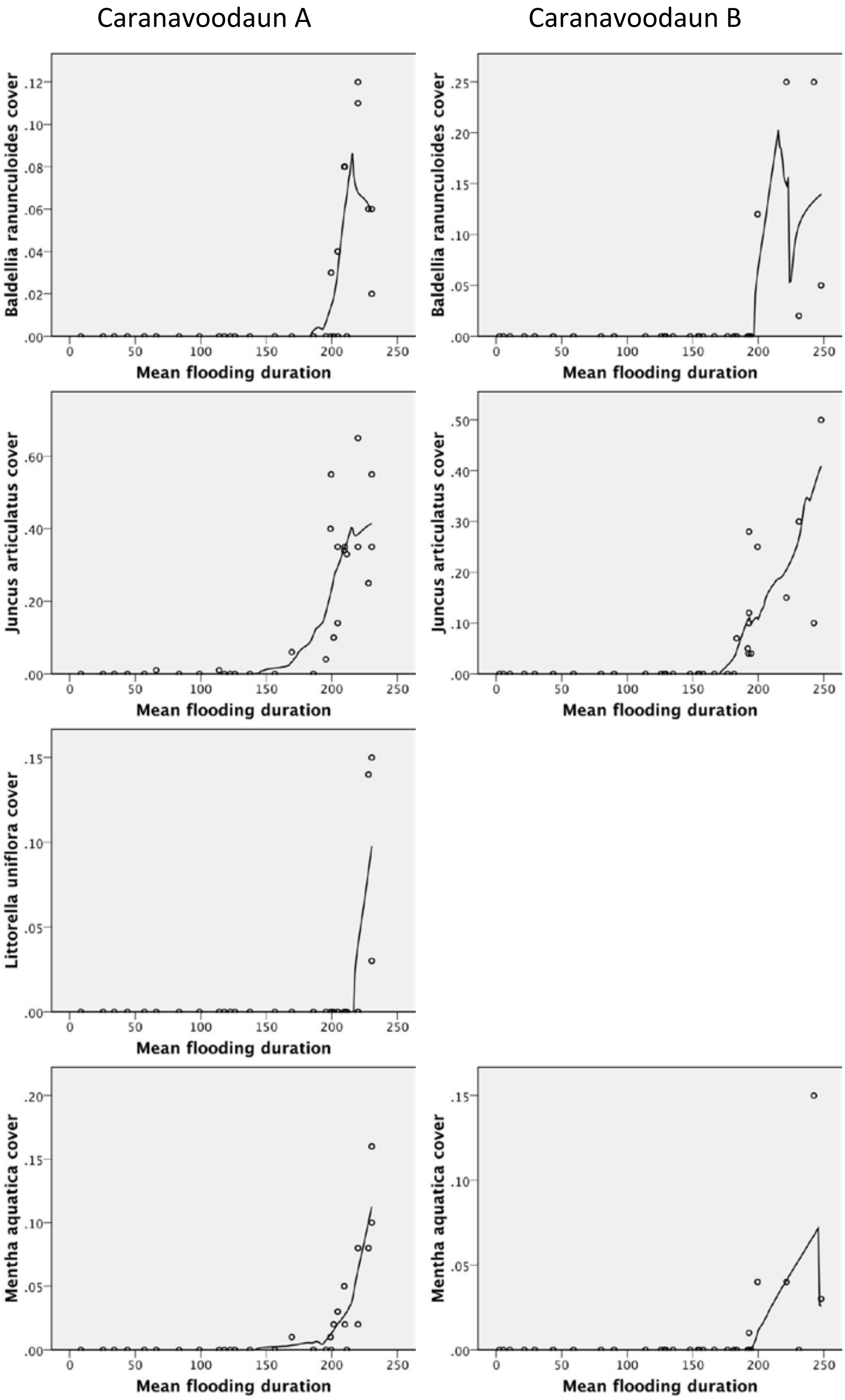


Figure 7.59 For legend see next page

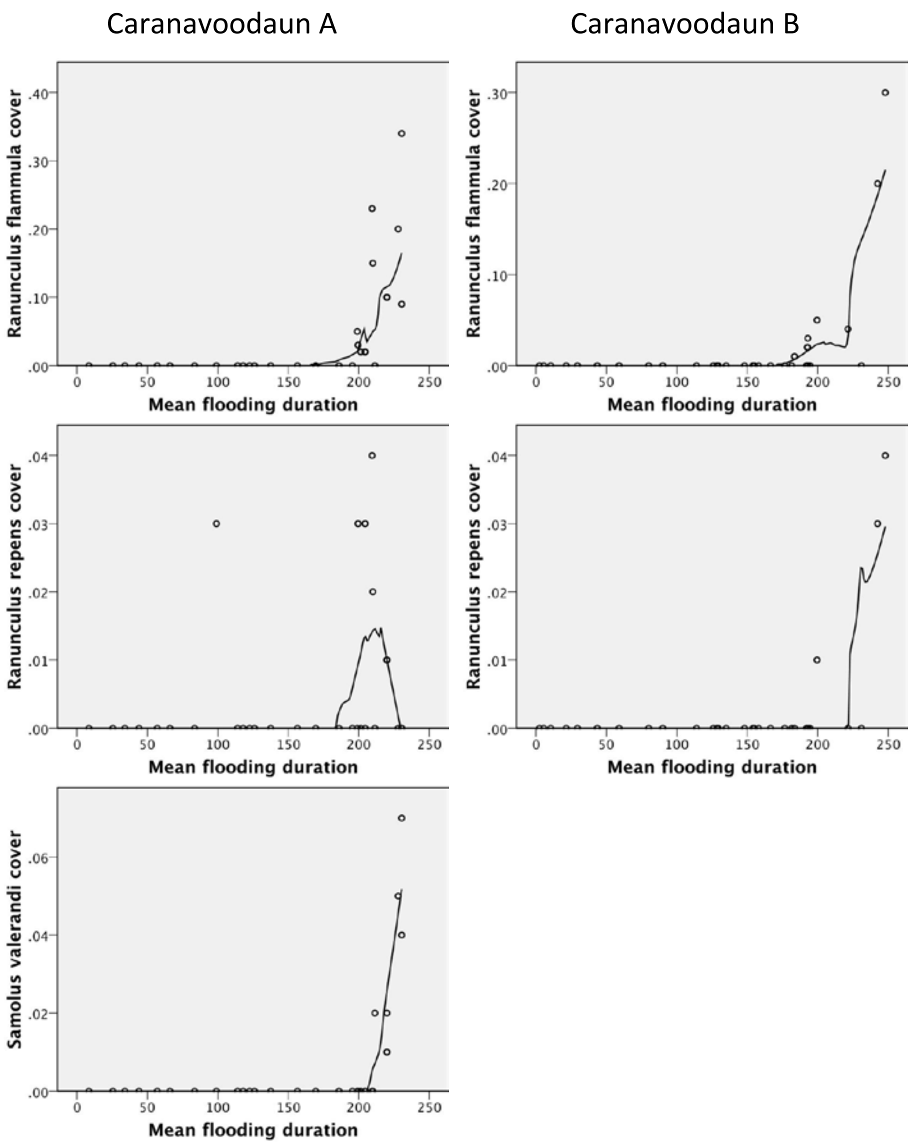


Figure 7.59 Species showing higher cover-abundance values at long flooding durations at Caranavoodaun A and B transects. Cover is measured as a proportion of total sample area, and mean flooding duration is the mean number of days flooded to the substrate surface during 2007/8. The trend lines are fitted by Lowess smoothing. Blanks indicate that the species was absent from a particular transect, or had very few occurrences and no clear trend.

7.5.3 Ecological Distribution of Mapped Communities

For many turloughs as the duration of flooding for any community increases so too does the frequency of inundation events (Figure 7.60). However in some communities the frequency of inundation declines as flooding durations become very long; this is noticeable at Lough Gealain, Skealoghan and Termon. At Blackrock the *Eleocharis acicularis* community experiences very long inundation periods but only during a single, long flooding event.

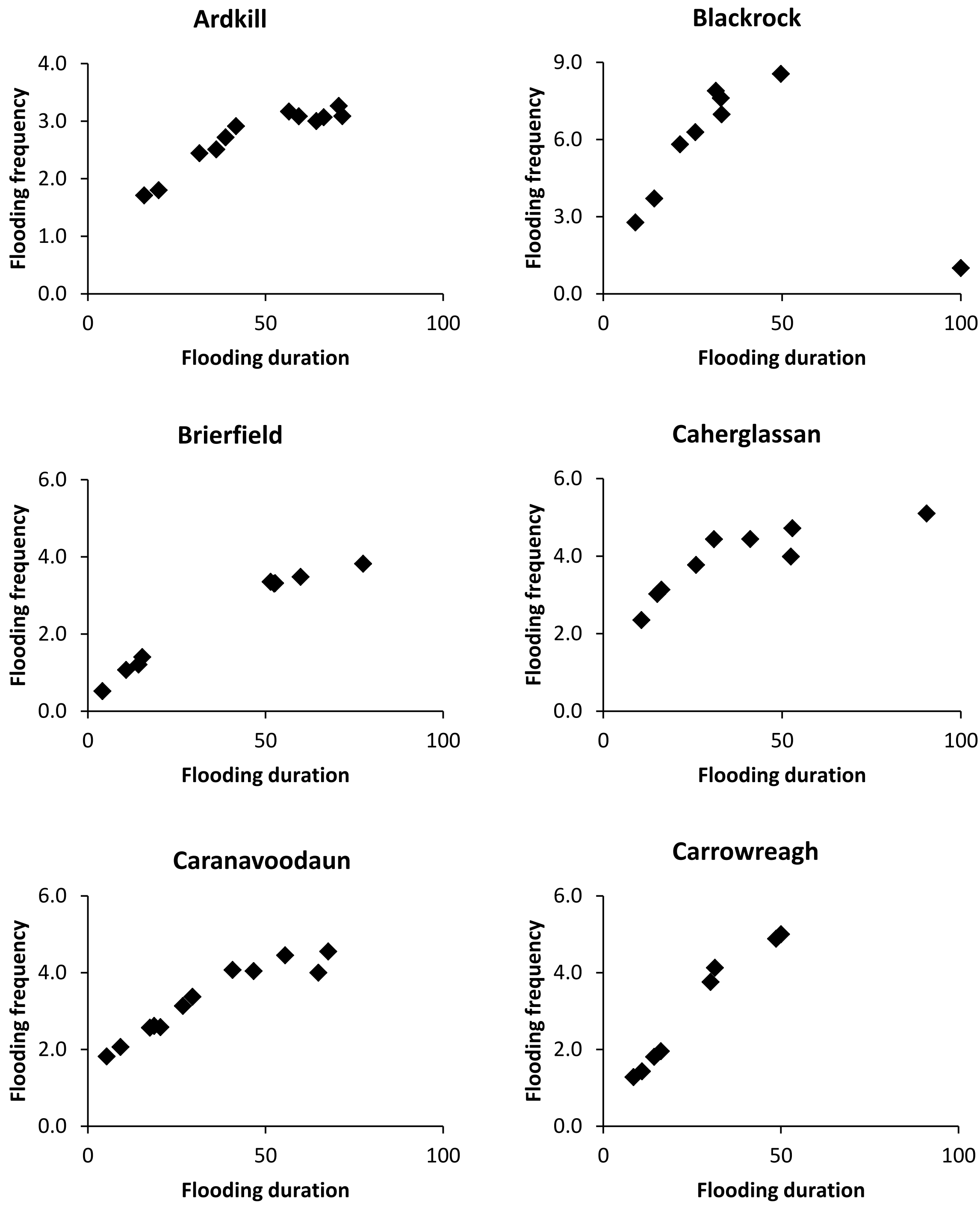


Figure 7.60 (Continues on next pages) Scatter plots of mean duration of flooding and mean frequency of flooding events to the substrate surface for the different communities in each turlough

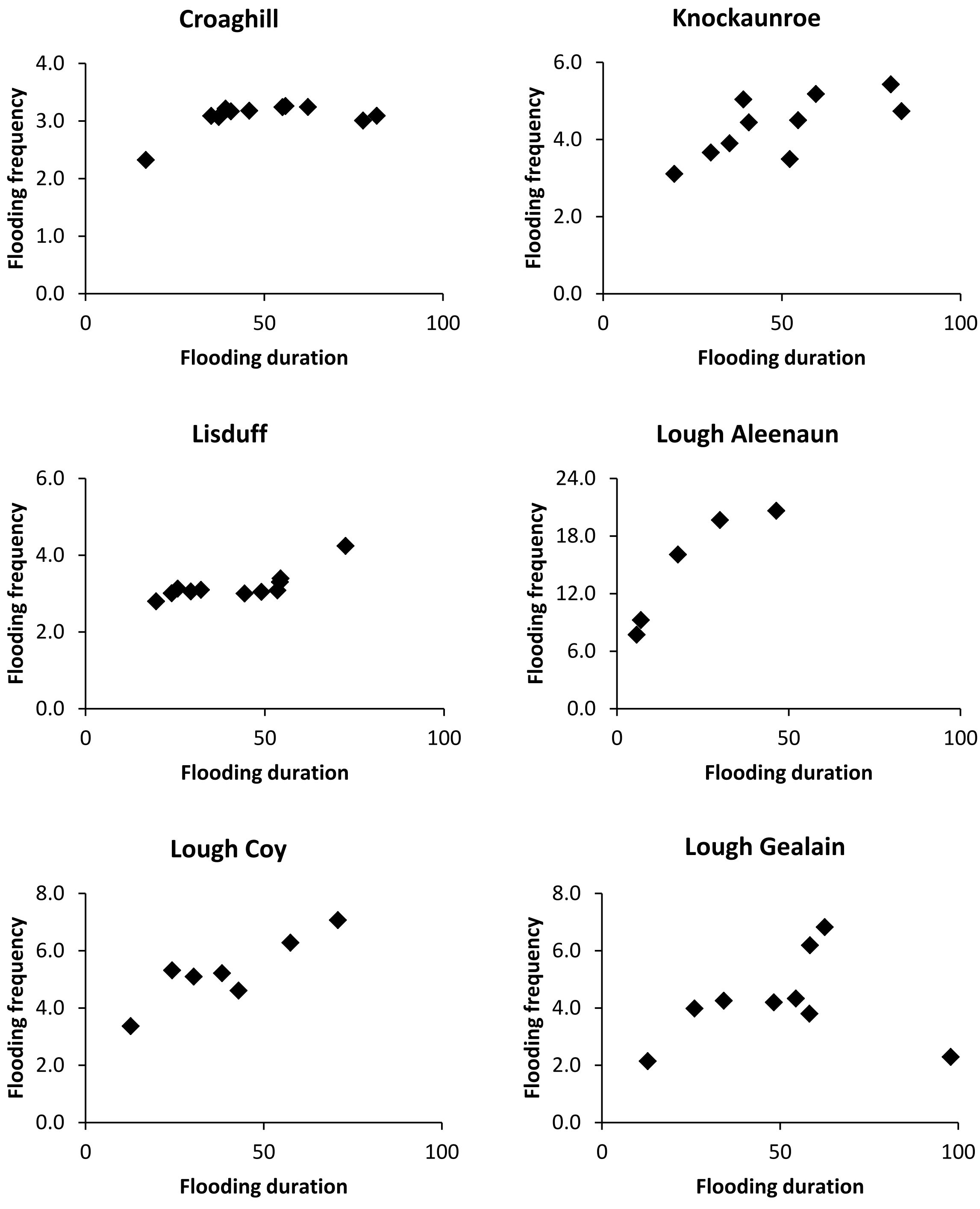


Figure 7.60 (cont.) Scatter plots of mean duration of flooding and mean frequency of flooding events to the substrate surface for the different communities in each turlough

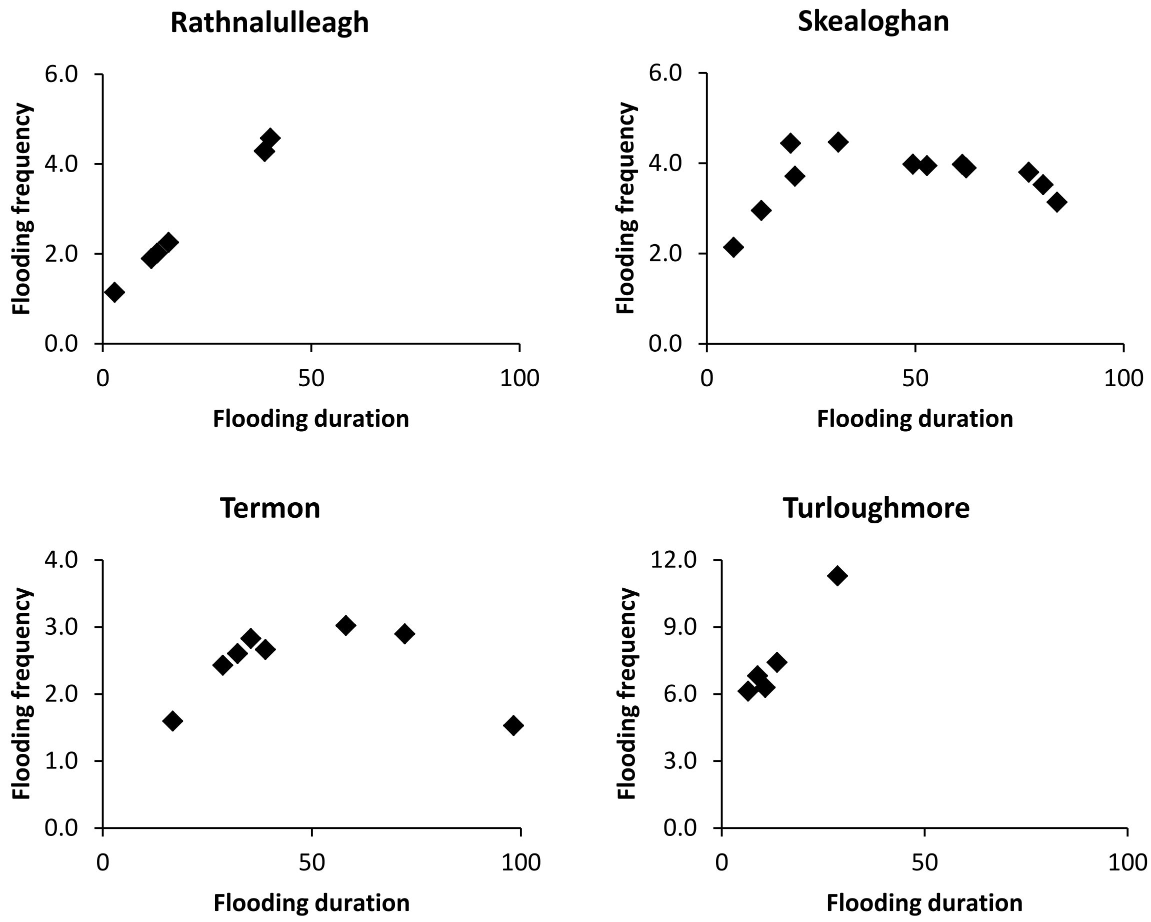
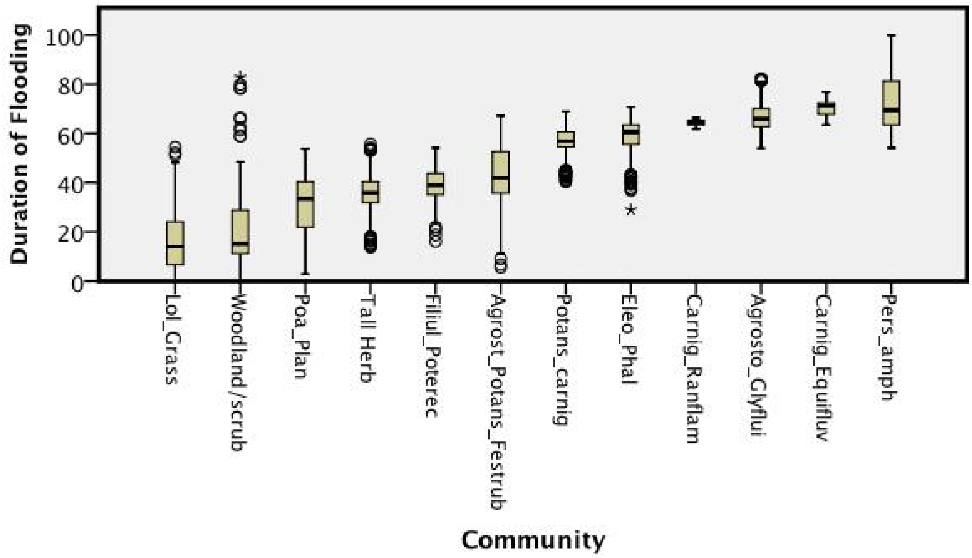


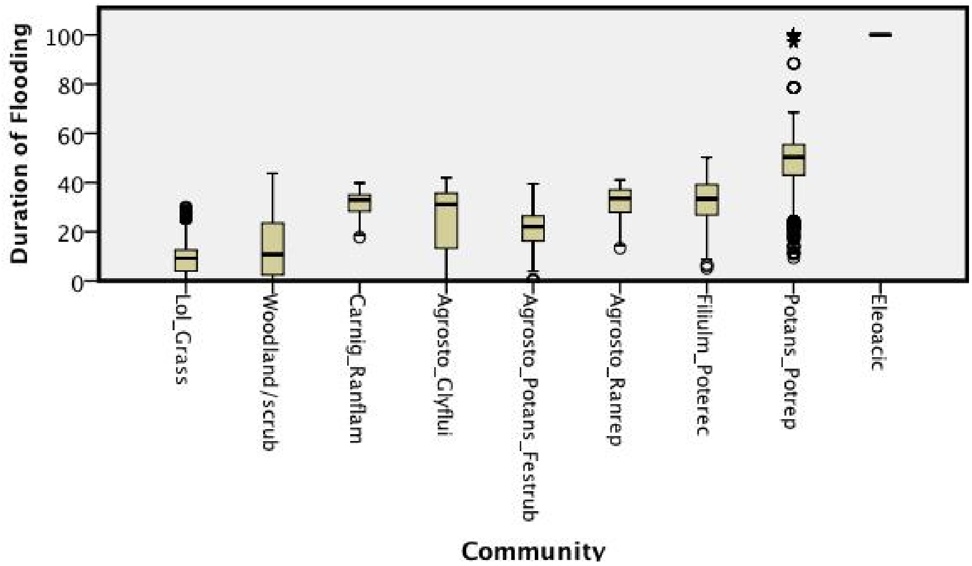
Figure 7.60 (cont.) Scatter plots of mean duration of flooding and mean frequency of flooding events to the substrate surface for the different communities in each turlough

Box plots showing the variation in duration of flooding in each community, calculated from the mapped vegetation communities in each turlough, are given in figure 7.61. In general different vegetation communities occupy different durations of inundation between turloughs, though there is considerable overlap. For many communities there are a large number of outliers; for example see Caherglassan, Croaghill, Knockaunroe. Often, communities occurring in the shorter flooding durations have positive outliers, while those from longer duration flooding have negative outliers – see for example Lough Gealain. This may be due to non-normally distributed data, where the shortest duration of flooding is set by the upper zone of the turlough, and the longest duration flooding by the maximum depth of the turlough. Other reasons for large overlaps and outliers are due to slight positional errors in the mapped community and the topographic profile interpolated from point elevations; this will be particularly noticeable on steeply sloping turloughs. Other reasons for the variation are likely to be the difficulty in defining vegetation boundaries which often intergrade even over short distances. Note that flooding duration data were not avalable ona comparative basis in all turloughs.

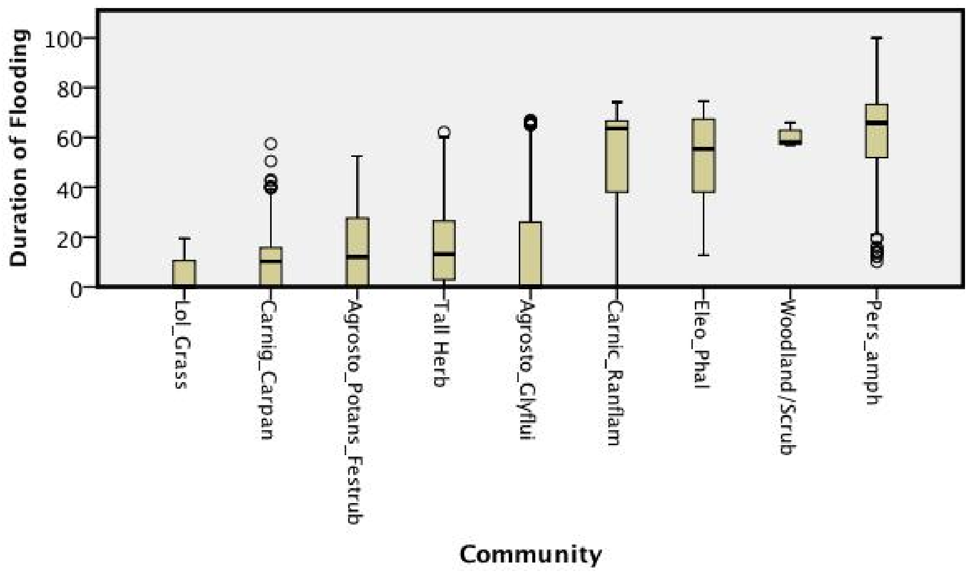
Ardkill



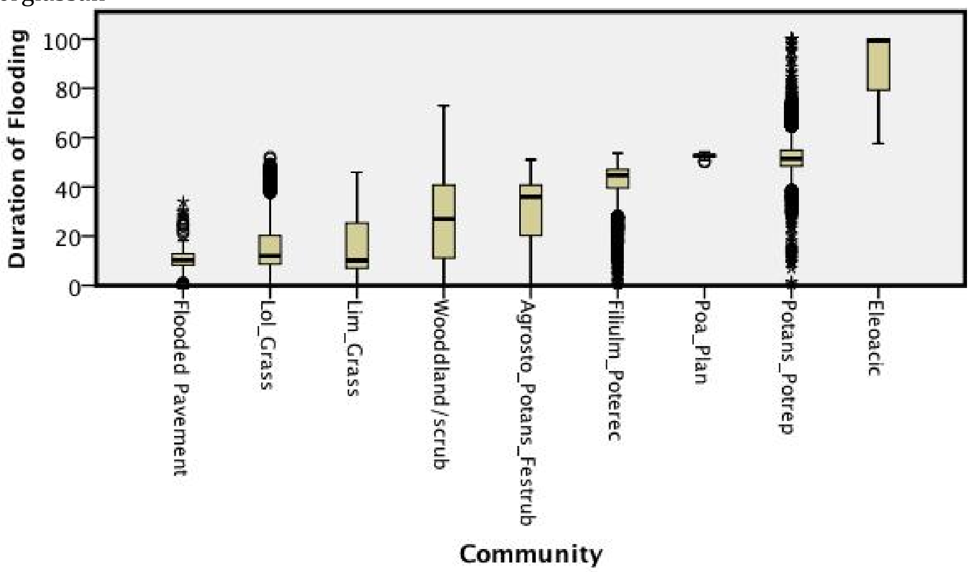
Blackrock



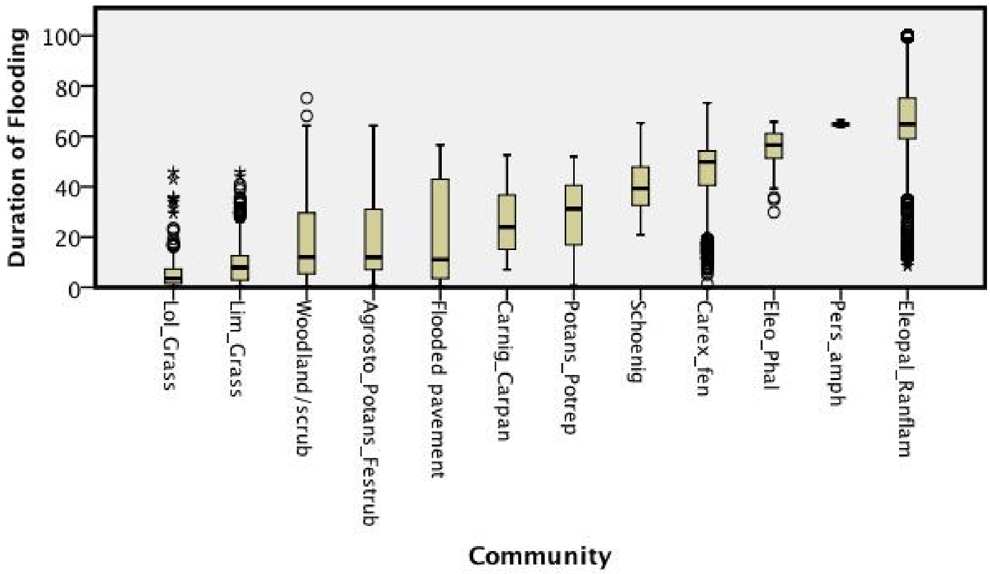
Brierfield



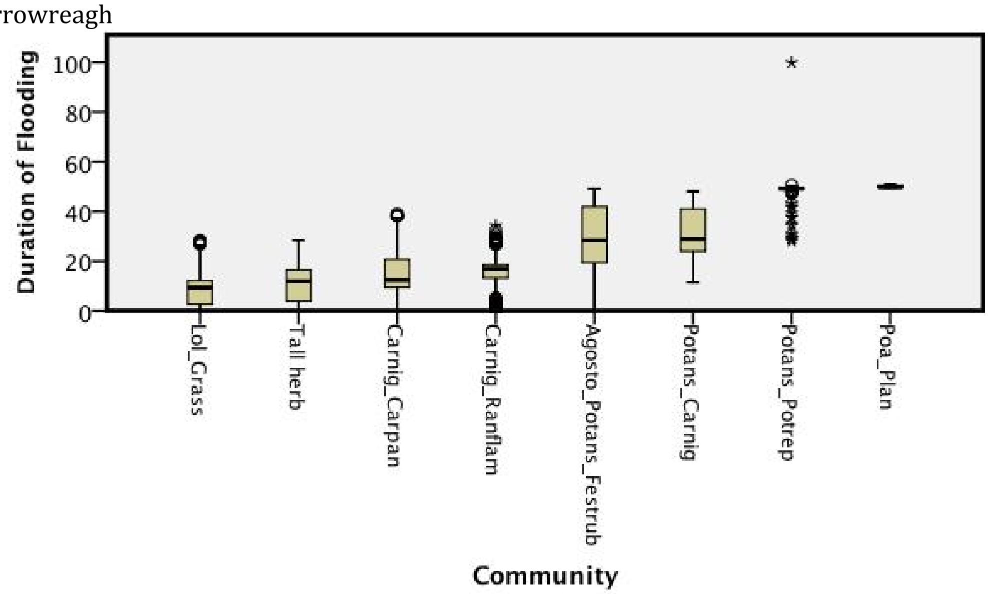
Caherglassan



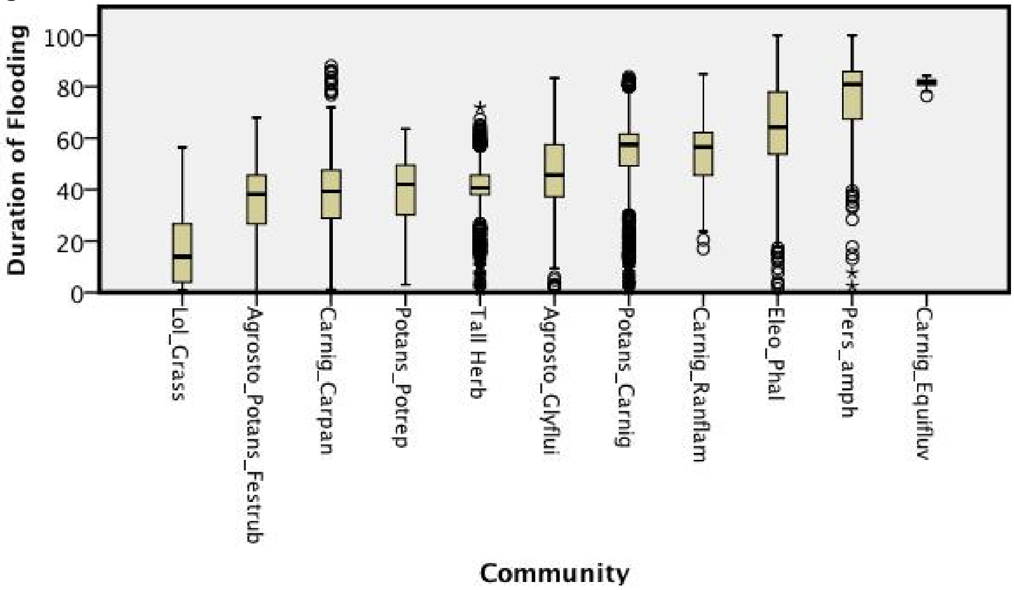
Caranavoodaun



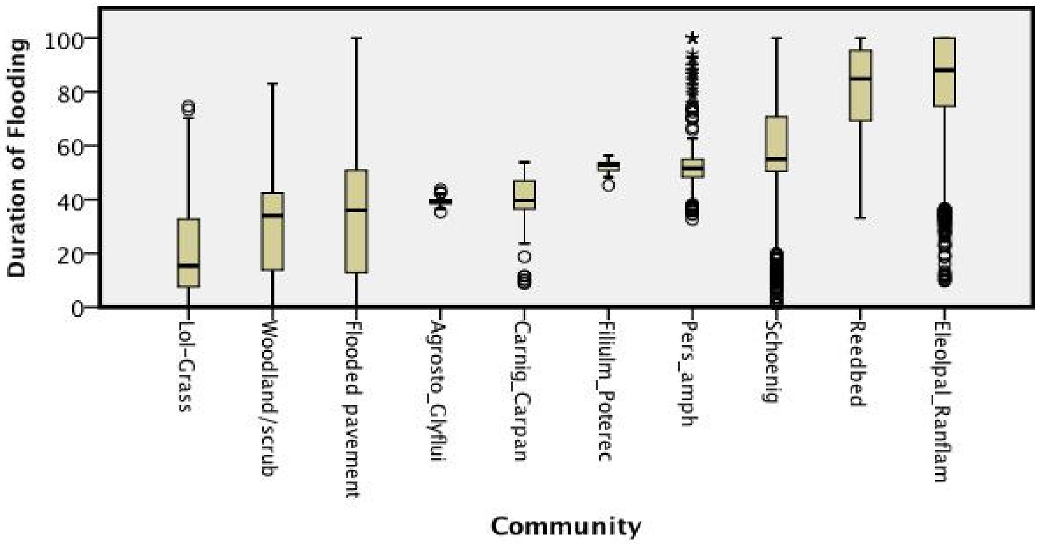
Carrowreagh



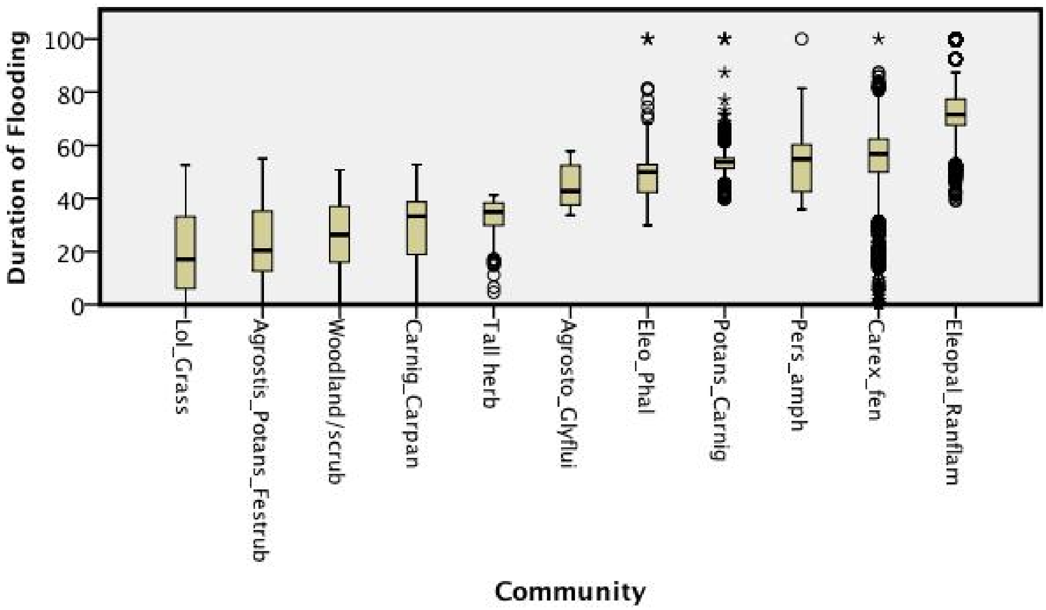
Croaghill



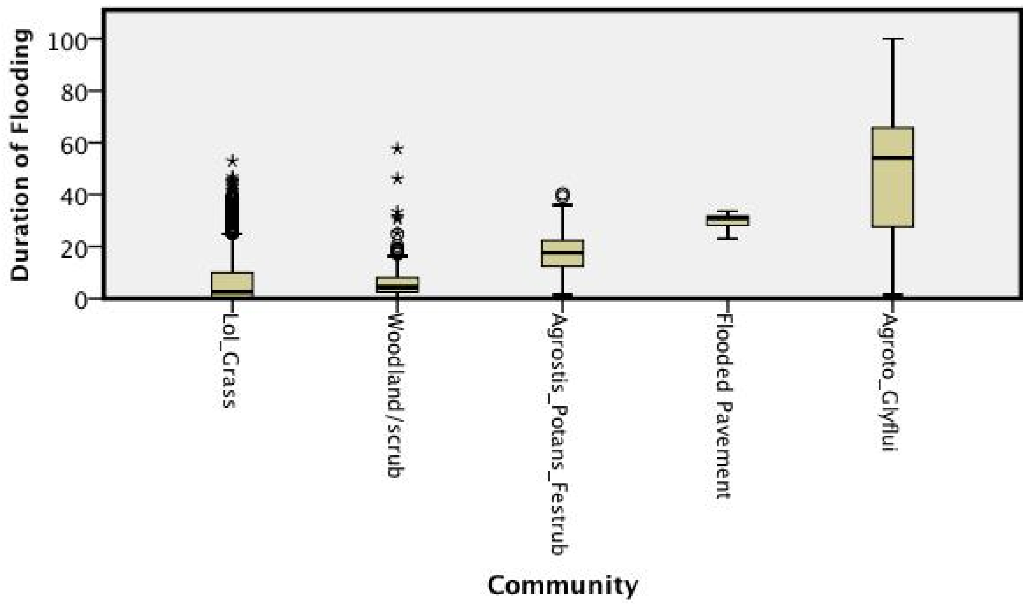
Knockaunroe



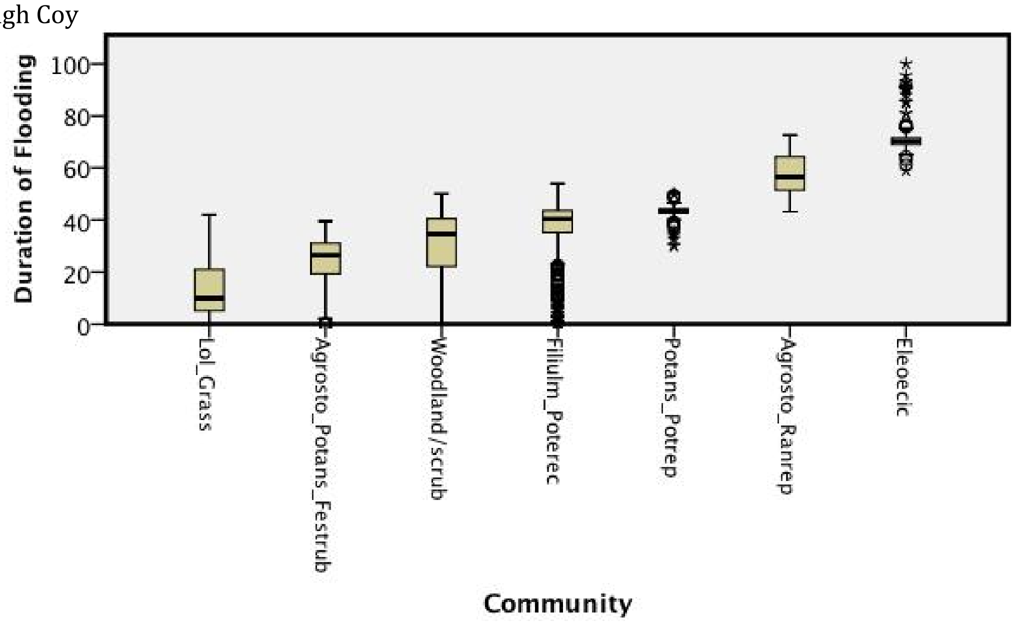
Lisduff



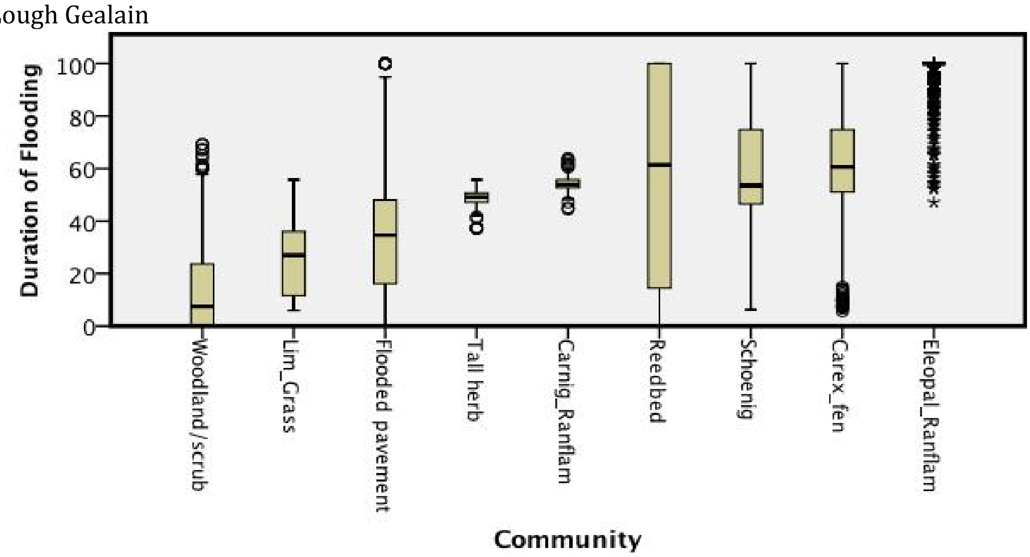
Lough Aleenaun



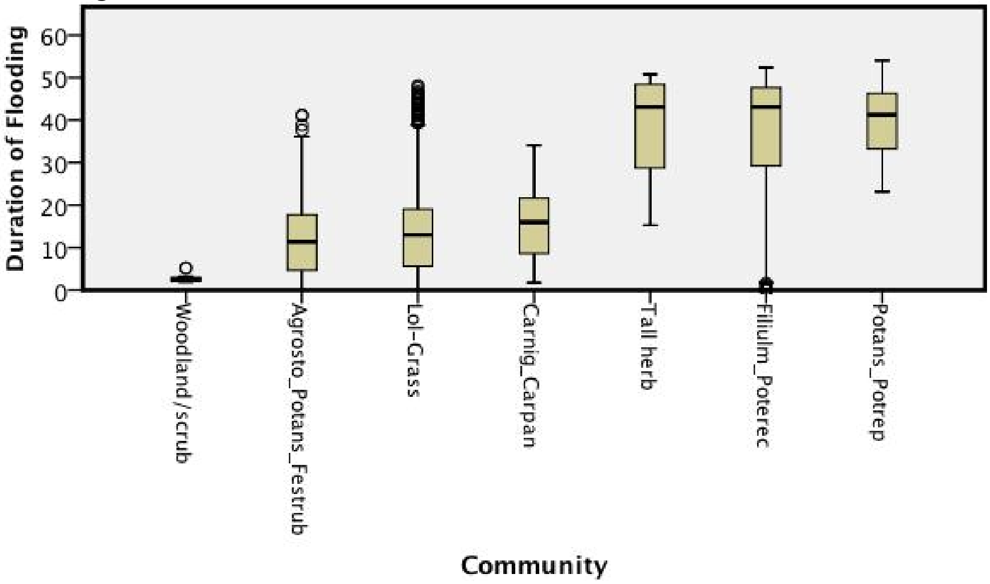
Lough Coy



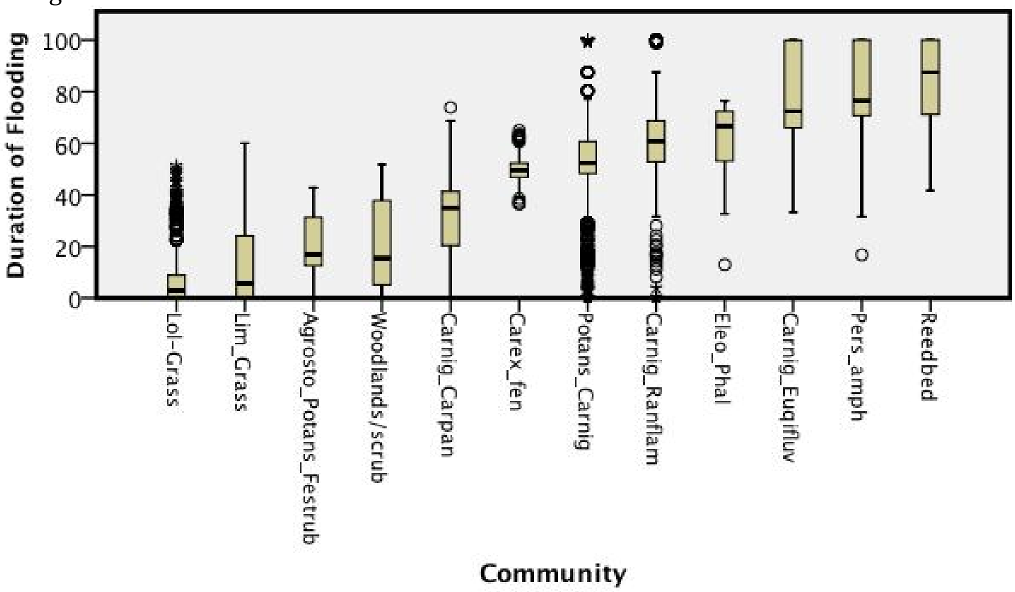
Lough Gealain



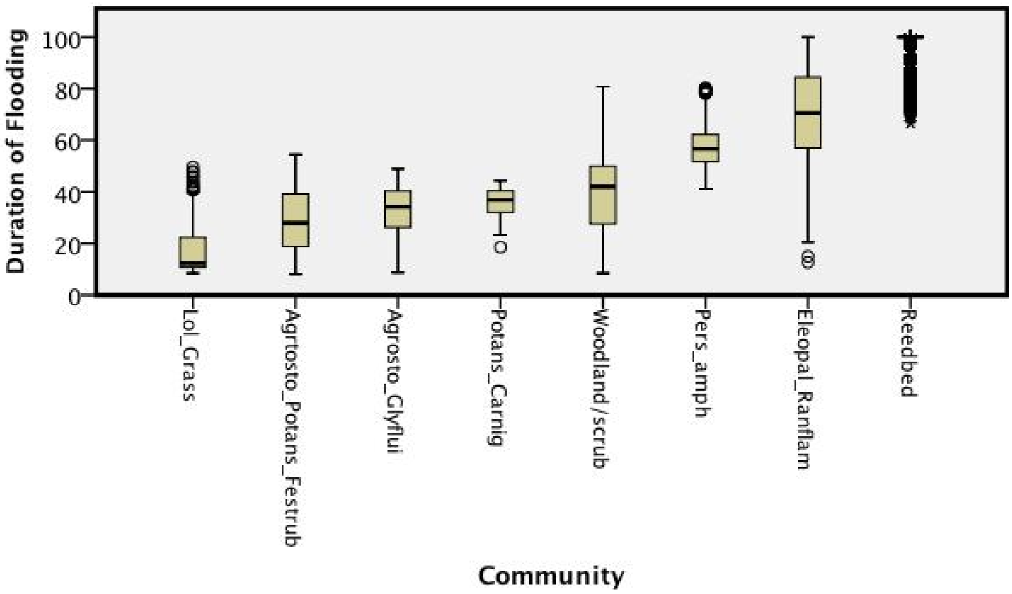
Rathnalulleagh



Skealoghan



Termon



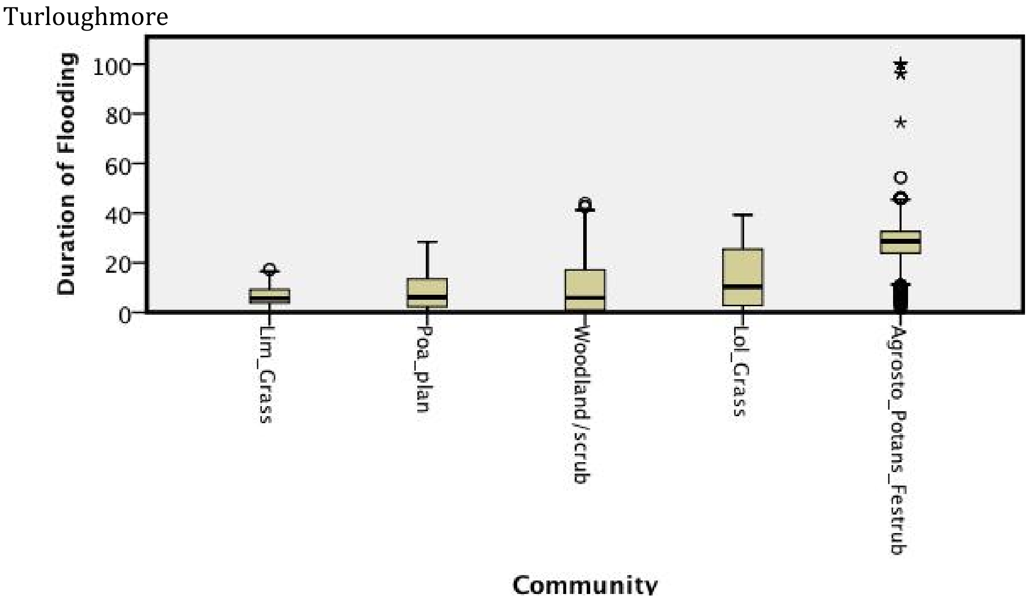


Figure 7.61 Boxplots of duration of flooding estimated for different vegetation communities in each turlough, calculated from a grid of points overlaid on the mapped vegetation communities. The horizontal line in the middle of the box represent the median value, the whiskers the highest and lowest statistically connected points. Outliers are indicated by circles, and extreme outliers by stars. The communities are ranked by mean flooding duration. Lack of comparable hydrological data resulted plots not being available for some turloughs. Abbreviations for vegetation communities are as follows:

Mapped Community Name	*Abbreviated name*
Agrostis stolonifera-Glyceria fluitans	*Agrosto_Glyflui*
Agrostis stolonifera-Potentilla anserina-Festuca rubra	*Agrosto_Potans_Festrub*
Agrostis stolonifera-Ranunculus repens	*Agrosto_Ranrep*
Carex nigra-Carex panicea	*Carnig_Carpan*
Carex nigra-Equisetum fluviatile	*Carnig_Equifluv*
Carex nigra-Ranunculus flammula	*Carnig_Ranflam*
Eleocharis acicularis	*Eleoacic*
Eleocharis palustris-Phalaris arundinacea	*Eleo_Phal*
Eleocharis palustris-Ranunculus flammula	*Eleopal_Ranflam*
Filipendula ulmaria-Potentilla erecta-Viola sp.	*Filiulm_Poterec*
Flooded Pavement	*Flooded pavement*
Limestone grassland	*Lim_Grass*
Lolium grassland	*Lol_Grass*
Molinia caerulea-Carex panicea	*Carex_fen*
Poa annua-Plantago major	*Poa_Plan*
Polygonum amphibium	*Pers_amph*
Potentilla anserina-Carex nigra	*Potans_Carnig*
Potentilla anserina-Potentilla reptans	*Potans_Potrep*
Reedbed	*Reedbed*
Schoenus nigricans fen	*Schoenig*
Tall herb	*Tall Herb*
Woodland/scrub	Woodland/scrub

Lolium grassland and Woodland/scrub communities often occur at the upper zones of a wide range of turloughs, from the oligotrophic Knockaunroe and Lisduff to the eutrophic Blackrock and Ardkill. There was a small amount of *Lolium* grassland at Brierfield and the community was absent from the highly oligotrophic Lough Gealain. The *Agrostis stolonifera-Potentilla* *anserina-Festuca rubra* community also occurs widely in the upper zones with shorter duration flooding. In the more oligotrophic turloughs the zones with the shorter duration flooding are often dominated by the Flooded Pavement and Limestone Grassland communities.

The *Carex nigra-Equisetum fluviatile, Polygonum amphibium,* and *Potentilla anserina-Potentilla reptans* communities are typical of the lower zones of more meso- to eutrophic turloughs; the *Polygonum* community is particularly characteristic of these turloughs with medium-high to very high TP. The *Eleocharis acicularis* community is also restricted to the lower zones of turloughs with medium-high log TP, but occurs with a specialized substrate type on mineral soils with little other vegetation. Note that the only relevee data collected for this community was from Garryland (which had incomplete hydrological records); at Garryland the community occured along drainage margins <u>above</u> the lowest point of the turlough, and therefore not in the longest duration flooding zones; at Blackrock, Caherglassan and Lough Coy the *Eleocharis acicularis* community occurred in the deepest parts of the turlough and was therefore subjected to longer duration flooding.

In the more oligotrophic turloughs with low to very low TP, the *Polygonum amphibium* communities are typically replaced by the *Eleocharis palustris-Ranunculus flammula* community which is extensive in the deeper parts of most oligotrophic turloughs (note relevés recorded over a wide range though). The community contains several aquatic and amphibious species (see table 7.51). In higher TP turloughs this community may be replaced by *Eleocharis palustris-Phalaris arundinacea* and *Potentilla anserina-Potentilla reptans* communities.

The middle zones with medium duration flooding of oligotrophic turloughs tend to be occupied by the sedge dominated communities: *Molinia caerulea-Carex panicea, Carex nigra-Carex panicea* and *Schoenus nigricans* fen. The latter is restricted to the more oligotrophic turloughs, while the *Carex nigra-Carex panicea* community occurs over a wider range of log TP, though is absent from turloughs with very high TP (see figure 7.62 below). In more eutrophic turloughs these sedge dominated communities of intermediate flooding duration are largely replaced by forb-rich communities such as the *Agrostis stolonifera-Ranunculus repens, Filipendula ulmaria-Potentilla erecta-Viola* sp. and *Potentilla anserina-Carex nigra* communities.

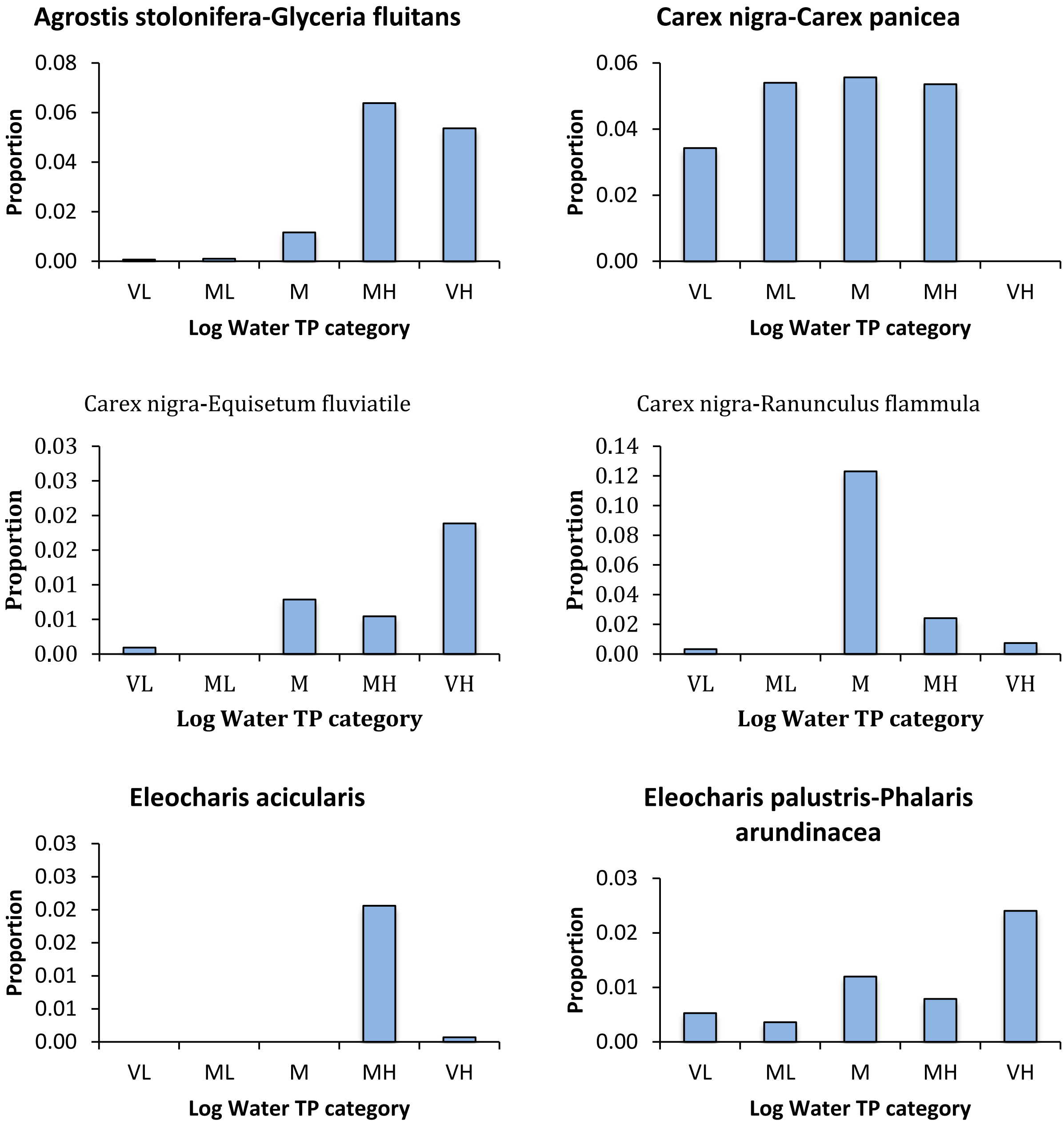


Figure 7.62 (see legend below)

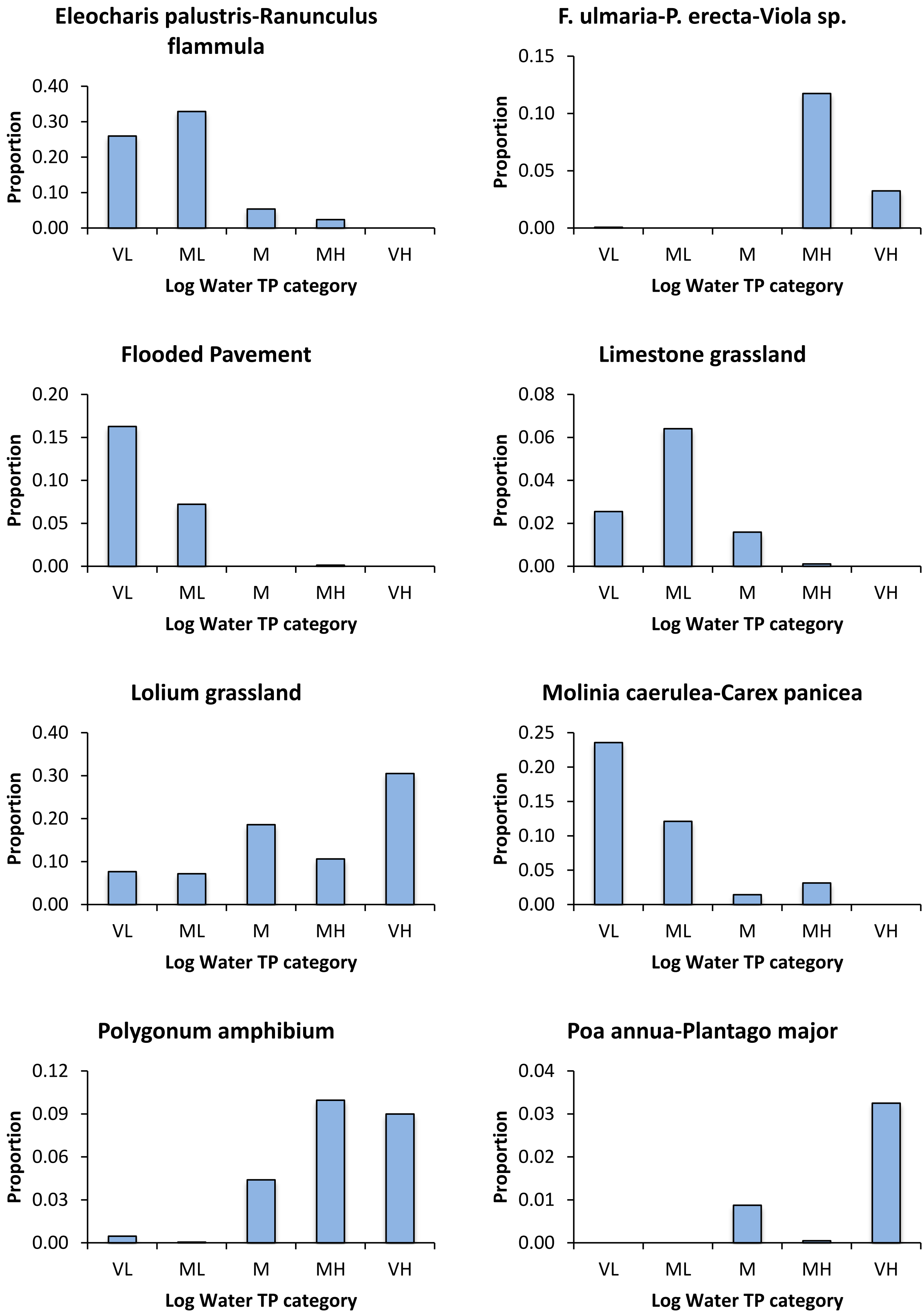


Figure 7.62 (see legend below)

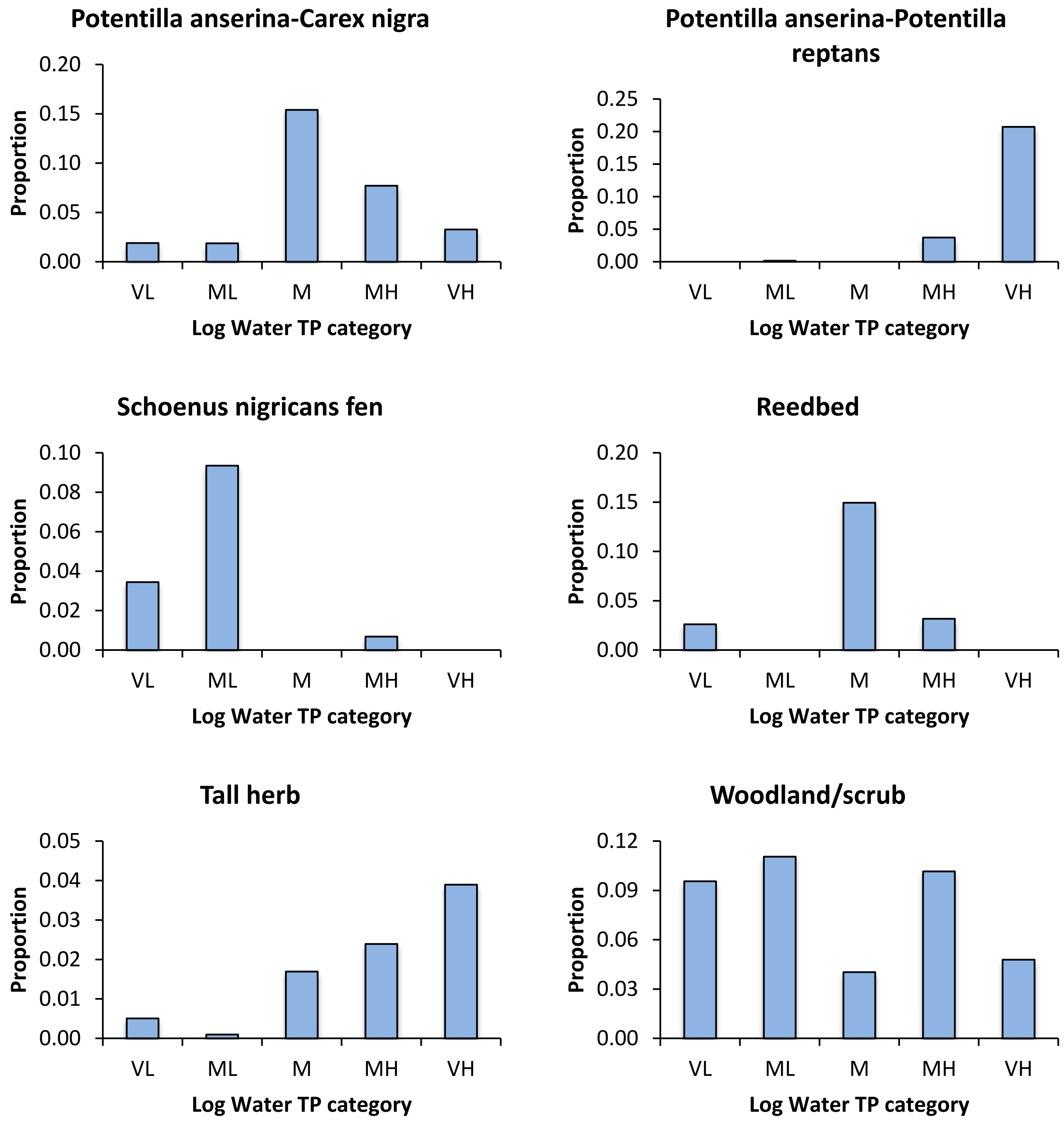


Figure 7.62 Mean proportion of turloughs covered by vegetation communities in five categories of log of water TP category: VL – Very low, ML – Medium low, M – Medium, MH – Medium high, VH – Very high.

Figure 7.62 shows the proportion of all turloughs within each water TP category occupied by each community. The *Eleocharis palustris-Ranunculus flammula*, Flooded Pavement, Limestone grassland, *Schoenus nigricans* fen communities were restricted to turloughs with low and very low TP. The *Molinia caerulea-Carex panicea* tended to decrease in proportion with increasing TP. All of these communities are characteristic of the more oligotrophic turloughs.

The *Carex nigra-Ranunculus flammula*, *Potentilla anserina-Carex nigra*, Reedbed communities were most frequent in turloughs with medium log TP. Because the TP scale was log transformed, these communities still occur in relatively unenriched sites.

The *Eleocharis acicularis, Poa annua-Plantago major* and *Polygonum amphibium* communities were most frequent in medium to high TP categories. This suggests a moderate amount of enrichment; the *Poa-Plantago* community occurs in areas disturbed or poached by grazing animals, whereas the *Polygonum* communities are restricted to the deeper zones of moderately eutrophic turloughs. The *Eleocharis acicularis* community is a specialized community restricted to deeper zones of turloughs with medium-high levels of TP on mineral soil substrates.

The *Agrostis stolonifera-Glyceria fluitans, Carex nigra-Equisetum fluviatile, Filipendula ulmaria-Potentilla erecta-Viola* sp., and *Potentilla anserina-Potentilla reptans* communities are restricted to turloughs with high or very high TP. In addition, the *Agrostis stolonifera-Ranunculus repens, Eleocharis palustris-Phalaris arundinacea, Lolium* grassland, and Tall herb communities tend to increase in proportion with increasing log TP. These communities are all typical of the more eutrophic turloughs, and in general indicate the generalized shift from sedge dominated communities in the more oligotrophic turloughs to forb dominated communities in eutrophic turlough.

The *Carex nigra-Carex panicea* community occurred in high proportion over a wide range of TP, but was absent from the very high TP category, indicating its absence in the most eutrophic turloughs. Finally, the *Agrostis stolonifera-Potentilla anserina-Festuca rubra* and Woodland/scrub communities showed variable proportions in different TP categories without clear trends. For the woodland/scrub community, this may represent a variety of different woodland/scrub types.

7.5.4 Using Vegetation to Estimate Trophic Status of Each Turlough

Figure 7.63 shows scatterplots of various environmental variables plotted against the Ellenberg values calculated for each turlough.

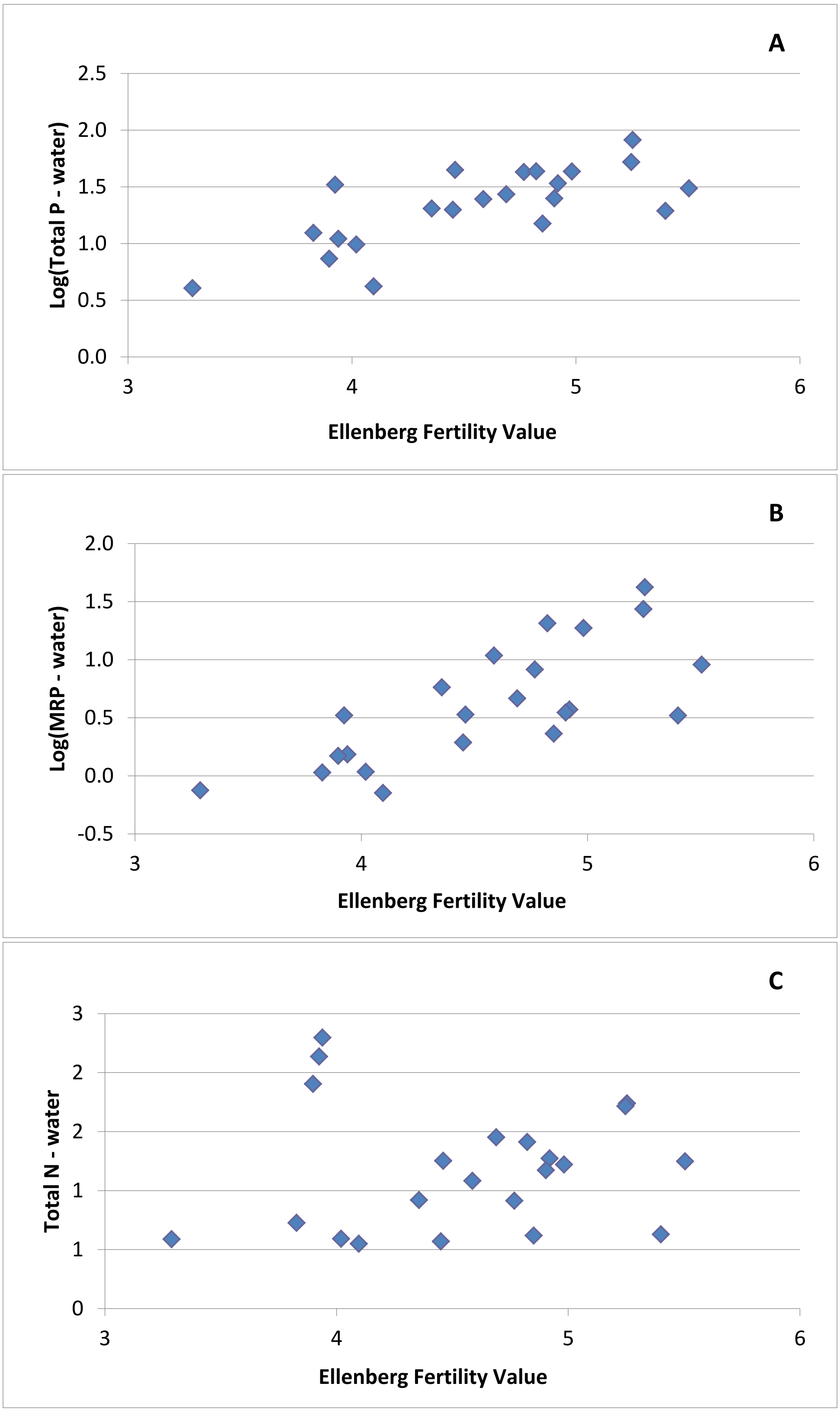


Figure 7.63 (continues on next page) Relationship between calculated Ellenberg fertility value and Total P (A), Molybdate-reactive (B) and Total N (C) in the water column for 22 turloughs

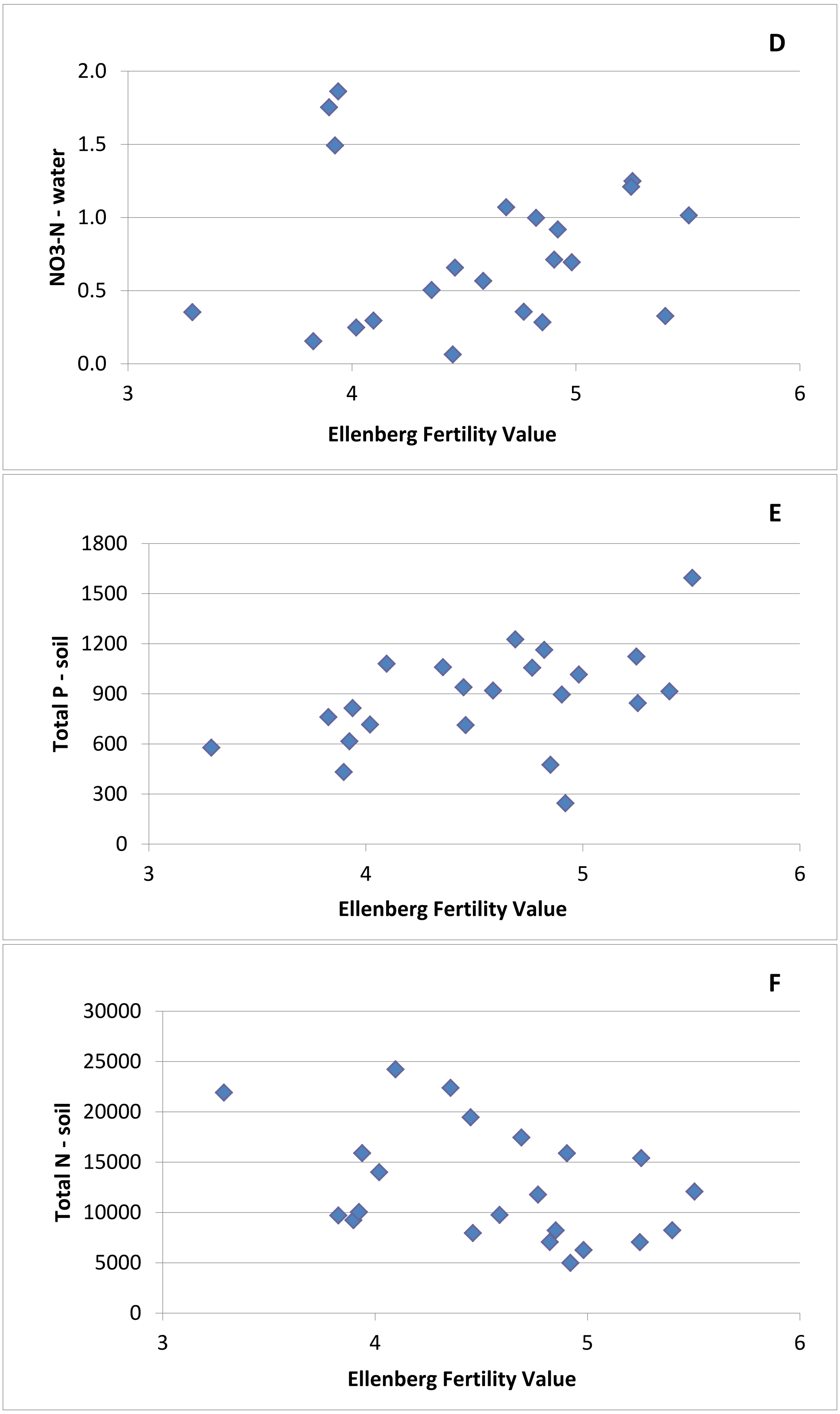


Figure 7.63 (continued) Relationship between calculated Ellenberg fertility value and NO_3-N (D) in the water column, and Total P (E) and N (F) in soils for 22 turloughs

Table 7.101 Pearson-product correlation coefficients between various derived measures of trophic status, and various relevant environmental variables in 22 turloughs.

Variable	*Trophic index*	*Ellenberg value*	*Prop Oligo*	*Prop oligo-meso*	*Oligo-meso less eutroph*
Ellenberg value	0.809	-			
Prop Oligo	-0.931	-0.818	-		
Prop oligo-meso	-0.837	-0.821	0.822	-	
Oligo-meso less eutroph	-0.847	-0.811	0.806	0.934	-
TP-water	0.711	0.631	-0.674	-0.71	-0.752
Log TP-water	0.880	0.725	-0.828	-0.787	-0.815
Log10 MRP-water	0.778	0.741	-0.770	-0.791	-0.765
TN-water	0.254	0.03	0.007	-0.109	-0.183
NO3-N-water	0.157	0.031	0.103	-0.046	-0.115
Soil TP	0.384	0.452	-0.496	-0.373	-0.347
Soil TN	-0.449	-0.418	0.274	0.582	0.546

The calculated Ellenberg values showed the strongest correlations (+ve) with log transformed total P and MRP in water (Figure 7.61, table 7.101) as expected from previous work, suggesting P is the most important nutrient in turloughs. There was a much weaker relationship with total P in soil. There was no relationship between Ellenberg value and Total N and NO_3-N in water, and a slight negative relationship with total N in soil

Regression equations:

$Log(waterTP) = (0.431 \times EF) - 0.631$; $F_{1,20} = 22.1$, $P<0.001$; $r^2 = 52.6\%$

$Log(waterMRP) = (0.646 \times EF) - 2.33$; $F_{1,20} = 24.4$, $P<0.001$; $r^2 = 54.9\%$

where TP = Total Phosphorus, MRP = Molybdate-reactive phosphorus, EF = Ellenberg fertility value

The strong, positive linear relationship with these measures of P and Ellenberg fertility suggests that Ellenberg fertility can be reliably used to predict P status of turloughs.

One problem with the calculation of Ellenberg values for turloughs as described above is the need to have accurate cover-abundance values for each species in every community, and an estimation of the area of each community. The proportion of the turlough occupied by oligotrophic communities has also been used to estimate sensitivity to enrichment. Here we calculated the proportion of oligotrophic communities (pOligo) and also modified that by inclusion of oligo-meso trophic communities (pOM), and examined the relationship with log (water TP). In both cases there were significant negative relationships (Figure 7.64), but there are numerous zero values where turloughs have no oligotrophic communities (Figure 7.2 A, B). While this may be useful in assessing sensitivity, it cannot be easily related to TP in an ecological sense. We therefore modified pOM by subtraction of the proportion of eutrophic communities to create a new index (pOM-E), which showed a better linear spread of points (Figure 7.62 C). Also of these variables showed a better linear fit to log(water TP) than the Ellenberg index.

Regression equations:

$Log(waterTP) = 1.549 - (0.932 \times pO)$; $F_{1,20} = 43.5$, $P<0.001$; $r^2 = 68.5\%$

$Log(waterTP) = 1.638 - (0.904 \times pOM)$; $F_{1,20} = 32.5$, $P<0.001$; $r^2 = 61.9\%$

$Log(waterTP) = 1.404 - (0.586 \times pOM - E)$; $F_{1,20} = 39.5$, $P<0.001$; $r^2 = 66.4\%$

where TP = Total Phosphorus,

pO = Proportion of oligotrophic communities

pOM = Proportion of oligo- and oligo-mesotrophic communities

pOM-E = pOM less the proportion of eutrophic communities

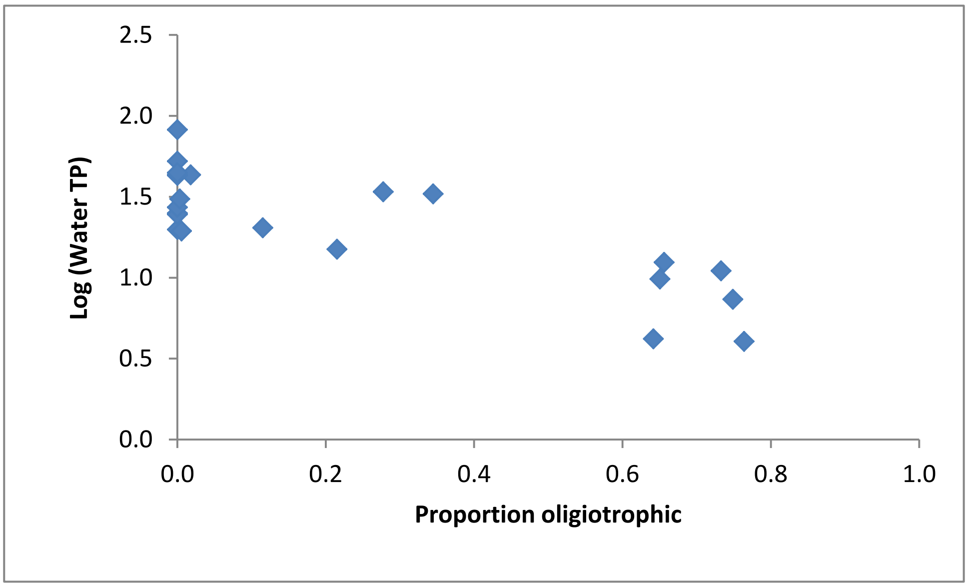
Finally, we calculated an index of trophic status (I_{TS}) based on the presence or frequency of species (as a proprtion of samples, in this case relevés, with the species) which showed obvious distribution patterns in relation to TP. This index showed a very strong positive linear relationship with log(waterTP), with a high r^2 value (Figure 7.64). The advantage of this approach is that it does not require vegetation mapping or extensive relevé analysis, but relies on the presence or frequency of a selected group of species in a series of samples.

Regression equation:

$Log(waterTP) = (0.812 \times I_{TS}) + 1.42$; $F_{1,20} = 67.9$, $P<0.0001$; $r^2 = 77.2\%$

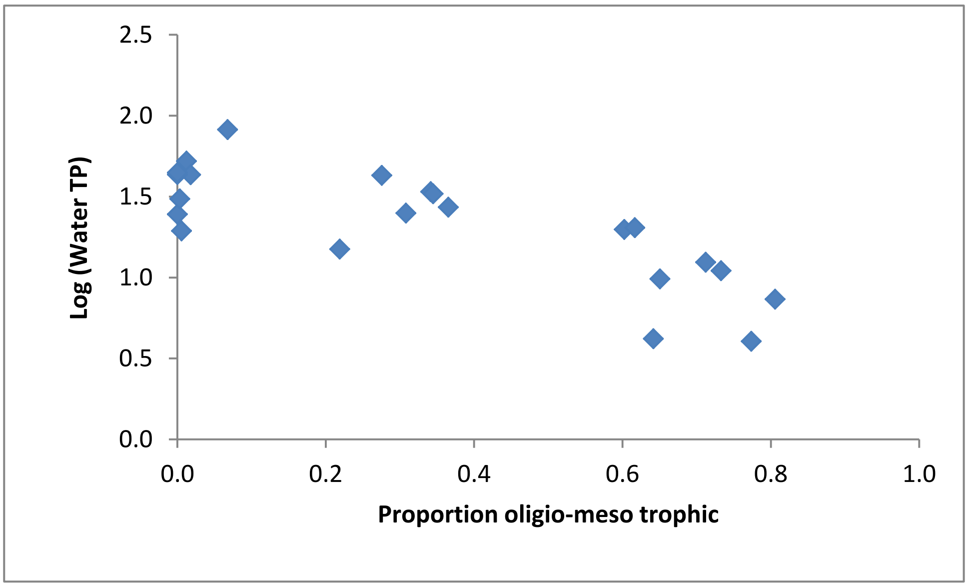
where TP = Total Phosphorus, I_{TS} = Index of Trophic Status

A



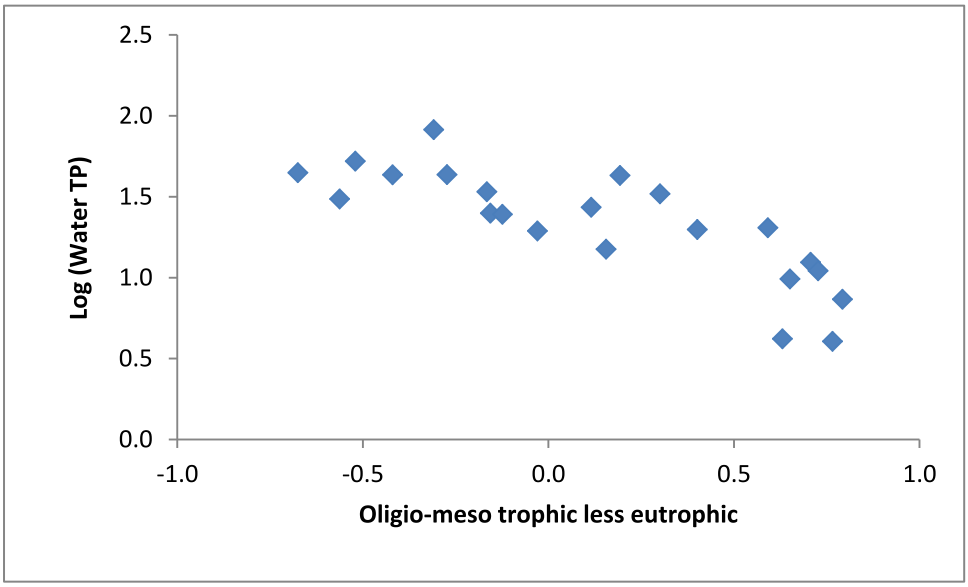
Log (Water TP)
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion oligiotrophic

B



Log (Water TP)
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion oligio-meso trophic

C



D

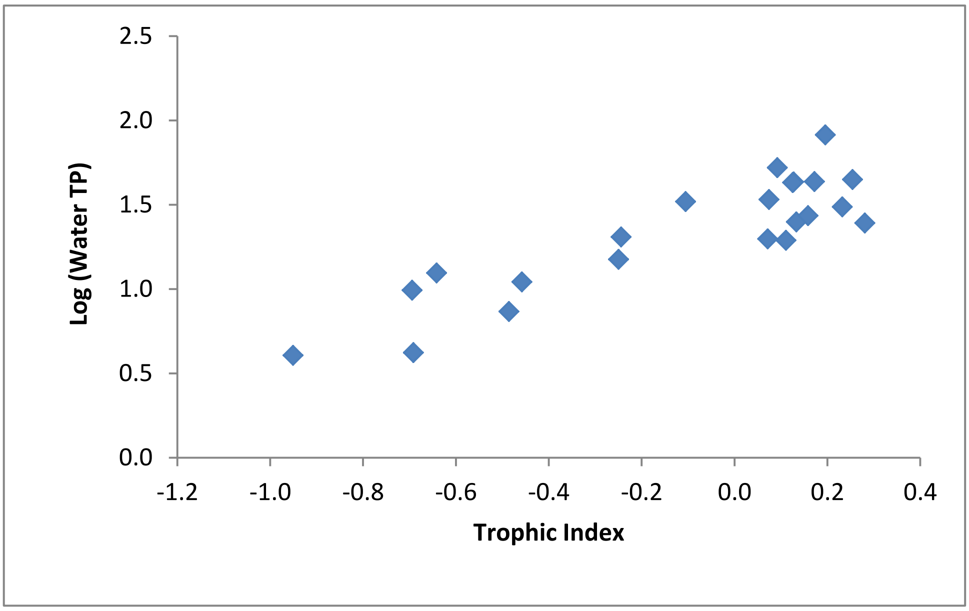


Figure 7.64 Log (water TP) plotted against the proportion of each turlough with oligtrophic communities (A), the proportion of oligo- plus oligo-mesotropic communities (B), an index where the proportion of eutrophic communites is subtratcted from the proportion oligo- plus oligo-mesotropic communities (C), and a trophic index based on the abundance or frequency of selected species (D)

7.6 Discussion

7.6.1 Vegetation Communities

Twenty eight plant communities were identified by cluster analysis and indicator species analysis. There was overlap between many of the plant communities in terms of species composition; this meant that few species were faithful to any one group. A number of species, however, were defined as indicator species for the particular group to which they were most faithful. Th following plant species were all widespread in the turlough studied: *Agrostis stolonifera*, *Potentilla anserina, Galium palustre, Ranunculus repens* and *Carex nigra*.

7.6.1.1 Vegetation Communities Classified and Described in this Chapter

The communities described in this study occur from the fringes of the turloughs right down to the bottom, and range from fully terrestrial grasslands to aquatic communities.

Molinio-Arrhenetheretea

Grassland communities dominated the upper zones of the turloughs surveyed during this study. The *Lolium perenne-Trifolium repens* community and the *Lolium perenne-Trifolium repens-Agrostis stolonifera* community both show an anthropogenic influence, with species such as *Lolium perenne*. These communities often grade into managed grazing land outside of the turlough boundary.

The Limestone Grassland community was most similar to the other grassland communities described here, although a number of species more typical of calcareous habitats were found.

The Flooded Pavement community was characterised by exposed limestone pavement, and *Potentilla fruticosa* was frequent here. This community was difficult to classify, however, and so was not assigned to a class.

Scheuchzerio-Caricetea fuscae

A number of communities were described which fall within the *Scheuchzerio-Caricetea fuscae*, or the small sedge communities as described by O'Connell *et al*. (1984) These were the *Schoenus nigricans* fen, the *Molinia caerulea-Carex panicea* community, the *Carex nigra-Carex panicea* community, and the *Carex nigra-Carex viridula* community.

These are communities that are characterised by species which require the water table to remain near the surface throughout the growing season – *Carex panicea*, *C. nigra* and *C. flacca* are all species which can compete effectively when the water levels remain consistently high (Gowing & Spoor, 1998).

Plantaginetea majoris

Ranunculo-Potentilletum anserinae

A number of communities defined herein correspond to those previously described by O'Connell *et al*. (1984) as belonging to the *Ranunculo-Potentilletum anserinae*. These are 'typical' turlough communities, occurring in a wide range of turloughs, and generally characterise the middle to lower zone of the turlough. Chiefly composed of species such as *Potentilla anserina, Carex nigra* and *Agrostis stolonifera*, there is a large amount of variation between the different variants of this association.

A number of communities show affinity with the *Eleocharis palustris* swamps of the NVC. These occur in areas which seem to retain water until late in the growing season, and have frequent and abundant species such as *Eleocharis palustris, Ranunculus flammula*.

Phragmitetea

Group 14, the Reedbed community, represents the tall sedge and reed swamp vegetation of turloughs, but was undersampled in this study. Other communities which seemed to belong to the *Phragmitetea* were the *Equisetum fluviatile-Menyanthes trifoliata* community, the *Agrostis stolonifera-Glyceria fluitans* community, and the *Carex nigra-Equisetum fluviatile* community.

Potametea

The *Potamogeton natans-Glyceria fluitans* community represents the permanently inundated part of the vegetation of turloughs.

Littorelletea uniflora

The *Eleocharis palustris-Ranunculus flammula* community and the *Eleocharis acicularis* communities belong to this class.

Polygono-Poetea annuae

The *Poa annua-Plantago major* community was the only community to belong to this class.

Other Communities

The *Rumex crispus-Alopecurus geniculatus* nodum of the *Plantaginetalia majoris* (Ivimey-Cook & Proctor, 1966) was not recorded during the field work for this thesis. It was, however, found in Lough Aleenaun during surveying work for mapping. It was found at a level that was not accessible due to flooding during field work.

7.6.1.2 Comparison with Previously Published Vegetation Communities

Two associations are repeatedly described in the literature as being typical of turloughs, these are the small sedge communities of the *Scheuchzerio-Caricetea fuscae* and the *Ranunculo-Potentilletum anserinae*. Both of these associations were well-represented in the current study. The *Carex nigra-Carex panicea* community (Group 8), the *Schoenus nigricans* fen (Group 21), the *Molinia caerulea-Carex panicea* community (Group 22) and the *Carex nigra-Carex viridula* community all belong to the *Scheuchzerio-Caricetea fuscae*. The *Ranunculo-Potentilletum anserinae* is represented by the *Phalaris arundinacea-Potentilla anserina* community (Group 9), the *Potentilla anserina-Carex nigra* community (Group 13), the *Carex nigra-Ranunculus flammula* community (Group 17), the *Potentilla anserina-Potentilla reptans* community (Group 19), the *Filipendula ulmaria-Potentilla erecta-Viola* sp. community (Group 20) and the *Carex nigra-Leontodon autumnalis* community. The remainder of the plant communities either belong to classes which are similar to those found just outside the turlough boundary, such as the *Molinio-Arrhenatheretea*, or to classes such as the *Phragmitetea* or *Potametea* which contain communities which require higher water levels.

The communities in this study could be assigned to previously published communities in most cases. Where there was no clear affinity for previously published communities, it is possible that the vegetation either represents a transition zone between different communities or a sub-community which was not previously defined, was not sampled in previous studies, or was insufficiently mature when recorded. Regan *et al*. (2007) suggest that the communities with abundant *Carex nigra* and *Potentilla anserina* represent a transition between the more sedge-dominated communities and the forb-dominated communities; we found that both of these species occurred in wide range of ecological conditions in turloughs.

Dune slack communities

It is perhaps initially surprising to see such a high level of affinity for the NVC dune slack communities amongst the turlough vegetation communities. Dune slacks and turloughs, however, share many environmental characteristics, which have lead to the formation of similar vegetation types. The dune slack communities mentioned occur in areas with high winter rainfall, and the water table is not far from the surface, resulting in localised winter flooding, and a damp substrate during the summer. Leaching from the sandy soils results in a relatively oligotrophic habitat. Gleying of the soils occurs in dune slacks as in turloughs (Ranwell, 1959), and dune slacks are often formed on calcareous substrates developed from shell sand. The similarities between some turlough vegetation communities and sand dune communities are referenced by Ivimey-Cook and Proctor (1966) and by Proctor (2010), but only in passing.

The use of MAVIS to calculate affinity of the vegetation types defined in this study with those of the NVC was of mixed use. The top goodness-of-fit scores ranged from 33.98% for Group 28 and MC10b to 65.89% for Group 15 and MG11. The former indicates a poor correlation between the communities, while the latter is a good fit; the discrepancies in these scores suggest that care must be taken when relying on these data.

Woodland Communities

Woodland communities were not specifically investigated in this study. Murphy (2008) examined woodland surrounding a small number of turloughs and delimited two woodland communities, based on canopy species and ground flora. The *Fraxinus-Filipendula* woodland was dominated by a canopy of *Fraxinus excelsior* with *Crataegus monogyna*, and a varied ground flora of mainly typical wet woodland herbs. The *Crataegus-Stellaria media* woodland was strongly dominated by *Crataegus monogyna*, with *Rhamnus cathartica* and few other species, the ground flora was diverse but dominated by the annual *Stellaria media*. While we regard these classifications as provisional as much more extensive sampling is needed, the *Crataegus-Stellaria media* woodland appears to be very distinct from other wet woodlands in Ireland and possibly of considerable conservation importance due to its very restricted distribution. Further, more detailed studies of turlough woodland structure and ecology are urgently needed.

7.6.1.3 Variation Between Sites

While much of the variation in turlough plant communities is due to hydrological regime, other factors such as soil type, nutrient status and management are also important drivers of variation in vegetation. There is, therefore, much variability between turloughs, as well as within turloughs. Some vegetation types only occur on certain substrates, for example the flooded pavement community occurs on exposed limestone pavement, and is therefore restricted in its range. Similarly, communities such as the *Potamogeton natans-Glyceria fluitans* community can only occur where there is permanent water throughout the year.

7.6.2 Mapped Communities

It was not always possible to map the communities described from the detailed analysis of the releve data; the mapped communities therefore differe somewhat from those described purely from releve data. Reasons for this are mainly centred around practical applications in the field: some communities were too small in extent to be mapped, others showed considerebale intergradation, and others proved very difficult to separate in the field. The techniques of cluster analysis and ordination used, while becoming standard methods for the analysis of plant community data, do not always represent ecologically pramatic solutions as a basis for mapping vegetation units.

The vegetation communities mapped show both differences and similarities with vegetation previously mapped by Goodwillie (1992), these are described in detail below (RG refers to maps produced by Goodwillie, 1992).

Ardkill

Soils

Two soil types were mapped here, *Very shallow poorly drained organic* and *Fen Peat*, the flatter area to the north east is fen peat.

Extent

The turlough as mapped by TCD extends further into the surrounding farmland than noted by RG.

Vegetation

When we visited, this turlough was heavily poached in the north west sector.

The area of Wet Annuals/temporary pond in the bottom of the basin is similar in both maps. The extent of the *P. amphibium* community is also similar in both maps. However, no woodland was recorded on the RG map; there was woodland recorded on our map, but this occurred outside RG boundaries.

At the north eastern end, which is heavily grazed by cattle, our map map shows *Potentilla anserina-Glyceria fluitans* while RG has mapped Tall Herb; this could be a change in vegetation effected by management change? Also, while RG mapped Poor Grassland grading down into *P. reptans* Species Rich, our map has a greater extent of our equivalent to his Poor Grassland which transitions into *Potentilla anserina-Glyceria fluitans* (RG = Wet Annuals). This area has very patchy vegetation; the natural topographic variation may also affect community determination. RG mapped an area of Open Water, when we mapped this area it was generally surrounded by *P. amphibium*, which transitioned into standing water over mud and exposed areas of mud.

In the mid northern upper zone, our map shows *Potentilla anserina-Glyceria fluitans* around poached areas. RG has *P. reptans* species-rich and species-poor, and Sedge Heath to the north. Our map shows ruderals where there is intense poaching, and then transitions to *A. stolonifera-P. anserina-F.rubra* (= poor grassland of RG) and *Lolium* grassland – a change possibly due to an increase in grazing intensity, with accompanying enrichment either through dunging or other inputs.

In the centre to the east of the hill, the area of Tall Herb has increased in our map when compared to the RG map. There has been no grazing there for 5 years according to local information. Also, in the south, RG has Sedge Heath and Poor Grassland where we mapped

Tall Herb. There is limited grazing here, probably very light. The Tall Herb community could have developed from a variety of other communities. Mowing was evident in the extreme south west. In the south, there is a ditch dug out, which is now covered with brambles and hedgerow species.

In the north central area there is heavy grazing, and there is much *Iris pseudacorus*. RG mapped *P. reptans* SR, whereas our map shows *A. stolonifera-P. anserina-F. rubra* (= Poor Grassland) transitioning to *Potentilla anserina-Glyceria fluitans* (=Wet Annuals). RG also has a narrower band of Poor Grassland, which seems to have expanded in the TCD map. The change from *P. reptans* to Wet Annuals may possibly based on hydrological change, perhaps because of previous intense grazing followed by recovery.

RG mapped Reedbed slightly to the south east of the centre – this was recorded by TCD as an area of Peaty Pond. This could indicate a decrease in *Schoenoplectus*, although it could be difficult to separate RG's Peaty Pond and Reedbed – our scheme has Reedbed as more closed vegetation, dominated by stands of tall reedy species such as *Schoenoplectus*.

Summary

This turlough is larger in extent than previously mapped; there is a correspondingly larger area of grassland. There appear to be some differences in the extent and composition of the more aquatic vegetation types in the lower zones, which may be linked to hydrology. Heavy grazing and the accompanying poaching also seem to have effected changes in the vegetation. Conversely, some areas seem to have reduced amounts of grazing, resulting in increased coverage of the Tall Herb vegetation type.

Ballinderreen

Soils

There were a number of different soil types mapped: *Very shallow poorly drained organic, Very shallow well drained organic, Fen Peat, Deep well drained mineral*. The majority of the turlough was *Very shallow poorly drained organic*, with a large part of the central basin *Very shallow well drained organic*, and some Fen Peat in the southern basin.

Extent

The turlough as mapped by TCD extends beyond the RG boundary. There is also a section in the east which was mapped as turlough by RG but was not flooded during our survey.

Vegetation

In both maps, there are large areas of *Schoenus* Fen and of *Eleocharis palustris-Ranunculus flammula* (RG=Marl Pond); these areas are largely in agreement between the two maps.

RG recorded *Potentilla fruticosa/Frangula* woodland in the north central area, whereas we mapped flooded pavement with scrub. RG recorded no woodland in the far south, whereas we recorded some (relatively mature) woodland. This seems to have been missed by RG as it is unlikely to be Marl Pond in this location, and the OS 6" maps suggest woodland near to the boundary.

In the south-west of south basin RG recorded Tall Herb grading into Poor Grassland, while TCD has recorded *Lolium* grassland – this could be evidence of grazing pressure or improvement. In the north-west of the north basin, RG recorded Poor Grassland while TCD recorded *Potentilla anserina-Carex nigra* and *Carex nigra-Carex panicea* communites; this may be due to an increase in flooding.

Summary

Ballindereen turlough has a greater extent than mapped by RG. There are larger areas of grassland and woodland in the turlough, largely as a result of this. The areas of *Schoenus* Fen and *Eleocharis palustris-Ranunculus flammula* (RG=Marl Pond) mapped in both surveys are very similar in extent and position. There is some evidence of change due to increased grazing (Tall herb and Poor Grassland now mapped as *Lolium* grassland), and possibly hydrological change.

Blackrock

Soils

The main part of the central basin is *Shallow poorly drained mineral*, with a patch of *Shallow well drained mineral* to the south*.* The majority of the edges of the basin is *Very shallow well drained mineral*, with some small patches of *Shallow well drained mineral* .

Extent

The turlough extends beyond the RG boundaries to all sides, fairly extensively to the north.

Vegetation

Areas of Dry *C. nigra* from the RG map correspond well with *Shallow poorly drained mineral* soil type. Our map shows *Potentilla anserina-P. reptans* (RG=*P. reptans* Species Poor), but there are patches dominated by *C. nigra*, creating a mosaic dominated by *Potentilla anserina-P. reptans*. These communities can be fairly similar, and the differences may be due to different interpretations of the vegetation, but perhaps the proportion of *P. reptans* has increased – this may indicate increased nutrient levels.

In the south west RG has mapped lots of *Lolium* grassland, whereas the TCD map shows obvious transition to *A. stolonifera-P. anserina-F.rubra* (= Poor Grassland) from enriched areas above. This may be as a result of a change in grazing intensity.

The extreme south is very difficult to map; it is very poached, hard to determine vegetation type, there are lots of changes over short distances. RG has mapped Peaty Pond and *Wet C. nigra*, whereas our map shows *Agrostis stolonifera-Ranunculus repens*, ruderals, *C. nigra-Ranunculus fammula*. There seems to be an increased grazing effect, with a large number of ruderal species. There is a narrow channel that seems too low within the basin for the *Lolium* grassland as mapped by RG – possibly mismapped by RG. A deep depression is obvious on the contour map.

On the *A. stolonifera-P. anserina-F.rubra* lower tongue, there is a slight ridge which extends a bit further east, with some scrubby vegetation. RG mapped this ridge as *Lolium* grassland – this is either a vegetation change from grassland to scrub, or again mismapped.

To the north of the centre, we mapped a rather large area of *Poa annua-Plantago major* (RG=Dry Ruderals). This area was mapped by RG as Limestone Grassland. This region is fairly poached, so this is possibly due to grazing pressure; livestock may have selectively grazed the Limestone Grassland. The areas are very similar on the RG and TCD maps, but now have a very different community to that mapped by RG – these communities are very distinct and unlikely to be misinterpretted.

RG mapped *Lolium* grassland down to the stream towards the north, whereas TCD mapped *P. anserina-P. reptans* (RG=*P. reptans* SP) with some patches of *Filipendula ulmaris-P. erecta-Viola* sp. (RG=*P. reptans* SR) – this might have been mismapped by RG as the area appears to be far too deep within the turlough to support *Lolium* grassland. Another explanation is that Goodwillie encountered recently sown *Lolium*, which has not persisted and reverted the the *P. anserina-P. reptans* community.

There is woodland on the steep slope to the south east. RG mapped one block of woodland on the slope at the boundary, while TCD mapped this going further north east, and also to the south west of this. A line of dead scrub was visible at the bottom end during our survey; possibly the woodland mapped by RG has retreated upslope to areas he thought outside the turlough boundary, possibly due to increased flooding.

Eleocharis acicularis was recorded on our map, some following along the stream along with *Limosella aquatica*, other ruderals and *Rorippa amphibia.* This was recorded in a slightly different location to RG, possibly due to water levels, time of visit etc. RG has this further to the south west, where it was also found during our survey, but was considered too small an area to map. This community may shift about depending on the flooding regime each season.

A patch of Limestone Grassland in the north area mapped by RG is now Dry Ruderals on the TCD map – this is an obvious change, probably due to grazing effects.

Summary

There is a considerable increase in the extent of the turlough when compared to the RG map; and as a result more woodland and grassland is considered part of the turlough vegetation. It is possible that hydrological variation in Blackrock over several years may be influencing vegetation patterns, this is a very 'flashy', deep turlough through which very large volumes of water pass (*Chapter 3: Hydrology*). There appear to be some obvious changes in limestone grassland and ruderal communities, likely due to localised changes in grazing pressure.

Brierfield

Soils

The majority of the basin consists of *Marl with peaty topsoil*.

Extent

The RG boundary agrees fairly well with our boundary; the turlough extends a little further on the western side, and up towards the north.

Vegetation

The large areas of *Carex nigra-Ranunculus flammula* and Peaty *C. nigra* mapped by RG in the southern end of the basin match up well in both maps. Also in the south, RG recorded Tall Herb, while the TCD map shows *Carex nigra-Carex panicea* (RG=Sedge Heath), much *Juncus* was recorded here. In the south-west, RG recorded Peaty *C. nigra* and Poor Grassland, while the TCD map shows Tall Herb. In the south east of the basin there is a stretch of grassy *P. amphibium*, with lots of *Phalaris arundinacea*. One of the Peaty *C. nigra* fields (to the south of the turlough, third from far west) was noted as mown when visited in 2008.

RG has an *Oenanthe aquatica* community mapped in the north east – this was recorded by ourselves, but mapped as *P. amphibium*. In the north centre of the basin, there is a large stand of *Equisetum fluviatile*. RG recorded this as the *P. amphibium* community. To the north west, RG mapped *P. amphibium*, whereas the TCD map has more *Carex nigra-Ranunculus flammula* and *Potentilla anserina-C. nigra* (RG=Peaty and Wet *C. nigra)*. There is a crannog with relatively tall specimens of *Salix*, and another further north but these patches were too small to map. RG may not have recorded the *Salix* if it was much smaller 20 years ago.

In the centre west, RG mapped Peaty Grassland; our map has *Potentilla anserina-C. nigra* and *A. stolonifera-P. anserina-F.rubra* (= poor grassland of RG). There are a number of drainage channels which traverse the basin; they seem to be periodically cleared (clearance was noted in 2009). RG mentions little grazing.

Summary

Overall, there is a fair amount of agreement between the maps. The vegetation seems to suggest that the turlough is now damper in the central area, but perhaps drier in the north west. The turlough seems to retain water until late in the season.

Caherglassan

Soils

The central area of the basin is comprised of *Mineral alluvium* and *Shallow poorly drained mineral*, with the edges consisting of *Very shallow poorly drained mineral* and some small patches of *Mineral alluvium* .

Extent

The turlough extends beyond the boundaries mapped by RG on almost all sides, quite considerably on the south east end.

Vegetation

RG has *P. reptans* Species Rich (our *Filipendula ulmaris-P. erecta-Viola* sp) dominating most of the basin, while TCD has *Potentilla anserina-P. reptans* (RG= *P. reptans* SP). The areas of *Eleocharis acicularis* match up fairly well.

Woodland matches in the central part of the turlough, but in the north and south the TCD map has more woodland patches, often defined by field boundaries. This is only evident to the north and north east in RG's maps. This woodland is mostly *Crataegus*, with a little *Rhamnus* and some *Fraxinus*. There seems to have been recent scrub development in fields with little grazing. The woodland understorey on the northern side has little ground vegetation due to grazing. Understorey vegetation consists primarily of *Stellaria media* and other ruderals likely introduced by grazing animals. This is probably a management issue which will affect the woodland vegetation here. *Thalictrum flavum* was found here. Where RG recorded Limestone Grassland to the north, TCD has mapped woodland and *Potentilla anserina-Carex nigra* (RG=Wet *C. nigra*).

To the south east, we mapped ridges with grassland, but RG has *P. reptans* SP. RG mapped a field full of Dry Ruderals in the south centre – in our map this is *Potentilla anserina-Carex nigra* and suggests that damage caused by poaching has recovered as these two communities are very unlikely to be misidentified for each other. In the southern central region of the turlough basin, RG has mapped a large area as *Lolium* grassland, while the TCD map shows a smaller patch, of *Filipendula ulmaris-P. erecta-Viola* sp. (RG=*P. reptans* SR).

Summary

There is broad similarity between the maps, apart from some scrub/woodland encroachment. There is some evidence of some local recovery from overgrazing (see ruderals mentioned above), even though the turlough is fairly well grazed in general. Our greater extent of woodland may also reflect local (field scale) changes in management. On the north side, there is grazing on the edge of the woodland, perhaps preventing regeneration/encroachment of the woodland.

Caranavoodaun

Soils

The main basin is *Fen Peat*, with *Very shallow well drained organic* on higher ground around the edges. There are some small patches of *Marl with peaty topsoil* surrounding the fen peat in the east.

Extent

The turlough extends considerably beyond the boundaries mapped by RG.

Vegetation

There is woodland encroachment evident around the majority of the boundary in the south, east and west. *P. reptans* SP (our *Potentilla anserina-P. reptans*) was recorded by RG in the south, but not found here by ourselves.

Our map shows more *Eleocharis palustris-Ranunculus flammula* (=Marl Pond) than the RG map – our definition of this 'Marl Pond' community may however be broader than RG's. There seems to be a reduced amount of Sedge Fen in favour of *Eleocharis palustris-Ranunculus flammula*.

We recorded more Flooded Pavement that RG, but this may correspond with the *Potentilla/Frangula* woodland of RG's map, who mapped much less Flooded Pavement.

The TCD map shows Limestone Grassland to the north east on a raised area, while RG recorded this as Sedge Fen (our *Molinia-Carex panicea*) – possibly mismapped by RG. The RG map shows Tall Herb to the north west, while the TCD map has recorded scrubby Limestone Grassland and *Molinia-Carex panicea*.

There are small seemingly permanent pools containing *Potamogeton*; while one of these was mapped by RG there are further small pools at one point to the west of the lower central lobe that were not mapped by RG, but were mapped by ourselves.

RG recorded a large area of *Schoenus* Fen in the eastern end, only a small patch was mapped by orselves; there is a patch of *P. reptans* SP (our *Potentilla anserina-P. reptans*) recorded by RG in the south west end that we did not find.

Summary

Overall, the vegetation suggests that the turlough now remains wetter for longer in the centre, as described by a shift towards more aquatic vegetation in the middle of the basin. Scrub encroachment into the turlough suggests decreased grazing.

Some damage (poaching) was recorded near the gate to the south, and in the north near to the wet are on the south side of the western tongue.

Carrowreagh

Soils

The soils are *Shallow poorly drained mineral* in the southern and north western ends, with the remainder *Very shallow poorly drained mineral*.

Extent

The extents match quite closely, although the TCD map extends slightly beyond the RG boundary in some places, and does not quite reach the end of the far south eastern arm as mapped by RG.

Vegetation

Note: the two white areas in the RG map are limestone grassland. In the south east arm RG mapped lots of Tall Herb, while we mapped very different communities which include some Tall Herb (but this area was difficult to define, many different vegetation types).

We recorded *Carex nigra-C. panicea* (RG=Sedge Heath), *Carex nigra-Ranunculus flammula* (RG=Peaty *C. nigra*), *P. anserina-C. nigra* (RG=Wet *C. nigra*) and towards the centre of the basin *A. stolonifera-P. anserina-F.rubra* (= Poor Grassland).

RG mapped a patch of Dry Ruderals near the road, we recorded this obvious area as *A. stolonifera-P. anserina-F.rubra* grading into *P. anserina-C. nigra*, again suggesting that vegetation can recover from the overgrazed/trampled annual-ruderal community. Some of the other patches of ruderals match up between maps. One patch of ruderals recorded by RG was recorded as a small pool by us; this may have been the result of extreme poaching.

In the west of the basin, both maps show Sedge Heath and Peaty Grassland (our *Carex nigra-C. panicea*). RG has Limestone Grassland where we recorded *A. stolonifera-P. anserina-F.rubra* (= Poor Grassland). There seems to be a septic tank input from the buildings.

Summary

The vegetation in this turlough seems quite changed from that recorded by RG. The turlough seems to remain wetter than before in the eastern area. There has probably been a change in grazing in the western end, perhaps as a consequence of a change in hydrology, the spread of *A. stolonifera-P. anserina-F. rubra* (= Poor Grassland) may be caused by heavy grazing here by sheep and cattle; the Limestone Grassland recorded by RG has gone. The turlough is potentially affected by drainage, and increasing nutrient input; point source input seems important here.

Coolcam

Soils

The majority of the basin is Mineral alluvium, with some patches of *Marl alluvium*, *Shallow poorly drained mineral*, *Predominantly shallow soils derived from calcareous rock or gravels with/without peaty surface horizon* and *Lacustrine-type soils*.

Extent

The contour map was not completed for this turlough; the TCD map therefore remains within the boundaries mapped by RG.

Vegetation

Note: the white areas on the RG map are *Oenanthe aquatica*

RG has mapped a large expanse of his *Oenanthe aquatica* community in the centre of the turlough, which we recorded as *P. amphibium*. This is a difficult area to get to in the field, RG used aerial photos. There is lower confidence for community identification and boundaries for the central areas as mapped by TCD, as aerial photos were also used. A landowner reported to us that it used to dry out completely, but hasn't done so in the last ten years. We recorded lots of *P. amphibium* and *Sparganium*, but little *Oenanthe aquatica*.

In the south eastern sector, areas are maped similarly but with very different communities. RG recorded Wet *C. nigra* (our *Potentilla anserina-C. nigra*) while the our maps show *P. amphibium* (with a lot of *Phalaris*), also some Tall Herb and of *A. stolonifera-P. anserina-F.rubra* (RG= Poor Grassland). RG has other areas of Wet *C. nigra* in the centre that were not found by the TCD survey. RG mapped larger areas of Marl Pond, which were mapped by TCD as Open Water/*P. amphibium*.

On the western margin, we mapped *Lolium* grassland and *Carex nigra-C. panicea*, whereas RG had Wet *C. nigra* and *P. amphibium*.

Summary

There seems to be less fluctuation in water level than previously – the vegetation suggests that the turlough has become wetter for longer in the middle, and perhaps drier at the edges.

Croaghill

Soils

The majority of the soil in the basin is Fen Peat, with some small patches of *Shallow well drained mineral, Very shallow poorly drained organic* and *Cutaway/cutover peat.*

Extent

The extents largely agree, although the TCD map falls short of the RG boundary in some parts, and extends beyond it in others.

Vegetation

Note: white patches in the RG map are *Oenanthe aquatica*

RG has mapped large areas of the *Oenanthe aquatica* community, which falls into our *P. amphibium* community.

RG's Peaty Pond in the south of the turlough is largely gone. There is a permanent pond in the south, but TCD has mapped *Potentilla anserina-C. nigra* grading into *Carex nigra-C. panicea*. RG has mapped *P. reptans* SP in the south, which we found to be largely replaced *P. amphibium* instead – these two communities are very different and unlikley to be misidentified for each other.

The vegetation mapped by TCD as Tall Herb in the centre is very variable, with a peaty influence; there is some *Salix* sp. here. RG has the same – perhaps more extreme. In our map this is surrounded by *Carex nigra-Ranunculus flammula* (RG=Peaty *C. nigra*) and *Potentilla anserina-P. reptans* (RG=*P. reptans* SP). RG has Peaty *C. nigra* and more *P. reptans* SP.

In the northern end of the basin, TCD has mapped Tall Herb around a grassy *P. amphibium* scraw, which surrounds permanent water. RG has Peaty Pond – this could be a difference in interpretation. Also to the north, RG mapped Wet *C. nigra* – our map shows *Carex nigra-C. panicea* which grades into *Carex nigra-Ranunculus flammula* as the depth of the turlough increases. There is very heavy grazing in the NE end of the turlough, with a lot of poaching.

In the western end, RG recorded Grassy *P. amphibium*, whereas TCD mapped *P. amphibium* surrounded by *Carex nigra-Ranunculus flammula*. Further to the east, RG has *P. amphibium* surrounding *Lolium* grassland – in the TCD map there is much less of each, with different boundaries.

Summary

There are some differences in community interpretation. Some apparent mismapping by RG, for example he has mapped a Peaty Pond on a small ridge in the south centre of the basin. There have been some subtle shifts in communities – possibly related to water drainage patterns. Our map has much less Peaty Pond than the RG map. As with Coolcam, with which Croaghill is hydrologically linked (see *Chapter 3: Hydrology*), the vegetation suggests that Croaghill may have become wetter, perhaps with longer duration flooding, that at the time of Goodwillie's (1992) survey.

Garryland

Soils

In the bottom of the basin, soils are *Very shallow poorly drained organic*, with *Shallow poorly drained mineral* around the edges. There are two patches of *Deep poorly drained mineral*.

Extent

The contour map was not completed for this turlough; our map therefore remains within the boundaries mapped by RG.

Vegetation

There is intensive grazing throughout this turlough by sheep and cattle.

Our survey recorded wet mud in the south east arm, which will possibly develop later in the season to *Eleocharis acicularis* as mapped by RG. We recorded *E. acicularis* along the margins of the stream, but these areas were too small to map. We did not find the large patches of *Eleocharis acicularis* mapped by RG in the northern part of the basin, this community now seems to be restricted to stream margins in Garryland. RG has mapped dry woodland in the south west arm to the south west extremity – our map has open rock on the west and southwest, with no trees. The trees are further back in from the turlough, this community would perhaps be *Agrostis stolonifera-Ranunculus repens* if no rocks. This may be evidence of loss of woodland, or mismapped margins; it is unlikely that woodland would be abutting the *E. acicularis* community.

On the eastern side, the hedgerow has expanded, giving scrub and woodland in our map where RG recorded Sedge Heath and *P. reptans* SP. Our map shows more extensive *Agrostis stolonifera-Ranunculus repens* (RG=Dry *C. nigra*) than the RG map, especially in the south west arm. Our map shows *Filipendula-P. erecta-Viola* (RG= *P. reptans* SR), where RG has *P. reptans* SP (our *P. anserina-P. reptans*), but there are fine scale differences in extent.

RG recorded Tall Herb in the north and parts of the south west, whereas our map shows none. Some small patches of Tall Herb vegetation were recorded amongst large rocks and boulders in this area, but not a sufficiently large patch to map; this may be indicative of increased grazing

The woodland mapped by RG in the south western end no longer there – this area and along the north western end had large boulders and a *C. nigra* community in between. This may be a loss of woodland or a mismapped margin (probably mismapping).

Summary

RG's woodland to the SW seems to be mismapped. There is woodland/scrub expansion on the eastern side. In general, the maps are broadly similar. RG mapped a far great extent of *E acicularis* than TCD.

Kilglassan

Soils

The majority of the basin is *Fen Peat*, with some *Very shallow well drained organic* around the periphery.

Extent

RG's boundary extends beyond that which we consider a turlough, encompassing Peaty Grassland (we recorded rushy vegetation here). Our boundary exceeds the RG boundary in the north west.

Vegetation

The area of Wet *C. nigra* (our *Potentilla anserina-C. nigra*) seems to correspond quite well between RG and TCD maps in the north and the south.

Our map shows *P. amphibium* in the centre of the turlough, whereas RG recorded Grassy *P. amphibium*; this may be due to a difference in interpretation of the vegetation types. RG recorded *P. reptans* SR (our *Filipendula-P. erecta-Viola*) in fair amount in the south, grading into Wet *C. nigra* (our *Potentilla anserina-C. nigra*) Our map shows less *P. reptans* SR and Dry *C. nigra*. We mapped small hollows in the south as *Agrostis stolonifera-Ranunculus repens* (RG=Dry *C. nigra*), these may have been overlooked by RG. The RG map does not show a wetter area just south of the centre in the northern basin, as mapped by TCD.

RG recorded temporary pond, while the TCD map shows *P. amphibium* – these vegetation types are likely to be similar, different interpretations of the same community.

Our map has a patch of *C. nigra-Ranunculus flammula* (RG=Peaty *C. nigra*) to the north of the main basin; RG mapped this area as Wet *C. nigra*.

Summary

Overall there seems to be a fairly good match between the maps. There are minor differences, probably in interpretation or classification of the vegetation. Some fine scale features affecting a change in the vegetation may have been missed by RG.

Knockaunroe

Soils

The majority of the soils are *Peat Marl*, with some patches of *Very shallow poorly drained organic*.

Extent

The turlough extends considerably beyond the boundary mapped by RG.

Vegetation

Note: the white areas on RG's map are Tall Sedge

The TCD map covers a much larger area, but within the RG boundary, seems quite similar. There are large areas of Marl Pond, with patches of Sedge Fen, on both maps. The areas of Flooded Pavement correspond between the two maps. RG mapped a large patch of *Schoenus* Fen which was not recorded by TCD. RG mapped Sedge Fen and *Schoenus* Fen to the east, but our map shows flooded pavement. We recorded a larger expanse of Reedbed in the central area than in the RG maps.

On the north side there is very dense *Potentilla fruticosa* scrub.

There is evidence of woodland clearing from western protrusion between 2000 and 2005 aerial photos. This has been replaced by *Lolium* grassland. Mark Murphy noted some rubble tipping towards the western end in 2008.

Summary

There is generally broad agreement between the maps.

Lisduff

Soils

The soils are mostly *Fen Peat*, with some *Very shallow poorly drained organic* around the very edges.

Extent

The boundaries agree quite well, but there is a large arm to the north west which has been mapped as turlough by RG but is not flooded. The turlough also extends a little beyond RG's boundary in the north.

Vegetation

Our map has much more *Eleocharis palustris-Ranunculus flammula* (RG=Marl Pond, this includes much of the area marked by RG as Wet *C. nigra* and Sedge Fen. Our map also has more *Molinia-Carex panicea* (RG=Sedge Fen), whereas in the RG map this is recorded as Wet *C. nigra*. Our survey found lots of intergradations between *Eleocharis palustris-Ranunculus flammula* and *Molinia-Carex panicea*.

RG recorded *P. amphibium* to the east, but this was not found by TCD, although some isolated patches were found in sink holes too small to map. RG mapped extensive Sedge Heath (our *Carex nigra-C. panicea*) at the east and west, whereas we found very little, although our map does show some in the south, where RG mapped Poor Grassland.

The central area was largely ungrazed at the time of the our survey. A new fence has been erected; this will affect grazing patterns in the future. Cattle come into the turlough from the eastern side. There is a machinery storage area on the south side of the north west arm, where trucks, JCBs etc. seem to be held.

There is evidence of nutrient enrichment in the south east arm, *P. amphibium* communities (as seen by RG), and lots of *Agrostis stolonifera*. RG mapped Dry Ruderals in the south west in the channel there, whereas our map shows *Eleocharis palustris-Phalaris arundiacea*.

Summary

The TCD map is dominated by *Eleocharis palustris-Ranunculus flammula* and *Molinia-Carex panicea* (RG=Sedge Fen and Marl Pond), whereas the RG map is dominated by sedges; this may reflect slight differences in community interpretation or intergradation. The maps are however relatively different, potentially due to changes in hydrology and/or nutrient enrichment. Many of the communities here seem transitional and difficult to assign.

Lough Aleenaun

Soils

There is *Marl with peaty topsoil* in the centre of the basin, surrounded by *Very shallow poorly drained organic* with *Very shallow well drained organic* along the margins.

Extent

The turlough extends beyond RG's boundary in the south and north east, but does not quite meet the RG boundary in the north west.

Vegetation

This turlough experiences a lot of natural disturbance (it is the flashiest turlough in the study), coupled with some kind of eutrophication: it has high soil total N, and also has high soil TP. There is also physical damage from overgrazing, so some direct fertilizer input is possible, or a possible point source input.

The RG map shows the basin dominated by Wet *C. nigra* (our *Potentilla anserina-C. nigra*) whereas the TCD maps show *Agrostis stolonifera-Glyceria* (RG=Wet Annuals) in place of the *C. nigra*. (RG's description of the Wet *C. nigra*, however mentions lots of poaching and ruderal species such as *Rumex* spp., *Polygonum persicaria* and abundant *Agrostis stolonifera*, which may be enough to place this vegetation type into our *Poa annua–Plantago major* community). The *Agrostis stolonifera-Glyceria* community recorded here was very variable, with some grassy patches, some *Rumex* spp., some *Ranunculus trichophyllus*. Much *Glyceria fluitans* was recorded in the western part. The western part is wetter, apart from the central channels. Our map has exposed mud, with some *Eleocharis acicularis,* which occurred in stands too small to map, in the central channel.

RG suggests evidence of clearance of boulders etc. We found evidence of scrub encroachment, perhaps from pavement and Limestone Grassland. RG has recorded *Lolium* grassland to the south, this is mostly gone in our map; this is probably an area that was seeded with *Lolium* but has failed to persist.

Summary

The vegetation in this turlough appears to have changed greatly between the two maps, RG's description of the Wet *C. nigra* community he recorded, however, suggests that this very wet, ruderal-rich community may have been a good fit with our *Agrostis stolonifera-Glyceria*, as mapped. The areas of grassland around the periphery of the turlough seem to have shrunk somewhat, possibly due to a change in hydrological regime. There is also some woodland encroachment.

Rathnalulleagh

Soils

The bottom of the basin is mainly *Shallow poorly drained mineral*, with some *Shallow well drained mineral* around the periphery. There are also small pockets of *Very shallow well drained mineral*.

Extent

The extents match fairly well, although the turlough exceeds RG's boundary somewhat in the south west, north west and north. The northwestern arm of the turlough is shifted slightly to the west, when compared with RG's map.

Vegetation

The basin is dominated by *P. reptans* species rich (=our *Filipendua-Potentilla erecta-Viola* community) in both cases, but with large patches of Dry *C. nigra* (= our *Agrostis stolonifera-Ranunculus repens*) in the RG map not found by our survey. Some Dry Ruderals were recorded along the drains but not mapped as the area was too small. Our map has a block of Tall Herb, a single ungrazed field; RG has Tall Herb further to the north. This is most likely a grazing issue.

We mapped *Carex nigra-C. panicea* (RG=Sedge Heath) to the west (with a relatively large proportion of rushes, *Iris* and *Filipendula*) but between these larger species the community seemed to be *Carex nigra-C. panicea*. RG mapped Poor Grassland and Peaty Grassland, which we did not map. Our map shows lots of *Lolium* Grassland, which has apparently increased at the north-west of the turlough. RG has a patch of Poor Grassland in part of the north centre which was not found by TCD.

The north eastern arm as mapped by ourselves seems different to the RG map, our map shows *Lolium* grassland and *Agrostis-Potantilla anserina-F. rubra* (RG=Poor Grassland), (there are stands of *Iris* here too), while RG has mapped *P. reptans* SR and a small patch of Wet Annuals.

RG mapped the edges as Poor Grassland, we mapped them as *Lolium* grassland, this may be evidence of improvement. The Peaty Grassland section (as mapped by RG) was found to be very rushy, had some *Iris, Filipendula*, with *Carex nigra-C. panicea* community in between the stands

Summary

There is broad agreement between the maps, although the vegetation around the periphery seems to have changed. Large areas of Dry *C. nigra* mapped by RG were not found by ouselves. There is evidence of improvement, through grazing or management.

Skealoghan

Soils

Broadly speaking, the northern half of the turlough is *Fen Peat*, while the southern part is *Very shallow well drained organic*.

Extent

The turlough extends beyond RG's boundary, although the western arm seems slightly shifted south compared to our map. There is an area of non-turlough grassland in the south east that extends into RG's boundary.

Vegetation

The southern end of the RG map has Dry *C. nigra* (our *Agrostis stolonifera-Ranunculus repens* community) this area was mapped as *Potentilla anserina-Carex nigra* (RG=Wet *C. nigra*) by ourselves.

The Reedbed mapped by both seem similar, our Reedbed has perhaps been mapped more accurately with the benefit of GPS. RG recorded far more Sedge Fen, whereas we mapped more *Potentilla anserina-Carex nigra*. The areas of Peaty Pond (= our *Equisetum fluviatle* communities) match up fairly well.

RG recorded much *P. amphibium* to the south of the raised area; we mapped this as *Potentilla anserina-Carex nigra* (RG=Wet *C. nigra*). Our map shows *P. amphibium* to the western central area, whereas this was not recorded by RG. RG mapped Grassy *P. amphibium*, but the our map shows *Potentilla anserina-Carex nigra* to the north, with some *P. amphibium* towards the base.

RG recorded lots of Dry *C. nigra*, as has TCD (our *Agrostis stolonifera-Ranunculus repens* community). TCD and RG mapped the same area of Limestone Grassland, but there are some differences in boundaries between the two.

Summary

The differences in communities are mostly due to differences in interpretation. The change in the extent of *P. amphibium*, however, may indicate a change in hydrology.

Termon

Soils

The soils are mostly *Marl alluvium*, with some *Very shallow poorly drained organic* right along the edges.

Extent

The extents agree in general, although the turlough extends beyond RG's boundary in the north.

Vegetation

Note: the band of vegetation around the western arm in the RG map is Temporary Pond, and the orange section in the centre of the turlough is *Cladium* fen. *Cladium* Fen does not seem to be as extensive in TCD maps as in RG maps. The TCD map shows more Reedbed extending towards the northern edge of the turlough than RG map.

To the east, RG recorded Sedge Fen (our *Molinia-Carex panicea*), Wet *C. nigra* (*Potentilla anserina-Carex nigra)*, then at the extreme east Dry *C. nigra* (our *Agrostis stolonifera-Ranunculus repens* community) surrounding a small depression. We recorded *Eleocharis palustris-Ranunculus flammula* (Rg=Marl Pond) surrounding *P. amphibium* in a hollow, with some Wet Annuals; RG may have mismapped around the hollow or the hydrological regime may have changed.

There was much poaching in the central eastern part of the turlough.

There is a blank portion of the map marked by a question mark in the RG map – this was not accessible during the TCD survey, and based on aerial photographs has been mapped as Open Water.

There is a field boundary through the centre of the turlough; the south-east portion of the basin seems to have more varied communities, possibly a result of different land use.

Summary

This is a very wet turlough that seems to retain water for most of the year. The two maps are broadly in agreement, although there seems to have been some change in the eastern area, possibly due to a change in hydrology.

Turloughmore

Soils

Soils in this turlough are mainly *Shallow poorly drained mineral*, with a patch of *Very shallow well drained organic in* the very south and another in the centre. There is also an area of *Lacustrine-type soils* in the north.

Extent

This turlough is considerably larger than mapped by RG.

Vegetation

This turlough is heavily grazed by sheep and cattle. The vegetation consists mainly of *Lolium* grassland and *Agrostis-Potantilla anserina-F. rubra* (RG=Poor Grassland). Our map shows some Limestone Grassland near the hummock just north of the centre (*Filipendula vulgaris* was found here). There are mown areas in the centre, mainly wet grassy fields. No Dry *C. nigra* equivalent was found during our survey. There is a large area of ruderals to the north/centre/west, apparently a recent change.

Aerial photos show evidence of woodland clearing; woodland was obvious in the north corner of the turlough in the 2000 photos, while in the 2005 photos it was gone.

Some scrub occurs in the southern end of the basin, growing over what was recorded by RG as flooded pavement.

Summary

There seems to have been a gradual agricultural improvement of the site, lowering diversity.

General remarks on comparison between maps

There are broad areas of agreement between the maps produced here in section 7.5.2 and those produced by Goodwillie (1992). In some cases the areas of outlined vegetation match up very closely, this is remarkable given that our maps were produced using handheld GPS devices capable of either 1 m or 10 cm horizontal accuracy, whereas those of Goodwillie were produced by consideration of aerial photographs and field estimation. Nevertheless, there are several impotant differences in the two sets of maps, and several factors are likely responsible for these:

- Differences in mapping approach (see above) and mis-mapping
- Differences in interpretation of communities – our communities were based on multivariate analysis of a large number vegetation relevés, whereas those of Goodwillie were based on field observation and a limited number of relevés.
- Changes in vegetation over time; this has clearly happened for some communities which are very distinct are unlikely to have been confused .

The latter point is perhaps of most interest. There is for example evidence of shift in the ruderal communities that result from over grazing and particularly rampling by grazing animals. These ruderal communities, dominated by speces such as *Poa annua* and *Plantago major*, are readily identifiable. There is evidence of local shifts within several turloughs, likely reflecting different patterns of grazing, and of stock entry/exit from the grazing areas of turloughs. In some cases, there appears to be evidence that areas formerly dominated by this community could recover to other turlough communities; this hypothesis could be tested with further experimentation restricting grazing.

Woodland and scrub communites show different distributions over the two surveys in some turloughs. This may be partly a difference in interpretation, but it seems clear that in some turloughs the amount of woodland has declined over time. In others it has increased (e.g. Caherglassan), where the increase may be due to different patterns of grazing.

Some of the changes in vegetation suggest changes in nutrient input, with for example evidence of more eutrophic communities at Lough Aleenaun. For other turloughs, changes in communities suggest shifts in the hydrological regimes, with evidence of increased flooding freqeuncy and duration where, for example, *Polygonum amphibium* communities seem to have increased. In other turloughs, particularly at the margins, increases in *Lolium* grassland and related communites which are not tolerant of prolonged inundation may indicate reduced flood frequency and duration (see below), or agricultural improvement.

7.6.3 Vegetation Ecology – Relevé data

A wide range of hydrology, soil properties, hydrochemistry, and management regimes were found in the turloughs in this study. Many of the plant communities occurred in a range of turloughs with a variety of environmental conditions, thereby showing their adaptability to and tolerance of varied environmental and ecological factors. Other plant communities, however, such as those which were correctly classified by the Discriminant Analysis, were more restricted in their range, either due to a reliance on certain hydrological conditions, nutrient levels, or management, or a combination of factors.

7.6.3.1 Environmental Variables

Hydrology

The frequency of flood events for each vegetation community showed a large degree of variation (see Section 7.5.4.1). This demonstrates the dynamic nature of the turlough environment, and highlights the challenges this habitat presents for the plants which live there. The communities occurring around the fringes of the turlough basin, such as Group 10 *Lolium perenne-Trifolium repens* and Group 15 *Lolium perenne-Trifolium repens-Agrostis stolonifera* can experience a wide range of flooding frequency at shallower depths of flooding, but lmited variation at 50 cm flooding. These flood events are likely to be short in duration, given the overall short inundation period recorded for these communities. Communities which occur in the bottom of turlough basins, such as Group 14 Reedbed and Group 24 *Potamogeton natans-Glyceria fluitans* experience lower frequencies of flooding; but these flood events last longer, as evidenced by the greater mean duration of flooding found for these communities.

A number of communities experienced a wide range of duration of flooding, for example Group 18 *Agrostis stolonifera-Glyceria fluitans* had the greatest range, from 120 days to 547 days (see Section 7.5.4.1). This community contains species such as *Agrostis stolonifera*, which can tolerate a range of environmental conditions, and is found all along the flooding gradient. It may also be the case that flooded grassland is quickly colonised by opportunistic amphibious (or ruderal) species, so the long-term hydrological regime may not have a huge influence on the presence or absence of the community. The two *Lolium* grassland communities in Cluster 7, Group 10 *Lolium perenne-Trifolium repens* and Group 15 *Lolium perenne-Trifolium repens-Agrostis stolonifera*, were found to have the shortest mean durations of flooding. Group 10 had a mean duration of flooding of 107 days, while Group 15 had a longer mean duration of flooding, at 188 days. These communities can occur on the same soil types (Figure 7.72) and in the same turloughs (Section 7.5.1), so it is likely that duration of flooding affects plant community composition in this case. Group 10, which has species more typical of managed grasslands, experienced the least amount of inundation, while Group 15 experienced slightly longer inundation and has a greater proportion of ruderal species. Group 14 Reedbed and Group 24 *Potamogeton natans-Glyceria fluitans* had the longest mean durations of flooding, on the other hand, and these communities are very reliant on retaining water throughout the growing season, with obligate aquatic species such as *Potamogeton natans* and *Glyceria fluitans*.

A reduction in the duration of inundation may result in the loss of some species. A study investigating the effects of water extraction on a *Junco-Molinion* grassland found that *Parnassia palustris* and *Ophioglossum vulgatum* decreased in abundance following lowering of the water table (ter Braak & Wiertz, 1994). It is important to note that vegetation communities, within turloughs as in other wetlands, may not show an immediate response to changes in the hydrological regime; some species may exhibit inertia in response to changes in flooding pattern (Large *et al*., 2007). The hydrological regime of turloughs can vary widely from year to year, and it is likely be that long-term patterns of flooding rather than that of a single year or even two years (such as the hydrological data here), may structure the vegetation. Flooding can also affect vegetation communities through the influence it has on the recruitment of plant species. One study has found that the survival of tall forb seedlings is significantly decreased by inundation (Lenssen *et al*., 1998); while Crawford (2008) states that annual plant species are much underrepresented in wetland vegetation communities.

A wide range of mean maximum flooding depths was found. Vegetation communities usually associated with the fringes of the turlough basin were found to have the lowest mean maximum depth; Group 5 Limestone Grassland, Group 8 *Carex nigra-Carex panicea*, Group 10 *Lolium perenne-Trifolium repens*, Group 12 *Filipendula ulmaria-Vicia cracca* and Group 15 *Lolium perenne-Trifolium repens-Agrostis stolonifera* all had mean values for maximum depth of < 1.5m. Group 19 *Potentilla anserina-Potentilla reptans*, Group 20 *Filipendula ulmaria-Potentilla erecta-Viola* sp. and Group 26 *Eleocharis acicularis* were all associated with very high mean values for maximum quadrat depth. These communities were recorded only in Garryland and Blackrock turloughs, which are two of the deepest turloughs in this study. Floodwaters this deep may exert extra pressures on the plants which occur there; at c. 10 m deep, only very specialised plants can persist throughout the winter. Species such as *Potentilla reptans* and *Potentilla anserina* can tolerate these conditions by persisting throughout the flooded period as underground rhizomes; they are then able to grow rapidly on recession of the floodwaters, taking advantage of an initial lack of competition to become established before other species.

Many turloughs have more than one cycle of flooding and emptying, and plant communities experience a range of frequencies of flood events, as evidenced above. In order to give an indication of the timing of important flooding event, therefore, the beginning of the longest wet and longest dry periods were calculated for each relevé. The date of the start of the longest dry period showed a large degree of variation, even within different plant communites. As might be expected, communities occurring in the bottom of the turlough basin that experienced long durations of inundation had later dates for the start of the longest dry period than those occurring on the turlough periphery.

Soils

A wide range of soil nutrient concentrations were found in the turloughs in this study (see Section 7.5.4.2 and *Chapter 6: Soils and Landuse*). Mean total phosphorus concentration ranged from 245 mg kg^{-1} (Coolcam) to 1594 mg kg^{-1} (Lough Aleenaun). These two turloughs are visible as outliers in the boxplot for TP (Figure 7.32). Lough Aleenaun has previously been described as being heavily managed, with rock clearance and heavy grazing (Goodwillie, 1992); in this study, all land-parcels were designated as 'grazed'. This suggests that there may be nutrient enrichment from grazing livestock. Coolcam, on the other hand, is a very wet turlough and retains water throughout the summer, and while cattle have access to some areas, grazing may be limited. Coolcam turlough also had the lowest mean total nitrogen (4983 mg kg^{-1}), while Knockaunroe had the highest (24233 mg kg^{-1}).

No strong relationships between soil nutrients and turlough vegetation communities were found. In this study, however, the soil nutrient data used were single data points for each turlough, which were amalgamations of soil samples from the upper, middle and lower zones of the turlough basin. While this approach gives a broad indication of the soil nutrient status of a turlough, the highly heterogeneous nature of turlough soil means that point data, ideally related to the relevés, would be more useful, but were beyond the scope of this project.

A total of 13 different soil types were associated with the vegetation communities in this study. Some of the vegetation communities were recorded on only one soil type; Group 28 Flooded Pavement and Group 23 *Carex nigra-Leontodon autumnalis* were found only on Alluvium, Group 26 *Eleocharis acicularis* was recorded only on Poorly-drained Mineral, and Group 20 *Filipendula ulmaria-Potentilla erecta-Viola* sp. was recorded only on Well-drained Mineral. This suggests that these communities are restricted to these soil types.

Water chemistry

There was a large amount of variation in nutrient levels between turloughs in this study. Mean total phosphorus ranged from 4.0 to 82.1 μg l^{-1}. Four of the turloughs had mean TP concentrations indicating an oligotrophic status, 12 had mean TP values indicative of mesotrophic status, while six had mean TP levels indicating eutrophic status.

While nitrogen is often found to be the limiting nutrient in primary production in aquatic ecosystems, phosphorus is generally the limiting nutrient in terrestrial ecosystems (Smith *et al*., 1999). TP concentration in turlough floodwaters was found to be the limiting factor in phytoplankton biomass accumulation (Cunha Pereira *et al*., 2010) and the composition of phytoplankton (Cunha Pereira *et al*., 2011) and invertebrate communities (Porst & Irvine, 2009). In this study, however, which was concerned with mostly the terrestrial phase of turlough vegetation, TP seems to be a stronger driver of vegetation communities than TN – this is similar to findings reported in the literature recently (Williams *et al*., 2011).

Grazing

When relevés were assigned to 'grazed' or 'ungrazed' categories, based on their presence in land-parcels, four vegetation communities were found to occur only in ungrazed land-parcels. These communities were Group 14 Reedbed, Group 21 *Schoenus nigricans* fen, Group 23 *Carex nigra-Leontodon autumnalis* and Group 28 Flooded Pavemnt.

Grazing can exert pressures and affect plant community composition as outlined in the introduction. Grazing has also been found to be an important driver of turlough vegetation in previous studies (e.g. Ní Bhriain *et al.*, 2003). In this study, however, the level of grazing recorded at individual relevés was not as important as other variables, and did not have significant correlation with any of the ordination axes.

Recording grazing intensity in a relevé may not be the best way to estimate grazing intensity over the growing season. Rotational grazing of cattle can mean that vegetation is grazed intensively for a number of days before the vegetation is allowed to recover for a number of weeks. The timing of relevé recording in this cycle will obviously affect the estimate of grazing intensity. Other studies on grazing intensity in turloughs have been on a smaller scale, e.g. just one turlough (Moran *et al*., 2008) or two turloughs (Ní Bhriain *et al*., 2003). These studies had the advantage of smaller scale, whereby more detailed information could be obtained for the land-parcels they examined, as well as being concerned with a smaller number of vegetation communities, which may show differences more easily. Even these smaller scale studies, however, found it difficult to disentangle the effects of the underlying geomorphology and trophic status on vegetation types. Moran *et al*. (2008) state *'It appears that the management practices are regulated by the inherent grazing potential of the site and soil properties, which in turn are shaped by the hydrological regime',* while Ni Bhriain *et al*. commented, on the differences in vegetation found in two different turloughs, *'…as substrate and hydrology differ between the sites, it is not possible to attribute these differences to management alone*.' Experimental manipulation of grazing intensity, through, for example, the erection of long-term grazing exclosures, may be necessary to properly examine the effects of grazing in isolation on vegetation communities.

Some vegetation communities, such as Group 14 Reedbed and Group 21 *Schoenus nigricans* fenwere only recorded in ungrazed land-parcels. It is likely that these communities grow on very marginal land which is either very wet (Reedbed) and/or low in nutrients (*Schoenus*) and so supports poor quality forage for grazing animals. Other vegetation communities were only recorded in 'grazed' land-parcels. These consisted of managed grassland (Group 10 *Lolium perenne-Trifolium repens*, Group 15 *Lolium perenne-Trifolium repens-Agrostis stolonifera*) communities dominated by ruderal species which benefit from the disturbance of grazing animals (Group 1 *Poa annua-Plantago major* , Group 26 *Eleocharis acicularis*) and herb-rich communities with a short sward height which may benefit from grazing to keep the vegetation open (Group 19 *Potentilla anserina-Potentilla reptans*, Group 20 *Filipendula ulmaria-Potentilla erecta-Viola* sp.). The other communities occurred in both grazed and ungrazed areas.

7.6.3.2 Most Important Drivers of Turlough Vegetation

Building on the understanding of the relationships between ecological and management variables developed in the previous sections, NMS, Discriminant Analysis and BIO-ENV were then used to identify the variables with the strongest relationships to the vegetation communities. These results are summarised in Table 7.102. Each of these analyses had strengths and weaknesses, and they were all carried out for different reasons.

NMS was used to give an indication of the relationships between each vegetation type and the environmental variables. The position of the vegetation groups in the ordination space, and how they are arranged upon various axes which are related to the environmental variables gave an indication of which factors were important for which vegetation group. Correlations between the environmental variables and the ordination axes were also carried out; while these give a statistical value for the relationship, care must be taken when interpreting these results.

Discriminant analysis was carried out in order to determine which of the quantitative variables explained most of the differences between vegetation groups. A drawback of this analysis is that categorical data are not appropriate, and so only continuous data were included.

Table 7.102 Summary of important variables associated with turlough vegetation as determined by NMS, Discriminant Analysis and BIO-ENV.

Analysis	*Most important variables*	*Notes*
NMS	Dur0cm WaterTP DryDate	These are the variables with the highest correlations with the ordination axes.
Discriminant analysis	Dur0cm MDQuad Water TP Water TN	These are the variables identified by Discriminant Analysis as most important in distinguishing between vegetation groups.
BIO-ENV	Dur0cm Water TP DryDate Grazed/Ungrazed Freq0cm	This is the combination of five variables identified by BIO-ENV as explaining most variation in the species matrix.

BIO-ENV was then carried out to determine the combination of environmental variables (both quantitative and categorical) which explained most of the variation in the biotic assemblage (i.e. the species abundance matrix).

When correlations between variables were calculated, maximum quadrat depth was correlated with duration of flooding (0.422) – this is unsurprising, as the deeper a point is within a turlough, the more likely it is to be flooded for a longer duration. Maximum quadrat depth was also correlated with frequency of flooding (at 0 cm, but not at 50 cm above the substrate). Frequency of flooding was also negatively correlated with water alkalinity (-0.435), suggesting that those turloughs with more alkaline water may experience less changeable water levels. Frequency of flooding was positively correlated with soil total phosphorus.

Water TP was negatively correlated with Axis 3 of the NMS ordination (Table 7.91) and less strongly negatively correlated with Axis 1. Water TP was also positively correlated with Fertility (Table 7.90) this suggests that Water TP is an important driver of turlough vegetation communities. Total phosphorus concentrations in water have been found to be the limiting factor in phytoplankton growth (Cunha Pereira *et al*., 2010), and it seems that the same may hold true for plant communities. Species richness was negatively correlated with duration of flooding, indicating that a limited number of species can tolerate long periods of inundation.

Discriminant Analysis indicated that Duration flooded to 0 cm, Maximum flood depth at quadrat, WaterTP and Water TN were the most important environmental variables. However, as categorical variables cannot be used in Discriminant Analysis, such as whether or not a land-parcel was grazed, and soil type were not included. On the basis of the quantitative variables, just 31.2% of relevés were placed into the correct vegetation groups by discriminant analysis. While this is a very low number, when the classification table was examined (Table 7.95), some of the vegetation groups were well-classified; others were completely mis-classified. This suggests that, for the well-classified groups, the environmental variables included in the analysis are enough to predict, with varying degrees of confidence, which vegetation type will occur. For others, more information is likely needed.

The BIO-ENV procedure found that a combination of five variables gave the highest correlation with the vegetation data, at 0.307: Duration flooded to 0 cm, Water TP, Frequency of flooding at 0 cm, Julian day of first drying and whether or not the land-parcel was grazed. While this is not a very high degree of correlation, relatively low correlations have been reported in the literature (e.g. 0.470: King & Buckney, 2000; 0.288: Gioria *et al*., 2010).

The results presented here from all three multivariate analyses demonstrate that duration of flooding and water total phosphorus concentration were the variables which most clearly influence turlough vegetation. The start date of the dry period and frequency of flooding were also shown to be important. The other hydrological variables recorded do not seem to have the same degree of effect. It is remarkable that the vegetation, and plant species distribution, showed little influence of soil nutrients but were instead most strongly realted to water TP. Phosphate is taken up by the roots of terrestrial plants from the substrate, so the relationships between water TP and vegetation must be mediated by P fluxes from the floodwater via the soil, probably involving specific pools of soil phosphorus. More detailed study of soil P fractions and vegetation at the relevé level would be required to resolve this.

7.6.3.3 Comparison with Previous Studies

The findings presented here are similar to those from other studies on wetlands. Wheeler and Proctor (2000), in a study of ecological gradients and floristic variation of north-west European mires, found that most of the variation was accounted for by just three ecological gradients: pH, the availability of nitrogen and phosphorus, and the hydrological gradient. Similar findings were reported by de Becker *et al*. (1999), who concluded that water regime and soil type/management were the main drivers of vegetation community change in a floodplain mire.

Similar findings have also been presented on turloughs; Regan *et al*. (2007) determined that date of emptying of the turlough (corresponding to Julan date of first drying here) and water phosphorus and nitrogen were among the most important drivers of turlough vegetation communities. Moran *et al*. (2008) found that the main factors affecting turlough plant community composition were hydrological regime and grazing.

7.6.3.4 Communities Which are Restricted in their Range or Show an Association with Certain Variables

Discriminant Analysis highlighted those groups with restricted range, i.e. those which were classified correctly based on the variables included in the analysis. These were Group 9 *Phalaris arundinacea-Potentilla anserina*, Group 14 Reedbed, Group 19 *Potentilla anserina-Potentilla reptans*, Group 21 *Schoenus nigricans* fen, Group 24 *Potamogeton natans-Glyceria fluitans*, Group 25 *Carex nigra-Carex viridula* and Group 26 *Eleocharis acicularis*. These groups were those for which > 60% of relevés were assigned to the correct vegetation group by Discriminant Analysis.

For other groups, however, none of the relevés were correctly classified. These were Group 1 *Poa annua-Plantago major*, Group 7 *Eleocharis palustris-Phalaris arundinacea*, Group 16 *Equisetum fluviatile-Menyanthes trifoliata*, Group 18 *Agrostis stolonifera-Glyceria fluitans* and Group 27 *Carex nigra-Equisetum fluviatile*. In some cases, relevés were assigned to similar communities, e.g. Group 19 *Potentilla anserina-Potentilla reptans* and Group 20 *Filipendula ulmaria-Potentilla erecta-Viola* sp. are floristically quite similar, but occur at different locations on the flooding gradient within the same turlough. Almost half of the relevés belonging to Group 20 were incorrectly assigned to Group 19, and a number of relevés belonging to Group 19 *e* were incorrectly assigned to Group 20. This suggests that, based solely on the variables included in the analysis, there is not sufficient difference in the environmental conditions between these communities to distinguish between them. They were both found on Well-Drained Mineral soils, but Group 19 was also found on Poorly-Drained Mineral soils – this suggests that Group 19 may be more tolerant of wetter conditions than Group 20.

7.6.4 Species Ecology

Species distributions in relation to flooding, nutrient status and management largely reflect the distributions of the vegetation communities which they constitute. As with the vegetation, species distributions seem to be most strongly influenced by duration of flooding, rather than frequency or timing of flooding. Phosphorus appears to be the more influential nutrient, particularly water TP compared to soil TP, and duration of flooding and water TP seem to be the major drivers of species distribution. These likely reflect both the ability to tolerate flooding and the nutrient requirements of the different species, coupled with biotic competition which results in some species better able to persist in certain combinations of flooding and nutrient status. However, many species showed a wide ecological amplitute, in relation to flooding duration or TP – those species which appear to be restricted to particular levels of flooding duration, or TP status, or combinations of these, are mentioned further in the final section on ecological indicators (section 7.6.6).

7.6.5 Species and Communities of Conservation Importance

Eleocharis acicularis – this species is restricted to zones with long duration flooding on mostly minneral soils and intermediate fertility. These zones are usually in the lowest parst of turloughs, but this may not always be the case, as for example at Garryland, where the species grows along the stream that flows at low water levels. Its occurrence at intermediate fertility levels may possibly be incidental, as it is more likely that the substrate type is a more important ecological driver. *E. acicularis* forms a distinct community in association with other annual species.

Frangula alnus – in turloughs *F. alnus* is restricted to flooded pavement communities, where usually grows prostrate over rocks. This community, and hence *F. alnus*, is restricted to the more oligotrophic turloughs. Erect forms of *F. alnus* occur in wet woodlands, particularly fen carr, but the prostrate form appears to be restricted to turloughs. The prostrate habit may be under genetic control, plants raised from seed at TCD Botanic Garden retain a prostrate growth form.

Limosella aquatica – *Limosella* occurs on bare mud in the deeper zones of turloughs, often in association with *Eleocharis acicularis*. It also occurs in other communities dominated by annuals colonisting bare ground, but in our relevés was only recorded with *E. acicularis*.

Potentilla fruticosa – *P. fruticosa* occurs mainly in flooded pavement or in shrub communities in the upper zones of turloughs subjected to relatively short duration flooding, though plants may be periodically completely submerged. Apart from flooded pavement, *P. fruticosa* also occurs at the edges of *Schoenus nigrcans* fen, and very occasionally in limestone grassland and the *Agrostis stolonifera-Potentilla anserina-Festuca rubra* community. As with *Frangula alnus*, *P. fruticosa* was entirely restricted to the more oligotrophic tuloughs. The species also occurs around lakeshores, but at least some of these also have fluctuating water levels over strongly calcareous substrates (e.g. Lough Bunny, Co. Clare) and in this sense the ecological niche is very comparable to the upper oligotrophic turlough zone.

Rorippa islandica – as with *Limosella*, *R. islandica* occurs in communities colonising bare areas. It often occurs in the *Eleocharis acicularis* community, but also occurs in other annual communities, including the *Poa annua-Plantago major* community.

Teucrium scordium – *T. scordium* restricted to the most oligotrophic turloughs, where it occurs in zones with long duration flooding. *T. scordium* occurs in a variety of communities, but these are typically sedge-dominated, though it occasionally occurs in communities with some *Polygonum amphibium*.

Viola persicifolia – this species occurs in the middle to upper zones of oligo- and mesotrophic turloughs, and in Ireland (though not elsewhere) is largely restricted to turloughs. It regularly hybridises with *V. canina*, and hybrids show a wide range of morphological variation making identification of 'pure' *persicifolia* phenotypes difficult. *Viola persicifolia* occurs in a variety of communities, but most frequently in *Potentilla anserina-Potentilla reptans* and *Agrostis stolonifera-Potentilla anserina-Festuca rubra* communites.

There are some interesting parallels among these species of conservation importance. Firstly, three of the species are annuals of bare muddy ground that is often inundated for long periods; these three species are often found in association with each other. They often occur in mesotrophic turloughs, but this may be due to their requirement for particular substrate types only found in certain turloughs which happen to be mainly mesotrophic. Clearly, the annual communities from the deeper zones of turloughs would repay more detailed ecological investigation.

Three other species are characteristic of the more oligotrophic turloughs, both around the upper margins on limestone pavement, and in the deeper zones subject to long inundation. The presence of *Plantago maritima* in the upper zones of strongly oligotrophic turloughs together with *Potentilla fruticosa*, *Frangula alnus* and several other species restricted to this habitat may well indicate that the upper margins of these turloughs have always had relatively open communities thoughout the Holocene, and hence may be of particular conservation importance.

Communities of High Conservation Value

There are a number of communities which do not commonly occur outside of turloughs, at least in Ireland, and which did not seem to fit with communities in the NVC, suggesting that their occurrence is limited, or at least not yet reported, in the rest of the British Isles. Given their restricted distribution, these communities are of high conservation value. In addition, some communities have been identified as those in which rare species occur. Communities suggested to have high conservation value are listed in Table 7.103.

The *Filipendula ulmaria-Potentilla erecta-Viola* sp. community is important as it contains *Viola persicaria* and hybrids, a Red Data Book species (Curtis & McGough, 1988). *Teucrium scordium* occurs within Group 23, the *Carex nigra-Leontodon autumnalis* community; even though it occurs at a relatively low frequency, it is an indicator species for this community. *T. scordium* is a Red Data Book species (Curtis & McGough, 1988).

Table 7.103 Turlough communities of high conservation value, with area mapped and numbers of localities

Community	Area mappped (ha)	Locations
Filipendula ulmaria-Potentilla erecta-Viola sp.	36.73	9
Schoenus nigricans fen	45.24	7
Carex nigra-Leontodon autumnalis	56.30	9
Carex nigra-Carex viridula community	?	2
Eleocharis acicularis community	4.45	4
Flooded pavement	32.33	7
Eleocharis palustris-Ranunculus flammula community	221.8	9

For mapping, the *Carex nigra-Carex viridula* community was included in *Schoenus nigricans* fen

The *Carex nigra-Carex viridula* and *Schoenus nigricans* fen communities did not show a high affinity with any NVC communities, suggesting they may not occur in the British Isles. For mapping they were combined, with the obvious feature in common being the abundance of the characteristic *Schoenus nigrcans*. It was similar to communities defined by previous studies on turlough vegetation, suggesting its distribution may be restricted to turloughs; it appears to be rare within turloughs and had a patchy distribution which prevented it from being mapped accurately; it would certainly repay further study – particularly the *Carex nigra-Carex viridula* at Knockaunroe and Carranavoodaun. These communities are also likely of considerable conservation importance as they are restricted to the more oligotrophic turloughs; they may therefore be useful as ecological indicators, but also are likely to be highly sensitive to any nutrient inputs. The *Eleocharis palustris-Ranunculus flammula* is similarly of conservation importance, being the community most often associated with the longest flooded regions of mostly (but not exclusively) oligotrophic turloughs. The mapped community perhaps had a slightly narrower focus towards the more oligtrophic turloughs than the relevé data, and is probably much closer to Goodwillie's (1992) Marl Pond.

Group 26, the *Eleocharis acicularis* community is of very high conservation value; it has a restricted distribution in a limited numnber of turloughs. *Rorippa islandica* and *Limosella aquatica*, both listed in the Red Data Book (Curtis & McGough, 1988) occur within this community. The Flooded Pavement community (Group 28) is also of high conservation value, especially as habitat for *Potentilla fruticosa*, a species which is rare throughout the British Isles and largely restricted to the fringes of some turloughs in Ireland (Elkington & Woodell, 1963, Webb & Scannell, 1983). Flooded pavement appears to occur fairly widely among turloughs formed in proximity to limestone pavement, these are typically the more oligtrophic turloughs. Again, detailed study of the vegetation transition from limestone pavement to turlough communities on a small scale would be beneficial.

On a similar vein, further study of the ecology and consevation importance of woodlands at the upper zones of turloughs would be beneficial. For example, at Coole the woodland grades into flooded pavement with large clints supporting woodland floor communities and the deeper grykes with shade-tolerant wetland plants; these associations are highly unusual and require further study.

Several turloughs are considered to be of conservation importance, as they present excellent examples of this geographically restricted habitat. These sites should be give highest priority for conservation because of the vegetation communities that they contain, and also because they are likely to be highly sensitive to nutrient enrichment. They are:

- Lough Gealain – a very highly oligotrophic system (marginal ultra-oligotrohic) with an important range of vegetation communites, which shows very low human impact.
- Knockaunroe – an oligotrophic turlough with a very wide range of typical turlough plant commuities and several rare species.
- Caranavoodaun, Roo West, Lisduff – all of these turloughs contain communites and species typical of oligotrophic communities.

7.6.6 Ecological Indicators

Several species and communities appear to be restricted ecologically within turloughs, especially in relation to what we consider to be the main ecological drivers of vegetation development in turloughs: duration of flooding and ground water phosphorus. Several species and communities appear to be restricted to particular levels of flooding and/or water TP; they are listed in Table 7.104. All of these potential indicators should be verified using independent data sets before being applied as ecological indicators of turlough ecological conditions.

Values derived from vegetation data have also been used as indicators of ecological conditions in turloughs. These include Ellenberg values for wetness and fertility, modified for use with the flora of the British Isles by Hill *et al*. (1999). Here we found that Ellenberg wetness scores, weighted by the abundance of different species in relevés, correlated well with flooding duration, as has also been reported at the relevé level for Skealoghan turlough by Williams *et al.* (2011). Ellenberg fertility values were also calculated from characteristic species of each community provided by Goodwillie (1992), and the area of each community used to provide an estimate of overall turlough trophic status (Working Group on Groundwater, 2004). This analysis was only based on a small number of species and did not accunt for any estimation of their abundance. Here we used the vegetation relevé data to provide an Ellenberg value for each relevé weighted by species cover-abundance. We also calculated a mean Ellenberg value for each turlough based on the area of each vegetation community within it, this provides a more accurate estimate of the turlough-level fertility index. We found this index to be highly correlated with water TP and MRP (but not with other water or substrate nutrients).

One problem with using this approach is the complexity involved acquiring the estimate of, in this case, water TP or MRP. A series of relevés needs to be taken from the turlough and the area of each community mapped, a time consuming and costly exercise; it may well be more appropriate to take a single or small number of direct measurements of water TP. However single (or small numbers) of point samples cannot adequately assess the variation to which plant communities are exposed. One advantage of using a vegetation based indicator is that it will 'integrate' recent ecological effects over a considerable time period. We devised simplified indices to estimate turlough water TP using several methods. The proportions of oligo-trophic and oligo-meso trophic communites correlated well with TP, and this was improved by subtrating the area of eutrophic communities. However, these methods still require the area of each community to be estimated. We then devised an index based on the presence or proportion of a comparatively small number of species, the advantage here is that the presence or frequency can easily be calculated from a series of samples without the need to identify all species and without the the need to map vegetation communities. This index provided the strongest linear relationship with water TP of any indicator; it therefore provides a more simple, reliable and improved method of estimating turlough P status than using Ellenberg fertility values.

Table 7.104. Potential plants species and community indicators of ecological conditions in turloughs

Species/community	***Notes***
Eleocharis palustris-Ranunculus flammula commu *Baldellia ranunculoides* *Carex elata* *Littorella uniflora* *Teucrium scordium* Flooded pavement community	Long duration flooding, low P
Schoenus nigricans fen *Danthonia decumbens* *Parnassia palustris* *Potentilla fruticosa* *Schoenus nigricans* *Molinia caerulea-Carex nigra* community	Short duration flooding, low P
Carex hostiana *Carex viridula agg.* *Cirsium dissectum*	Low P
Eleocharis acicularis community *Polygonum amphibium* communities *Eleocharis acicularis* *Oenanthe aquatica* *Polygonum amphibium* *Rorippa amphibia*	Long duration flooding, medium to high P
Bellis perennis *Cardamine pratensis* *Carex hirta* *Filipenula ulmaria* *Rumex crispus* *Trifolium repens*	Short-medium duration flooding, medium-high P
Eleocharis palustris *Equisetum fluviatile* *Glyceria fluitans*	Long duration flooding
Lolium grassland communities Limestone grassland community Woodland & Scrub communities	Short duration flooding
Sedge-dominated communities	Low P
Herb-dominated communities	Medium-High P
Poa annua/Plantago major community	Over grazing and especially trampling and poaching by stock
Tall herb community	Possibly reduced grazing pressure, moderate P

7.7 Summary

- Twenty-eight vegetation communities were described from multivariate analyses of relevés taken in 22 turloughs.

- These communities were used as a basis (with slight modification) for mapping of vegetation units in the field; vegetation maps of the 22 turloughs are provided and are also available as GIS layers.
- In general these vegetation communities conform well with communities described previously from turloughs using a variety of quantitative and qualitative approaches.
- The duration of flooding an total phosphorus in the flood water of turloughs (water TP) were the environmental variables most closely associated with the distribution of vegetation communites and vascular plant species. Duration of flooding and water TP are likely to be the most important ecological drivers of turlough vegetation.
- Grazing intenstity is also linked with vegetation community development, but grazing is also closely linked with the duration of flooding, and without information from manipulative experiments, grazing effects are likely to remain confounded with flooding duration.
- Several species and vegetation communities show marked distribution patterns in association with duration of flooding and water TP; these species and communities may be useful as indicators and for monitoring the ecological status of turloughs.
- An index of nutrient status (linked to water TP) was devised from the presence or frequncy of selected turlough species, this index is simple to apply and more robust than previously used indicators based on Ellenberg fertility values.
- Several vascular plant species and communities are of conservation importance, their ecological requirements are described based on quantitative analysis. Turloughs of conservation importance, mostly the more oligotrophic turloughs, are also suggested as being of international conservation importance due to the plant communites they contain and their likely sensitivity to nutrient enrichment.

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Appendix 7.1. Key to Vegetation Community Identification

1. Vegetation of exposed limestone pavement — **Flooded pavement**
Not as above — 2

2. Vegetation predominantly ruderal species, or open ground — 26
Vegetation not predominanlty ruderal species or open ground — 3

3. Vegetation predominantly woody (trees, scrub, bushes) — **Woodland & Scrub**
Vegetation predominantly of herbs — 4

4. Vegetation predominantly terrestrial — 5
Vegetation predominantly aquatic/wetland plants — 21

5. Vegetation dominated by grasses or sedges — 6
Vegetation dominated by forbs — 17

6. Vegetation dominated by grasses — 8
Vegetation dominated by sedges — 11

WOODLAND/SCRUB (usually 'Upper Basin')

6. Vegetation dominated by *Crataegus monogyna* and *Rhamnus cathartica*, with *Prunus spinosa*, *Fraxinus excelsior* and *Rubus caesius* — **Rhamnus wood**
Not as above — 7

7. Vegetation dominated by *Fraxinus excelsior, Crataegus monogyna, Quercus robur, Salix cinerea* — **Dry wood**
Vegetation dominated by *Frangula alnus*, with *Rhamnus cathartica, Rubus caesius* and occasionally *Potentilla fruticosa* — **Flooded pavement (Frangula/Potentilla scrub)**

GRASS DOMINATED (usually 'Upper Basin')

8. Grassland with *Lolium perenne*, *Trifolium repens*, *Bellis perennis*, *Festuca rubra*, *Ranunculus acris* — **Lolium grassland**
Not as above — 9

9. Grassland with *Agrostis stolonifera*, *Potentilla anserina*, *Leontodon autumnalis*, *Ranunculus repens*, *Filipendula ulmaria*, *Elytrigia repens*, *Festuca arundinacea* — **Agrostis stolonifera-Potentilla anserina-Festuca rubra**
Not as above — 10

10. Grassland with *Festuca rubra*, *Lotus corniculatus*, *Potentilla erecta*, *Succisa pratensis*, *Plantago lanceolata*, *Carex panicea*, *Carex flacca*, *Agrostis*, *Galium verum*, *Molinia caerulea*, *Plantago maritima* — **Limestone grassland**
Grass dominated vegetation **lower** in the basin, with abundant *Phalaris arundinacea*, *Potentilla anserina*, *Eleocharis palustris*, *Polygonum amphibium* — **Eleocharis palustris-Phalaris arundinacea**

SEDGE DOMINATED (Sedges always present and usually dominant, usually 'Mid' to 'Lower' Basin)

11. Conspicuous tufts of *Schoenus nigricans*, with *Molinia caerulea*, *Succisa pratensis, Carex nigra, Potentilla erecta, Cirsium dissectum, Achillea ptarmica* — **Schoenus fen**
Not as above — 12

12. *Carex nigra* dominant/abundant, with conspicuous *Potentilla anserina*, *Ranunculus repens*, *Agrostis stolonifera* — 13

Not as above 14

13. *Potentilla anserina* abundant, with *Galium palustre, Mentha aquatica, Phalaris arundinacea, Polygonum amphibium, Carex hirta, Potentilla reptans, Stellaria media* **Agrostis stolonifera-Ranunculus repens**
Galium palustre, Hydrocotyle vulgaris, Mentha aquatica, Leontodon autumnalis, Cardamine pratensis, Filipendula ulmaria, Myosotis scorpioides, Juncus spp, *Polygonum amphibium* **Potentilla anserina-Carex nigra**

14. Abundant *Carex nigra*, with *Mentha aquatica, Ranunculus flammula, Hydrocotyle vulgaris, Galium palustre, Potentilla anserina, Equisetum fluviatile, Agrostis stolonifera, Eleocharis palustris, Menyanthes trifoliata* **Carex nigra-Ranunculus flammula**
Not as above 15

15. Abundant *Carex panicea, Molinia caerulea, with Agrostis stolonifera, Mentha aquatica, Hydrocotyle vulgaris, Leontodon autumnalis, Potentilla anserina, Ranunculus flammula, Carex viridula, Galium palustre, Carex* spp, *Lotus corniculatus, Potentilla erecta, Juncus* spp **Molinia caerulea-Carex panicea**
Constant *Carex panicea*, with *Carex nigra, Juncus* spp, *Trifolium repens, Agrostis stolonifera, Hydrocotyle vulgaris, Potentilla erecta, Molinia caerulea, Galium palustre, Leontodon autumnalis, Festuca rubra, Prunella vulgaris, Ranunculus flammula, Ranunculus repens, Carex flacca, Carex hostiana, Mentha aquatica, Succisa pratensis* **Carex nigra-Carex panicea**

FORB DOMINATED (Sedges often present and may be abundant, but vegetation dominated by forbs)

16. *Filipendula ulmaria* conspicuous 17
Not as above 18

17. Tall vegetation, with *F. ulmaria, Vicia cracca, Carex hirta, Festuca arundinacea, Phalaris arundinacea* **Tall herb**
Shorter vegetation, grazed, with *F. ulmaria, Potentilla erecta, Viola spp., Lotus corniculatus, Potentilla anserina, Carex nigra, Potentilla reptans, Galium boreale, Galium verum, Sagina nodosum* **Filipendula ulmaria-Potentilla erecta-Viola sp.**

18. *Potentilla reptans* very conspicuous/dominant, with *Potentilla anserina*, *Agrostis stolonifera, Ranunculus repens, Rumex crispus, Carex nigra, Filipendula ulmaria, Viola* spp **Potentilla anserina-Potentilla reptans**
Vegetation lower in the basin, *Potentilla anserina* dominant/abundant 19

19. Vegetation dominated by *P. anserina*, with *Agrostis stolonifera, Carex nigra, Ranunculus repens, Galium palustre, Mentha aquatica, Phalaris arundinacea, Polygonum amphibium, Carex hirta, Potentilla reptans, Stellaria media* **Agrostis stolonifera-Ranunculus repens**
Potentilla anserina abundant, not necessarily dominant. Abundant *Ranunculus repens, Agrostis stolonifera, Carex nigra, Galium palustre, Hydrocotyle vulgaris, Cardamine pratensis, Filipendula ulmaria, Myosotis scorpioides, Juncus* spp, *Polygonum amphibium* **Potentilla anserina-Carex nigra**

AQUATIC/WATER'S EDGE

20. Permanent water, with *Potamogeton* spp 21
Temporary water, may be flooded or not, amphibious species 22

21. Open water, vegetation characterised by *Potamogeton* spp, *Glyceria fluitans* **Open water**
Permanent water, with *Schoenoplectus lacustris* and/or *Carex elata, Phragmites australis* **Reed bed**

22. Abundant *Eleocharis acicularis* **Eleocharis acicularis**
Not as above 23

23. *Polygonum amphibium* abundant/dominant **Polygonum amphibium**
Not as above 24

24. Vegetation comprised of *Mentha aquatica, Ranunculus flammula, Juncus* spp, *Littorella uniflora, Eleocharis palustris, Hydrocotyle vulgaris, Baldellia ranunculoides, Galium palustre, Carex viridula* **Eleocharis palustris-Ranunculus flammula**
Not as above 25

25. *Equisetum fluviatile, Menyanthes trifoliata* abundant **Eleocharis palustris-Phalaris arundinacea**
Agrostis stolonifera abundant, with wetland/annuals such as *Myosotis scorpioides, Galium palustre, Glyceria fluitans, Mentha aquatica, Eleocharis palustris,* possibly bare ground **Agrostis stolonifera-Glyceria fluitans**

RUDERALS/OPEN GROUND

26. Wettish areas near water, with abundant *Agrostis stolonifera*, annuals and wetland species such as *Myosotis scorpioides, Galium palustre, Glyceria fluitans, Mentha aquatica, Eleocharis palustris,* possibly bare ground **Agrostis stolonifera-Glyceria fluitans**
Ruderal species, possibly on poached ground, with *Polygonum aviculare, Plantago major, Poa annua, Agrostis stolonifera, Stellaria media, Ranunculus repens, Matricaria matricioides, Rorippa palustris* **Poa annua-Plantago major**
Abundant *Eleocharis acicularis* **Eleocharis acicularis**

Appendix 7.2. Species Frequency in Relevés in Relation to Flood Duration and Total Phosphorus in the Floodwater

Frequency of species recorded in relevees partitioned into categories of flooding duration and log (waterTP). The number of relevees in each category combination is given: where five or fewer relevees occurred in a given flooding/TP combination these are highlighted in blue – percentage values here are less reliable than in combinations with a larger number of relevees. Frequency classes are highlighted to show trends as follows:

Fill	Frequency
	100-80
	80-60
	60-40
	40-20
	20-0

1. Very short duration flooding

Flood duration category	Very short				
Log Water TP Category	**Very low**	**Medium low**	**Medium**	**Medium high**	**Very high**
No. of relevés	***1***	***3***	***21***	***37***	***3***
Achillea ptarmica	0.00	0.00	0.00	5.41	0.00
Agrostis capillaris	0.00	0.00	0.00	13.51	0.00
Agrostis stolonifera	100.00	33.33	71.43	78.38	66.67
Alisma plantago-aquatica	0.00	0.00	0.00	2.70	0.00
Alopecurus geniculatus	0.00	0.00	4.76	2.70	33.33
Bellis perennis	0.00	0.00	23.81	24.32	0.00
Briza media	0.00	66.67	9.52	2.70	0.00
Caltha palustris	0.00	0.00	0.00	2.70	0.00
Cardamine flexuosa	0.00	0.00	0.00	5.41	0.00
Cardamine pratensis	0.00	0.00	33.33	35.14	33.33
Carex disticha	0.00	0.00	4.76	16.22	66.67
Carex flacca	0.00	33.33	28.57	27.03	33.33
Carex hirta	0.00	0.00	23.81	21.62	33.33
Carex hostiana	100.00	66.67	19.05	13.51	0.00
Carex nigra	100.00	66.67	28.57	29.73	0.00
Carex panicea	0.00	33.33	38.10	45.95	0.00
Carex viridula agg.	100.00	0.00	4.76	0.00	0.00
Cerastium fontanum	0.00	0.00	9.52	10.81	66.67
Cirsium arvense	0.00	0.00	14.29	8.11	0.00
Cirsium dissectum	100.00	33.33	0.00	5.41	0.00
Cirsium vulgare	0.00	0.00	0.00	2.70	66.67
Cynosurus cristatus	0.00	0.00	9.52	27.03	0.00
Danthonia decumbens	0.00	0.00	0.00	2.70	0.00
Deschampsia cespitosa	0.00	0.00	0.00	5.41	33.33
Eleocharis palustris	0.00	0.00	4.76	0.00	0.00
Elymus repens	0.00	0.00	9.52	5.41	33.33
Equisetum fluviatile	0.00	0.00	0.00	2.70	0.00
Equisetum palustre	0.00	0.00	19.05	2.70	0.00
Festuca arundinacea	0.00	33.33	9.52	27.03	33.33
Festuca ovina	0.00	0.00	0.00	8.11	0.00
Festuca pratensis	0.00	0.00	0.00	10.81	0.00
Festuca rubra	0.00	66.67	42.86	43.24	33.33
Filipendula ulmaria	0.00	0.00	47.62	37.84	33.33
Galium boreale	0.00	0.00	0.00	2.70	0.00
Galium palustre	0.00	33.33	28.57	37.84	33.33

Flood duration category	Very short				
Log Water TP Category	Very low	Medium low	Medium	Medium high	Very high
No. of relevés	***1***	***3***	***21***	***37***	***3***
Galium verum	0.00	0.00	9.52	5.41	0.00
Glyceria fluitans	0.00	0.00	0.00	5.41	0.00
Hippuris vulgaris	0.00	0.00	0.00	2.70	0.00
Holcus lanatus	0.00	33.33	14.29	18.92	33.33
Hydrocotyle vulgaris	0.00	33.33	9.52	13.51	0.00
Iris pseudacorus	0.00	0.00	4.76	5.41	33.33
Juncus acutiflorus	0.00	0.00	23.81	21.62	0.00
Juncus articulatus	0.00	0.00	9.52	13.51	0.00
Lathyrus pratensis	0.00	0.00	33.33	2.70	0.00
Leontodon autumnalis	0.00	0.00	23.81	56.76	33.33
Leontodon hispidus	0.00	0.00	9.52	13.51	0.00
Leontodon saxatilis	0.00	0.00	0.00	2.70	0.00
Linum catharticum	0.00	0.00	0.00	2.70	33.33
Lolium perenne	0.00	33.33	42.86	45.95	0.00
Lotus corniculatus	0.00	100.00	28.57	21.62	33.33
Mentha aquatica	100.00	0.00	0.00	16.22	0.00
Menyanthes trifoliata	100.00	0.00	0.00	0.00	0.00
Molinia caerulea	100.00	100.00	23.81	24.32	0.00
Mosses	0.00	0.00	23.81	0.00	0.00
Myosotis scorpioides	0.00	0.00	0.00	10.81	66.67
Parnassia palustris	0.00	33.33	9.52	0.00	0.00
Phalaris arundinacea	0.00	33.33	9.52	2.70	0.00
Phleum bertolonii	0.00	0.00	0.00	10.81	0.00
Phleum pratense	0.00	0.00	9.52	16.22	33.33
Plantago lanceolata	0.00	33.33	23.81	32.43	0.00
Plantago major	0.00	0.00	0.00	21.62	0.00
Poa annua	0.00	0.00	0.00	2.70	0.00
Poa pratensis	0.00	0.00	14.29	2.70	0.00
Polygonum amphibium	0.00	0.00	4.76	2.70	0.00
Polygonum aviculare	0.00	0.00	0.00	2.70	0.00
Potentilla anserina	0.00	33.33	19.05	48.65	33.33
Potentilla erecta	0.00	66.67	28.57	37.84	33.33
Potentilla reptans	0.00	0.00	4.76	2.70	0.00
Prunella vulgaris	0.00	33.33	23.81	43.24	0.00
Ranunculus acris	0.00	0.00	42.86	40.54	0.00
Ranunculus flammula	0.00	0.00	0.00	8.11	0.00
Ranunculus repens	0.00	0.00	23.81	45.95	33.33
Rorippa amphibia	0.00	0.00	0.00	5.41	0.00
Rorippa islandica	0.00	0.00	0.00	0.00	0.00
Rumex acetosa	0.00	0.00	4.76	18.92	66.67
Rumex crispus	0.00	0.00	4.76	5.41	33.33
Rumex obtusifolius	0.00	0.00	4.76	10.81	0.00
Sagina nodosa	0.00	0.00	4.76	0.00	0.00
Senecio aquaticus	0.00	0.00	42.86	21.62	0.00
Stellaria media	0.00	0.00	0.00	8.11	0.00
Stellaria palustris	0.00	0.00	0.00	5.41	0.00
Succisa pratensis	0.00	66.67	33.33	18.92	0.00
Taraxacum officinale ag.	0.00	66.67	28.57	13.51	33.33
Trifolium pratense	0.00	33.33	14.29	21.62	0.00
Trifolium repens	0.00	0.00	66.67	94.59	66.67
Valeriana officinalis	0.00	0.00	33.33	2.70	0.00
Veronica beccabunga	0.00	0.00	0.00	2.70	0.00

Flood duration category	Very short				
Log Water TP Category	**Very low**	**Medium low**	**Medium**	**Medium high**	**Very high**
No. of relevés	***1***	***3***	***21***	***37***	***3***
Veronica scutellata	0.00	0.00	0.00	0.00	0.00
Vicia cracca	0.00	33.33	28.57	10.81	66.67
Veronica catenata	0.00	0.00	0.00	2.70	0.00

2. Short duration flooding

Flood duration category	Short				
Log Water TP Category	**Very low**	**Medium low**	**Medium**	**Medium high**	**Very high**
No. of relevés	***9***	***5***	***30***	***49***	***34***
Achillea ptarmica	0.00	0.00	0.00	2.04	0.00
Agrostis capillaris	11.11	0.00	6.67	14.29	5.88
Agrostis stolonifera	33.33	60.00	76.67	81.63	76.47
Alisma plantago-aquatica	0.00	0.00	0.00	2.04	0.00
Alopecurus geniculatus	0.00	0.00	30.00	8.16	8.82
Bellis perennis	0.00	0.00	10.00	12.24	14.71
Briza media	0.00	20.00	3.33	0.00	0.00
Caltha palustris	0.00	0.00	0.00	6.12	0.00
Cardamine flexuosa	0.00	0.00	0.00	6.12	0.00
Cardamine pratensis	11.11	20.00	46.67	34.69	20.59
Carex disticha	0.00	0.00	3.33	14.29	2.94
Carex flacca	66.67	80.00	6.67	6.12	5.88
Carex hirta	0.00	20.00	20.00	36.73	26.47
Carex hostiana	33.33	20.00	3.33	2.04	0.00
Carex nigra	44.44	60.00	40.00	51.02	32.35
Carex panicea	55.56	80.00	26.67	10.20	14.71
Carex viridula agg.	44.44	20.00	3.33	2.04	2.94
Cerastium fontanum	0.00	0.00	10.00	12.24	41.18
Cirsium arvense	0.00	0.00	13.33	8.16	8.82
Cirsium dissectum	11.11	0.00	6.67	0.00	8.82
Cirsium vulgare	0.00	0.00	3.33	0.00	14.71
Cynosurus cristatus	0.00	20.00	6.67	4.08	2.94
Danthonia decumbens	22.22	40.00	0.00	0.00	2.94
Deschampsia cespitosa	0.00	0.00	0.00	10.20	14.71
Eleocharis palustris	0.00	0.00	16.67	8.16	0.00
Elymus repens	11.11	0.00	10.00	18.37	14.71
Equisetum fluviatile	0.00	0.00	16.67	6.12	2.94
Equisetum palustre	0.00	0.00	3.33	8.16	0.00
Festuca arundinacea	0.00	20.00	6.67	18.37	23.53
Festuca ovina	22.22	40.00	0.00	2.04	0.00
Festuca pratensis	0.00	0.00	0.00	10.20	2.94
Festuca rubra	44.44	20.00	20.00	26.53	23.53
Filipendula ulmaria	11.11	40.00	13.33	57.14	76.47
Galium boreale	33.33	0.00	0.00	2.04	11.76
Galium palustre	22.22	0.00	40.00	59.18	17.65
Galium verum	22.22	20.00	6.67	4.08	23.53
Glyceria fluitans	0.00	0.00	3.33	16.33	0.00

Flood duration category	Short				
Log Water TP Category	Very low	Medium low	Medium	Medium high	Very high
No. of relevés	*9*	*5*	*30*	*49*	*34*
Gnaphalium uliginosum	0.00	0.00	0.00	0.00	5.88
Holcus lanatus	0.00	20.00	3.33	4.08	5.88
Hydrocotyle vulgaris	0.00	40.00	6.67	22.45	17.65
Iris pseudacorus	0.00	0.00	0.00	4.08	2.94
Juncus acutiflorus	0.00	0.00	10.00	12.24	0.00
Juncus articulatus	11.11	0.00	13.33	4.08	11.76
Juncus bulbosus	0.00	20.00	0.00	0.00	0.00
Lathyrus pratensis	0.00	0.00	0.00	2.04	8.82
Leontodon autumnalis	44.44	0.00	40.00	38.78	58.82
Leontodon hispidus	11.11	20.00	6.67	0.00	5.88
Leontodon saxatilis	22.22	0.00	3.33	2.04	8.82
Linum catharticum	11.11	0.00	0.00	0.00	0.00
Lolium perenne	0.00	20.00	30.00	14.29	11.76
Lotus corniculatus	55.56	100.00	23.33	18.37	44.12
Lythrum portula	0.00	0.00	3.33	2.04	0.00
Mentha aquatica	11.11	0.00	13.33	24.49	2.94
Menyanthes trifoliata	0.00	0.00	6.67	2.04	0.00
Molinia caerulea	66.67	60.00	13.33	16.33	8.82
Mosses	22.22	0.00	30.00	4.08	5.88
Myosotis scorpioides	0.00	0.00	6.67	36.73	29.41
Parnassia palustris	33.33	20.00	3.33	0.00	0.00
Phalaris arundinacea	0.00	40.00	20.00	22.45	0.00
Phleum bertolonii	0.00	0.00	0.00	10.20	2.94
Phleum pratense	11.11	0.00	6.67	4.08	5.88
Plantago lanceolata	33.33	60.00	16.67	20.41	35.29
Plantago major	0.00	0.00	10.00	24.49	26.47
Plantago maritima	11.11	40.00	6.67	0.00	0.00
Plantago media	0.00	0.00	0.00	0.00	20.59
Poa annua	0.00	0.00	3.33	2.04	17.65
Poa pratensis	0.00	0.00	16.67	0.00	0.00
Polygonum amphibium	0.00	0.00	16.67	10.20	5.88
Polygonum aviculare	0.00	0.00	6.67	2.04	5.88
Polygonum hydropiper	0.00	0.00	0.00	2.04	2.94
Polygonum persicaria	0.00	0.00	0.00	2.04	5.88
Potentilla anserina	11.11	40.00	56.67	69.39	64.71
Potentilla erecta	55.56	100.00	13.33	22.45	29.41
Potentilla fruticosa	44.44	0.00	0.00	0.00	0.00
Potentilla reptans	0.00	0.00	16.67	14.29	26.47
Prunella vulgaris	33.33	20.00	20.00	4.08	11.76
Prunus spinosa	33.33	20.00	0.00	0.00	5.88
Ranunculus acris	11.11	0.00	3.33	10.20	2.94
Ranunculus flammula	11.11	20.00	3.33	6.12	0.00
Ranunculus repens	11.11	40.00	53.33	67.35	47.06
Rhamnus cathartica	11.11	0.00	0.00	0.00	0.00

Flood duration category	Short				
Log Water TP Category	**Very low**	**Medium low**	**Medium**	**Medium high**	**Very high**
No. of relevés	***9***	***5***	***30***	***49***	***34***
Rorippa amphibia	0.00	0.00	0.00	2.04	0.00
Rumex acetosa	11.11	0.00	6.67	30.61	32.35
Rumex crispus	11.11	0.00	23.33	20.41	14.71
Rumex obtusifolius	0.00	0.00	10.00	2.04	0.00
Sagina nodosa	0.00	0.00	0.00	0.00	14.71
Schoenus nigricans	22.22	0.00	0.00	0.00	0.00
Senecio aquaticus	0.00	0.00	6.67	10.20	2.94
Stellaria media	0.00	0.00	3.33	14.29	11.76
Succisa pratensis	66.67	100.00	10.00	0.00	0.00
Taraxacum officinale ag.	22.22	0.00	30.00	4.08	5.88
Thymus praecox	33.33	0.00	0.00	0.00	0.00
Trifolium pratense	11.11	20.00	3.33	0.00	0.00
Trifolium repens	33.33	80.00	53.33	61.22	44.12
Valeriana officinalis	0.00	0.00	6.67	0.00	0.00
Veronica catenata	0.00	0.00	3.33	2.04	0.00
Veronica scutellata	0.00	0.00	3.33	2.04	0.00
Vicia cracca	11.11	20.00	20.00	10.20	32.35
Viola persicifolia	0.00	0.00	0.00	2.04	0.00
Viola riviniana	11.11	0.00	0.00	0.00	0.00
Viola sp.	22.22	0.00	0.00	0.00	14.71

3. Medium duration flooding

Flood duration category	Medium				
Log Water TP Category	**Very low**	**Medium low**	**Medium**	**Medium high**	**Very high**
No. of relevés	***56***	***23***	***26***	***101***	***60***
Achillea ptarmica	8.93	21.74	0.00	0.00	0.00
Agrostis capillaris	0.00	0.00	0.00	2.97	3.33
Agrostis stolonifera	69.64	47.83	73.08	76.24	78.33
Alisma plantago-aquatica	0.00	0.00	3.85	3.96	1.67
Alopecurus geniculatus	0.00	0.00	3.85	5.94	1.67
Baldellia ranunculoides	7.14	0.00	0.00	0.00	0.00
Bellis perennis	0.00	17.39	3.85	0.00	0.00
Briza media	1.79	0.00	0.00	0.99	0.00
Callitriche spp	0.00	0.00	3.85	0.99	0.00
Caltha palustris	0.00	0.00	0.00	1.98	1.67
Cardamine flexuosa	0.00	0.00	0.00	4.95	0.00
Cardamine pratensis	3.57	13.04	30.77	14.85	5.00
Carex disticha	0.00	0.00	19.23	5.94	1.67
Carex elata	5.36	0.00	0.00	0.00	0.00
Carex flacca	30.36	47.83	7.69	1.98	8.33
Carex hirta	0.00	8.70	15.38	27.72	23.33
Carex hostiana	32.14	43.48	0.00	1.98	1.67
Carex nigra	50.00	30.43	73.08	49.50	48.33
Carex panicea	55.36	65.22	19.23	14.85	20.00
Carex viridula agg.	35.71	26.09	0.00	10.89	0.00
Cerastium fontanum	0.00	0.00	0.00	18.81	21.67

Flood duration category	Medium				
Log Water TP Category	Very low	Medium low	Medium	Medium high	Very high
No. of relevés	*56*	*23*	*26*	*101*	*60*
Cirsium arvense	0.00	4.35	0.00	0.00	0.00
Cirsium dissectum	21.43	26.09	7.69	0.99	1.67
Cirsium vulgare	0.00	0.00	0.00	0.00	3.33
Cynosurus cristatus	0.00	4.35	0.00	1.98	0.00
Danthonia decumbens	5.36	8.70	0.00	0.00	1.67
Deschampsia cespitosa	0.00	0.00	7.69	1.98	1.67
Eleocharis acicularis	0.00	0.00	0.00	3.96	0.00
Eleocharis palustris	17.86	4.35	26.92	15.84	13.33
Elymus repens	5.36	0.00	0.00	7.92	10.00
Equisetum fluviatile	3.57	0.00	30.77	10.89	3.33
Equisetum palustre	0.00	0.00	0.00	0.00	0.00
Festuca arundinacea	1.79	8.70	7.69	3.96	5.00
Festuca ovina	8.93	26.09	0.00	0.99	0.00
Festuca pratensis	0.00	0.00	0.00	1.98	0.00
Festuca rubra	8.93	4.35	7.69	5.94	6.67
Filipendula ulmaria	19.64	17.39	30.77	35.64	60.00
Galium boreale	12.50	0.00	0.00	10.89	25.00
Galium palustre	44.64	17.39	57.69	51.49	53.33
Galium verum	12.50	4.35	0.00	4.95	15.00
Glyceria fluitans	7.14	4.35	7.69	8.91	1.67
Gnaphalium uliginosum	0.00	0.00	0.00	4.95	0.00
Hippuris vulgaris	0.00	0.00	0.00	0.00	0.00
Holcus lanatus	0.00	4.35	0.00	1.98	0.00
Hydrocotyle vulgaris	32.14	56.52	65.38	25.74	21.67
Iris pseudacorus	0.00	0.00	3.85	2.97	6.67
Juncus acutiflorus	10.71	0.00	7.69	9.90	0.00
Juncus articulatus	23.21	17.39	26.92	11.88	10.00
Juncus bulbosus	5.36	0.00	7.69	4.95	0.00
Lathyrus pratensis	0.00	0.00	3.85	0.00	1.67
Leontodon autumnalis	55.36	47.83	46.15	45.54	36.67
Leontodon hispidus	3.57	26.09	0.00	0.00	0.00
Leontodon saxatilis	3.57	4.35	3.85	0.99	0.00
Linum catharticum	5.36	13.04	0.00	0.00	0.00
Littorella uniflora	0.00	0.00	0.00	1.98	0.00
Lolium perenne	0.00	8.70	11.54	2.97	0.00
Lotus corniculatus	35.71	56.52	23.08	32.67	46.67
Lysimachia vulgaris	0.00	0.00	3.85	3.96	5.00
Lythrum portula	1.79	0.00	0.00	2.97	0.00
Mentha aquatica	55.36	30.43	57.69	42.57	13.33
Menyanthes trifoliata	0.00	0.00	15.38	4.95	0.00
Molinia caerulea	44.64	73.91	26.92	13.86	11.67
Mosses	33.93	17.39	11.54	24.75	25.00
Myosotis scorpioides	3.57	0.00	0.00	12.87	18.33
Oenanthe aquatica	0.00	0.00	3.85	6.93	5.00
Parnassia palustris	1.79	4.35	3.85	0.00	0.00
Phalaris arundinacea	3.57	30.43	26.92	45.54	13.33
Phleum bertolonii	0.00	8.70	0.00	0.99	0.00

Flood duration category	Medium				
Log Water TP Category	**Very low**	**Medium low**	**Medium**	**Medium high**	**Very high**
No. of relevés	***56***	***23***	***26***	***101***	***60***
Phleum pratense	0.00	0.00	0.00	1.98	5.00
Plantago lanceolata	17.86	34.78	23.08	14.85	23.33
Plantago major	0.00	0.00	0.00	26.73	8.33
Plantago maritima	7.14	21.74	0.00	0.00	0.00
Plantago media	0.00	0.00	0.00	0.00	8.33
Poa annua	0.00	0.00	0.00	6.93	11.67
Poa pratensis	0.00	0.00	7.69	0.99	0.00
Polygonum amphibium	5.36	21.74	23.08	22.77	13.33
Polygonum aviculare	0.00	0.00	0.00	7.92	1.67
Polygonum hydropiper	0.00	0.00	0.00	4.95	0.00
Polygonum persicaria	0.00	0.00	3.85	5.94	5.00
Potamogeton natans	3.57	0.00	0.00	1.98	0.00
Potentilla anserina	46.43	34.78	76.92	73.27	90.00
Potentilla erecta	33.93	56.52	38.46	16.83	20.00
Potentilla fruticosa	19.64	0.00	0.00	0.00	0.00
Potentilla reptans	0.00	13.04	19.23	27.72	35.00
Prunella vulgaris	16.07	30.43	3.85	2.97	0.00
Prunus spinosa	8.93	0.00	3.85	0.00	0.00
Ranunculus acris	0.00	0.00	3.85	0.99	0.00
Ranunculus flammula	37.50	34.78	34.62	10.89	3.33
Ranunculus repens	26.79	26.09	69.23	66.34	58.33
Ranunculus trichophyllus	0.00	0.00	0.00	5.94	0.00
Rhamnus cathartica	10.71	0.00	0.00	0.00	1.67
Rorippa amphibia	0.00	0.00	0.00	2.97	3.33
Rorippa islandica	0.00	0.00	0.00	2.97	0.00
Rumex acetosa	0.00	0.00	0.00	17.82	31.67
Rumex crispus	3.57	0.00	15.38	15.84	30.00
Rumex obtusifolius	0.00	0.00	3.85	1.98	1.67
Sagina nodosa	0.00	0.00	0.00	0.00	6.67
Schoenoplectus lacustris	0.00	0.00	3.85	0.00	0.00
Schoenus nigricans	14.29	8.70	0.00	0.00	0.00
Senecio aquaticus	0.00	0.00	11.54	2.97	0.00
Sparganium emersum	0.00	0.00	0.00	0.00	0.00
Stellaria media	0.00	4.35	3.85	15.84	6.67
Stellaria palustris	0.00	0.00	19.23	0.00	0.00
Succisa pratensis	32.14	52.17	7.69	6.93	5.00
Taraxacum officinale ag.	1.79	0.00	3.85	0.00	8.33
Teucrium scordium	14.29	0.00	0.00	0.00	0.00
Thymus praecox	8.93	0.00	0.00	0.00	0.00
Trifolium pratense	1.79	13.04	0.00	1.98	3.33
Trifolium repens	19.64	43.48	19.23	41.58	28.33
Valeriana officinalis	0.00	0.00	0.00	0.00	0.00
Veronica beccabunga	10.71	0.00	0.00	0.99	0.00
Veronica catenata	0.00	0.00	0.00	2.97	0.00
Veronica scutellata	0.00	0.00	7.69	4.95	1.67
Vicia cracca	8.93	8.70	15.38	3.96	20.00
Viola canina	0.00	4.35	0.00	7.92	1.67

Flood duration category	Medium				
Log Water TP Category	Very low	Medium low	Medium	Medium high	Very high
No. of relevés	***56***	***23***	***26***	***101***	***60***
Viola persicifolia	0.00	0.00	0.00	5.94	11.67
Viola riviniana	10.71	0.00	0.00	3.96	1.67
Viola sp.	10.71	0.00	0.00	0.00	15.00

4. Long duration flooding

Flood duration category	Long				
Log Water TP Category	Very low	Medium low	Medium	Medium high	Very high
No. of relevés	***16***	***31***	***37***	***38***	***38***
Achillea ptarmica	12.50	3.23	0.00	0.00	0.00
Agrostis stolonifera	62.50	51.61	64.86	65.79	57.89
Alisma plantago-aquatica	0.00	0.00	8.11	0.00	5.26
Alopecurus geniculatus	0.00	0.00	0.00	2.63	7.89
Baldellia ranunculoides	12.50	3.23	13.51	2.63	0.00
Bellis perennis	0.00	9.68	0.00	2.63	0.00
Briza media	6.25	0.00	0.00	0.00	0.00
Callitriche sp	0.00	0.00	0.00	26.32	0.00
Caltha palustris	0.00	0.00	0.00	5.26	5.26
Cardamine flexuosa	0.00	0.00	2.70	0.00	0.00
Cardamine pratensis	0.00	0.00	27.03	15.79	2.63
Carex disticha	0.00	0.00	2.70	0.00	0.00
Carex elata	12.50	0.00	8.11	0.00	0.00
Carex flacca	31.25	29.03	0.00	0.00	0.00
Carex hirta	0.00	0.00	5.41	2.63	7.89
Carex hostiana	43.75	35.48	2.70	5.26	2.63
Carex nigra	37.50	58.06	32.43	36.84	28.95
Carex panicea	43.75	41.94	0.00	7.89	0.00
Carex viridula agg.	18.75	32.26	5.41	2.63	0.00
Cerastium fontanum	0.00	0.00	0.00	2.63	0.00
Cirsium dissectum	18.75	6.45	2.70	2.63	0.00
Cynosurus cristatus	6.25	0.00	0.00	0.00	0.00
Danthonia decumbens	6.25	0.00	0.00	0.00	0.00
Deschampsia cespitosa	0.00	0.00	0.00	2.63	0.00
Eleocharis acicularis	0.00	0.00	0.00	21.05	0.00
Eleocharis palustris	18.75	19.35	72.97	52.63	71.05
Elymus repens	0.00	0.00	2.70	0.00	0.00
Equisetum fluviatile	0.00	6.45	35.14	23.68	21.05
Festuca ovina	12.50	9.68	0.00	0.00	0.00
Filipendula ulmaria	12.50	6.45	0.00	2.63	7.89
Galium boreale	12.50	0.00	0.00	0.00	0.00
Galium palustre	62.50	41.94	59.46	28.95	52.63
Galium verum	12.50	0.00	0.00	0.00	0.00
Glyceria fluitans	12.50	3.23	27.03	21.05	18.42
Gnaphalium uliginosum	0.00	0.00	0.00	7.89	0.00
Hippuris vulgaris	0.00	3.23	18.92	2.63	0.00
Holcus lanatus	0.00	0.00	0.00	0.00	0.00
Hydrocotyle vulgaris	18.75	77.42	51.35	13.16	28.95

Flood duration category	Long				
Log Water TP Category	Very low	Medium low	Medium	Medium high	Very high
No. of relevés	*16*	*31*	*37*	*38*	*38*
Iris pseudacorus	0.00	0.00	0.00	2.63	2.63
Juncus acutiflorus	6.25	3.23	13.51	2.63	0.00
Juncus articulatus	18.75	45.16	10.81	13.16	0.00
Juncus bulbosus	6.25	9.68	5.41	10.53	0.00
Lathyrus pratensis	0.00	0.00	2.70	0.00	0.00
Leontodon autumnalis	43.75	48.39	2.70	5.26	2.63
Leontodon hispidus	12.50	16.13	0.00	0.00	0.00
Leontodon saxatilis	6.25	3.23	0.00	0.00	0.00
Linum catharticum	0.00	3.23	0.00	0.00	0.00
Littorella uniflora	6.25	9.68	10.81	0.00	0.00
Lotus corniculatus	31.25	12.90	0.00	2.63	0.00
Lysimachia vulgaris	0.00	0.00	0.00	5.26	10.53
Lythrum portula	6.25	0.00	0.00	13.16	0.00
Mentha aquatica	68.75	58.06	54.05	34.21	57.89
Menyanthes trifoliata	6.25	6.45	13.51	2.63	2.63
Molinia caerulea	31.25	54.84	8.11	2.63	0.00
Mosses	25.00	6.45	0.00	2.63	0.00
Myosotis scorpioides	0.00	0.00	2.70	7.89	28.95
Oenanthe aquatica	0.00	0.00	24.32	5.26	26.32
Phalaris arundinacea	6.25	29.03	32.43	23.68	39.47
Phleum bertolonii	6.25	6.45	0.00	2.63	0.00
Plantago lanceolata	6.25	12.90	0.00	2.63	0.00
Plantago major	0.00	6.45	0.00	0.00	0.00
Plantago maritima	6.25	6.45	0.00	0.00	0.00
Poa annua	0.00	0.00	0.00	2.63	0.00
Poa pratensis	0.00	12.90	0.00	0.00	0.00
Polygonum amphibium	0.00	12.90	51.35	50.00	68.42
Polygonum aviculare	0.00	0.00	0.00	5.26	0.00
Polygonum hydropiper	0.00	0.00	0.00	7.89	2.63
Polygonum persicaria	0.00	3.23	0.00	7.89	10.53
Potamogeton gramineus	0.00	0.00	13.51	2.63	0.00
Potamogeton natans	12.50	3.23	2.70	2.63	2.63
Potentilla anserina	56.25	54.84	51.35	47.37	65.79
Potentilla erecta	31.25	16.13	0.00	2.63	0.00
Potentilla fruticosa	6.25	0.00	0.00	0.00	0.00
Potentilla reptans	0.00	9.68	5.41	2.63	0.00
Prunella vulgaris	0.00	12.90	0.00	0.00	0.00
Prunus spinosa	12.50	0.00	0.00	0.00	0.00
Ranunculus acris	6.25	0.00	0.00	0.00	0.00
Ranunculus flammula	37.50	70.97	37.84	21.05	0.00
Ranunculus repens	25.00	19.35	32.43	28.95	44.74
Ranunculus trichophyllus	12.50	0.00	0.00	15.79	10.53
Rhamnus cathartica	6.25	3.23	0.00	0.00	0.00
Rorippa amphibia	0.00	0.00	16.22	7.89	52.63
Rorippa islandica	0.00	0.00	0.00	18.42	0.00
Rumex acetosa	0.00	0.00	0.00	0.00	0.00
Rumex crispus	0.00	0.00	0.00	5.26	5.26

Flood duration category	Long				
Log Water TP Category	Very low	Medium low	Medium	Medium high	Very high
No. of relevés	***16***	***31***	***37***	***38***	***38***
Rumex obtusifolius	0.00	0.00	0.00	15.79	0.00
Schoenoplectus lacustris	0.00	0.00	2.70	0.00	2.63
Schoenus nigricans	6.25	19.35	0.00	0.00	0.00
Senecio aquaticus	0.00	0.00	0.00	5.26	0.00
Sparganium emersum	0.00	0.00	5.41	2.63	7.89
Stellaria media	0.00	0.00	0.00	5.26	13.16
Stellaria palustris	0.00	0.00	8.11	0.00	0.00
Succisa pratensis	25.00	19.35	0.00	0.00	0.00
Taraxacum officinale agg.	0.00	9.68	0.00	0.00	2.63
Teucrium scordium	43.75	0.00	2.70	0.00	0.00
Thymus praecox	6.25	0.00	0.00	0.00	0.00
Trifolium pratense	0.00	9.68	0.00	0.00	0.00
Trifolium repens	6.25	6.45	0.00	0.00	0.00
Veronica beccabunga	31.25	0.00	0.00	0.00	0.00
Veronica catenata	0.00	0.00	8.11	0.00	0.00
Veronica scutellata	0.00	0.00	13.51	2.63	2.63
Vicia cracca	6.25	0.00	5.41	2.63	5.26
Viola canina	0.00	6.45	0.00	0.00	0.00
Viola riviniana	12.50	0.00	0.00	0.00	0.00

5. Very long duration flooding

Flood duration category	Very long				
Log Water TP Category	Very low	Medium low	Medium	Medium high	Very high
No. of relevees	***9***	***20***	***15***	***7***	***1***
Achillea ptarmica	11.11	0.00	0.00	0.00	0.00
Agrostis stolonifera	66.67	50.00	40.00	14.29	0.00
Alisma plantago-aquatica	0.00	0.00	0.00	28.57	0.00
Baldellia ranunculoides	22.22	30.00	20.00	0.00	0.00
Callitriche sp	0.00	0.00	0.00	14.29	0.00
Cardamine pratensis	11.11	0.00	13.33	14.29	0.00
Carex elata	22.22	0.00	13.33	0.00	0.00
Carex flacca	0.00	15.00	0.00	0.00	0.00
Carex hirta	0.00	0.00	6.67	0.00	0.00
Carex hostiana	0.00	20.00	0.00	0.00	0.00
Carex nigra	33.33	35.00	6.67	0.00	0.00
Carex panicea	22.22	5.00	0.00	0.00	0.00
Carex viridula agg.	44.44	25.00	0.00	0.00	0.00
Cirsium dissectum	11.11	0.00	0.00	0.00	0.00
Eleocharis palustris	44.44	20.00	53.33	71.43	0.00
Equisetum fluviatile	0.00	15.00	40.00	0.00	0.00
Filipendula ulmaria	0.00	0.00	6.67	0.00	0.00
Galium boreale	11.11	0.00	0.00	0.00	0.00
Galium palustre	33.33	15.00	33.33	0.00	0.00
Galium verum	11.11	0.00	0.00	0.00	0.00
Glyceria fluitans	22.22	20.00	33.33	14.29	0.00
Hippuris vulgaris	0.00	5.00	0.00	0.00	0.00

Flood duration category	Very long				
Log Water TP Category	**Very low**	**Medium low**	**Medium**	**Medium high**	**Very high**
No. of relevees	***9***	***20***	***15***	***7***	***1***
Hydrocotyle vulgaris	11.11	65.00	13.33	14.29	0.00
Juncus acutiflorus	0.00	5.00	0.00	0.00	0.00
Juncus articulatus	66.67	45.00	0.00	0.00	0.00
Juncus bulbosus	0.00	15.00	0.00	0.00	0.00
Leontodon autumnalis	22.22	20.00	0.00	0.00	0.00
Littorella uniflora	44.44	30.00	0.00	0.00	0.00
Lolium perenne	0.00	0.00	0.00	0.00	0.00
Lotus corniculatus	11.11	0.00	0.00	0.00	0.00
Mentha aquatica	77.78	65.00	66.67	71.43	100.00
Menyanthes trifoliata	0.00	0.00	13.33	0.00	0.00
Molinia caerulea	11.11	15.00	0.00	0.00	0.00
Myosotis scorpioides	0.00	0.00	0.00	0.00	100.00
Oenanthe aquatica	0.00	30.00	13.33	57.14	100.00
Phalaris arundinacea	0.00	15.00	6.67	0.00	0.00
Polygonum amphibium	11.11	5.00	60.00	100.00	100.00
Polygonum persicaria	0.00	5.00	13.33	0.00	0.00
Potamogeton gramineus	0.00	0.00	26.67	0.00	0.00
Potamogeton natans	11.11	35.00	20.00	0.00	0.00
Potentilla anserina	11.11	50.00	26.67	14.29	0.00
Potentilla erecta	11.11	0.00	0.00	0.00	0.00
Potentilla fruticosa	11.11	0.00	0.00	0.00	0.00
Prunus spinosa	11.11	0.00	0.00	0.00	0.00
Ranunculus flammula	66.67	65.00	40.00	0.00	0.00
Ranunculus repens	11.11	35.00	0.00	14.29	0.00
Rhamnus cathartica	11.11	0.00	0.00	0.00	0.00
Rorippa amphibia	0.00	5.00	6.67	14.29	0.00
Schoenoplectus lacustris	11.11	5.00	33.33	0.00	0.00
Schoenus nigricans	11.11	0.00	0.00	0.00	0.00
Sparganium emersum	0.00	10.00	6.67	28.57	0.00
Stellaria palustris	0.00	0.00	6.67	0.00	0.00
Succisa pratensis	11.11	0.00	0.00	0.00	0.00
Teucrium scordium	11.11	0.00	0.00	0.00	0.00
Thymus praecox	11.11	0.00	0.00	0.00	0.00
Veronica beccabunga	11.11	0.00	0.00	0.00	0.00
Veronica catenata	0.00	0.00	0.00	28.57	0.00
Viola canina	11.11	0.00	0.00	0.00	0.00

Chapter 8. Aquatic Invertebrate Communities

K. Irvine & G. Porst

Box sampling for aquatic invertebrates, Termon.

Photo: H. Cunha Pereira

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8.1 Introduction

The importance of turloughs for nature conservation is well established, reflected in their designation as a priority habitat under the European Habitats Directive (92/43/EEC). Under the Water Framework Directive (2000/60/EC) (WFD), they have been classified as a *Water Dependent Habitat.* Turloughs provide habitat for a variety of rare terrestrial and aquatic invertebrates, and those dependent on the aquatic-terrestrial ecotone (e.g. Ali *et al*., 1987; Bilton; 1988; Reynolds 2000, 2003; Sheehy Skeffington *et al*., 2006). There has, however, been hardly any work on assessing turlough aquatic invertebrate spatial or temporal patterns, or community structure across a range of anthropogenic pressures. Within standing waters there is a continuing challenge to assess response of invertebrate communities to such pressures, against a background of seasonal variability and, to meet the demands of the WFD, in relation to a *reference condition.* As an important habitat protected by the Habitats Directive there is need for an integrated strategy to protect both terrestrial and aquatic phases, requiring understanding of ecology both within the turlough and the interaction with the ground water. This, then, leads to a need to harmonise the requirements of both Directives in order to guide *programmes of measures* that meet targets for both enhancement of biodiversity and to meet the environmental targets under the WFD. The invertebrate part of this NPWS funded project *Assessing the Conservation Status of Turloughs,* addressed some of the fundamental gaps in our knowledge of aquatic invertebrates in turloughs. The work was conducted through one PhD studentship (Porst, 2009). The work set out to:

- Identify invertebrate communities, and relative abundance of taxa, across habitats and sites, and turlough types
- Provide comprehensive taxa lists and assessment of biodiversity importance
- Assess response of invertebrate communities to defined pressures, of hydrology and nutrient enrichment
- Identify the feasibility of different invertebrate taxa to provide meaningful monitoring tools.
- Identify important seasonal trends in invertebrate communities
- Recommend measures for the protection and enhancement of invertebrate communities.

The project sampled both littoral and open water invertebrates but, owing to time for sample processing, concentrated on the littoral invertebrates as a priority. General understanding of plankton communities in standing water is considerably more advanced than that of the littoral invertebrates. There is also a greater policy driven link with the WFD in concentrating on the littoral communities, which are sampled routinely across Irish lakes as part of the WFD implementation. The thesis has, so far, led to two peer reviewed papers (Porst and Irvine, 2009 a, b), which addressed, respectively, invertebrate communities across a range of nutrient concentrations sampled with a box sampler, and the variability of macroinvertebrate communities across the turloughs in contrasting habitats. Reported here is a summary of the main findings from the work, roughly following the layout of Porst (2009), and covering the goals of the project, indicated in bullet points above. Sampling protocols and site selection were agreed through project internal working groups and project steering meetings.

8.2 Methods

8.2.1 Site Selection and Sampling Methods

The invertebrate sampling covered the 22 turloughs, selected to represent the hydrological and geographical gradient described in *Chapter 2: Site Selection*. Samples for water chemistry followed protocols described in *Chapter 4: Turlough Water Chemistry and Algal Biomass*, section 4.2. Estimates of hydroperiod were based on detailed water level records and defined as the time each turlough was inundated during one year, as described in *Chapter 3: Hydrology*, section 3.8. A turlough was defined as 'dry' when the hydrological "diver", which was placed at the lowest point in each turlough, clearly identified a dry spell (no water) or when only a minimal amount of water e.g. a little puddle or water in swallow hole was remaining. Multimodal flooding events were factored in the calculations to give a total number of days of inundation. Hydrological areal reduction rate was calculated for a subset of turloughs with the purpose to provide a metric for the speed at which water levels change in each turlough. It was calculated as the average rate of decrease in planar flooded area between the time of maximum and minimum areal inundation. The maximum areal inundation was defined as the maximum stage and volume of each turlough, whereas the minimum areal inundation coincided with the drying of the turlough, or, if a permanent water body was present throughout the year, the surface area of the permanent water body was used (dA/dT m^2/Day where dA= maximum areal inundation and dT=time between maximum areal inundation and emptying of turlough/non permanent water body).

Sampling of invertebrates was carried out during two successive flooding seasons (2006/2007 and 2007/2008). Macroinvertebrates were collected from the littoral zone using either a box sampler after O'Connor *et al.* (2004), or by sweeping the substrate with a 1 mm mesh sized standard Freshwater Biological Association (FBA) pond net. The box sampler (50 cm long x 40 cm wide x 50.5 cm high) was created by cutting out the bottom of a sturdy plastic storage box. The box was placed over respective sampling sites and organisms trapped within the box removed with a small net with a mesh size of 1mm, sieved, and washed into collection bottles. Sweep netting comprised sampling for invertebrates within the accessible area of each turlough proportional to habitat availability, modified after Biggs *et al.* (1998). The sweep net samples comprised a three-minute sampling time, which was subdivided proportionally to each habitat's availability. Single habitat sampling reduces variance and increases power for detecting change among sites (Resh & Jackson, 1993**;** Pinel-Alloul *et al.*, 1996; Johnson *et al*. 2004; White and Irvine, 2003; Tolonen *et al*., 2001). For the assessment of maximum species diversity, however, a more intensive sampling approach is required (Della Bella *et al*., 2005). Comparability of the different methods was, however, assessed by means of hierarchical cluster analysis. Clustering of turloughs sampled in April 2007 using the two different sampling strategies (multi-habitat s single-habitat box sampling and sweep net) resulted in similar grouping of turloughs, demonstrating reliable comparability of methods (Figure 8.1 b and Figure 8.7, respectively) (Porst, 2009).

In April 2007, samples of "open-water" cladocerans and littoral chydorids were collected from twenty turloughs (insufficient water or access difficulties prevented sampling from Blackrock and Turloughmore). In every turlough, samples were collected using a 60 µm mesh size zooplankton net collecting three open-water cladoceran zooplankton samples by horizontal hauls of the net from the shore at three random locations. Open-water cladoceran zooplankton samples were pooled, washed into collection bottles and preserved with 90% IMS for later identification in the laboratory. At all twenty turloughs, separate sampling for chydorids was carried out with the use of a perspex tube (diameter 5.5 cm, volume 2276 cm^2) after Irvine *et al.* (1989). All available habitats in each turlough were sampled proportional to their abundance in accessible areas as for the collection of macroinvertebrate sweep net samples. For every chydorid sample a total of 25 l was collected by rapidly lowering the perspex tube to the substratum, sealing the end with a rubber ball and collecting the content in a container. The sample was subsequently sieved through a 60 µm mesh size sieve, and washed into collection bottles. Separate samples of cladoceran zooplankton and chydorids were identified and enumerated in the laboratory. Where subsampling of samples was necessary no less than 20% of each sample was analysed following methods by de Eyto *et al.* (2003). All samples, from littoral or open water were preserved *in situ* in 90% IMS.

Macroinvertebrates were identified using the keys by Ashe *et al*. (1998), Brooks and Lewington (1997), Edington and Hildrew (1995), Elliott and Mann (1979), Elliott *et al*. (1988), Fitter and Manuel (1986), Friday (1988), Gledhill *et al.* (1993), Holland (1972), Hynes (1977), Macan (1977), Miller (1996), Nilsson (1997), Reynoldson and Young (2000), Richoux (1982), Savage (1989, 1999) and Wallace *et al*. (2003). Macroinvertebrates were identified to the lowest taxonomic level, generally species. Diptera and Trichoptera pupae, Hydrachnidia, Ostracoda and Oligochaeta were, however, identified to order and all other Diptera and Collembola to family level only. Random samples were identified by an independent individual to ensure quality assurance of identification. Identifications of rare species were verified by established experts. Cladoceran zooplankton and separate chydorid samples were identified using keys by Scourfield and Harding (1966) and Amoros (1984). Quality of identification was assured by cross-identification of random samples by established experts.

8.2.2 Details of Individual Studies and Statistical Analysis

8.2.2.1 Macroinvertebrate and Cladoceran Zooplankton Communities

Table 8.1 List of turloughs studied, their ID, TP concentrations per sampling month, number of habitats sampled in each sampling month and respective hydroperiods.

Turlough	*ID*	*TP ($\mu g\ L^{-1}$)* [1]		*Nr of habitats sampled*		*Hydroperiod (days)* [2]
		Nov 06	*Apr 07*	*Nov 06*	*Apr 07*	
Ardkill	1	34	98	2	1	296
Ballindereen	2	7	5	3	2	239
Blackrock	3	56	--	1	--	196
Brierfield	4	14	15	1	2	331
Caherglassan	5	46	38	1	1	365
Caranavoodaun	6	12	11	1	1	228
Carrowreagh	7	56	36	1	1	220
Coolcam	8	9	27	1	1	365
Croaghill	9	11	14	1	1	365
Garryland	10	21	12	1	1	221
Kilglassan	11	16	18	1	1	365
Knockaunroe	12	1	3	2	2	231
Lisduff	13	5	8	1	2	256
Lough Aleenaun	14	23	31	1	1	194
Lough Coy	15	62	25	1	1	365
Lough Gealain	16	5	2	2	2	230
Rathnalulleagh	17	62	43	1	2	214
Roo West	18	4	8	1	1	231
Skealoghan	19	14	20	1	1	252
Termon	20	4	11	2	1	365
Tullynafrankagh	21	16	18	4	2	365
Turloughmore	22	36	--	1	--	139

The 22 turloughs were sampled for littoral macroinvertebrates in November 2006, and 20 were sampled in April 2007 (Table 8.1). In April, Turloughmore and Blackrock had already dried out. Samples were collected using the FBA net and a proportional multiple habitat approach modified after Biggs *et al*. (1998). The sampling was carried out about one month after flooding of turloughs (autumn sampling) had started and again before water receded in April 2007 (spring sampling). Samples were, subsequently, sieved through a 500 μm mesh before preserving in 90% industrial IMS, for later sorting and identification. Where samples had a very high abundance of macroinvertebrates they were split prior to sorting and taxonomic identification following methods by Donohue (2008). Only the spring samples were enumerated for the zooplankton and chydorid samples, as it was considered that this would be the most informative time for the effect of nutrient status on the communities.

Relationships of macroinvertebrate taxon richness and log-transformed abundance to log-transformed TP concentrations and number of habitats sampled were assessed using Pearson product-moment correlations. Spearman rank-order correlation investigated the influence of hydroperiod on macroinvertebrate taxon richness and abundances, respectively. Average values for samples from 22 turloughs (22 sampled in November 2006 and 20 sampled in April 2007) were used in the analysis. Total abundance recorded in Turloughmore was excluded from the analysis owing to its extreme outlier character. Relationships of cladoceran zooplankton and log-transformed chydorid taxon richness and respective log-transformed abundances, to macroinvertebrate taxon richness and log-transformed TP were investigated using Pearson product-moment correlations. Correlation of cladoceran zooplankton and chydorid taxon richness and abundances with hydroperiod of turloughs was, furthermore, investigated using Spearman rank-order correlation. TP concentrations recovered from Ardkill were excluded from the analysis owing to its strong outlier character. Data normality was verified using the Shapiro Wilk test and homogeneity of variance checked with the Leven's test before choosing parametric or nonparametric statistical analysis.

Spearman rank-order correlation tested the relationships between environmental variables (TP, hydroperiod and number of habitats sampled) and the respective abundances of Amphipoda, Aranea, Bivalvia, Coleoptera, Diptera, Ephemeroptera, Gastropoda, Heteroptera, Hirudinea, Hydrachnidia, Isopoda, Lepidoptera, Odonata, Oligochaeta, Ostracoda, Plecoptera, Trichoptera and Turbellaria in the two different seasons.

To identify the similarities of communities among sampling season, the similarity percentage routine SIMPER (PRIMER® 6) was carried out. This method decomposes Bray-Curtis similarities among all pairs of samples, within *a priori* defined groups (in this case individual turloughs), into percentage contributions from each species to the respective similarities (Clarke & Warwick, 2001). Dissimilarities of seasonal turlough samples of each individual turlough were computed using the same method, in order to investigate changes in the macroinvertebrate community of each turlough with sampling season. Cluster Analysis and Multi-Dimensional Scaling (MDS) ordination on log (x+1) transformed total abundance macroinvertebrate data assessed similarity of samples. Cluster Analysis and MDS were based on a Bray-Curtis similarity matrix, with clusters formed using the average group linkage method. The similarity profile (SIMPROF) permutation test, which tests for statistically robust clusters of *a priori* undefined groups (Clarke & Gorley, 2006) was incorporated into the Cluster Analysis.

Canonical Correspondence Analysis (CCA) was performed to examine the ability of the environmental variables TP, season, number of habitats sampled and hydroperiod to explain the variability present in the macroinvertebrate community (CANOCO Version 4.5). CCA is a non-linear eigenvector ordination technique in which the axes are constrained to be linear combinations of the measured environmental variables. The ordination was performed on log(x+1) transformed macroinvertebrate abundance data using automatic forward selection of the environmental variables to obtain the conditional effects for each variable and down-weighting of rare species. When selecting the down-weighting option in CANOCO version 4.5, species with a total frequency less than 20% of the maximum recorded total frequency are weighted in proportion to their frequency, divided by 20% of the maximum recorded total frequency (ter Braak & Šmilauer, 2002). Treating each variable as the sole predictor variable in a first step, all environmental variables were ranked on the basis of the variance they explained separately, thus representing marginal effects. The explanatory effect of each variable was evaluated for its significance using Monte Carlo permutation tests with 999 permutations.

To assess the similarity of macroinvertebrate sample ordinations of different seasons, turlough samples were ranked according to their arrangement in the 2D CCA ordination created using the log (x+1) transformed abundance macroinvertebrate data. Turlough ranks of each season were correlated using Spearman rank-order correlation.

8.2.2.2 Spatial Variability of Macroinvertebrates

Variability *within* and *between* turloughs was investigated across six turloughs which were sampled more intensively, using 5 replicate samples. In two of these, Brierfield and Lisduff, five replicate samples from each of two dominant habitat types (submerged grassland <10 cm height, and grassland emerging over the water surface >30 cm) were collected in April 2007 using the box sampler. Both habitats were sampled at 30-40 cm water depth in each turlough, with habitats in Brierfield dominated by the emergent *Glyceria fluitans* and in Lisduff by the submerged *Agrostis stolonifera*. Within-habitat variability of macroinvertebrate assemblages was studied further across four submerged grassland habitat sites in four additional turloughs in spring 2008. Blackrock, Roo West and Termon were sampled in April 2008. Owing to high water levels preventing access in April, Caranavoodaun was sampled in May 2008. In order to see if the varying sampling times had an influence on results, Termon was sampled additionally in June 2008.

Statistical analysis tested for between-habitat (Brierfield and Lisduff) and within-habitat differences (Blackrock, Caranavoodaun, Roo West and Termon). A one-way analysis of variance (ANOVA) was used to test for significant differences in taxon richness between habitats in Lisduff and Brierfield and between the four grassland habitat sites sampled in the four turloughs Blackrock, Caranavoodaun, Roo West and Termon. All replicate samples were included in the analysis (n=5 per habitat and per site in each turlough). The degree of variability of taxon richness within replicate samples was estimated by the coefficient of variation (CV):

$$CV = s.d. / \overline{x} * 100$$

Multivariate analysis using hierarchical cluster analysis, non-metric multidimensional scaling (MDS), and SIMPROF, tested for similarities of community structure. Differences in community composition among habitats were, furthermore, analyzed using the similarity percentages routine SIMPER (PRIMER® 6). By decomposing Bray-Curtis similarities among all pairs of samples, within defined groups (in this case habitats in each turlough), SIMPER computes the percentage contributions of individual species to respective group differences (Clarke & Warwick, 2001).

8.2.2.3 Comparison of Littoral Invertebrates of Eight Turloughs Across a Nutrient Gradient and with Varying Hydroperiod

To study the association of invertebrate communities to variables indicative of nutrient state and to hydroperiod, five replicate samples were collected from the dominant habitat type, submerged grassland, using the box sampler from eight turloughs (Table 8.2). Differences among turloughs were tested for with one-way analysis of variance (ANOVA) on total abundance and taxon richness. The relationship between nutrient status and invertebrate communities was assessed using Pearson product–moment correlation (comparing, respectively, mean abundance and log-transformed mean taxon richness, with log-transformed TP and TN concentrations) and Spearman rank-order correlation to compare, respectively, mean abundance and log-transformed mean taxon richness with turbidity, chlorophyll a, conductivity and hydroperiod. Data normality was verified using the Shapiro Wilk test and homogeneity of variance checked with the Leven's test before choosing parametric or nonparametric statistical analysis. Cluster analysis and multi-dimensional scaling (MDS) ordination on log (x+ 1) transformed total abundance macroinvertebrate data assessed similarity of samples. Hierarchical cluster analysis, MDS and SIMPROF tested for similarities across communities. Contributions of individual species to differences to the grouping of clusters or MDS plots was calculated using the similarity percentages routine SIMPER in PRIMERs 6 (Clarke & Warwick, 2001).

Table 8.2 Summary of eight turloughs sampled with a box sampler and concentrations of key water chemistry variables and hydroperiod.

Turlough	*TP ($\mu g\ L^{-1}$)*	*Turbidity (NTU)*	*Chl a ($\mu g\ L^{-1}$)*	*TN ($mg\ L^{-1}$)*	*Conductivity ($\mu S\ cm^{-1}$)*	*Hydroperiod (weeks/year)*
Ballindereen	5	1.41	1.54	0.081	405	34
Brierfield	15	2.2	1.06	0.192	393	46.5
Caherglassan	38	4.53	13.52	0.512	388	52
Caranavoodaun	11	4.05	1.31	0.231	461	24
Kilglassan	18	3.25	1.95	0.062	357	52
Lisduff	8	1.96	0.78	0.964	393	36
Roo West	8	1.57	1.27	0.042	307	30
Termon	15	1.69	4.35	0.072	418	52

8.2.2.4 The importance of Hydrological Regime for Seasonal and Inter-annual Patterns of Macroinvertebrates in Turloughs

We used the four most intensively studied turloughs to investigate the effect of hydrological regime on the seasonal pattern of invertebrate communities. Blackrock has a short hydroperiod and high areal reduction rate (dA/dT (m^2/Day), and high nutrient concentrations. It represents the most disturbed turlough of the subset studied. Caranavoodaun has an intermediate hydroperiod, and a lower areal reduction rate. Roo West has an areal reduction slightly faster than Caranavoodaun, but with a similar hydroperiod and nutrient status. Termon with the lowest areal reduction rate of this sub-set of turloughs, can be considered the most hydrologically stable of the four, maintaining some standing water throughout the year. Its nutrient concentrations are a little higher than those of Caranavoodaun and Roo West.

From December 2007 to April 2008, aquatic macroinvertebrates were sampled monthly with the box sampler. Additionally, in order to test for inter-annual variation in invertebrate succession, samples collected from Termon in November, January, April and June over the 2006/2007 flooding season were included in the analysis, as were additional samples collected from Caranavoodaun in May 2008 and Termon in June 2008. On each sampling occasion, five well-spaced replicate samples were collected from the dominant habitat, submerged grassland, within the accessible and wadable zone. Exact sampling locations, therefore, varied with water level.

The effect of time on macroinvertebrate species richness was tested using repeated measures analysis of variance (RM ANOVA) in SPSS® (version 15, IBM Company, Chicago, Illinois) on synchronized, consecutive sampling data from December 2007 - April 2008. As RM ANOVA is restricted to a balanced design, data from May and June 2008 could not be included in this analysis. Separate analysis was carried out dividing taxa into *permanent* and *ephemeral* taxa after Williams (1997) and Lahr (1997). These terms are used to categorise autecological traits of colonisation, persistence and dispersal. *Permanent* taxa comprised mainly crustaceans (Amphipoda and Isopoda), bivalves, gastropods, flatworms, leeches, ostracods, oligochaetes and collembolans, and can be considered passive dispersers. *Ephemeral* taxa comprised primarily coleopterans, trichopterans, dipterans, hemipterans, ephemeropterans and Odonata species, and can be considered active dispersers. Least significant difference (LSD), with Bonferroni corrections was used for *post hoc* testing. A one-way analysis of variance (one-way ANOVA) tested for significant differences among average seasonal taxon richness of turloughs. Variability of taxon richness within replicate samples was estimated by the coefficient of variation (CV).

The distance-based linear model DISTLM (PRIMER® version 6 with PERMANOVA +, PRIMER-E Ltd, Ivybridge) was used to analyse the relationship between the multivariate species data set and hydroperiod and total phosphorus (TP) concentrations of turloughs (Anderson *et al*. 2008) using the *Best* selection procedure with 9999 permutations in combination with the *BIC* criterion. DISTLM is based on a distance-based redundancy analysis (dbRDA) that tests the hypothesis of no relationship between macroinvertebrate community structures and environmental variables. The analysis was based on Bray-Curtis similarities on log(x+1) transformed total abundance data.

To assess seasonal and inter-annual variation within macroinvertebrate assemblages, similarity of samples was assessed using log(x+1) transformed total abundance macroinvertebrate data for Multi-Dimensional Scaling (MDS) ordination based on a Bray–Curtis similarity matrix. Different groups observed in the MDS-ordination were used as grouping factor (three turlough phases: filling, aquatic and drying phase) for a subsequently applied two-way crossed analysis of similarities (factors phase and turlough) (ANOSIM; PRIMER® version 6), which tested for differences among observed groups using 9999 permutations. The similarity percentages routine SIMPER in PRIMER® 6 was used to identify taxa contributing most to dissimilarities of each grouping factor (Clarke & Warwick 2001).

8.3 Results

8.3.1 Macroinvertebrate and Cladoceran Zooplankton Communities Sampled across 22 Turloughs.

8.3.3.1 Macroinvertebrates

Total number of littoral macroinvertebrate taxa found in the sweep samples ranged from 7 (Rathnalulleagh) to 34 (Skealoghan) in November 2006, and from 9 (Carrowreagh) to 36 (in both Skealoghan and Tullynafrankagh) in April 2007. In April the Carrowreagh taxa were dominated (68%) by chironomids, but in November 2006, when 19 taxa were found, the dominating group was *Agabus* larvae with only four chironomids found in the sample. Carrowreagh is one of the more nutrient enriched turloughs (TP: 56 and 36 μg l^{-1} in November 2006 and April 2007, respectively). Rathnalulleagh, which had the lowest taxa richness in November 2006, is also eutrophic (TP: 62 and 43 μg l^{-1} in November 2006 and April 2007, respectively). Although 19 taxa were found in Rathnalulleagh in April 2007, these were dominated (44%) by oligochaetes. Other eutrophic turloughs with high dominance of particular taxa in November were Blackrock (ostracods) and Caherglassan (*Agabus* larvae and ostracods), and in April 2007, Ardkill (oligochaetes), and Coy (ostracods). However, no simple relationship with the taxa groups (chironomids and oligochaetes) often associated with eutrophic conditions was evident across all turloughs, with some lower nutrient (<20 µg TP l^{-1}) sites (Brierfield, Coolcam, Termon, Tullnafrankagh) also having high abundance of one or both of these groups. Lough Allenaun, with an intermediate nutrient status (TP: 23 and 31 µg l^{-1} in November 2006 and April 2007, respectively) was dominated (85%) by chironomids in November 2006 and by oligochaetes (61%) in April 2007. Overall there was no statistical relationship ($P>0.05$) found between taxa richness and TP, but there was with hydroperiod (Spearman $r=0.66$; $P<0.001$; $n=22$). There were, however, negative correlations found between TP and abundances of Trichoptera ($r = -0.68$, $P<0.01$) in November 2006 and with Aranea ($r=-0.46$, $P<0.5$) and Odonata ($r=-0.44$; $P<0.5$) in April 2007, and positive correlations with ostracods on both dates (November $r = 0.50$; April: $r = 0.51$, both $P<0.05$).

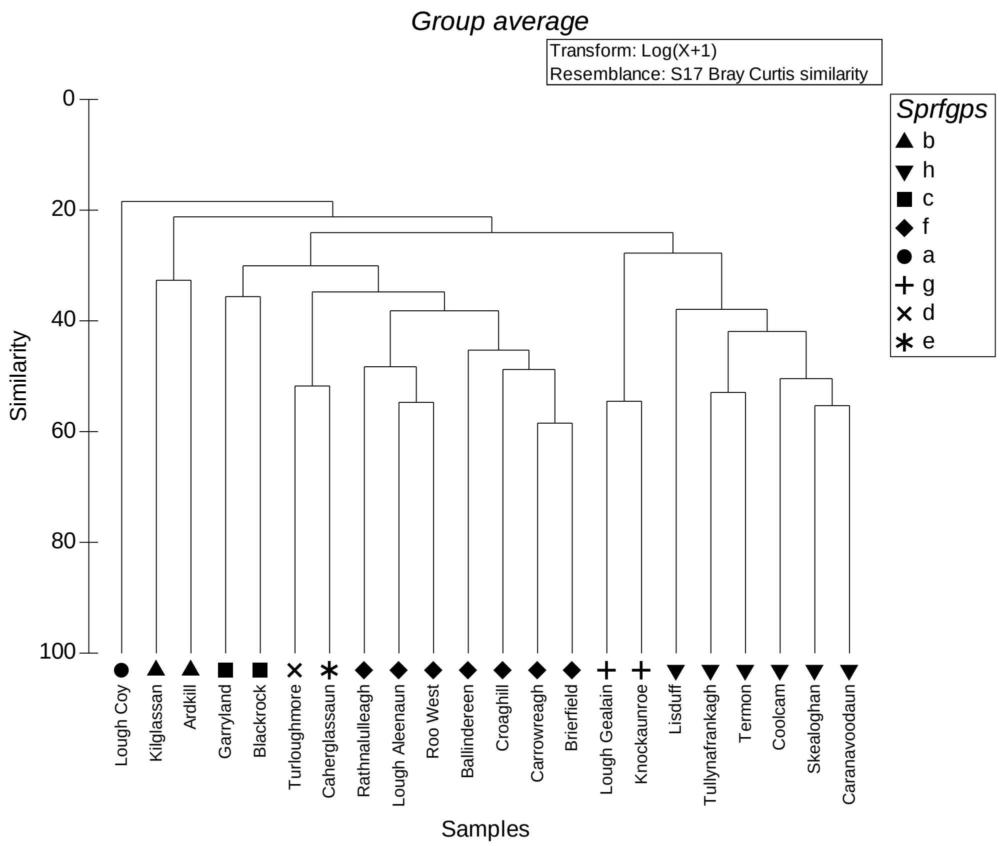
The similarity percentage routine SIMPER identified overall similarity of turloughs sampled in November 2006 to be 27.6% and in April 2007 32.3%. Turlough macroinvertebrate communities differed between sampling months by 76.4%, suggesting a strong seasonal influence on macroinvertebrate community structure, which is investigated further in section 8.3.4. While macroinvertebrates contributing strongly to overall turlough similarity in November 2006 were Ostracoda sp., *Galba truncatula* and *Agabus* sp. larvae (17.6%, 12.4% and 12.1% contribution to overall similarity of samples, respectively), macroinvertebrates playing a major part in overall similarity among turloughs in April 2007 were Chironomidae sp., *Agabus* sp. larvae, Diptera pupae and Oligochaeta sp. (17.7%, 14.9%, 8.6% and 8.5% contribution to overall similarity of samples, respectively).

Hierarchical cluster analysis revealed a tendency of similar groupings of turloughs, clustering the majority of turloughs in similar significant groups identified with the similarity profile test (SIMPROF) in both sampling months (Porst, 2009). SIMPROF identified eight and five significantly different groups of turloughs in November 2006 and April 2007, respectively. Invertebrates communities from turloughs sampled in April 2007 were more similar to each other compared with November 2006 (last cluster at 23.8% similarity and 18.4%, respectively) corresponding with results from the SIMPER analysis (Figure 8.1 a & b). Clustering of turloughs sampled in April 2007 using the two different sampling strategies (multi-habitat sweep net and single-habitat box sampling) resulted in similar grouping of turloughs suggesting that variation of macroinvertebrate community structure within turloughs is nested in among-turlough variation (Figure 8.1 b and Figure 8.7).

Table 8.3 Summary statistics of CCA ordination on macroinvertebrate log(x+1) abundances data, using automatic forward selection of four environmental variables (n=42).

	Axis 1	*Axis 2*	*Axis 3*	*Axis 4*	*Total inertia*
Eigenvalues	0.275	0.156	0.104	0.068	
Species-environment correlations	0.908	0.872	0.865	0.826	
Cumulative percentage variance					
of species data	8.4	13.1	16.3	18.4	
of species-environment relation	45.7	71.5	88.7	100	
Total inertia					0.603

a)



b)

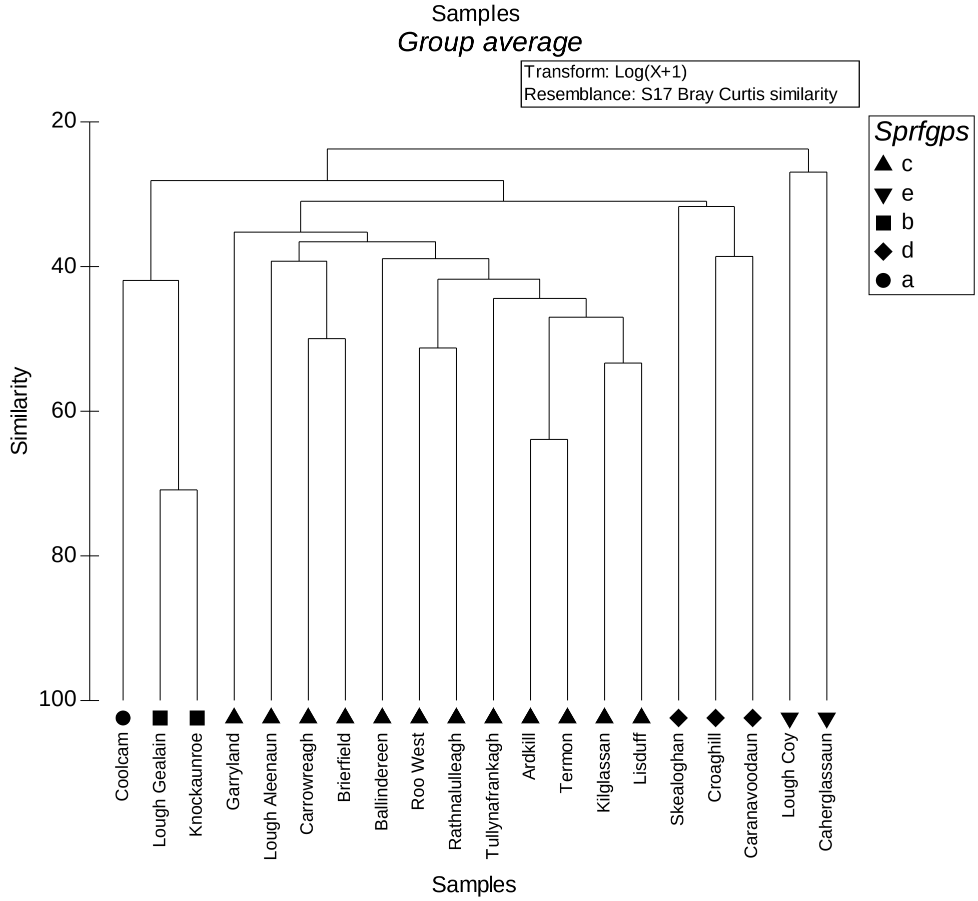


Figure 8.1 Hierarchical cluster analysis dendrogram of macroinvertebrate species log(x+1) transformed total abundance data of a) 22 turloughs sampled in November 2006 and b) 20 turloughs sampled in April 2007.

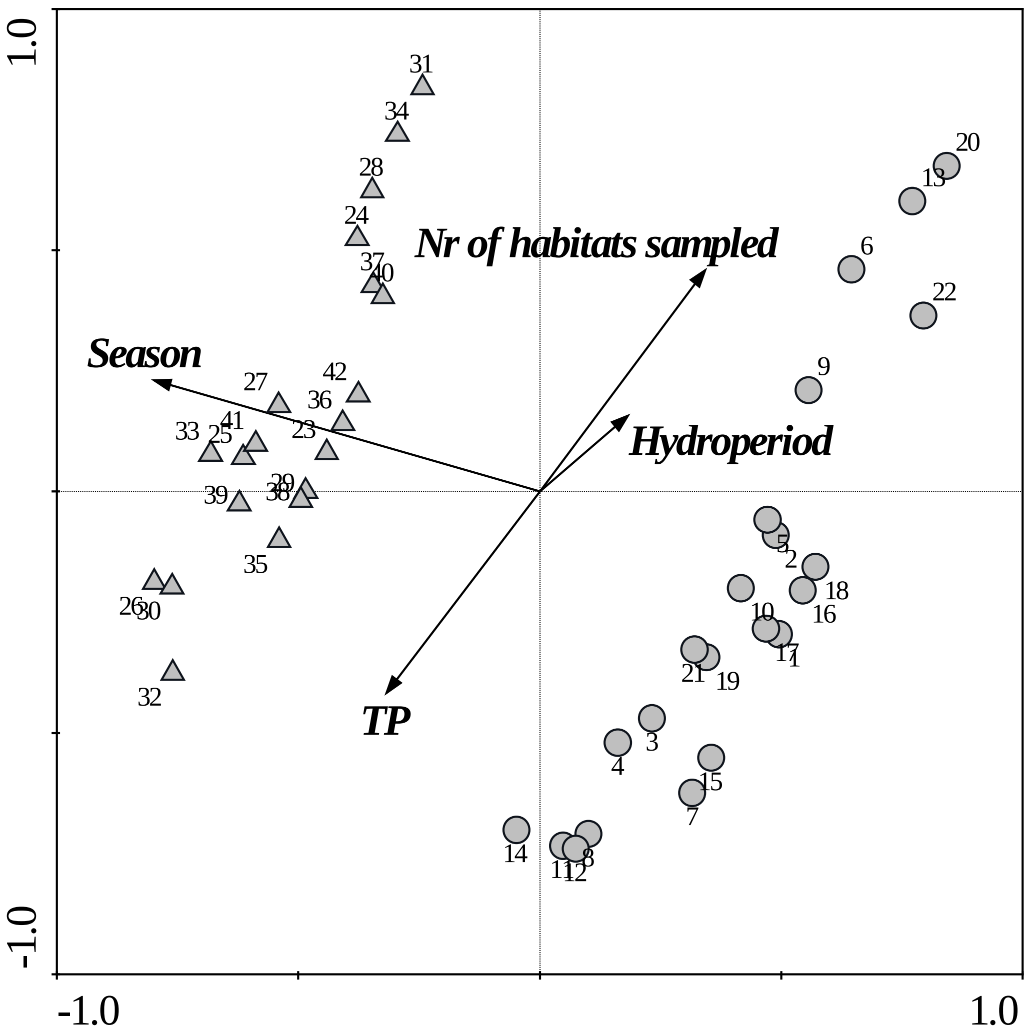


Figure 8.2 Axes 1 and 2 of the CCA ordination generated using automatic forward selection of four environmental variables and log(x+1) transformed macroinvertebrates abundances data (n=42). Circles are representing macroinvertebrate samples collected in November 2006, triangles those collected in April 2007.

The four environmental variables measured (season, number of habitats sampled, TP, and hydroperiod) could explain 60% of the total variability in the macroinvertebrate community matrix, with axes 1 and 2 of the ordination explaining 72% of the variance present in the biological data using canonical correspondence analysis (CCA) (Table 8.3). Monte Carlo permutation tests indicated that the environmental variables season, number of habitats sampled, and TP were significant in explaining some of the variation in the macroinvertebrate log(x+1) abundance data (all $P<0.01$), whereas hydroperiod did not improve significantly the explanation of the variability in the biological data set ($P=0.126$, $F=1.22$). The length and direction of the arrows in the 2D CCA ordination indicate the gradients and the relative importance of the environmental variables in explaining the variation in the biological community (Figure 8.2). The results of the automatic forward selection of the four environmental variables are summarized in Table 8.4. The marginal effects (the percentage variance explained by each environmental variable when used as sole predictor) indicated that season explained the most variation in the biological data set. The conditional effects show the environmental variables in order of their inclusion in the model, together with the additional variance each variable explains at the time it was included (Lambda-A), its significance (P-value) and its test statistic (F-value). Spearman rank-order correlation of turlough sample ranks of the two sampling seasons according to their arrangement in the CCA ordination (Figure 8.2) showed that the alignment of turlough samples to each other was similar among seasons (R=0.732, P<0.001, n=42), concurring with trends seen in cluster dendrograms.

Table 8.4 Summary of automatic forward selection in CCA ordination using log(x+1) transformed macroinvertebrate abundance data and four environmental variables (n=42).

Marginal Effects		***Conditional Effects***			
Variable	Lambda1	Variable	Lambda A	P	F
Season	0.26	Season	0.26	0.001	3.38
Nr habitats	0.15	Nr habitats	0.13	0.006	1.88
TP	0.15	TP	0.12	0.004	1.65
Hydroperiod	0.10	Hydroperiod	0.09	0.126	1.22

8.3.3.2 Cladocerans

Combining the results from the sampling with the net and tube, a total of 29 cladoceran species were found in the 20 turloughs sampled in April 2007. Recorded taxa included common species such as *Chydorus sphaericus* and *Daphnia pulex*, to rare species such as *Alona rectangular* and *Alonopsis elongata* found only in Croaghill and Lough Gealain, respectively. While some taxa such as *Alona rectangula*, *A. rustica*, *Alonella excisa* and *Alonopsis elongata* only occurred in turloughs with low to medium TP concentrations, the more common *Chydorus sphaericus* and *Daphnia pulex* were found across the whole range of TP concentrations (Table 8.5).

A significant positive correlation was found between log-transformed TP and both log-transformed cladocerans collected with the net and chydorid abundance from the tube samples (r=0.529, P<0.05; and r=0.498, P<0.05, respectively; n=19 in both cases), using Pearson product-moment correlation. A negative correlation was found between net-collected cladoceran taxon richness and log-transformed TP (Pearson product-moment correlation: r=-0.506, P<0.05). Spearman rank-order correlation indicated a positive relationship of both net-collected cladoceran zooplankton and tube-collected chydorid abundance with turlough hydroperiod (r=0.556, P<0.05 and r=0.489, P<0.05, respectively; n=20 in both cases).

Table 8.5 Summary of cladoceran taxa (presence indicated with 1) found in 20 turloughs in April 2007 combining records from open water zooplankton and chydorid sampling protocols. Order of turloughs is ranked according to total phosphorus (TP) concentrations. Taxa with an asterix can be considered rare.

	Lough Gealain	Knockaunroe	Ballindereen	Roo West	Lisduff	Caranavoodaun	Termon	Garryland	Croaghill	Brierfield	Tullynafrankagh	Kilglassan	Skealoghan	Lough Coy	Coolcam	Lough Aleenaun	Carrowreagh	Caherglassan	Rathnalulleagh	Ardkill
Acroperus angustatus			1	1																1
Acroperus harpae			1												1					1
Alona affinis	1	1	1	1		1	1	1	1			1	1		1	1	1	1		1
Alona excisa			1			1							1							
Alona guttata			1			1	1	1												1
Alona intermedia			1						1											
Alona quadrangularis								1		1			1	1						
*Alona rectangula**									1											
Alona rustica			1	1		1			1											
Alonella excisa	1	1	1	1	1	1		1	1			1	1	1						
Alonella nana		1				1														
*Alonopsis elongata**	1																			
Chydorus globosus	1				1						1									
Chydorus latus							1						1		1		1	1		
Chydorus ovalis										1										
Chydorus piger									1											
Chydorus sphaericus	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Daphnia pulex	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
*Eurycercus glacialis**						1			1				1							
Eurycercus lamellatus	1	1	1	1	1		1			1	1	1	1	1	1	1		1		1
Graptoleberis testudinaria		1	1	1		1			1	1		1	1	1		1		1		
Lathurona rectirostris	1	1	1	1	1	1	1			1		1	1							1

Table 8.5 (continued) Summary of cladoceran taxa (presence indicated with 1) found in 20 turloughs in April 2007 combining records from open water zooplankton and chydorid sampling protocols. Order of turloughs is ranked according to total phosphorus (TP) concentrations. Taxa with an asterix can be considered rare

	Lough Gealain	Knockaunroe	Ballindereen	Roo West	Lisduff	Caranavoodaun	Termon	Garryland	Croaghill	Brierfield	Tullynafrankagh	Kilglassan	Skealoghan	Lough Coy	Coolcam	Lough Aleenaun	Carrowreagh	Caherglassan	Rathnalulleagh	Ardkill
Leydigia leydigi							1									1				
Peracantha truncata																			1	
Pleuroxus laevis	1			1		1		1		1	1		1							
Pleuroxus trigonellus				1				1				1	1							
Polyphemus pediculus	1							1												
Rhynchotalona rostrata																				1
Simocephalus vetulus	1	1	1	1	1		1				1	1	1		1	1	1	1		1
TP µg l^{-1}	2	3	5	8	8	11	11	12	14	15	18	18	20	25	27	31	36	38	43	98

8.3.2 Spatial Variability of Macroinvertebrates

8.3.2.1 Between-Habitat Variability

Taxon richness did not vary significantly among habitats sampled in April 2007 in turloughs Lisduff and Brierfield (one-way ANOVA: $F_{1,9}$=1.33 and $F_{1,9}$=0.02 in Lisduff and Brierfield, respectively; P>0.05 in both cases). Highest average taxon richness was found in submerged grassland in Lisduff (15.2±1.04 s.e.; n=5), but highest variability in taxon richness in emergent grassland in Lisduff (C.V.=23.7%), with lowest among emergent grassland in Brierfield (C.V.=12.5%) (Table 8.6).

Table 8.6 Summary statistics of total taxa recovered from each habitat (s.g.=submerged grass; e.g.=emergent grass) in two turloughs, minimum, maximum and average taxon richness recovered from a single sample and coefficient of variation (C.V.) of taxon richness (n=5 per habitat). Samples collected in April 2007.

Turlough	*Habitat*	*Total*	*Minimum*	*Maximum*	*Average±s.e.*	*C.V. (%)*
Lisduff	s.g.	31	12	20	15.2±1.04	19.4
Lisduff	e.g.	26	9	17	13.0±1.11	23.7
Brierfield	s.g.	26	11	17	13.4±0.94	19.5
Brierfield	e.g.	25	11	15	13.2±0.59	12.5

Hierarchical cluster analysis in combination with the SIMPROF-test detected significant differences in community structure between habitat types in Brierfield (π=4.58; P<0.001 for total abundance data) and between the two turloughs (π=6.72; P<0.001 for total abundance data) in both the total abundance and the presence/absence data sets. No significant differences were found between habitats in Lisduff (Figure 8.3a) in both data sets. The results were supported by the MDS plots (Figure 8.3b). *Within* turlough variability of invertebrate community composition was nested within *among* turlough variability.

Greater dissimilarity of macroinvertebrate community structure was identified between habitats in Brierfield (Table 8.7). While the majority of the predominant invertebrate species occurred in both habitats in differing abundances, some taxa showed preferences for one particular habitat type. For example, *Berosus signaticollis* was recovered only from submerged grassland in Lisduff, whereas *Argyroneta aquatica* was collected only from emergent grassland and *Omphiscola glabra* only from submerged grassland in Brierfield.

8.3.2.2 Within-Habitat Variability

Average taxon richness in grassland habitat samples (n=20 per turlough) collected between April and June 2008 varied among turloughs. Highest average taxon richness was found in Caranavoodaun (18.7±0.5 s.e.) sampled in May 2008 and Termon (26±0.97 s.e.) in June 2008, suggesting an increase of taxon richness over time of flooding. Nested ANOVA indicated that taxon richness differed significantly among turloughs (F = 58.40, P <0.001) but no significant difference (P>0.05) was found among the four grassland habitat sites within turloughs. Variability in taxon richness among replicate samples was highest in site one in Blackrock (C.V.=25%) and lowest in site one in Termon in June 2008 (C.V.=5.9%) indicating a negative correlation of variability with increasing hydroperiod. The average coefficient of variation per turlough was also highest in Blackrock and lowest in Termon in June 2008 (C.V.=9.2%).

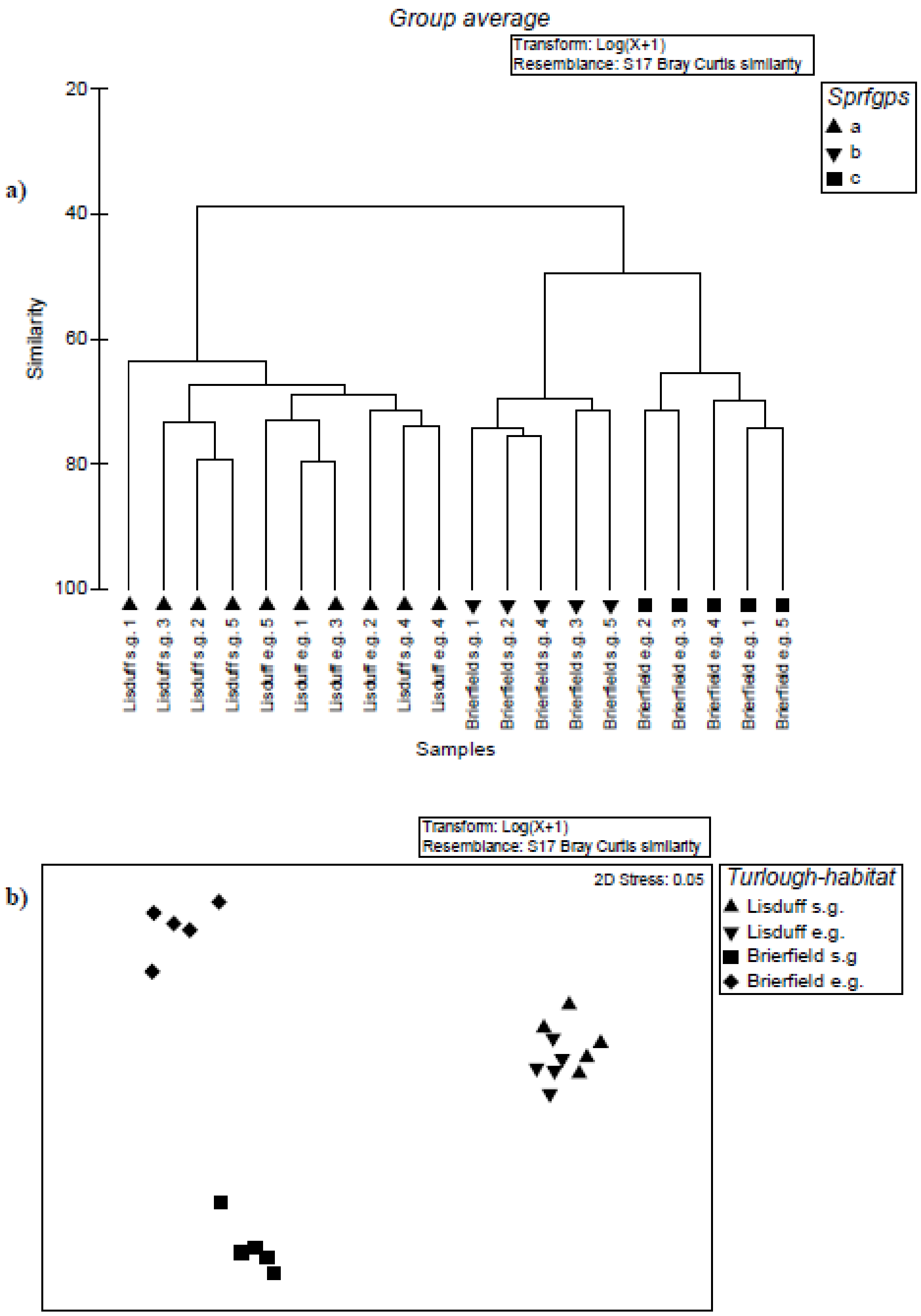


Figure 8.3 Hierarchical cluster analysis dendrogram and **b)** MDS plot of macroinvertebrate species log(x+1) transformed total abundance data from submerged (s.g.) and emergent grassland habitat (e.g.) in Brierfield and Lisduff (n=5 per habitat; n=10 per turlough) (Sprfgps = SIMPROF-groups identified using SIMPROF-test).

Macroinvertebrate communities differed among turloughs and among sampling month in their composition and overall abundance (Table 8.8). For example, Blackrock was dominated mainly by Diptera, Gastropoda and Oligochaeta and showed lowest overall macroinvertebrate abundance, while Ephemeroptera were almost exclusively and Odonata, including the rare turlough spreadwing *Lestes dryas*, solely found in Caranavoodaun and Termon. Roo West had high Coleoptera abundance, with four macroinvertebrate taxa of high conservation value (*Agabus labiatus*, *Graptodytes bilineatus*, *Hygrotus quinquelineatus* and *Berosus signaticollis*).

Very high numbers of the UK Red Data Book category one (vulnerable) gastropod *Omphiscola glabra* were found in this turlough.

Table 8.7 Summary results from SIMPER analysis showing cumulative contribution (Cum%) of contributing taxa to habitat (submerged grassland=s.g.; emergent grassland=e.g.) dissimilarities (in %) (only first 10 contributing taxa are presented) (n=5 per habitat).

Lisduff submerged grass & Lisduff emergent grass			*Brierfield submerged grass & Brierfield emergent grass*		
Average dissimilarity = 33.47			Average dissimilarity = 50.44		
Species	Cum.%	higher presence	Species	Cum.%	higher presence
*Graptodytes bilineatus**	9.4	s.g.	*Agyroneta aquatica*	9.9	only e.g.
Limnephilus centralis	15.1	s.g.	*Agabus* sp. (larvae*)*	17.8	s.g.
*Berosus signaticollis**	20.4	only s.g.	*Omphiscola glabra**	25.3	only s.g.
Oligochaeta sp.	25.1	e.g.	*Ostracoda* sp.	31.7	s.g.
Hydrachnidia sp.	29.3	e.g.	*Halticinae* sp.	38.2	e.g.
Polycelis nigra/tenuis	33.5	s.g.	*Graptodytes bilineatus**	43.8	s.g.
Sympetrum sanguineum	37.5	s.g.	*Dryops* sp. (larvae)	49.1	e.g.
Asellus aquaticus	41.3	s.g.	*Culicidae* sp.	54.0	s.g.
Chironomidae sp.	44.9	e.g.	*Chironomidae* sp.	58.1	s.g.
Culicidae sp.	48.4	s.g.	*Rhantus* sp. (larvae)	62.2	e.g.

Taxa marked with * are considered rare/restricted, e.g. their occurrence can be restricted to the turlough environment and are considered to be of high conservation value.

Table 8.8 Pooled macroinvertebrate abundances recovered from four turloughs sampled for within-habitat variability. BR=Blackrock; CV=Caranavoodaun; RW=Roo West; TM=Termon (n=20 per turlough and sampling occasion).

Class/Order	*Family*	*Species*	*BR Apr 08*	*CV May 08*	*RW Apr 08*	*TM Apr 08*	*TM Jun 08*
Acari	Hydrachnidia	*Hydrachnidia* sp.		30	5	19	4
Amphipoda		*Gammarus lacustris*			8	1	8
		Gammarus sp. (juveniles)	1		3		15
Aranea	Argyronetidae	*Agyroneta aquatica*				1	84
Bivalvia	Sphaeriidae	*Pisidium/Sphaerium sp.*		91			39
Coleoptera	Chrysomelidae	*Halticinae* sp.				1	2
	Curcolionidae	*Curculionidae* sp.		19		2	35
	Dryopidae	*Dryops* sp.					2
		Dryops sp. (larva)		7		2	9
	Dysticidae	*Dytiscus* sp. (larva)		1		1	7
		Ilybius sp. (larva)		2	18	39	
		Rhantus sp. (larva)	2	5	18	12	
		*Agabus labiatus **			2	1	
		Agabus nebulosus		3	13	10	1
		Agabus sp. (larva)		100	123	61	1
		Hydaticus sp. (larva)		1	105	99	
		Colymbetes fuscus			1		
		*Graptodytes bilineatus **		21	55		
		Graptodytes sp. (larva)			15		
		Hydroporus erythrocephalus			1	1	
		Hydroporus palustris		10	6	10	24

Table 8.8 (continued)

Class/Order	*Family*	*Species*	*BR Apr 08*	*CV May 08*	*RW Apr 08*	*TM Apr 08*	*TM Jun 08*
		Hydroporus pubescens			1		
		Hydroporus tessellatus			2		
		Hydroporus sp. (larva)		12		3	
		Hygrobia hermanni				1	
		Hygrotus inaequalis			1		42
		Hygrotus impressopunctatus		13	3	11	
		*Hygrotus quinquelineatus**		2	3	1	13
		Hyphydrus ovatus				1	33
		Laccophilus minutus				6	15
		Laccophilus sp. (larva)				5	
		Porhydrus lineatus		4		1	14
		Porhydrus sp. (larva)		23			49
		Rhantus exsoletus			1	5	4
		Rhantus frontalis				1	1
	Elmidae	*Oulimnius* sp.			4		
	Haliplidae	*Haliplus fulvus*					1
		Haliplus sp. (larva)				5	2
		Haliplus sp. ruficollis group (females)				1	1
		Haliplus variegatus					1
	Hydraenidae	*Ochthebius minimus*					1
	Hydrophilidae	*Berosus signaticollis**		21	2		
		Berosus sp. (larva)		18			
		Helophorus brevipalpis			1		1
		Helophorus sp. (female)		1			
		Laccobius biguttatus					6
	Noteridae	*Noterus clavicornis*				1	9
Collembola	Isotomidae	*Isotomurus* sp.			2		
Diptera	Ceratopogonidae	*Ceratopogonidae* sp.		1		5	
	Chironomidae	*Chironomidae* sp.	76	71	161	157	57
	Culicidae	*Culicidae* sp.		31		1	
	Psychodidae	*Psychodidae* sp.	5		6	3	
	Tipulidae	*Tipulidae* sp.		2	3	18	
		Diptera sp. (pupa)	10	32	20	4	10
Ephemeroptera	Baetidae	*Cloeon dipterum*		85			19
		Cloeon simile	1	28			3
	Caenidae	*Caenis horaria*				5	
		Caenis luctuosa		1			15
Gastropoda	Elobiidae	*Phytia myosotis*	11				
	Gastrodontidae	*Zonitoides* sp.	4		87		
	Hydrobiidae	*Bithynia tentaculata*		2			204
	Lymnaeidae	*Galba truncatula*	64	42		27	105
		*Omphiscola glabra**	10		257		
		Radix balthica		107		1	44
	Succineidae	*Succinea putris*	123			3	2
	Physidae	*Physa fontinalis*		1			4
	Planorbidae	*Planorbarius corneus*					2
		Planorbis contortus					1
		Planorbis crista		1		3	165
		Planorbis laevis		4			21

Table 8.8 (continued)

Class/Order	*Family*	*Species*	*BR Apr 08*	*CV May 08*	*RW Apr 08*	*TM Apr 08*	*TM Jun 08*
Heteroptera	Corixidae	*Callicorixa praeusta*	1	1		1	
		Corixa punctata				3	
		Corixinae Instar I & II		2			86
		Corixinae Instar III		1			11
		Hesperocorixa linnaei				1	
		Hesperocorixa sahlbergi	1				
	Notonectidae	*Notonecta glauca*				1	
		Notonectidae sp. (larva)		2			33
	Velidae	*Velia* sp. (larva)		1			
	Glossiphonidae	*Glossiphonia complanata*		1		1	1
		Theromyzon tessulatum					3
	Gnathobdellae	*Haemopis sanguisuga*		1			
Isopoda	Asellidae	*Asellus aquaticus*	8	9		67	1862
Lepidoptera	Pyralidae	*Acentria ephemerella*					5
Odonata	Coenagrionidae	*Coenagrion puella/ pulchellum*		23			
		Ischnura elegans					6
		Coenagrionidae sp.					5
	Lestidae	*Lestes* sp.		10			54
		*Lestes dryas**		8			10
		Lestes sponsa		1			33
	Libellulidae	*Sympetrum sanguineum*		256			433
Oligochaeta		*Oligochaeta* sp.	568	75	365	255	12
Ostracoda		*Ostracoda* sp.	40	1	49	119	17
Trichoptera	Leptoceridae	*Mystacides longicornis*					2
		Triaenodes bicolor		3			168
	Limnephilidae	*Limnephilus auricula*	6				
		Limnephilus centralis		52		14	9
Class/Order	*Family*	*Species*	*BR Apr 08*	*CV May 08*	*RW Apr 08*	*TM Apr 08*	*TM Jun 08*
		Limnephilus decipiens		1			
		Limnephilus lunatus		15		2	
		Limnephilus marmoratus		17		8	2
	Polycentropodidae	*Cyrnus trimaculatus*				1	
		Trichoptera sp. (pupa)		1			23
Turbellaria	Planaridae	*Polycelis nigra/tenuis*		22	1	2	31
Total abundance			***931***	***1295***	***1342***	***1004***	***3882***

Taxa marked with * are considered rare/restricted, e.g. their occurrence can be restricted to the turlough environment and are considered to be of high conservation value.

The SIMPROF test, which was incorporated in the hierarchical cluster analysis, identified no significant differences among macroinvertebrate samples collected from different grassland sampling sites in turloughs sampled in April 2008 (see Figures 4, 5 & 6 in Porst & Irvine, 2009b) of either total abundance or presence/absence data. Samples collected at different grassland sites in Caranavoodaun in May 2008 and Termon in June 2008, however, identified two significantly different groups (SIMPROF test employing total abundance data: Caranavoodaun: $\pi=1.64$, $P<0.01$; Termon: $\pi=0.7$, $P<0.01$) (See Figures 7a & 8a in Porst & Irvine 2009b). No significant difference was found among grassland sampling sites in the same turloughs using presence/absence data. The MDS plot generated using total abundance data of all grassland habitat macroinvertebrate samples collected in each turlough (n=20 per turlough) revealed that invertebrate community structures within the turloughs were, nevertheless, highly distinct. Samples clustered closely together with no overlap among turloughs (Figure 8.4). Similar results were obtained using the presence/absence data set. The MDS plot revealed a closer clustering of turloughs sampled in the same month (April 2008) compared with later samples collected in May 2008 and June 2008, suggesting a spatio-temporal interaction in invertebrate community structure (Figure 8.4).

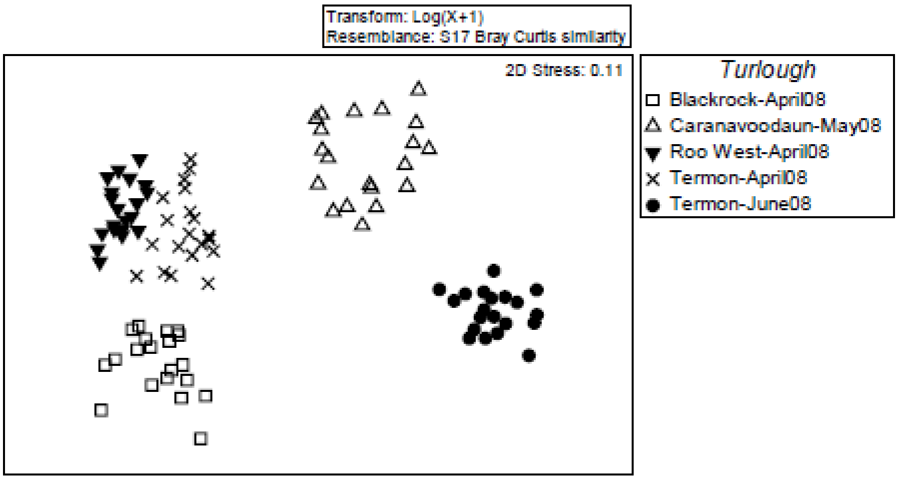


Figure 8.4 MDS plot of macroinvertebrate species log(x+1) transformed abundance data of turloughs sampled in April 2008 till June 2008 (n=20 per turlough and sampling occasion).

8.3.3 Comparison of Littoral Invertebrates of Eight Turloughs Across a Nutrient Gradient and with Varying Hydroperiod.

8.3.3.1 Abundance and Taxon Richness

Taxon richness and abundance of invertebrates were significantly different among turloughs (one-way ANOVA: $F_{7,39}$ = 5.515 and $F_{7,39}$ = 9.84, respectively; P <0.001 in both cases). Pair wise comparisons between turloughs using the least significant differences (LSD) test for *post hoc* testing identified differences between samples in 19 (abundance) and 9 (taxon richness) of the possible 28 comparisons (P <0.05 in both cases). Mean abundances varied considerably among turloughs (Figure 8.5), with highest numbers in Termon (146.6 ± 18.6 95% *c.l.*; n=5), with the longest hydroperiod of the eight turloughs investigated, and lowest in Caranavoodaun (56 ± 13.9 95% *c.l.*; n=5). Highest mean taxon richness (Figure 8.6) occurred in Kilglassan (18.4 ± 2.6 95% *c.l.*; n=5) and lowest in Ballindereen (10.8 ± 1.6 95% *c.l.*; n=5) and Caranavoodaun (10.8 ± 3.6 95% *c.l.*; n=5). Average taxon richness in all eight turloughs was 14, ranging from 7 to 21 species. A significant positive correlation was found between mean abundance and log-transformed mean taxon richness (*r* = 0.71, P<0.05). No significant correlations were found between either mean abundance or log-transformed mean taxon richness and log_TP, log_TN, turbidity, chlorophyll a and conductivity, respectively. Hydroperiod correlated positively with mean abundance and mean taxon richness (*r* = 0.88, P<0.01 and *r* = 0.74, P<0.05, respectively).

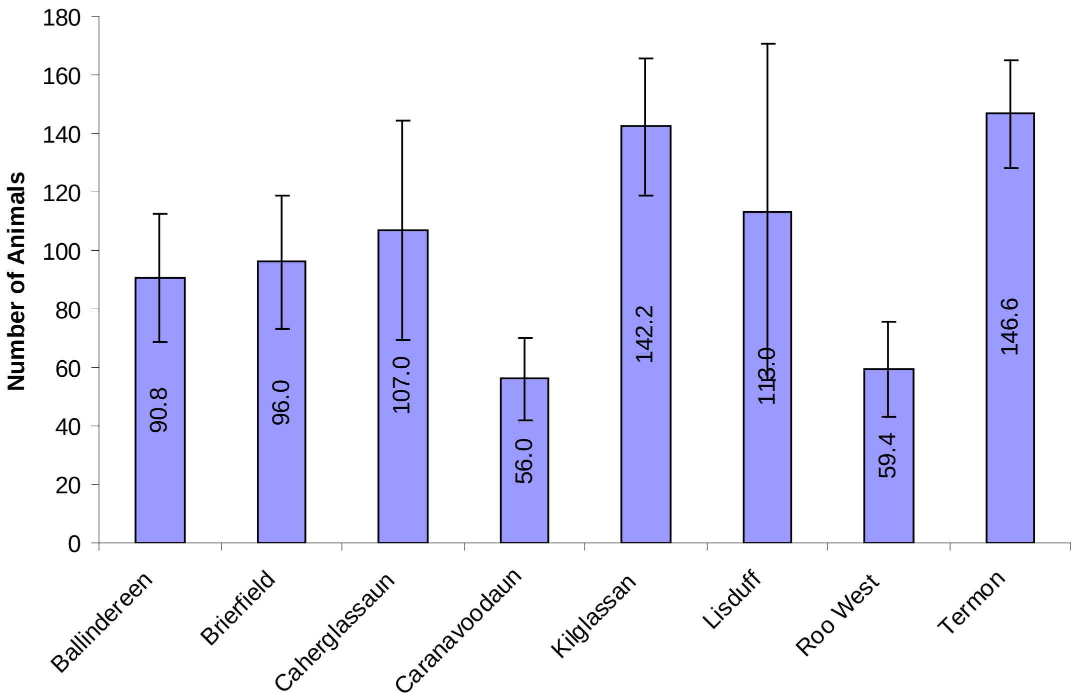


Figure 8.5 Mean abundance of macroinvertebrates recorded per turlough. Error bars are 95% *c.I.* (n=5).

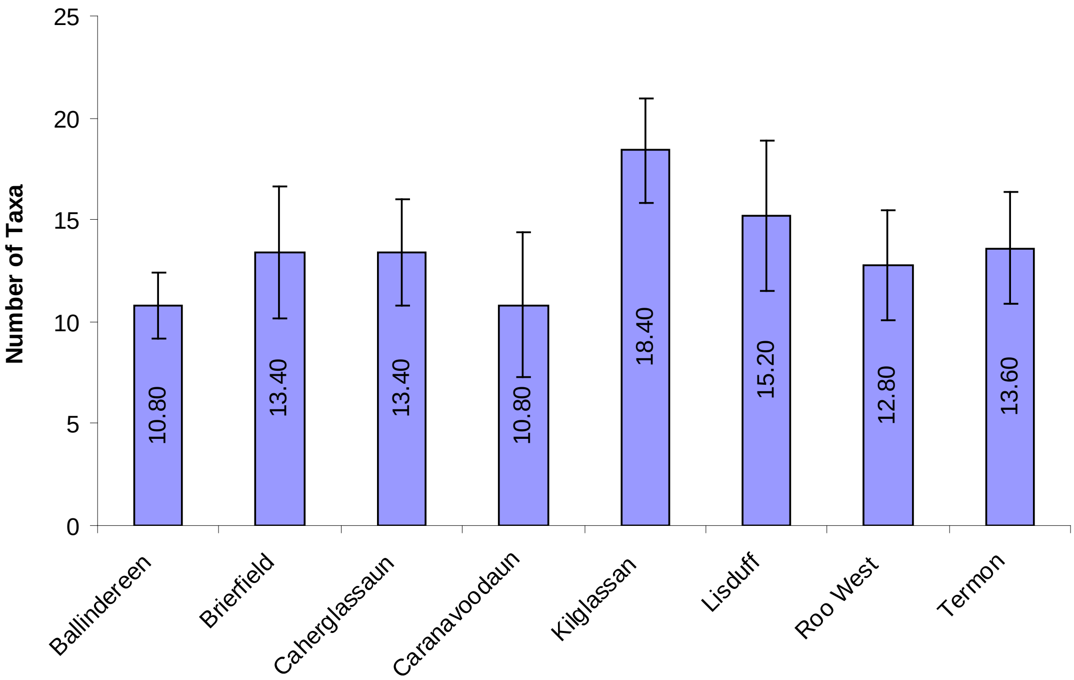


Figure 8.6 Mean number of macroinvertebrate taxa recorded per turlough. Error bars are 95% *c.I.* (n=5).

Macroinvertebrate community structure varied among turloughs (Tables 8.9 and 8.10). For example, Lisduff was dominated by Coleoptera, Isopoda and Oligochaeta, while Caherglassan had high abundances of Diptera and Gastropoda. Highest mean numbers of Coleoptera were found in Kilglassan, highest proportions of Isopoda were found in Lisduff and very high abundances of Diptera were found in Brierfield, Caherglassan and Termon. High numbers of Odonata (both *Lestes* sp. and *Sympetrum sanguineum*) were found only in Caranavoodaun. Six rare/restricted species of conservation concern were found in five of the eight replicately sampled turloughs (Table 8.9).

Table 8.9 Pooled species abundances of macroinvertebrates found in eight turloughs. BN=Ballindereen; BF=Brierfield; CN=Caherglassan; CV=Caranavoodaun; KN=Kilglassan; LF=Lisduff; RO=Roo West; TN=Termon (n=5 per turlough). Species marked with ***** are considered rare/restricted species, e.g. their occurrence can be restricted to the turlough environment and are considered to be of high conservation value

Class/Order	*Family*	*Species*	*BN*	*BF*	*CN*	*CV*	*KN*	*LF*	*RO*	*TN*
Acari	Hydrachnidia	*Hydrachnidia* sp.	4				2	14		2
Amphipoda	Gammaridae	*Gammarus lacustris*	1						11	
		Gammarus sp. *juveniles*							1	2
Araneae	Argyronetidae	*Agyroneta aquatica*						1		
Coleoptera	Chrysomelidae	*Halticinae* sp.	7	8						1
		Donacia sp (larvae)						2		
	Curculionidae	*Curculionidae* sp.	2				2			
	Dryopidae	*Dryops* sp.					1			
		Dryops sp. *(larvae)*		1	2		3	3	2	1
	Dysticidae	*Dytiscus* sp. *(larvae)*								1
		Ilybius sp. *(larvae)*	2	1			2		1	8
		Rhantus sp. *(larvae)*	1	4			14	5	2	6
		Agabus bipustulatus	3							
		Agabus labiatus *****						1	1	
		Agabus nebulosus	2		1		1			
		Agabus sp. *(larvae)*	116	63		20	181	49	65	31
		Hydaticus sp. *(larvae)*				1				2
		Graptodytes bilineatus *****		14				102	2	
		Hydroporus erythrocephalus						5		1
		Hydroporus palustris		4	4				2	
		Hydroporus pubescens	3							
		Hygrotus inaequalis	2	1		2	2	1		
		Hygrotus impressopunctatus						1	2	
		Hygrotus quinquelineatus *****			5	1			2	
		Hygrotus sp. *(larvae)*	2			2	11		8	
		Laccophilus minutus			1				1	
		Laccophilus sp. *(larvae)*			1		10			4
		Rhantus exsoletus				1				1
	Haliplidae	*Haliplus fulvus*						1	1	
		Haliplus sp. *(larvae)*			1				1	1
	Hydraenidae	*Ochthebius minimus*	3				2			
	Hydrophilidae	*Berosus signaticollis* *****				7		7	2	
		Cercyon tristis					1			
		Helophorus brevipalpis	7	1		1	7	5	2	
		Hydrobius fuscipes					1			
Diptera	Ceratopogonidae	*Ceratopogonidae* sp.								4
	Chironomidae	*Chironomidae* sp.	56	214	209	13	96	31	79	216
	Culicidae	*Culicidae* sp.		13		33		4		
	Psychodidae	*Psychodidae* sp.			1					1
	Stratiomyidae	*Stratiomyidae* sp.		1						
	Tabanidae	*Tabanidae* sp.								5

Class/Order	Family	Species	BN	BF	CN	CV	KN	LF	RO	TN
Diptera	Tipulidae	*Tipulidae* sp.		3					1	11
		Diptera pupae	4	4	25	1	1	1	2	2
Ephemeroptera	Baetidae	*Cloeon dipterum*			23	11	19	1	12	4
	Baetidae	*Cloeon simile*			1			4	1	2
	Caenidae	*Caenis horaria*			14					
	Leptophlebiidae	*Leptophlebia vespertina*		4			5			
Gastropoda	Gastrodontidae	*Zonitoides* sp.		1				1		
	Lymnaeidae	*Galba truncatula*				1	3	1		
		Lymnaea fusca	93							
		Lymnaea stagnalis					1			
		*Omphiscola glabra**		20						
		Radix balthica	1		1	1	1	2	4	
		Succinea putris					21	3		
	Physidae	*Physa fontinalis*			1					
	Planorbidae	*Planorbis contortus*			133					
		Planorbis crista		2			4	1		
		Planorbis planorbis							7	
	Valvatidae	*Valvata cristata*		2						
Heteroptera	Corixidae	*Corixa punctata/iberica*		1						
		Sigara falleni			2					
	Corixinae	*Corixinae Instar I & II*	1				18			2
	Notonectidae	*Notonecta glauca*							1	1
	Velidae	*Microvelia reticulata*								1
Hirudinea	Glossiphonidae	*Glossiphonia complanata*					1	1	1	
	Gnathobdellae	*Haemopis sanguisuga*				1		1		
Isopoda	Asellidae	*Asellus aquaticus*	92	2	22		29	155		27
		Asellus meridianus			28					
Odonata	Lestidae	*Lestes* sp.				7				
		Lestes dryas *				11				
	Libellulidae	*Sympetrum sanguineum*	1			113	20	5	22	
		Anisoptera sp. *(larvae)*				33			2	
		Zygoptera sp. *(larvae)*		1			5			
Oligochaeta		*Oligochaeta* sp.	46	58	22	16	225	109	40	312
Ostracoda		*Ostracoda* sp.	3	53	11	1	5		8	84
Plecoptera	Nemouridae	*Nemoura cinerea*	1			1				
Trichoptera	Limnephilidae	*Limnephilus auricula*				1	2			
		Limnephilus centralis					7	24	3	
		Limnephilus lunatus		2						
		Limnephilus marmoratus					1	3		
		Anabolia brevipennis			3	1				
		Trichoptera sp. *pupae*	1							
Turbellaria	Turbellaria	*Polycelis nigra/tenuis*		2	24		7	21	8	

8.3.3.2 Cluster Analysis

Hierarchical cluster analysis grouped all replicate samples within turloughs together (Figure 8.7), with no significant differences (SIMPROF) among replicate samples per turlough. The six turloughs Ballindereen, Brierfield, Kilglassan, Lisduff, Roo West and Termon clustered at about 43%. This group was only being joined by Caherglassan turlough at about 34% and finally by Caranavoodaun at about 28 % similarity.

Table 8.10 Mean abundance of macroinvertebrate orders (± s.e.) found in samples of eight turloughs (n=5).

	Ballindereen	***Brierfield***	***Caherglassan***	***Caranavoodaun***	***Kilglassan***	***Lisduff***	***Roo West***	***Termon***
Acari	0.8 ± 0.4				0.4 ± 0.2	2.8 ± 0.4		0.4 ± 0.4
Amphipoda							2.4 ± 1.2	0.4 ± 0.2
Araneae						0.2 ± 0.2		
Coleoptera	30 ± 7.7	19.4 ± 3.6	3 ± 2.1	7 ± 3.4	47.6 ± 8	36.4 ± 9.3	18.8 ± 5.9	11.4 ± 4.2
Diptera	12 ± 2.2	47 ± 8.3	47 ± 4.4	9.4 ± 1.9	19.4 ± 2.9	7.2 ± 1.8	16.4 ± 2.8	47.8 ± 9.9
Ephemeroptera		0.8 ± 0.6	7.6 ± 2.4	2.2 ± 0.6	4.8 ± 2.3	1 ± 0.8	2.6 ± 1.2	1.2 ± 0.8
Gastropoda	18.8 ± 4.6	5 ± 2.0	27 ± 11.6	0.4 ± 0.4	6 ± 2.4	1.6 ± 1.4	2.2 ± 0.8	
Heteroptera	0.2 ± 0.2	0.2 ± 0.2	0.4 ± 0.2		3.6 ± 1.4		0.2 ± 0.2	0.8 ± 0.6
Hirudinea				0.2 ± 0.2	0.2 ± 0.2	0.4 ± 0.4	0.2 ± 0.2	
Isopoda	18.4 ± 2.3	0.4 ± 0.2	10 ± 3.1		5.8 ± 2.2	31 ± 10.5		5.4 ± 1
Odonata	0.2 ± 0.2	0.2 ± 0.2		32.8 ± 4.8	5 ± 1.6	1 ± 0.5	4.8 ± 2.7	
Oligochaeta	9.2 ± 2.3	11.6 ± 1.7	4.4 ± 1.4	3.2 ± 0.8	45 ± 3.7	21.8 ± 5.2	8 ± 1.1	62.4 ± 4.2
Ostracoda	0.6 ± 0.4	10.6 ± 2.3	2.2 ± 0.8	0.2 ± 0.2	1 ± 0.3		1.6 ± 0.7	16.8 ± 4.4
Plecoptera	0.2 ± 0.2			0.2 ± 0.2				
Trichoptera	0.2 ± 0.2	0.4 ± 0.2	0.6 ± 0.4	0.4 ± 0.4	2 ± 1.1	5.4 ± 3.1	0.6 ± 0.7	
Turbelaria		0.4 ± 0.2	4.8 ± 1.2		1.4 ± 0.6	4.2 ± 1.2	1.6 ± 1.2	
Total	***90.6***	***96***	***107***	***56***	***142.2***	***113***	***59.4***	***146.6***

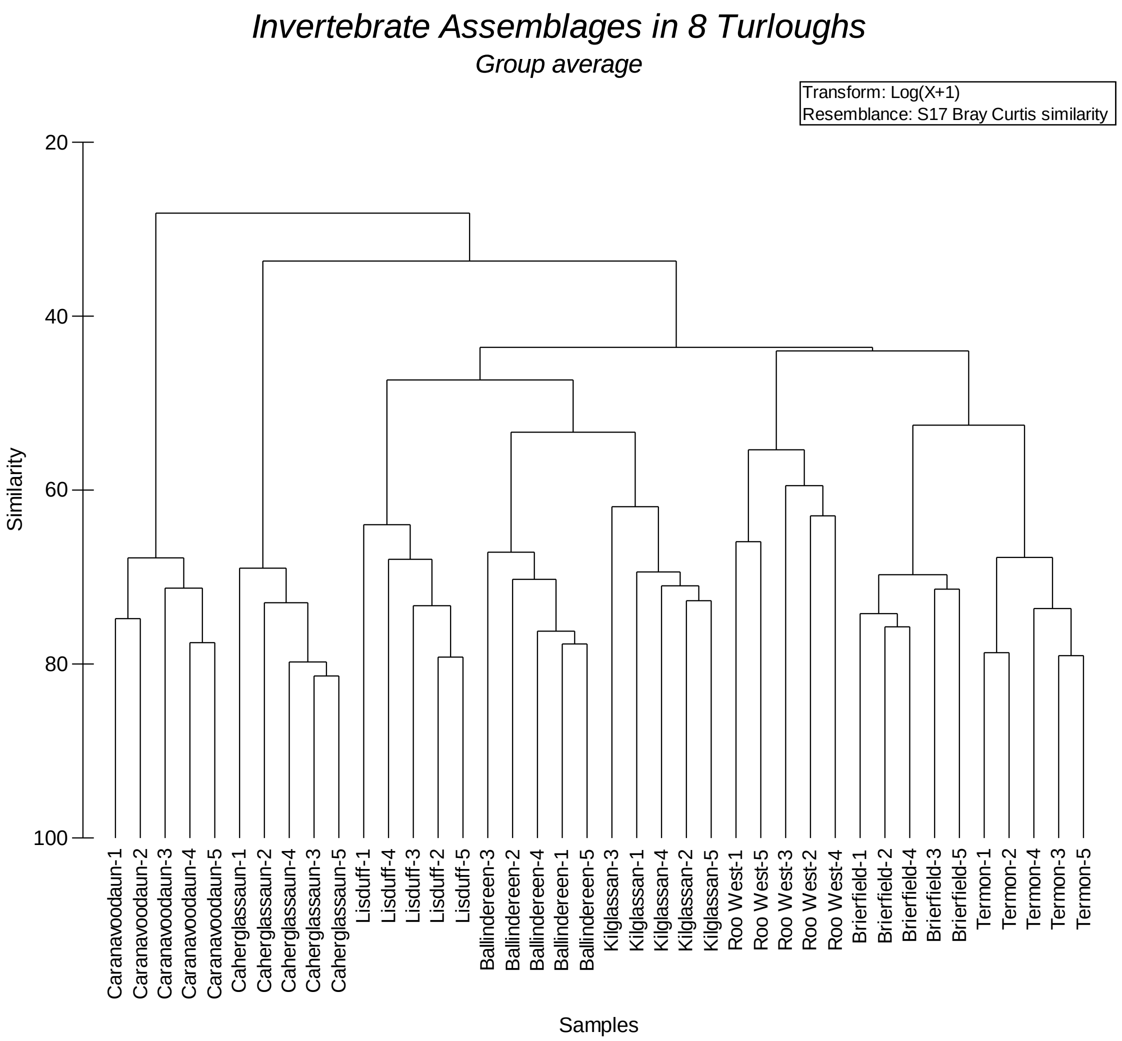


Figure 8.7 Hierarchical cluster analysis dendrogram of macroinvertebrate species log(x+1) transformed total abundance data of eight turloughs sampled with a box sampler (n=5 per turlough).

The average similarity of replicate samples of the 6 turloughs Ballindereen, Brierfield, Lisduff, Roo West and Termon was identified as 48 % by the SIMPER routine. Chironomidae sp., Oligochaeta sp. and *Agabus* sp. larvae contributed 24%, 23.4% and 22.4%, respectively, to average similarity of this group. The high presence of *Planorbis conturtus* and *Asellus meridianus* and the absence of *Agabus* sp. larvae in Caherglassan samples accounted for 10.5%, 5.9% and 9.4% of the average dissimilarity (66.3%) of this turlough compared with the other six. Caranavoodaun differed from the group of six turloughs by 70.6%. The dissimilarity was mainly caused by the high occurrence of *Sympetrum sanguineum*, Anisoptera sp. larvae and Culicidae sp. (respectively, 9.7%, 7.3% and 6.4% of dissimilarity).

8.3.3.3 Non-Metric Multidimensional Scaling (MDS)

The non-metric multidimensional (MDS) scaling plot concurred with results from the Cluster Analysis and the SIMPER routine. The six turloughs Termon, Brierfield, Roo West, Kilglassan, Ballindereen and Lisduff showed higher similarities to each other compared with Caranavoodaun and Caherglassan. Replicate samples clustered together, with almost no overlap with other turloughs (Figure 8.8).

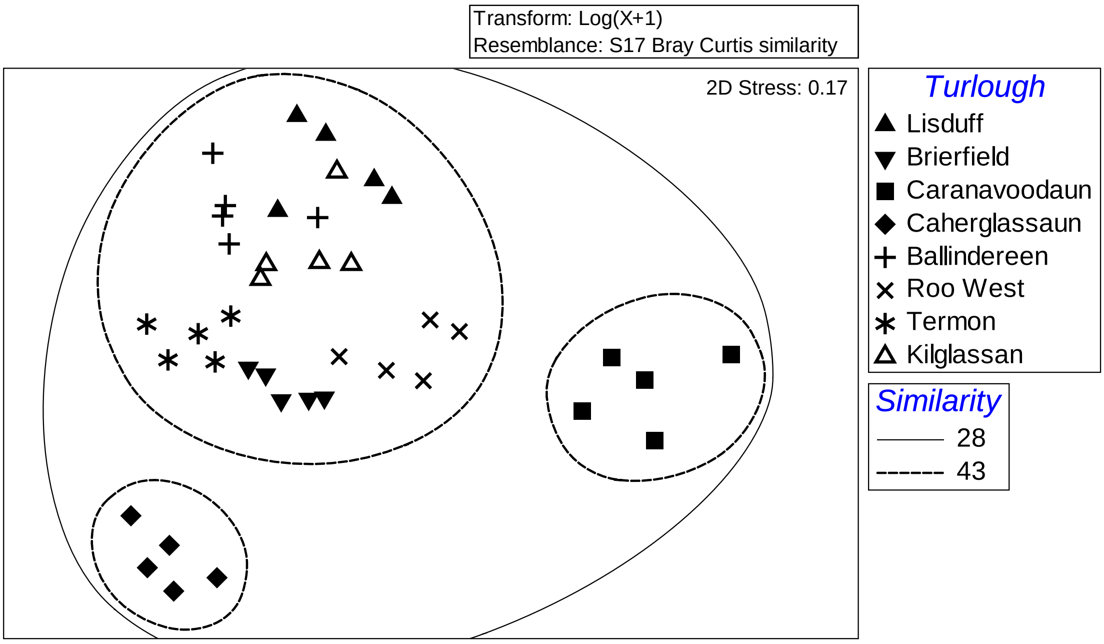


Figure 8.8 MDS plot of macroinvertebrate species log(x+1) transformed total abundance data of eight turloughs (n=5 per turlough), overlaid with similarity levels from Cluster Analysis.

8.3.4. The Importance of Hydrological Regime for Seasonal and Inter-Annual Pattern of Macroinvertebrates in Turloughs

During the 2007/2008 season mean monthly taxon richness varied among turloughs and months (Figure 8.9a), with a significant effect of time (month) on both the whole invertebrate community, as well as *permanent* and *ephemeral* taxon richness separately (Repeated measures ANOVA, $P < 0.001$). Taxon richness in sampling periods December 2007 - February 2008 (1-3) and March - April 2008 (4-5) differed significantly from each other (Table 8.11). Average seasonal taxon richness differed significantly among turloughs (one-way ANOVA, $P < 0.001$) with the highest seasonal average occurring in Termon (13.4±2.3 *s.e*) and the lowest in Blackrock (7.2±0.8 *s.e*). This concurred with respective hydroperiods and a negative effect of high areal reduction rates (Figure 8.9b). Taxon richness C.V. generally decreased until February/March 2008, increasing again from March/April with turlough draining, and showing a negative trend with increasing turlough hydroperiod (Figure 8.10).

Table 8.11 Results of repeated measures ANOVA testing for effects of time on taxon richness for the whole community and different life-cycle groups in turloughs for consecutive sampling months December 2007 – April 2008 (n=5 per turlough in each month; d.f., degrees of freedom; MS, mean sum of squares; *Significant ($P < 0.05$) Bonferroni and LSD pair-wise tests).

Groups	*df*	*MS*	*F-value*	*P-value*	*Post hoc*
Whole community	4,99	53.62	19.88	<0.001	1-3*4-5
Permanent residents	4,99	10.94	7.84	<0.001	2*5, 3*4-5
Ephemeral residents	4,99	25.53	13.67	<0.001	1*4-5, 2*3-5

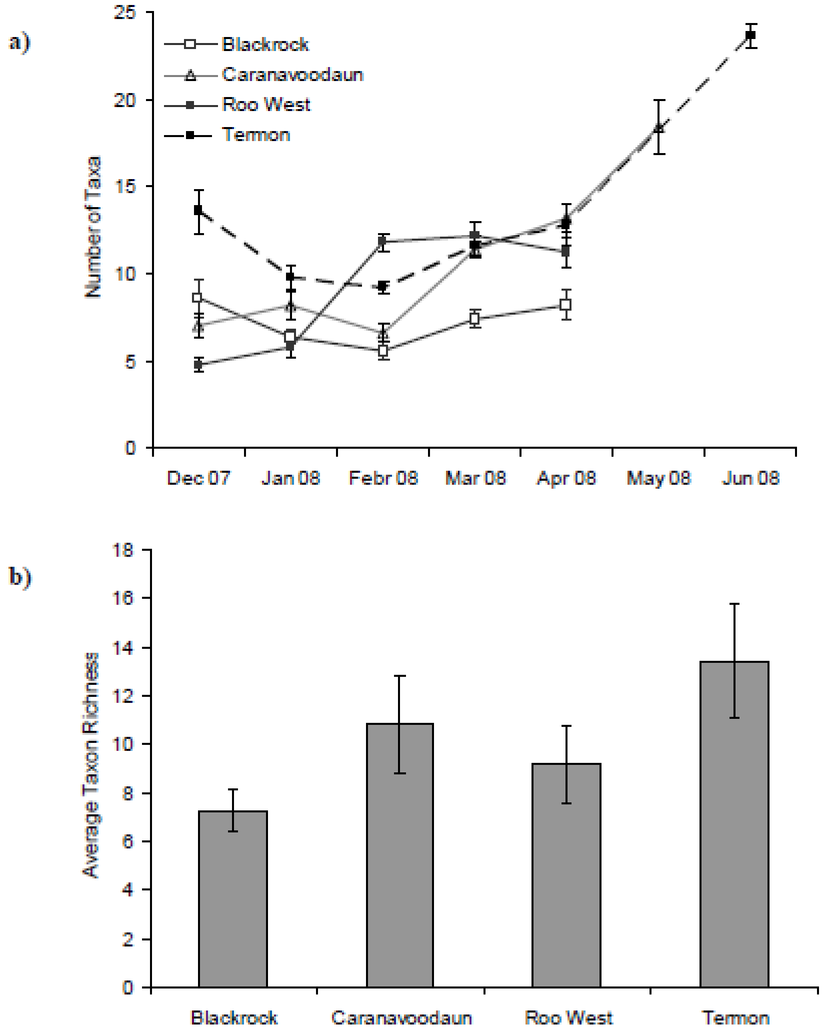
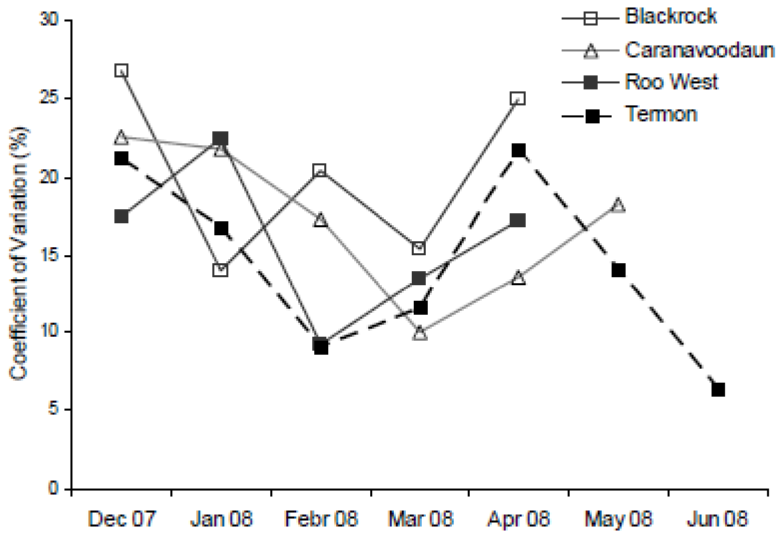


Figure 8.9 Seasonal variation of average number of macroinvertebrate taxa recorded per turlough (**a**, n=5 per month and turlough), average seasonal taxon richness during sampling season 2007/2008 per turlough (**b**, n=25 in Blackrock and Roo West; n=30 in Caranavoodaun and Termon). Error bars indicate standard error.

Greater abundances of *ephemeral* taxa were found later in the season in Caranavoodaun, Roo West and Termon. This trend was also seen in Blackrock at the start of sampling season 2007/2008, but changed from February 2008 towards an increase in *permanent* taxa in March and April 2008. Increasing ratio of *ephemeral/permanent* taxa later in the season reflected a general decrease of oligochaetes in all four turloughs, and a decrease in Isopoda in Termon in both years, which were only present in substantial numbers in this turlough. Ephemeroptera, Trichoptera (late instars) and Odonata larvae, furthermore, only appeared later in the season and showed increasing abundances at the end of the flooding period, but were only present in Termon and Caranavoodaun. Coleoptera were found early in the season in low numbers, and increased over time in all four turloughs.

Hydroperiod had a significant effect on the community structure of macroinvertebrates, explaining 12.5 % of the variability observed in the seasonal data (DISTLM, $p < 0.05$). No significant relationship was found between TP concentrations and the species-derived multivariate data cloud.

a)



b)

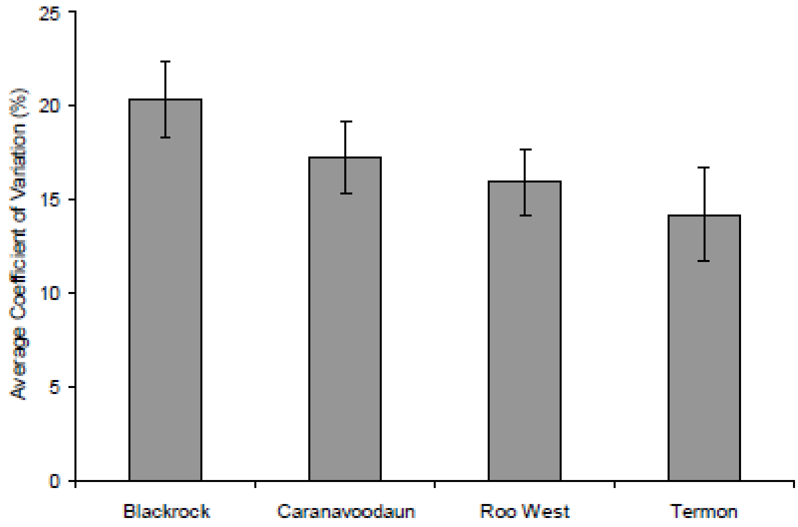


Figure 8.10 Seasonal variation of coefficient of variation of taxon richness (**a**, n=5 per month and turlough), and average seasonal coefficient of variation of taxon richness during sampling season 2007/2008 per turlough (**b**, n=5 in Blackrock and Roo West; n=6 in Caranavoodaun and Termon). Error bars indicate standard error.

MDS in combination with ANOSIM identified three different groups of macroinvertebrate samples corresponding with, respectively, the filling phase (December 2007 – February 2008), aquatic phase (March – April 2008) and drying phase (May –June 2008: ANOSIM, global R = 0.741, P < 0.001; Figure 8.11). SIMPER analysis characterised the aquatic phase by increasing abundances of Coleoptera larvae and adults, while, for example, appearances or higher abundances of Ephemeroptera, Odonata and Trichoptera taxa distinguished the drying from the filling and aquatic phase (Table 8.12).

In Termon, macroinvertebrate succession showed inter-annual similarities, with succesional pattern shifting by about one month (Figure 8.12). There were three distinct wet phases in both seasons (2006/2007: ANOSIM, global R = 0.999, P < 0.001; filling phase: November

2006, aquatic phase: January 2007, drying phase: April-June 2007; for 2007/2008 wet phases see above).

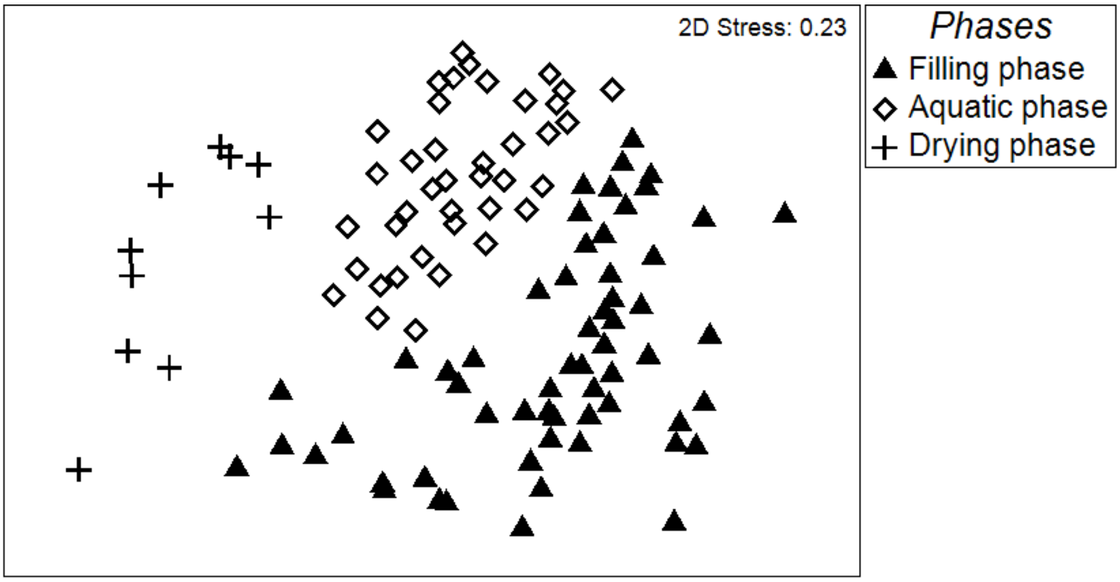


Figure 8.11 Multidimensional scaling (MDS) ordinations of macroinvertebrate communities of four turloughs, based on log(x+1) transformed abundance data and Bray-Curtis similarity matrix. Different wet phases are indicated in the plot.

Table 8.12 Summary results from SIMPER analysis showing cumulative contribution (Cum%) of contributing taxa to wet phase (filling phase=f.p.; aquatic phase=a.p.; drying phase=d.p.) dissimilarities (in %) (only first 25 contributing taxa are presented).

Groups Filling phase & Aquatic phase			***Groups Filling phase & Drying phase***			***Groups Aquatic phase & Drying phase***		
Average dissimilarity = 64.59%			Average dissimilarity = 76.23			Average dissimilarity = 76.18		
Species	Cum.%	higher presence	Species	Cum.%	higher presence	Species	Cum.%	higher presence
Ostracoda	7.65	a.p.	*Sympetrum sanguinem*	4.34	only d.p.	*Sympetrum sanguinem*	3.87	only d.p.
Tipulidae	12.54	a.p.	*Lestes* sp.	8.34	only d.p.	*Lestes* sp.	7.41	only d.p.
Agyroneta aquatica	17.21	f.p.	*Pisidium/Sphaerium* sp.	11.85	d.p.	*Pisidium/Sphaerium* sp.	10.57	only d.p.
Hydrachnidia	21.77	f.p.	*Radix balthica*	15.23	d.p.	*Radix balthica*	13.54	d.p.
Agabus sp. (larva)	25.81	a.p.	*Cloeon dipterum*	18.47	only d.p.	*Cloeon dipterum*	16.36	only d.p.
Galba truncatula	29.47	a.p.	Curculionidae	21.37	d.p.	Curculionidae	18.97	d.p.
Diptera pupae	33.11	only a.p.	*Porhydrus* sp. (larva)	24.06	d.p.	Ostracoda	21.56	a.p.
Omphiscola glabra	36.48	a.p.	*Limnephilus centralis*	26.69	only d.p.	*Porhydrus* sp. (larva)	24.1	d.p.
Psychodidae	39.48	a.p.	*Cloeon simile*	29.17	only d.p.	Tipulidae	26.25	a.p.
Ilybius sp. (larva)	42.48	a.p.	*Galba truncatula*	31.47	f.p.	*Dryops* sp. (larva)	28.37	d.p.
Zonitoides sp.	45.25	a.p.	Tipulidae	33.73	f.p.	*Cloeon simile*	30.48	only d.p.
Hydroporus palustris	47.61	a.p.	Culicidae	35.73	only d.p.	*Zonitoides* sp.	32.59	only a.p.
Asellus aquaticus	49.91	a.p.	*Coenagrion puella*	37.73	only d.p.	*Polycelis nigra/tenuis*	34.53	d.p.
Isotomidae	52.19	f.p.	*Dryops* sp. (larva)	39.73	d.p.	*Hydroporus palustris*	36.44	d.p.
Agabus nebulosus	54.38	a.p.	Oligochaeta	41.71	f.p.	*Limnephilus centralis*	38.31	d.p.
Hydaticus sp. (larva)	56.44	a.p.	*Hydroporus palustris*	43.65	d.p.	Oligochaeta	40.13	a.p.
Graptodytes bilineatus	58.42	a.p.	Hydrachnidia	45.51	f.p.	*Bithynia tentaculata*	41.89	only d.p.
Ceratopogonidae	60.36	f.p.	*Planorbis crista*	47.36	only d.p.	*Planorbis crista*	43.64	only d.p.
Succinea putris	62.3	a.p.	Corixinae Instar I & II	49.22	only d.p.	Corixinae Instar I & II	45.4	only d.p.
Helophorus brevipalpis	64.21	a.p.	Notonectidae sp. (larva)	51.07	only d.p.	Notonectidae sp (larva)	47.16	only d.p.
Chironomidae	66.1	a.p.	*Lestes sponsa*	52.93	only d.p.	*Lestes sponsa*	48.91	only d.p.
Rhantus sp. (larva)	67.95	a.p.	*Limnephilus marmoratus*	54.77	only d.p.	*Triaenodes bicolor*	50.67	only d.p.
Berosus signaticollis	69.79	a.p.	*Limnephilus lunatus*	56.59	d.p.	*Asellus aquaticus*	52.42	a.p.
Gammarus sp. (juveniles)	71.49	a.p.	*Triaenodes bicolor*	58.33	d.p.	Hydrachnidia	54.16	a.p.
Agabus labiatus	72.89	a.p.	*Lestes dryas*	60.02	only d.p.	Culicidae	55.85	only d.p.

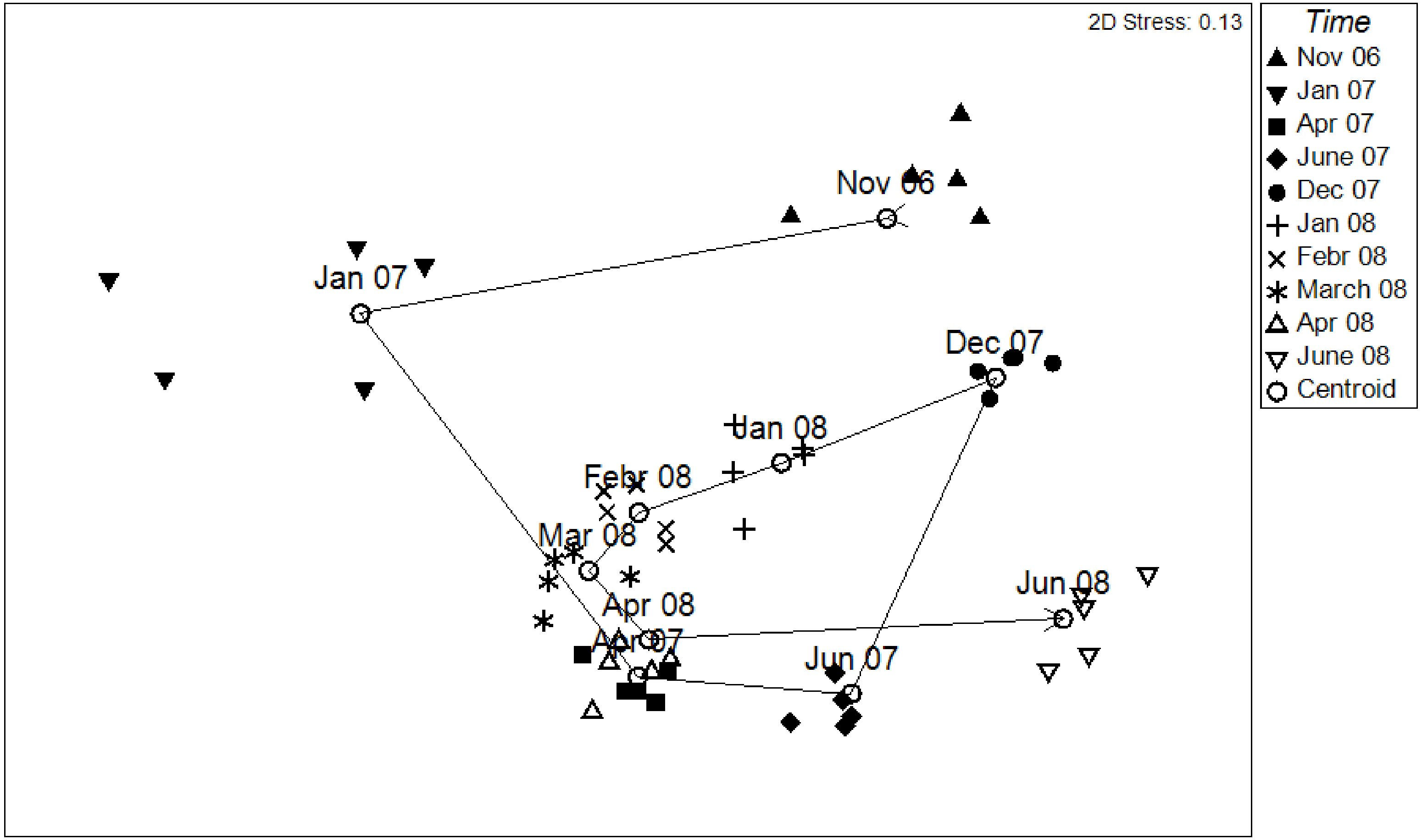


Figure 8.12 Multidimensional scaling (MDS) ordinations of macroinvertebrate communities over two successive sampling periods in Termon, based on log(x+1) transformed abundance data and Bray-Curtis similarity matrix. Trajectories indicate the chronological sequence of samples.

8.4 Discussion

8.4.1 Introduction

The overall aim of this study was to investigate the effects of season, habitat, hydroperiod and water chemistry on the distribution of turlough aquatic invertebrate communities. Twenty-two turloughs, selected as representative of geographical distribution and hydrological conditions were included in the study. These were examined for general patterns of macroinvertebrates and cladoceran communities associated with trophic, hydrological and morphological conditions. Within that larger group, four turloughs were studied more intensively to assess macroinvertebrate temporal and spatial variation and seasonal response to hydrological disturbance; and eight turloughs (including three of those used in the spatial and temporal study) were used to test for relationships of macroinvertebrates with a suite of environmental variables across a nutrient gradient. Here we summarise the importance of season, habitat, nutrients and hydroperiod for turlough invertebrate communities.

8.4.2 Season

Season has a strong influence on macroinvertebrate biodiversity and community structure. Trends identified in the detailed study on successional patterns in macroinvertebrate communities conducted in four turloughs were verified by an independent data set of twenty-two turloughs using a multi-habitat sampling approach. Both studies identified season as important for structuring macroinvertebrate assemblages of turloughs. Differences in macroinvertebrate community composition among sampling months reflect life-stages of macroinvertebrates. Early season species (described as *permanent* by Williams, 1997) were identified as those possessing resting/dormant stages, or resistance to desiccation allowing them to take advantage of the turlough environment before the community diversified. Macroinvertebrate species which arrive later may be considered *ephemeral*, depend largely on migration or aerial dispersal as they do not possess adaptations to loss of aquatic habitats. These results concur with other studies on macroinvertebrate succession in temporary freshwaters (Boix *et al.*, 2004; Jocqué *et al.*, 2007; Lahr, 1997; Lahr *et al.*, 1999; Wiggins, 1980). Changes in taxa abundance, relating to phenology, leads to an increase in spatial variation in macroinvertebrate community structure as the season progresses. Temporal change applies at both annual and inter-annual scales. Onset of flooding (which was about one month later in 2007/2008 compared with the previous year) could drive seasonal patterns. This presents a complexity for routine monitoring of turlough macroinvertebrate communities. Monitoring programmes relying on single annual samples could lead to an underestimation of turlough biodiversity, and negatively influence quality scores if taxa such as Ephemeroptera, Odonata or Trichoptera are included as indicator taxa of anthropogenic disturbances. These animals can emerge before water recedes in spring or early summer. Single season sampling could, moreover, overlook short-lived or egg-diapausing macroinvertebrate taxa. The highly variable turlough environment requires a flexible and adaptable sampling programme, that is designed, for example, to answer specific questions involving comparative analysis across turloughs, or seasonally repeated sampling to assess overall conservation status. Variable starts of the flooding cycle should be taken as an orientation rather than sticking to a fixed sampling-month regime. Thus, adequate turlough sampling is better aligned with the start of the turlough flooding season and temporally stratified according to the needs of the monitoring.

8.4.3 Habitat

Seasonal variability is superimposed on variability among habitats. Habitat heterogeneity is important for macroinvertebrate communities in standing freshwaters (Heino, 2000; Hinden *et al.*, 2005; Stoffels *et al.*, 2005; Tolonen *et al.*, 2001, 2003; van den Berg *et al.*, 1997; White & Irvine, 2003), with various macrophyte communities or sediment types associated with distinct macroinvertebrate assemblages (Brauns *et al.*, 2007; Cheruvelil *et al.*, 2000; Hinden *et al.*, 2005; Pieczyńska *et al.*, 1998; Tolonen *et al.*, 2001; van den Berg *et al.*, 1997). A positive influence of habitat heterogeneity on macroinvertebrate taxon richness in the turloughs concurs with studies in other standing waters (Brönmark, 1985; Jeppesen *et al.*, 2000; Tolonen *et al.*, 2003). Seasonal changes of habitat availability in turloughs likely accentuates these differences, with changes in habitat preferences of certain taxa as a result of different life-cycle stages affecting community structures (Pieczyńska *et al.*, 1998; Solimini *et al.*, 2006).

In the turloughs, certain macroinvertebrate taxa of conservation concern were associated with particular habitats. For a comprehensive conservation assessment, a sampling regime incorporating all available habitats in a turlough seems necessary. Nevertheless, variation *within* turlough macroinvertebrate communities is generally nested *among* turlough variability. This adds weight to the usefulness of macroinvertebrates as reliable indicators of change even across a range of habitat types, despite the inherent spatial variation of littoral zones. Similar results were found by White and Irvine (2003) in a study on twenty-one Irish lakes. Whether one or multiple habitats should be sampled for monitoring purposes should depend on the objective of the sampling. If the aim is detecting a pressure response, routine standardisation among turlough sampling of the most dominant turlough habitat (submerged grassland) seems appropriate. Stratified sampling reduces inherent spatial 'noise' and facilitates cost and time effective monitoring. The results of this study emphasize the suitability of a single or pooled submerged grassland macroinvertebrate sample for routine turlough monitoring as required under the WFD. For a comprehensive survey of turlough macroinvertebrate biodiversity as required for conservation assessment under the EC Habitats Directive, sampling all available habitats in a turlough would be more useful. Thorough sampling also, of course, enhances the possibility of the detection of local and internationally rare taxa.

8.4.4 Nutrients

The importance of trophic conditions for structuring macroinvertebrate assemblages in freshwater environments is widely acknowledged (Brauns *et al.*, 2007; Brodersen *et al.*, 1998; Heino, 2000; Langdon *et al.*, 2006; Rasmussen, 1988; Tolonen *et al.*, 2001; Tolonen *et al.*, 2005; White & Irvine, 2003). This study also identified total phosphorus (TP) concentrations as important in structuring macroinvertebrate communities of turloughs. Separating the effects of habitat structure on macroinvertebrate assemblages from those of nutrient trophic state can, however, be difficult as these are often interrelated (Brauns *et al.*, 2007; Brodersen *et al.*, 1998; Solimini *et al.*, 2006). In the turloughs, taxa groups responded to increased nutrient concentrations with higher abundances of Diptera and Ostracoda, while Aranea, Odonata and Trichoptera showed a significant negative correlation with nutrient state. These findings correspond to those from various other studies (e.g. Hellawell, 1986; Moore, 1980; Nelson & Thompson, 2004; Resh & Jackson, 1993; Yılmaz & Külköylüoğlu, 2006). Certain cladoceran taxa presence and abundance also showed associations with nutrient state of turloughs. Low tolerance of *Alonopsis elongata* to eutrophication has been reported previously (de Eyto *et al.*, 2003; Fryer, 1993; Irvine *et al.*, 2001). It was found in only one turlough; which had low nutrient status. Other species such as *Alona rustica* and *Alonella excisa* were predominantly detected in turloughs of low to medium trophic state, concurring with de Eyto *et al*. (2002, 2003). Decrease of biodiversity owing to eutrophication of waters has been previously reported (Brodersen *et al.*, 1998; de Eyto, 2001; Duigan & Murray, 1987) and was reflected in the decrease of cladoceran taxon richness with nutrient concentrations across the turloughs. The increase of cladoceran abundance with trophic state reflects higher phytoplankton production and, hence, food availability (Canfield & Jones, 1996; Karjalainen *et al.*, 1999; McCauley & Kalff, 1981; Tolonen *et al.*, 2005). No evidence was, however, found for the influence of nutrient concentrations on macroinvertebrate taxon richness and abundance. Reynolds (2000) also found nutrient concentrations to be unimportant in determining faunal community diversity in turloughs.

Nutrient enrichment, however, also appeared to influence the seasonal patterns of macroinvertebrates in turloughs. This was characterised by a general dominance of taxa considered tolerant to pollution in turloughs with high trophic state (mainly oligochaetes and chironomids) (Brodersen *et al.*, 1998; Hellawell, 1986; Pinel-Alloul *et al.*, 1996), and a trend of more susceptible taxa (if present) disappearing towards the end of the season in turloughs with high nutrient concentrations. Climate change will possibly increase the number of stressors affecting turlough ecosystems. Thus, priority should be given to the reduction of already existing pressures such as nutrient enrichment. While the spatial and temporal variability of the comparatively complex macroinvertebrate communities could be challenging for routine turlough sampling, some chydorid taxa have the potential to be used as relatively straightforward elements for monitoring ecological change.

8.4.5 Hydroperiod

The temporary nature of the turlough environment poses a challenge to its faunal communities. Different macroinvertebrate taxa have adapted in various ways to the repeating occurrence of flood water recession in turloughs in order to mature, reproduce or disperse before the end of the wet cycle. Adaptations include the production of resting eggs and resistance to desiccation, migration of adults to permanent waters, or survival over a dry period as terrestrial adults (Lahr *et al.*, 1999; Williams, 1987). The occurrence of uncommon invertebrate taxa is a feature of many temporary waters (Collinson *et al.*, 1995; Della Bella *et al.*, 2005; Williams, 1987) and concurs with findings of invertebrate species and assemblages of restricted distribution and high conservation value in this study. Several rare invertebrate taxa and assemblages were detected such as the characteristic 'edge moss dwelling' beetle community or the glacial relict species *Eurycercus glacialis.* Such rare taxa are often reported as sensitive to anthropogenic disturbances such as nutrient enrichment (Bilton, 1988; Shirt, 1987). The loss of water during the periodically occurring dry phase of turloughs may not only support very distinct invertebrate communities, but also confer specific advantages to particular rare species. The absence, or likely low numbers, of fish in turloughs provides an environment suitable for large-bodied planktonic, or semi-planktonic, organisms such as *Eurycercus glacialis* (Duigan and Frey, 1987), and possibly also enabling the persistence of some littoral macroinvertebares such as the rare damselfly *Lestes dryas.*

The importance of hydroperiod and, thus, habitat permanence for the diversity of macroinvertebrate communities in temporary wetlands has been reported by several authors (Collinson *et al.*, 1995; Kiflawi *et al.*, 2003; Schneider & Frost, 1996; Waterkeyn *et al.*, 2008; Williams *et al.*, 2003). The dry phase of a turlough can be defined as a natural disturbance for the faunal communities of turloughs and the associated hydroperiod length was found to affect seasonal patterns of turlough macroinvertebrates. Macroinvertebrate communities of turloughs with a short hydroperiod and, thus, high disturbance were identified to be characterised mainly by invertebrates well adapted to the recurring stress of floodwater recession. Wiggins (1980) found the same to be true for faunal communities of temporary pools. Interannual variability of taxa composition was furthermore found to be related to interannual differences in hydroperiod (Schneider & Frost, 1996). With increasing habitat persistence, influence of disturbance becomes less and biotic interactions more important (Schneider, 1999). Across the studied turloughs, taxon richness increased over time. This temporal gradient of biodiversity likely reflects longer exposure for colonization and emergence from resting stages (Cayrou & Céréghino, 2005; Holland and Jenkins, 1998; Spencer *et al.*, 1999). CCA results suggested that hydroperiod had, however, a low influence on community structures of macroinvertebrates relative to effects of season, nutrient concentrations and number of habitats sampled. The effect of hydroperiod on community structure was nevertheless evident in the positive correlation of Heteroptera and Trichoptera with increasing habitat permanence. Thus, effects of hydroperiod are directly linked to macroinvertebrate life-stages and the strong identified seasonal effect had likely an overriding effect in the CCA analysis.

Hydroperiod variability among turloughs and years illustrates the highly dynamic nature of turloughs, and presents even greater difficulty for developing a classification system than that of permanent standing waters. The concept of water body types and, by inference, type-specific reference condition, is controversial (Moss *et al*. 1994) and one which ignores the multidimensional continua of ecological conditions, comprising a matrix of physical, chemical and biotic interactions, all nested within a biogeographical framework. This variability would seem even more accentuated for turloughs than standing waters (Visser *et al*. 2006). Turlough monitoring protocols need a flexible approach, geared towards flooding regimes, variable hydrocycles and an acknowledgement that the individual turloughs may be quite distinctive, irrespective of what policy makers may consider convenient.

8.4.6 Macroinvertebrate Distinctiveness and Conservation Value

The highly individual character of turlough macroinvertebrate communities was a recurrent feature of this study. Replicate macroinvertebrate turlough samples repeatedly formed highly distinct clusters and certain macroinvertebrate taxa showed associations to certain morphological (e.g. Odonata in well-vegetated habitats of Caranavoodaun) or water chemical characteristics (e.g. Diptera and Gastropoda in nutrient rich waters of Caherglassan) of the turloughs. As reported for lakes (White & Irvine, 2003), spatial variation *within* turloughs was nested *among* turloughs. This coupled with the unique physical features of the turloughs and low intensity predation can largely explain the high conservation value of turlough invertebrate communities. This also means that localized anthropogenic impact can be highly detrimental to the conservation of the patchwork of turlough communities.

In the intensive survey of eight turloughs (Table 8.9) up to four rare/restricted taxa of six uncommon species discovered were found in five of the turloughs. This highlights the contribution of turloughs to regional biodiversity and their high conservation value. The coleopterans recorded during this intensive turlough survey comprised species of a characteristic 'edge-moss-dwelling' turlough community, identified by Bilton (1988), which is considered of high conservation value and unknown from Great Britain (Foster *et al.*, 1992). This assemblage, which is reported to be very susceptible to disturbance by human sources such as heavy grazing and nutrient enrichment, includes the 'nationally notable B species' (Great Britain) *Hygrotus quinquelineatus*, *Agabus labiatus* and *Berosus signaticollis*. They are frequently accompanied by other typical turlough beetles including *Agabus nebulosus*, *H.*

impressopunctatus and *Helophorus* sp. (Bilton, 1988), which were also found during this survey. The Red Data Book category three species (rare and threatened) *Graptodytes bilineatus*, together with *Agabus labiatus* and *Dryops similaris* (not recorded during this survey) were, furthermore, described as most sensitive to disturbances (Bilton, 1988). The mud snail *Omphiscola glabra* (UK RDB category one — vulnerable) is known as a temporary pond specialist and typically found on its own or accompanied only by very few molluscs species (Bratton, 1991).

Local habitat conditions contribute to turlough conservation value. For example, the high occurrence of *Sympetrum sanguineum* observed in Caranavoodaun reflects its preference for shallow well-vegetated ponds, situated in woodland. Its adults typically perch in bankside trees while feeding (Brooks & Lewington, 1997). *S. sangiuneum* as well as the scarce emerald damselfly *Lestes dryas* complete their live cycle within one year, allowing them to breed in seasonal pools with thick vegetation such as Caranavoodaun (Brooks & Lewington, 1997). *L. dryas* is considered the rarest Irish damselfly and is especially threatened by intensive grazing, which removes shelter for adult damselflies and reduces suitable areas for reproduction (Nelson & Thompson, 2004). Thus, the comparably low grazing pressure (Ní-Bhriain *et al.*, 2002) and relatively low nutrient status (TP=11 μg l^{-1}; TN=0.23 mg l^{-1}; Chl a=1.31 μg l^{-1}), together with its surrounding hazel woodland and well vegetated littoral/shore zone make Caranavoodaun an ideal habitat for both Odonata species. Their mutual occurrence furthermore agrees with findings by Moore (1980), who reported *S. sanguineum* in two out of four *L. dryas* freshwater sites in Ireland. While the absence or low density of fish in many turloughs is likely important for their invertebrate community composition, and is a plausible factor for persistence of *L. dryas* in Caranavoodaun, this may also contribute to the presence of other conservation features. The smooth newt *Triturus vulgaris* was detected in Brierfield, a turlough which usually holds some water even during summer when newt tadpoles metamorphose. *T. vulgaris* is probably the top-predator in this turlough. Temporal and spatial habitat complexity was suggested by Reynolds (2000) to allow for the coexistence of predators with characteristic turlough invertebrates.

While the turlough assemblage of invertebrates include notable species it is, however, the community dynamics that provide overall the most important conservation attribute. Turlough invertebrate communities show a marked seasonal pattern of assemblages, reflecting variable extent of disturbance driven by flooding and emptying of turloughs. This is important for turlough conservation because it negates a view that turlough invertebrates represent any sort of stable community type across a hydrological gradient. Furthermore, depending on the onset of flooding, seasonal patterns can vary across years. This accentuates the unreliability of not only monitoring once a year, but any assumptions that a particular month will represent similar conditions in different years. An important feature of nature conservation is the protection of naturalness. This includes the maintenance of the highly dynamic hydrology of turloughs, and requires prohibiting further alterations to natural hydrology. Complete anthropogenic drainage of turloughs removes habitat refugia for the aquatic invertebrates. Although little is understood on the dynamics of recolonisation of turloughs, it is likely to be important for community diversity.

8.5 Conclusions

The main conclusions from the study of the invertebrates in the turloughs are:

- Turlough macroinvertebrate communities are highly distinct and conducive to simple and cost-effective routine monitoring regimes. A single submerged grassland habitat sample located in any location of a turlough can provide a reliable metric of the macroinvertebrate community. This stratified sampling reduces inherent spatial 'noise' and is, thus, suited for the detection of pressure gradients.

- The number of habitats sampled should depend on the questions addressed by sampling objectives. When sampling to assess overall biodiversity, signal precision should be sacrificed in order to obtain a more comprehensive survey of turlough biodiversity by adopting a multi-habitat sampling approach.
- Season had a significant influence on macroinvertebrate community structure, varying among months and years. Samples collected late in the season could lead to an underestimation of turlough biodiversity and reduce quality scores if based on emerged taxa. Turlough sampling should be responsive to variable commencements of flooding. Timing and frequency of sampling should be appropriately stratified depending on monitoring objectives.
- Macroinvertebrate community structure varied with increased nutrient state of the turloughs. Total phosphorus concentrations explained a significant amount of variance in the biological data set and a change in abundance of taxonomic groups with nutrient enrichment was detected. Macroinvertebrate seasonal pattern seem vulnerable to nutrient enrichment. Some macroinvertebrate orders and chydorid taxa have the potential to be used as biotic elements for monitoring of ecological change of turloughs.
- Hydroperiod and rate of areal reduction of water in turloughs impacted macroinvertebrate community structure.
- Turloughs are inherently variable systems that might negate the development of simple type-specific reference conditions as required for lakes under the WFD. Turlough sampling regimes need a flexible approach and should be geared towards the start of the flooding season and variable hydrocycles.
- Conservation objectives should respect the importance of naturalness which, in turloughs, includes a dynamic hydrology and low nutrient status.

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Chapter 9. Integration of Work Packages: Turlough Ecological Functioning

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Turlough ecology is driven by a complex interaction between hydrology, nutrient status, landuse and biotic interactions; Caherglassan, Co. Galway. *Photo: M. Murphy*

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9.1 Introduction

Turloughs are essentially seasonally flooded wetlands and their ecological functioning is generally assumed to conform to the more general wetlands characteristics, at least in terms of vegetation communities (O'Connell *et al.*, 1984; Goodwillie 1992, 2003; Visser *et al.*, 2006, Regan *et al.*, 2007). Intermittent inundation creates a number of challenges for biota. For instance, the depth, duration and frequency of flooding is considered the primary factor affecting plant communities in intermittently flooded wetlands (de Becker *et al.,* 1999; Casanova & Brock, 2000; Thompson & Finlayson, 2001). Trophic conditions are considered another important influence on vegetation communities in wetlands. Forb-dominated communities are associated with higher nutrient concentrations, while the sedges generally dominate in more nutrient-poor conditions (O'Connell *et al.,* 1984). Many wetlands have been used historically for grazing (Williams, 1990) and, particularly in the absence of wild large herbivores, maintaining certain levels of livestock grazing are likely to be important for maintaining biodiversity (Bignal & McCracken, 1996).

Despite the presumed general similarity of turloughs to wetlands in general, the high dependence of turloughs on groundwater and the specific geological setting in karst limestone result in specialised physico-chemical characteristics. These characteristics are considered sufficiently unique to designate turloughs a priority habitat under the EU Habitats Directive (92/43/EEC). In spite of this distinction, very little empirical work has been done to determine their ecological functioning and to verify the premise of the functional similarity of turloughs to the more general wetland characteristics. Whereas some studies investigated the relative importance of a subset of multiple drivers of turlough ecology (e.g. water chemistry, selected aspects of hydrology and soil properties in Regan *et al.,* 2007; hydrology, soil characteristics and grazing in Moran *et al.,* 2008) they focused on a single ecological receptor, namely vegetation. The aquatic phase dominates the annual hydrological cycle of many turloughs. Omitting aquatic organisms, and thus any ecological processes taking place during the flooded period, risks oversimplification of the understanding of turlough functioning. There have been relatively few studies on the phytoplankton of temporary lakes in general (Williams, 2006) which contrasts starkly with the extensive literature on the phytoplankton of permanent lakes. In spite of the various challenges imposed on aquatic life by periodical desiccation, turloughs develop phytoplankton biomass comparable to those of permanent lakes in summer (Cunha Pereira *et al.,* 2010) and phytoplankton are likely to play an important role in nutrient cycles. Turloughs provide habitat for a variety of aquatic invertebrates (e.g. Bilton, 1988; Reynolds, 2000 & 2003; Sheehy Skeffington *et al.*, 2006) but there has been little work on assessing their community structure or dynamics in relation to both natural and anthropogenic pressures in turloughs. Addressing these important and urgent knowledge gaps is needed to enable informed management of these priority habitats as well as fulfilment of legal requirement under the Habitats Directive and the Water Framework Directive (92/43/EEC and 2000/60/EC respectively).

By taking a holistic approach and integrating interdisciplinary insights from a broad range of turloughs, this chapter aims to assess the relative importance of multiple drivers, capturing those operating at both proximal (turlough basin) and distal (catchment) spatial scales, on multiple receptors, importantly, incorporating both terrestrial and aquatic ecology, to advance markedly the understanding of ecological functioning of turloughs.

This chapter integrates the ecological findings of multidisciplinary research project on turlough ecology and conservation undertaken in Trinity College Dublin and funded by the National Parks and Wildlife Service (with some additional funding from the Environmental Protection Agency). The chapter firstly characterises all important processes for ecological functioning of turloughs, represented by the individual model links (sections 9.2 and 9.3), by integrating biological, hydrological, hydrochemical, soil and landuse data generated from a broad range of turloughs. Secondly, having gathered this information, this chapter identifies key drivers and pressures affecting the ecological functioning of turloughs (section 9.4).

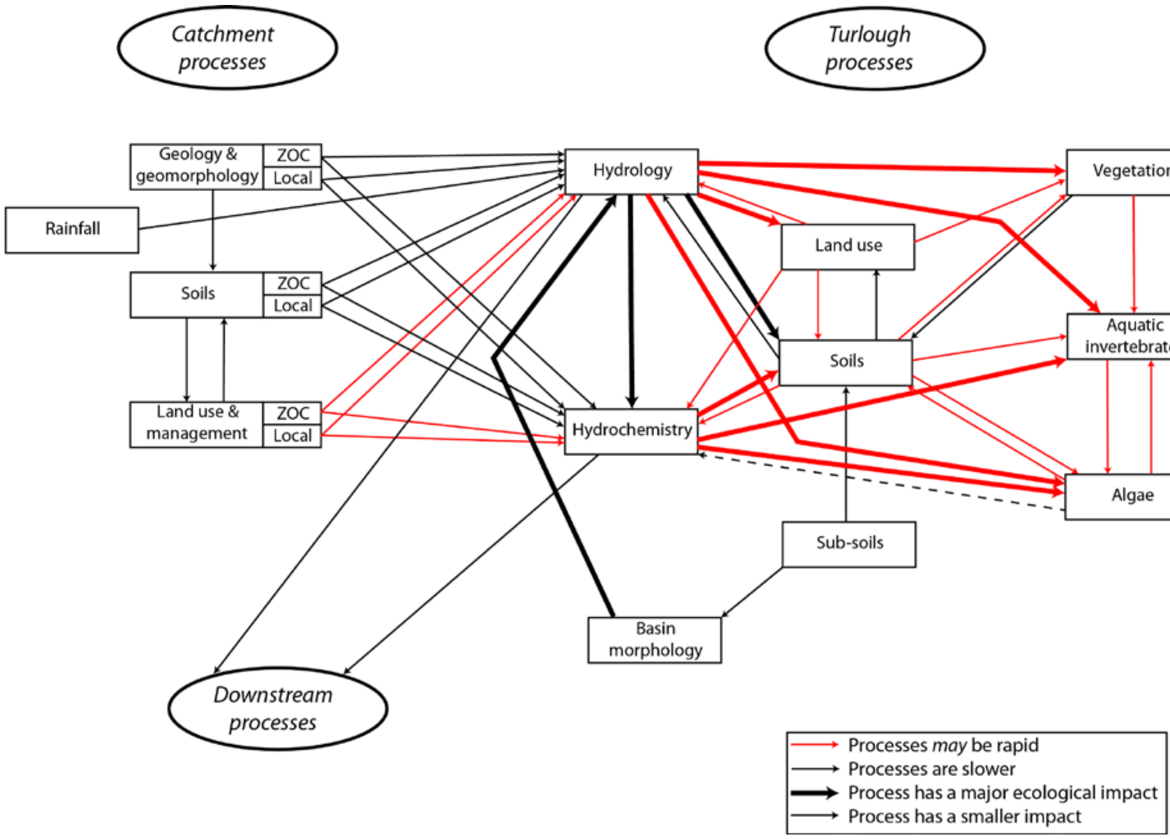

Figure 1 Conceptual model of turlough functioning indicating important interdependencies (arrows) among the physical, chemical and biological aspects of turlough functioning at the turlough and the catchment spatial scales. Catchment scale is further divided into local catchment and zone of groundwater contribution (ZOC; see text for further details). Thick and thin arrows indicate significance of ecological impacts (major and smaller, respectively), red and black arrows indicate response time ('may be rapid' and 'are slower', respectively).

9.1.1 Conceptual Model of Turlough Functioning

The hydrological regime and water chemistry are key elements of turlough functioning, conveying most processes of major ecological significance. They also play central roles in mediating the influence of catchment (geology and geomorphology, soils, landuse and management and rainfall) and turlough basin (morphology, landuse, soils and sub-soils) on key aspects of turlough ecology (vegetation, aquatic invertebrates and algae). Some of the turlough basin characteristics (landuse and soils), in addition to operating via hydrology and hydrochemistry, have direct ecological effects on turlough ecology. These interdependencies among the physical, chemical and biological factors influencing turloughs, including their response time and relative ecological importance, have been framed into a conceptual model depicting the ecological functioning of turloughs (Figure 9.1), which forms the framework of this chapter.

9.2 Catchment Processes

From the viewpoint of hydrological pathways, turlough catchment processes operate at two different spatial scales, which have been explicitly included in the model:

- local: overland flow, percolation through soils/subsoils and recharge through epikarst and local groundwater; this zone is defined by the morphology of the turlough and topography in the immediate vicinity,
- zone of groundwater contribution (ZOC): contributions through groundwater and stream flow from a wider area; this may either be defined hydraulically in terms of the contributing catchment area required to fill the turlough or topographically in terms of a conventional river basin catchment. The hydraulic ZOC is often much smaller than the whole catchment area.

9.2.1 Rainfall Effects on Hydrology

ZOC

Rainfall is the source of groundwater recharge, which in turn drives turlough hydrology. A clear example of this was seen in Turloughmore. Following the cessation of rainfall the net flow into the turlough rapidly becomes negative leading to a rapid fall in water levels. Such a flashy hydrological regime results in discrete flood events that correlate strongly to rainfall events. In less flashy turloughs like Coolcam, the reversal of flow direction is much slower, leaving the turlough at a relatively high level if/when rainfall resumes. The relative damping of response to rainfall is a reflection of the hydrogeological controls on the groundwater inflow to the turlough. However, while the magnitude of the water level peaks in turloughs in response to rainfall events can vary greatly, their timing shows a good correspondence with precipitation patterns across a wide set of turloughs. The storage effect in most turloughs gives a unimodal form to the annual hydrograph of water levels under the prevailing rainfall regime in the west of Ireland.

Duration and intensity of antecedent rainfall periods affects soil moisture in the catchment and storage within the aquifer, which has a significant impact on hydrologic response. Whereas hydrological regimes of turloughs during winter respond to rainfall events, even an intense rainfall during the summer period is unlikely to lead to turlough inundation owing chiefly to the typically lower antecedent rainfall compared with winter and the water storage deficit in the underlying karst.

Local

Local effects resemble those occurring within ZOC (see above).

9.2.2 Geology and Geomorphology Effects on Hydrology

ZOC

Most turloughs fill mainly by rising groundwater levels through estavelles and springs and ultimately empty through estavelles and swallow holes (Coxon & Drew, 1986; Gill 2010). Bedrock geology and geomorphology have major impacts on groundwater flows. The degree of bedrock karstification, including the size, orientation and connectivity of the flow paths present within the rock, influences the flooding regime of turloughs (Drew & Daly, 1993). The greater the extent of conduit flow, as opposed to diffuse flow, the shorter the travel time of water to the turlough. Traced underground travel times through the karst conduit system in the Gort Lowlands were up to 1,000 m h^{-1} (Drew, 2003). Such a rapid conduit flow induces fast groundwater recharge and hydrological response of turloughs in this area.

Quaternary (subsoils) geology and geomorphology affects the hydrological responses of groundwater to rainfall events. The permeability and thickness of the Quaternary deposits influence the hydrological pathways of groundwater recharge. Thinner or more permeable deposits favour increased infiltration and throughflow. On the other hand, thicker, lower permeability deposits (clayey glacial till) favour overland flow, which may increase point recharge through swallow holes and dolines.

The degree of development of epikarst (the shallow, fractured zone in the upper part of the karstified bedrock) has a strong effect on the contribution to turlough inflow/outflow in the local catchment. The effects of Quaternary glaciation has often resulted in infilling of fractures with clay or fine sediments, especially in topographic depressions, resulting in relatively low percolation rates either directly to a turlough or via geologically older conduit systems. Where minor collapse structures, such as dolines, occur in the catchment, percolation is naturally enhanced. These conditions often make the hydrological source catchment for the flows into a turlough extremely complex. Consequently, in many cases, the hydrological ZOC cannot be delimited as a continuous boundary.

<u>Local</u>

Turloughs receive local water inputs mainly by overland flow, throughflow within the Quaternary deposits (subsoils) and by epikarst/subcutaneous flow (e.g. Ford & Williams, 1989, p.162) within the upper part of the limestone. The permeability and thickness of the Quaternary deposits influences the hydrological pathways of turlough recharge; thicker, lower permeability deposits (clayey glacial till) favour overland flow, whereas thinner or more permeable deposits favour increased infiltration and throughflow. If the epikarst is highly developed, it may provide significant water storage, which may delay and attenuate inundation of a turlough. Even though these pathways are considered of secondary hydrological importance to most turloughs they can be important for physico-chemical properties of turloughs, particularly for the transfer of nutrients and suspended solids from the local catchment.

9.2.3 Geology and Geomorphology Effects on Hydrochemistry

<u>ZOC</u>

ZOC bedrock geology and Quaternary geology (subsoils) are expected to influence the major ionic composition of the turlough waters. Since, by definition, turloughs are located in limestone areas, the most important geological factor is the presence of non-calcareous rocks (e.g. sandstones and shales) in the ZOC, as for example in the Gort Lowland turloughs fed by sinking streams from the Slieve Aughty upland. Turloughs fed predominantly by such water will have lower pH, alkalinity and hardness. For example, as seen in Table 4.1 and section 4.3.1 (*Chapter 4: Water Chemistry and Algal Biomass*), Blackrock, Caherglassan, Lough Coy and Garryland have lower alkalinity than turloughs with ZOCs entirely on limestone.

Where subsoils are absent and patchy rendzina soils are developed directly on limestone, below average alkalinity is observed, as in the Burren turloughs such as Lough Gealain and Knockaunroe (Table 4.1 and section 4.3.1 of *Chapter 4*). This may be attributable to the lack of a continuous deep soil cover – rainwater recharging the karst aquifer through a complete soil cover will be in contact with higher soil carbon dioxide levels and be capable of dissolving more limestone. Where the subsoils are peats (see Catchment soils effects), there may be higher colour due to humic substances. As seen in Table 4.1 and section 4.3.1 (*Chapter 4*), Blackrock, Caherglassan, Lough Coy and Garryland had much higher colour than the other sites. If the peat is actively eroding there may be also input of suspended solids. (Note that turbidity, which is a measure of fine suspended solids, was highly correlated with colour; see Cunha Pereira, 2011, p. 228).

The likelihood of phosphorus transmission from the ZOC to the turlough will reflect the bedrock and Quaternary geology. The most important factor is the presence of point recharge to the limestone aquifer by sinking streams – phosphorus in the stream water will reach the turlough by rapid conduit flow with little attenuation (see Kilroy & Coxon, 2005 for a case example of phosphorus transmission to a karst spring from a contamination incident in a sinking stream). Closed depressions (dolines) are also potential routes for phosphorus entry: this will depend on the thickness of soil and sediment within the doline and on the geomorphology of the doline, i.e. solution versus collapse (see Mellander *et al.,* 2013 for a classification of dolines according to phosphorus transmission risk). Furthermore, limestone pavement with thin patchy soil cover will pose a risk of phosphorus transmission via the grykes (solutionally widened joints) provided a phosphorus source is present (see *Catchment soils effects on hydrochemistry* and *Catchment landuse effects on hydrochemistry*). However, because these areas tend to have a low landuse intensity, a significant negative correlation is observed between the proportion of bare rock from the CORINE land cover dataset and turlough total phosphorus (see Cunha Pereira, 2011, p. 162). Thicker, lower permeability Quaternary deposits in the ZOC are expected to favour phosphorus retention by adsorption and precipitation provided that they do not conduct water by overland flow to a swallow hole. However, peaty subsoils in the ZOC are positively correlated with turlough total phosphorus (see Table 11.4, *Chapter 11: Water Framework Directive Risk Assessment*); this may be due to a combination of poor phosphorus retention by peat soils (see *Chapter 11* section 11.4.3, and Daly *et al.,* 2001) and to the fact that runoff from peaty soils enters the karst aquifer via sinking streams.

Nitrate, being a highly soluble, mobile anion, is more likely than phosphorus to be readily transmitted to groundwater, so it is less likely to be strongly affected by Quaternary geology and bedrock geology including degree of karstification. Point recharge via swallow holes and dolines may allow rapid entry of nitrate to the aquifer, and a shallow patchy soil cover also increases the risk of nitrate entry (see Coxon, 2011, section 5.3.3.3). However, in the present study, the overriding factor in areas with shallow patchy soil such as the Burren is the low landuse intensity. Thus a highly significant negative relationship is observed between the proportion of bare rock from the CORINE land cover dataset and turlough water total nitrogen (see Cunha Pereira, 2011, p. 162), and as with the relationship between proportional rock and total phosphorus, this is attributed to the low landuse intensity in areas with a high proportion of bare rock. The presence of low permeability Quaternary deposits in the ZOC will favour denitrification and hence lower nitrogen input to the turlough by groundwater flow. However, low permeability deposits may favour nitrogen transmission to sinking streams by overland flow, so this factor is closely interlinked with hydrology.

<u>Local</u>

Local water inputs to the turlough will be mainly by throughflow / overland flow within the Quaternary deposits (subsoils) and by epikarst flow within the upper part of the limestone.

The permeability and thickness of the Quaternary deposits will influence the hydrological pathways and hence the hydrochemistry. Thicker, lower permeability deposits (clayey glacial till) will favour contaminant transport to the turlough from neighbouring fields by overland flow, whereas thinner or more permeable deposits will favour leaching of contaminants into the limestone. If the epikarst is highly developed, it may provide significant water storage, which may delay and attenuate contaminants e.g. phosphorus; temporarily stored contaminants may then be released from this zone by flood pulses (Field 1989).

9.2.4 Geology and Geomorphology Effects on Soils

ZOC

Soils are a product of parent material, climate, living organisms, topography and time (Gardiner & Radford, 1980). Turlough catchment soils are generally composed of basic soils derived from limestone glacial till; however, significant areas of acid soils may occur within the catchments of some turloughs (i.e. Rathnalulleagh, Carrowreagh, Coolcam and Croaghill) (*Chapter 11: Water Framework Directive Risk Assessment*).

Local

Local effects resemble those occurring within ZOC (see above).

9.2.5 Soil Effects on Hydrology

ZOC

Soil texture, i.e. the proportional content of its constituent particles (sand, silt, clay, etc.), and soil depth determine its permeability to rainfall events. Hence, soil characteristics affect the proportion of flow that runs into the aquifer or turlough via the rapid overland pathway, and the proportion that percolates via a slower pathway through the soil. This affects the magnitude and timings of hydrological response giving rise to either more sharply defined or more muted responses, respectively. Soil texture and depth also affects the degree of evapotranspiration from the surface and therefore the quantity of water that can recharge via either the more rapid or slower routes discussed above.

Local

Local effects resemble those occurring within ZOC (see above).

9.2.6 Soil Effects on Hydrochemistry

ZOC

Soils in the ZOC will influence turlough hydrochemistry both by their influence on hydrological pathways and through acting as a source of dissolved substances including nutrients, and of suspended solids. Peat soils provide humic substances which influence turlough water colour. As noted under *Catchment geology effect on hydrochemistry* (Section 9.2.3), highest colour is found in the Gort Lowland turloughs fed by sinking streams draining peaty soils on the Slieve Aughty uplands. Peat soils on low permeability glacial deposits may contribute to higher than average colour in some of the Roscommon turloughs, e.g.

Carrowreagh (Table 4.1 in *Chapter 4: Water Chemistry and Algal Biomass*). The proportion of peat in the ZOC (from the CORINE land cover dataset) is highly significantly correlated with turlough water colour (see Table 7.6 in Cunha Pereira, 2011).

Shallow, patchy rendzina soils associated with limestone pavement will provide little opportunity for phosphorus attenuation. Such areas tend to have low phosphorus inputs (see *Catchment landuse effects on hydrochemistry*), and the significant negative correlation between turlough total phosphorus and the proportion of bare rock and the proportion of extreme pathway susceptibility is attributed to this (Table 11.4 and section 11.4.3 of *Chapter 11: Water Framework Direct Risk Assessments for Turloughs*). Nonetheless it should be noted that these areas are potentially highly vulnerable to transmission of phosphorus.

Mineral soils derived from limestone till, e.g. shallow brown earths and grey brown podzolics, will generally provide good phosphorus attenuation by adsorption and precipitation (as noted in the catchment of Cregduff springs, Co. Mayo by Mellander *et al.*, 2013), with lower risk of phosphorus transmission to turloughs, provided high risk dolines are not present (see *Catchment geology effects on hydrochemistry* and *Catchment hydrology effects on hydrochemistry*). Acid soils were found to have a significant positive correlation with turlough total water phosphorus while basic soils were significantly negatively correlated with total water phosphorus (Table 11.4 and section 11.4.3 of *Chapter 11*). This may be due to greater phosphorus retention in calcareous soils, although as noted in section 11.4.3 there is also an interrelationship with landuse: acid soils are associated with unimproved pasture, and a link with soil drainage is suggested, with greater phosphorus loss from wet soils. It is also likely that in ZOCs with extensive limestone pavement, pressure from phosphorus enrichment is low due to very low intensity agriculture.

<u>Local</u>

Soils within the local topographic catchment will influence turlough hydrochemistry in a similar way to soils within the wider ZOC, with different soils having different risks of phosphorus transmission as noted above. The chief difference is in the case of phosphorus loss from poorly drained soils by overland flow and field drain flow – whereas such losses in the wider ZOC would reach the turlough via sinking streams, overland flow within the topographic catchment could reach the turlough directly.

9.2.7 *Soil Effects on Land Management

<u>ZOC</u>

Soil drainage characteristics are major determinants of the grazing potential of land, with a relatively lower production capacity associated with wet soils (Lee, 1974). An examination of the drivers of turlough water eutrophication indicates that turlough catchments with very thin or absent soils, such as within the Burren Co. Clare, have low landuse pressures (*Chapter 11: Water Framework Risk Assessment*). Typical tillage soils, on the other hand, are relatively deep with good drainage and a friable texture but very low proportions of tillage soils were found within the turlough catchments.

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* The lack of readily available, high resolution Irish land use data prevented an explicit examination of the links between soils and land use across turlough catchments.

Local

Local effects resemble those occurring within ZOC (see above).

9.2.8 *Landuse and Management Effects on Soils

ZOC

Grazing animals and organic and inorganic fertilisers contribute nutrients to catchment soils via excreta and land-spreading respectively. Catchment-scale fertiliser addition to soils and grazing densities are significant issues within the context of turlough floodwater quality given that diffuse nutrient losses from fertilised grassland and arable soils are the primary driver of the eutrophication of Irish waters (e.g. Tunney *et al.,* 2000; Carton *et al.,* 2008). The main reasons for losses are over-application and inappropriate application of organic and inorganic fertilisers (e.g. McDowell *et al.,* 2001; Kurz *et al.,* 2005). Nitrogen is readily leached through well drained soils and subsoils to groundwater whereas poorly drained soils with elevated soil phosphorus levels tend to lose phosphorus via overland flow (Kurz *et al.,* 2003).

Local

Many turloughs are surrounded by sloping, fertilised grassland from which they are likely to receive nutrient inputs via overland flow and soil/subsoil throughflow (*Chapter 6: Turlough Soils and Landuse*).

9.2.9 Landuse and Management Effects on Hydrology

ZOC

Different types of vegetation have varying water storage and evapotranspiration capacity. For example, vegetation in a forested catchment potentially has a greater rainfall retention potential than that of a closely-grazed pasture. Furthermore, land management affects the soil structure, influencing its moisture retention capacity. These factors affect hydrological pathways (runoff versus throughflow), and therefore hydrological response times.

Owing to the localised nature of groundwater flow through karst aquifers, they are particularly sensitive to activities which may interfere with these flow paths, such as artificial drainage (e.g. Kilglassan), particularly if it is deep enough to impact upon the main karst water table. Water abstraction has a similar but less pronounced effect, depending on the ratio of abstraction discharge to mean groundwater flow rate in the vicinity of a turlough.

Local

Local effects resemble those occurring within ZOC (see above).

9.2.10 Landuse and Management Effects on Hydrochemistry

ZOC

In the case of some turloughs, simple observation indicates that there is a relationship between the nature of the catchment and water quality in the turlough. Thus it is unsurprising that the Burren turloughs (Lough Gealain and Knockaunroe) in a karst landscape, which is not conducive to intensive agriculture, had low nutrient status. At the other end of the scale, Ardkill clearly had intensive agricultural activity in the immediate vicinity of the turlough and it seems highly likely that local sources explain its high nutrient status. However, it was not possible to develop a satisfactory model that could explain turlough water quality in terms of catchment characteristics (*Chapter 11: Water Framework Directive Risk Assessment*). While certain relationships were found between catchment characteristics (e.g. between turlough total phosphorus and the proportion of unimproved pasture from the CORINE land cover dataset) the underlying basis of such relationships is unclear. As noted under *Catchment soils effects on hydrochemistry*, the relationship between turlough total phosphorus and the proportion of unimproved pasture is linked with a relationship with acid soils. Potential reasons for the relationship with unimproved pasture are discussed in section 11.4.3 (*Chapter 11*), with one possibility being that areas of unimproved pasture correspond to areas with more acidic soils that are more prone to phosphorus loss. However, such explanations are speculative, and it should be noted that the subdivision of pasture into improved and unimproved was discontinued in the more recent CORINE 2006 dataset due to unreliability.

Possible reasons for the difficulty in relating landuse to turlough water chemistry include the fact that the true extent the catchment of most turloughs is not known exactly (*Chapter 3: Hydrology*), and hence land cover statistics for individual catchments may not be accurate. Second, it may be the case that factors that were not investigated (such as the presence of rapid transfer routes for nutrients from localised areas) could be important in determining the nutrient status of turloughs.

Contrary to expectations, no significant correlation was found between animal stocking density in the ZOC and either turlough water total phosphorus or total nitrogen (see Cunha Pereira, 2011, p. 162 for total phosphorus and total nitrogen correlations, and see *Chapter 11* of this report for total phosphorus correlations [Table 11.4] and discussion [section 11.4.3]). However, as noted in *Chapter 11*, the stocking densities are available at an inappropriate scale (District Electoral Divisions) and it is possible that the release of data at a finer scale might yield statistically significant relationships.

<u>Local</u>

Intensive landuse within the local topographic catchment can have an influence on turlough nutrients due to inputs via overland flow, throughflow or epikarst flow (see Section 9.2.11, *Catchment hydrology effects on hydrochemistry*). As noted above, an example of where this is thought to be significant is at Ardkill turlough.

9.2.11 Hydrology Effects on Hydrochemistry

<u>ZOC</u>

ZOC hydrology / hydrogeology is closely interlinked with bedrock geology and Quaternary geology (subsoils) because the nature of the hydrological pathways will reflect the geology. The nature of the karstification (extent of conduit flow versus diffuse flow) will influence the major ionic composition of the turlough waters. Turloughs fed by the major conduit system on the Gort lowlands have lower alkalinity, but it should be noted that this is related not just to the presence of conduit flow but to the presence of sinking streams fed by non-limestone waters (see Section 9.2.3 *Geology and geomorphology effects on hydrochemistry*).

The greater the extent of conduit flow, the shorter the travel time of water and contaminants to the turlough. Again this factor is also related to input of non-limestone surface waters (e.g. from Slieve Aughty) – the combination of surface stream flow and rapid conduit flow means that activities in the ZOC many kilometres away may impact on the turlough hydrochemistry in a short time frame, at the time of turlough filling. Note that in the Gort Lowlands, traced underground travel times through the karst conduit system range from 60 to 1,000 m h^{-1} depending on location and water levels (Drew, 2003). While the turlough is flooded, whether catchment activities have a rapid impact on water quality will depend on the internal turlough hydrology: whether the turlough fills and empties via an estavelle and acts as a storage for excess groundwater until the pressure drops in the underlying conduits, or whether there is significant turnover of water during the flooding season, with simultaneous inflows and outflow (i.e. surcharged tank versus flow through system, see *Chapter 3: Hydrology*).

As noted under Section 9.2.3 *Geology and geomorphology effects on hydrochemistry*, the degree of karstification will influence phosphorus transmission to the turlough from the ZOC. Sinking streams will be associated with conduit flow and greatest risk of phosphorus transmission. Other karst features, notably dolines, may also provide point input of phosphorus to the aquifer and thence to the turlough but this will depend on the nature of the dolines (see above).

<u>Local</u>

As noted under *Catchment geology effects on hydrochemistry*, the hydrological pathways within the local topographic catchment will be by overland flow and throughflow on or through the Quaternary deposits, or by epikarst flow / subcutaneous flow (see e.g. Ford & Williams, 1989, p.162) through the epikarst layer. Low permeability deposits will favour rapid contaminant transport to the turlough from neighbouring fields by overland flow and flow in field drains, whereas thinner or more permeable deposits will favour leaching of contaminants into the limestone, and slower transmission via the epikarst. As noted under *Catchment geology,* if the epikarst is highly developed, it may provide temporary water storage, delaying and attenuating contaminants such as phosphorus.

The comparability of turlough nitrogen and phosphorus concentrations and groundwater phosphorus and nitrogen concentrations (based on limited data, see section 7.3.4 of Cunha Pereira, 2011) suggests that nutrient inputs from the wider ZOC dominate over inputs from the local topographic catchment in most instances. However, local scale nutrient transfer pathways may be important at some sites, for example Ardkill turlough (see *Chapter 10: Conservation Status Assessment* and section 11.4.1 of Chapter 11, also section 7.3.4 and Table 7.3 of Cunha Pereira, 2011).

9.3 Turlough Processes

9.3.1 Basin Morphology Effects on Hydrology

Basin morphology, as a driver of hydrology, has a major ecological impact. Surface area to depth profile of the turlough determines the volume that the turlough can store under specific surcharge head levels in the underlying karst. Basin morphology influences a number of further important hydrological parameters such as the depth profile, or spatio-temporal patterns of inundation (see Chapter 3). From an ecological perspective, the duration of flooding, understood as the number of days for which a given habitat is submerged annually, appears the most important parameter.

9.3.2 Hydrology Effects on Hydrochemistry

Hydrology within the turlough is taken to refer to measures such as depth of flooding and duration of flooding. The turlough hydrochemistry shows seasonal patterns of variation which coincide with changes in the turlough hydrology, so there are statistical relationships between hydrological measures and hydrochemical variables, but it should be noted that these are not necessarily causal relationships, i.e. these are not necessarily hydrology effects on hydrochemistry, but may be changes in hydrochemistry that occur during the flooding season for various reasons. For example, turloughs show a decrease in alkalinity in the early part of the flooding season (see Cunha Pereira 2011, p. 39 & 44), and there is a negative correlation between alkalinity and the number of days from the date of first flooding (see Cunha Pereira, 2011, p. 228). This is attributed to precipitation of calcium carbonate, as found in earlier research by Coxon (1994). As another example, silicate shows a decline over the flooding season (see *Chapter 5: Turlough Algae*, Figure 5.9) and there is a highly significant negative correlation between silicate concentration and the number of days from the date of first flooding (see Cunha Pereira, 2011, p. 227): this relationship can be attributed to algal uptake of silica rather than a hydrology effect on silicate concentrations.

9.3.3 Hydrology Effects on Vegetation

The main influence of hydrology is through the duration of flooded period, whereas frequency of flooding has less effect (*Chapter 7: Turlough Vegetation: Description, Mapping and Ecology*). Flooding duration strongly influences vascular plant species distribution in turloughs (*Chapter 7*; Lynn & Waldren, 2003), as has been demonstrated in numerous other non-turlough studies (Blom *et al.*, 1994; Etherington & Thomas, 1986; Jones & Etherington, 1971; Laan & Blom, 1990; Voesenek & Blom, 1989, 1993; Waldren *et al.*, 1987). Flooding duration also influences zonation of vegetation communities (*Chapter 7*; see also Praegar, 1934).

Table 9.1. Selected vegetation communities and vascular plant species associated with particular total phosphorus concentration and/or flooding duration categories.

Total phosphorus concentration	Flooding duration	
	Short	Long
Varied	Limestone grassland community *Lolium* grassland communities Woodland & Scrub communities	*Eleocharis palustris* *Equisetum fluviatile* *Glyceria fluitans*
Low	*Molinia caerulea-Carex nigra* community *Schoenus nigricans* fen community *Danthonia decumbens* *Parnassia palustris* *Potentilla fruticosa* *Schoenus nigricans*	*Eleocharis palustris-Ranunculus flammula* community Flooded pavement community *Baldellia ranunculoides* *Carex elata* *Littorella uniflora* *Teucrium scordium*
Medium-high	*Bellis perennis* *Cardamine pratensis* *Carex hirta* *Filipenula ulmaria* *Rumex crispus* *Trifolium repens*	*Eleocharis acicularis* community *Polygonum amphibium* communities *Eleocharis acicularis* *Oenanthe aquatica* *Polygonum amphibium* *Rorippa amphibia*

Some species/communities are restricted to short duration flooding whereas others to long duration flooding: these species/communities have value as ecological indicators (Table 9.1). However, although duration of flooding is the major driver of species and vegetation community distribution *within* a given turlough, it cannot be used to predict vegetation communities *across different* turloughs due to a variety of other factors influencing species distribution and plant community diversity (*Chapter 7*).

9.3.4 Hydrology Effects on Aquatic Invertebrates

Total annual duration of inundation (hydroperiod) is an important driver of macroinvertebrate communities, influencing abundance and taxon richness (Porst & Irvine 2009a). The most permanent turlough, Termon, had the highest numbers of macroinvertebrates and relatively high mean taxon richness, whereas Caranavoodaun, a turlough which usually dries out completely during the summer months, had the lowest mean abundance and mean taxon richness. Both of these findings concur with characteristics of temporary ponds in general (Collinson *et al.,* 1995; Spencer *et al.,* 1999).

The dry phase of a turlough can be considered a natural disturbance and the hydroperiod length affects seasonal patterns of turlough macroinvertebrates (see Chapter 8). Turlough invertebrate communities show a marked seasonal pattern of assemblages, reflecting an ecological succession and variable extent of disturbance driven by flooding and emptying of turloughs (Porst, 2009). As in temporary ponds in general (Wiggins, 1980), macroinvertebrate communities of turloughs with a short hydroperiod and, thus, high disturbance are characterised mainly by taxa well adapted to the recurring stress of drought. Longer hydroperiods were associated with the macroinvertebrate groups Gastropoda, Heteroptera and Trichoptera as well as Chydoridae and open water Cladocera. Furthermore, the onset of flooding, which varies across years, is an important determinant of the seasonal succession.

The occurrence of dry phase of turloughs, with associated scarcity of fish, may not only result in very distinct invertebrate communities, such as the characteristic 'edge moss dwelling' beetle community (see *Chapter 8: Aquatic Invertebrate Communities*), but also confer specific advantages to particular rare species, such as the glacial relict cladoceran *Eurycercus glacialis* or the rare damselfly *Lestes dryas*.

9.3.5 Hydrology Effects on Algae

Water depth can influence algal growth, especially in winter, because algal cells in a deep circulating water column receive lower average illumination than those in a shallow (entirely illuminated) water column. Blackrock, Caherglassan, Lough Coy, Garryland are the four deepest turloughs in this study and therefore it is reasonable to conclude that water depth suppressed algal growth to some degree in these compared to the shallower turloughs. However, as stated above, these four turloughs also had highly coloured waters which similarly suppresses algal growth and consequently the influence of these two factors cannot be separated from one another in this study.

This project has shown (see *Chapter 4: Water Chemistry and Algal Biomass*; Cunha Pereira *et al.,* 2011) that turloughs develop as much algal biomass as do permanent lakes despite lacking an aquatic phase for much of the growing season (typically June – September). This is perhaps surprising because the algal populations of turloughs must start afresh at the onset of flooding each year and lack the obvious sources of inocula that are found in permanent lakes such as the sediment and the water column. However, some hydrological features of turloughs may favour the development of algal biomass. Firstly, as explained in *Chapter 3: Hydrology*, current thinking among hydrologists is that there is little water flow-through in some turloughs (the 'surcharged tank' type) from the time they fill until they drain. Therefore, outwash is not expected to be important over much of the flooding season in this type of turlough at least. Secondly, the lack of a continuous aquatic phase and of sediment as a repository for resting stages may be expected to militate against the development of zooplankton grazers and thus permit greater development of phytoplankton than would otherwise be the case. However, the importance of grazing by zooplankton cannot be fully assessed at the present time as it was not studied in detail in the project.

The phytoplankton of turloughs may be viewed as a truncated version of the succession that is often found in permanent lakes. Thus cryptophytes and diatoms are often dominant in the late winter and early spring of permanent lakes as they are in turloughs. The importance of green algae in late spring or early summer is common in permanent lakes and was found to be the case also in turloughs. However, turloughs lacked most of the K-selected genera of phytoplankton such as blue green algae as these mainly occur in mid or late summer in permanent lakes at which time turloughs are usually dry. Turloughmore had a particularly short hydroperiod and consequently had a particularly truncated succession of phytoplankton. This turlough was continuously dominated by r-selected, fast growing and small-celled organisms, such as cryptophytes, pennate diatoms (*Navicula*, *Nitzschia*), and, at times, centric diatoms. Therefore it is suggested that the succession of phytoplankton in turloughs is quite predictable from hydroperiod alone.

9.3.6 Hydrology Effects on Soils

Flood duration has an indirect effect on calcium carbonate content of soils. Flood waters are typically supersaturated with calcite (Coxon, 1994), which results in carbonate deposition under inundated conditions. It follows that longer inundation promote more calcium carbonate deposition in soils, thus flood duration exerts a positive influence on the calcium carbonate content of turlough soils (Chapter 6 in Coxon, 1986; Kimberley *et al.,* 2012). Waterlogging fills the soil pore spaces with water, and lowers the soil redox potential; this has important consequences for soil chemistry with rapid loss of nitrate, and greatly increased plant-available iron, manganese and sulphite is waterlogged soils (Ponnamperuma, 1972, 1984; Waldren *et al*., 1987; Reddy & DeLaune, 2008). Prolonged waterlogging of soils with moderate to high clay content can lead to gleying; waterlogging of organic soils can lead to fen peat development.

9.3.7 Hydrology Effects on Landuse

Flood duration directly influences the accessibility to turlough lands, and hence timing and duration of annual grazing regimes within all grazed turloughs. In addition, flood duration has an indirect effect on landuse. Longer inundation with waters supersaturated with calcite promotes less palatable sedge-dominated vegetation communities, thereby limiting grazing value of the land (see *Hydrology effects on soil* above; Kimberley *et al.,* 2012).

9.3.8 Hydrochemistry Effects on Soils

Certain terrestrial plant communities (including weedy species such as *Bellis perennis* and *Rumex crispus*) are associated with turloughs that have medium or high water total phosphorus (*Chapter 7: Turlough Vegetation: Description, Mapping and Ecology*). Furthermore, turlough vegetation was classified by Working Group on Groundwater (2004) into three levels of "trophic sensitivity" based on the proportion of enrichment-sensitive terrestrial plant communities (using Ellenberg fertility scores, after Hill *et al*., 1999) and this trophic sensitivity was strongly correlated with turlough total water phosphorus (see *Chapter 7: Turlough Vegetation: Description, Mapping and Ecology*). This is interpreted as an influence of water phosphorus on plant community structure, which is almost certainly mediated through soils, but the mechanism of phosphorus transfer from water column to vegetation is poorly understood. These findings suggest that there is a link between water total phosphorus and soil fertility in turloughs, though this requires further detailed examination.

Several mechanisms can be suggested which would result in the transfer of phosphorus from water to soil in turloughs. Sedimentation of phytoplankton, deposition of filamentous algal mats ('algal paper') followed by decay and mineralisation would enhance soil fertility. The co-precipitation of phosphorus with calcium carbonate has been shown to occur (Otsuki & Wetzel, 1972) in calcareous water bodies such as turloughs. In addition, particulate phosphorus from inflowing groundwater may settle onto soil. Furthermore, within wetlands, dissolved phosphorus in soil water or the water column may interchange with soil organic phosphorus via microbes, discrete phosphate minerals and metal oxides and clay mineral surfaces (Reddy & DeLaune, 2008) and similar processes may be taking place in turloughs. Nevertheless, none of the above phenomena were studied in detail in the project so their importance cannot be quantified at the present time.

Floodwater alkalinity is a likely key determinant of turlough soil calcium carbonate contents (Coxon, 1994). Cunha Pereira *et al.* (2010) reported that mean seasonal turlough alkalinities range between 112 and 236 mg l^{-1} and such variation is likely to influence the spatial distribution of calcium carbonate deposition (*Chapter 6: Turlough Soils and Landuse*). Available forms of nitrogen are unlikely to accumulate in turloughs owing to denitrification processes (*Chapter 6*).

9.3.9 Hydrochemistry Effects on Algae

Phosphorus is the primary determinant of phytoplankton biomass in turloughs (see *Chapter 5: Turlough Algae*; Cunha-Pereira *et al.,* 2011), as illustrated by the significant relationship between chlorophyll a (a proxy measure of algal biomass) and total phosphorus in most of the turloughs in this study. By contrast, there was no significant relationship between chlorophyll a and total nitrogen. The chlorophyll a-total phosphorus relationship in turloughs is indistinguishable statistically from that of permanent Irish lakes (Champ, 1998) and, furthermore, is very similar to that in permanent lakes in other countries (Cunha Pereira *et al.,* 2011). However, the chlorophyll a response in five of the turloughs (Blackrock, Caherglassan, Lough Coy, Garryland and Arkill) was notably suppressed compared to the majority of turloughs. It is likely that the deeper, more highly coloured waters of the first four of these turloughs were light-limited through the winter. Colour, by either suppressing light penetration (Havens, 2003; Havens & Nurnberg, 2004) or sequestering important ions (Jackson & Hecky, 1980), is known to inhibit phytoplankton development. While the above comments apply to the majority of the flooding season, there is evidence that Ardkill and, to a lesser extent, other turloughs could have been nitrogen-limited at the end of the flooding season.

Small clumps of filamentous algae may be found near the edges of all turloughs in late spring or early summer, even those with low nutrient status. However, more extensive development of filamentous algae, such as might be described as 'algal paper' on drying out, only occurred in turloughs with average total phosphorus concentration greater than 20 µg l^{-1} (see *Chapter 5*). Therefore, the presence of 'algal paper' on the turlough bed after drying out could be taken to indicate nutrient enrichment. However, the converse situation is not always true: 'algal paper' did not occur in all turloughs with average total phosphorus greater than 20 µg l^{-1} and therefore the absence of 'algal paper' cannot be taken to indicate that total phosphorus in a turlough is below this concentration threshold. Whereas redundancy analysis showed that total phosphorus was a key determinant of phytoplankton community composition, no clear bioindicators of trophic conditions have emerged (see *Chapter 5*).

9.3.10 Hydrochemistry Effects on Aquatic Invertebrates

The importance of trophic conditions for structuring macroinvertebrate assemblages in freshwater environments is widely acknowledged (Brodersen *et al.,* 1998; Tolonen *et al.,* 2005; Brauns *et al.,* 2007) and this study also identified total phosphorus concentrations in floodwater (a proxy for trophic conditions in most freshwaters) as important in structuring macroinvertebrate communities of turloughs (see *Chapter 8: Aquatic Invertebrate Communities*).

Phosphorus is the primary determinant of algal biomass, as illustrated by the significant relationship between chlorophyll *a* (a proxy measure of phytoplankton biomass) and total phosphorus in most of the turloughs in this study (Cunha Pereira *et al.,* 2011; see *Chapter 5: Turlough Algae*). The underlying mechanisms for the recorded associations between total phosphorus and invertebrate community composition are presumed to operate predominantly through bottom-up control of primary producers, and algae in particular.

Macroinvertebrate taxa groups which were recorded in higher abundances in increased phosphorus concentrations were Diptera and Ostracoda, while the abundance of Aranea, Odonata and Trichoptera showed a negative correlation with phosphorus concentration. Furthermore, the abundances of the Coleoptera *Agabus labiatus*, *A. nebulosus*, *Berosus signaticollis*, *Helophorus* sp., *Hygrotus quinquelineatus* and *H. impressopunctatus* were reduced in association with elevated phosphorus concentrations. These, however, were not necessarily causative relationships. The recorded associations were limited to individual taxonomic groups and did not translate to overall macroinvertebrate abundance or taxon richness, in agreement with earlier studies on turloughs (Reynolds, 2000).

Cladoceran taxa, on the other hand, showed a more pronounced association with nutrient concentrations. Overall cladoceran abundance increased but the number of recorded taxa decreased with increasing phosphorus concentrations (see *Chapter 8*). Similarly, decrease of Cladocera taxon richness in response to eutrophication of waters has been previously reported from permanent Irish lakes (de Eyto, 2001). Furthermore, certain species show distinct association with nutrient concentrations. *Alonopsis elongata*, which is intolerant to eutrophication (Irvine *et al.,* 2001; de Eyto *et al.*, 2003), was found only in the low nutrient Lough Gealain. Other species such as *Alona rustica* and *Alonella excisa* were predominantly detected in turloughs of low to medium trophic state, concurring with de Eyto *et al.* (2002; 2003). As with the macroinvertebrate fauna, further work is needed to identify causal relationships between Cladocerans and nutrient concentrations.

Nutrient enrichment also appeared to influence the seasonal patterns of macroinvertebrates in turloughs. This was characterised by a general dominance of taxa considered tolerant to nutrient pollution (mainly oligochaetes and chironomids) and a trend of more susceptible taxa (if present) disappearing towards the end of the season in turloughs with high nutrient concentrations.

9.3.11 Landuse Effects on Hydrology

Blocking of karst features (estavelles, swallow holes), in attempts to increase the availability of agricultural land, reduces connectivity of a turlough with the greater (ZOC) groundwater system. Impeding this connectivity results in a reduced rate of turlough filling, but, as an apparently unintended effect, it also slows down its emptying. Furthermore, the latter mechanism increases a risk of localised flooding when the local catchment receives excessive rainfall. Such blocking of flows in/out of a turlough will also change the flooding duration frequency relationship and, therefore, in the long term, the distribution of habitats.

9.3.12 Landuse Effects on Hydrochemistry

Application of fertiliser or slurry on turlough soil directly before flooding could lead to a direct input of nutrients into the turlough, posing a threat to water quality. This, however, does not seem to be a significant issue as it is unlikely to occur immediately before inundation. Turlough flooding is preceded by wet periods and application of fertiliser or slurry under such conditions would be considered a waste of resources from farmer's perspective. Deposition of excreta by grazing animals on soil directly before flooding, or into a turlough, could be a source of nutrient pollution although it is uncertain if this is of any significance. Washing slurry tanks in the turlough, on the other hand, and associated nutrient enrichment is potentially a significant issue as it occurs in at least some turloughs, as witnessed during this project.

Agricultural activities within the turlough basins taking place during the summer season may affect soil properties, with possible indirect effects on water chemistry when they become flooded. For example animal grazing could be expected to provide a source of nutrients to the turlough waters in the following flooding season, although turlough grazing intensities are generally low (see *Chapter 6: Turlough Soils and Landuse*). More significant is the feeding of stock directly in turloughs, with silage being occasionally fed in feeding rings, resulting in heavy localised poaching and an input of nutrients. Furthermore, fertiliser and slurry are applied within some turlough land parcels, increasing the nutrient content of turlough soils (Kimberley, 2003). However, as noted under Section 9.3.16 *Soil effects on hydrochemistry* below, experimental studies of phosphorus release from soil to floodwater did not provide any clear evidence of significant phosphorus release. The relationship between turlough phosphorus concentrations and groundwater phosphorus concentrations, albeit based on very limited data (see Section 9.2.11 *Hydrology effects on hydrochemistry* above), also suggests that nutrient inputs from within the turlough are insignificant compared with groundwater nutrient inputs in most instances. Nevertheless it is reasonable to presume that phosphorus release from grazing animal faeces as well as from the turlough soils occurs following flooding, so further investigations would be desirable.

9.3.13 Landuse Effects on Soils

Fertiliser is applied within some turlough land parcels however the application rates are not typically recorded. Fertiliser application affects the nutrient content of turlough soils and the species composition of vegetation communities (Kimberley, 2003). Turlough grazing intensities are generally low, but for some turloughs are high, particularly at certain times of the year (*Chapter 6: Turlough Soils and Landuse*). Poaching may occur in any turlough where livestock are allowed to graze wet soils. Shallow turlough soils with poor structure that remain wet during summer months are particularly vulnerable to poaching.

9.3.14 Landuse Effects on Vegetation

Grazing affects vegetation directly by herbage removal, but its effects on turlough vegetation appear to be dependent on trophic conditions. Grazing seems to have little impact in the more oligotrophic turloughs, which are mostly dominated by vegetation communities with a high abundance of sedges. These sedge-dominated communities are likely to be of low palatability to stock or be of poor nutritional value, and support a very low stocking density. Some of the most oligotrophic turloughs (e.g. Lough Gealain) appear to be ungrazed by domestic stock.

In contrast, grazing has more important ecological effects in more nutrient-rich turloughs. Here, excessive grazing results in altered species composition, and trampling by stock may lead to poaching of ground, destroying the vegetation structure which may be replaced by weedy ruderal species such as *Plantago major* and *Poa annua* (*Chapter 7: Turlough Vegetation: Description, Mapping and Ecology*). Heavily poached areas have distinctive communities (*Poa annua/Plantago major* community), but comparisons between our mapped vegetation communities (*Chapter 7*) and those of Goodwillie (1992) suggest that if grazing pressures are reduced these weedy communities may revert to more typical turlough vegetation, so overgrazed turloughs may in some cases be restored with appropriate conservation action and regulation of grazing. On the other hand, poaching may provide important recruitment sites for some annual turlough plant species of conservation interest, such as *Limosella aquatica* and *Rorippa islandica*. Stock feeding in turloughs may similarly lead to local nutrient inputs and poaching, and damage to vegetation locally. Removal or lack of maintenance of land parcel boundaries, particularly dry stone walls, results in greater dispersion of stock, reducing community level diversity.

There is also evidence that greatly reduced grazing in these meso- to eutrophic turloughs results in the dominance of tall herb communities and lower diversity (*Chapter 7*), reducing both species and community diversity. Sheep grazing (as at Garryland) results in very short swards and is probably detrimental to the turlough ecology, whereas cattle (and probably horse) grazing results in a more patchy, diverse community structure. The timing of stocking can also be important, as stock movement and restriction due to high floodwaters, can lead to localised poaching. Devising an appropriate grazing regime is an important challenge for turlough conservation management, which is hampered by lack of appropriate data on stocking density changes with time at the level of individual land parcels.

The natural hydrological regime has been altered by drainage in several turloughs (Coxon, 1986), including Ballindereen and Termon, and more recently Kilglassan (*Chapter 10: Conservation Assessment*). Drainage to alleviate the more extreme flooding is unlikely to have much impact on the vegetation zonation, but drainage channels that significantly alter the normal duration of flooding are likely to have very pronounced impacts on the distribution of turlough vegetation communities, and on the distribution of species with particular requirements for long duration flooding.

Land improvement can significantly affect turlough vegetation. Nutrient enrichment, sometimes due to direct fertilizer inputs into turlough land parcels, seems to result in an increase in *Rumex* species, particularly *R. acetosa* and *R. crispus*, and this association can be used as an indicator of adverse structure and function in turloughs (*Chapter 10: Conservation Status Assessment*). There is some experimental evidence from Coole Lough that fertilizer application greatly stimulates the growth of *Rumex acetosa*, *Potentilla anserina* and *Ranunculus repens* (D. Lynn, S. Waldren & S. Murphy, unpublished data). Bulldozing for land improvement has reportedly taken place in Lough Aleenaun (J. Ryan, Pers. comm.) resulting in severely degraded vegetation communities (*Chapter 10*). Agricultural improvement is often most obvious at the upper zones of turloughs basins which experience the shortest period of inundation. Removal of semi-natural limestone grasslands, scrub and marginal woodland and reseeding with *Lolium perenne* mixes occurs frequently, with obvious effects on turlough vegetation.

There is some evidence of local quarrying or gravel removal in some turloughs (e.g. Newtown), but this is mostly on a small scale. Cutting of peat has previously occurred in some turloughs where there are deep enough deposits to merit exploitation, Knockaunroe for example still contains rectangular pools formed by peat cutting. As with gravel removal, the effects are generally localised to small areas of the turlough basin.

9.3.15 Soil Effects on Hydrology

Effects of soils within the turlough basin on turlough hydrology resemble those occurring at the catchment scale (see Section 9.2.5 *Soils effects on hydrology* above).

9.3.16 Soil Effects on Hydrochemistry

Transfer of phosphorus from soil to floodwater was studied experimentally in the project (*Chapter 6: Turlough Soils and Landuse*) and results appear to show that turlough soils are not an important source of available phosphorus in floodwaters. The relationship between turlough phosphorus concentrations and groundwater phosphorus concentrations, albeit based on very limited data (see *Catchment hydrology effects on hydrochemistry* above), also suggests that nutrient inputs from within the turlough, including from turlough soils, are insignificant compared with groundwater nutrient inputs in most instances. Nevertheless, the release of particulate phosphorus to floodwaters remains a possibility but needs to be further investigated.

9.3.17 Soil Effects on Landuse

Calcium carbonate accumulation and soil wetness are likely to influence the vegetation communities and consequently the grazing potential of turlough land (*Chapter 6: Turlough Soils and Landuse*; Regan *et al.,* 2007; Kimberley *et al.,* 2012). Very high proportions of mineral and shallow organic soil types are grazed whereas significant proportions of poorly drained organic and peat soils are ungrazed. Marl soil types are generally ungrazed (*Chapter 6*). In general, shallow organic and marl type soils support a sedge-dominated sward that is likely to have lower nutritional value and be less palatable than grass swards, so these sedge dominated swards are lightly grazed at most.

9.3.18 Soil Effects on Vegetation

Phosphorus is the most important nutrient determining the composition and structure of turlough vegetation communities, whereas nitrogen has less predictable effects (Chapter 7).

Both plant community and species distributions are more closely linked to total phosphorus in floodwater than soils (see *Chapter 7: Turlough Vegetation: Description, Mapping and Ecology*). This suggests a rapid nutrient flux through soils to vegetation from water, but the underlying mechanism is poorly understood and requires further research. The close association of vegetation communities with total phosphorus concentration enables identification of indicator species/communities (Table 9.1) and appears conducive to the development of a vegetation index of turlough trophic conditions (see *Chapter 7*).

Despite this, there were some strong links between soil type and vegetation community (*Chapter 7*, Figure 7.36), though it is not clear whether this relationship between soil type and vegetation is causative or merely a result of correlation.

There are strong interactions between flooding regime and nutrient status on vegetation communities and species distributions, with some communities/species being restricted to a particular combination of flooding and nutrient level (*Chapter 7*: Table 7.98).

9.3.19 Soil Effects on Aquatic Invertebrates

Particulate organic matter in soil is likely a food source for deposit feeders, particularly oligochaete worms. This aspect, however, was not investigated in this study.

9.3.20 Soil Effects on Algae

There is also some experimental evidence that turlough soils can be a repository for algal spores during the dry season (Cunha Pereira, 2011) but the universality of this process needs further investigation. Such inocula would enable a relatively rapid colonisation after inundation and could explain, at least in part, why algal communities in turloughs show similar seasonal dynamics to those in permanent lakes.

9.3.21 Sub-soil Effects on Basin Morphology

The presence of marl (white calcareous silt) in the turloughs is associated with a flat floor (Coxon, 1987): the reason for this is that the marl is a lacustrine deposit dating from when these sites were permanent water bodies at the end of the last glaciation (Coxon & Coxon, 1994). The flat marl floor may be overlain by peat, and in most instances such turloughs have a flat floor, reflecting the underlying marl topography, although at some sites the peat can form a dome within the turlough (e.g. Croaghill turlough, Co. Galway; see Coxon, 1986, p. 389). Turloughs lacking marl and with mineral sediments including sand, silt and diamicton tend to have undulating floors (Coxon, 1987). These features affect the depth profiles of turloughs.

9.3.22 Sub-soil Effects on Soils

Subsoil type can influence, in particular, the nature of the sand/silt/clay fraction and the related properties of soil texture and structure (*Chapter 6: Turlough Soils and Landuse*; Coxon, 1986).

9.3.23 Vegetation Effects on Soils

The botanical origin of organic material is an important characteristic of organic soil (Wen, 1984). Less palatable sedge-dominated vegetation communities are associated with soils with higher soil moisture contents (*Chapter 7: Turlough Vegetation: Description, Mapping and Ecology*; Regan *et al.,* 2007) and sedge-dominated communities produce litter that is more difficult to decompose owing to higher concentrations of decay-resistant compounds (*Chapter 6: Turlough Soils and Landuse*; Berendse *et al.,* 1989). This may lead to the accumulation of fen peat.

9.3.24 Vegetation Effects on Aquatic Invertebrates

Vegetation provides structural habitat and a food source for aquatic invertebrates, and macroinvertebrate assemblages typically show distinct associations with various macrophyte communities and sediment types (Tolonen *et al.,* 2001; Hinden *et al.,* 2005). Thus, habitat heterogeneity is an important driver of macroinvertebrate community structure in standing freshwaters (van den Berg *et al.,* 1997; Cheruvelil *et al.,* 2000). Similarly to permanent lakes (Brönmark, 1985), habitat heterogeneity in the turloughs is positively associated with macroinvertebrate taxon richness (see *Chapter 8: Aquatic Invertebrate Communities*).

The within-turlough variability of invertebrate community structure among habitats recorded in this study was generally smaller than variability among turloughs (see *Chapter 8*) and significant difference between habitats were only recorded in only one of the two examined turloughs (Brierfield). In spite of this significant difference, only two species were recorded in distinct habitats (*Argyroneta aquatica* and *Omphiscola glabra* from emergent and submerged grasslands, respectively) with all other taxa occurring in both habitats, albeit in varying densities (Porst & Irvine 2009b), precluding identification of association of distinct communities with particular vegetation communities.

9.3.25 Aquatic Invertebrate Effects on Algae

The phytoplankton that developed over the late winter and early spring in turloughs, being frequently dominated by diatoms and cryptomonads, represent a suitable food source for zooplankton and therefore some impact by zooplankton on the phytoplankton communities of turloughs is to be expected. Whereas grazing may be shaping the well-defined seasonal succesion, this aspect was not studied and therefore the extent of the impact of zooplankton on phytoplankton cannot be quantified. Similarly, filamentous algae may represent a suitable food source for macro-invertebrates and could therefore have some impact on the development of filamentous algae, but this aspect was not investigated here.

9.3.26 Algae Effects on Hydrochemistry

The seasonal decline in alkalinity (Cunha Pereira, 2011) may be assumed to occur because of precipitation of carbonates. Carbonate deposition in turloughs occurs primarily because turlough waters are supersaturated with calcite (Coxon, 1994) though a localised biogenic component can occur as evidenced, for example, by the presence of encrusting algae in some turloughs. Cunha Pereira *et al.* (2011) showed that phytoplankton biomass (as chlorophyll *a*) reached a peak over winter months in most turloughs. The development of algal biomass necessitates a corresponding drawdown of available major nutrients such as soluble reactive phosphorus, nitrate and silicate. Therefore the decline in soluble reactive phosphorus to almost undetectable levels in some turloughs (e.g. Croaghhill, Rathnalulleagh and Ballindereen) may be attributed in part at least to algal uptake. Likewise the decline in silicate (*Chapter 5: Turlough Algae*) may be attributed partly to the development of diatoms, *Tribonema sp.* and chrysophytes all of which were common in turloughs at varying times through the flooding season. With respect to nitrate, it was concluded that that much of the decline in nitrate following the mid-winter peak probably arises from catchment processes and is therefore not due to uptake by algae (*Chapter 4: Water Chemistry and Algal Biomass*). The chief evidence for this is that the trend in nitrate in the River Owenshree (just upstream of Blackrock into which it flows) is very similar to that in Blackrock (Cunha Pereira, 2011). If uptake by algae were responsible for removal of nitrate then one would expect a steeper decline in nitrate in the turlough than in the stream. Additional evidence is that two of the turloughs (Lough Aleenaun and Turloughmore) filled and drained several times over the flooding season and yet still displayed the same systematic decline in nitrogen as that in most of the other turloughs; such a trend is suggestive of declining nitrogen concentration in inflowing waters rather than any removal process such as uptake by algae, within the turloughs.

9.3.27 Algae Effects on Soils

Algal mats deposited onto bare turlough soil from floodwaters are a potential source of nutrients to turlough vegetation communities following decomposition. Extensive algal mats were recorded in only four of the 22 turloughs however and this effect typically occurs within relatively small areas of the more nutrient-rich turloughs. The current understanding of the nutrient content of algal mats is inadequate to permit quantification of nutrient transfers via this mechanism (*Chapter 5: Turlough Algae*).

9.3.28 Algae Effects on Aquatic Invertebrates

Primary producers, including algae, provide food source to aquatic invertebrates. The relationship of phytoplankton biomass (approximated by chlorophyll a concentration) with invertebrate community structure generally mirrors that of nutrient concentration (de Eyto *et al.,* 2003; Porst, 2009; see Section 9.3.10 *Hydrochemistry effects on aquatic invertebrates*). It is, however, somehow weaker, owing predominantly to nutrient partitioning between phytoplankton and benthic algae.

9.4 Synthesis and Conclusions

The multidisciplinary nature of this project has enabled a holistic understanding of turlough ecology and conservation, incorporating geology and geomorphology, landuse and land management, soils, hydrology, hydrochemistry, soils, vegetation, aquatic invertebrates and algae, and encompassing the physical, chemical and biological aspects of turlough functioning. This multidisciplinarity, together with the broad spatial scale of this study, have facilitated important advances in the understanding of turlough ecological functioning, which enabled identification of flood duration, phosphorus concentration and grazing as the most important drivers of turlough ecology. Whereas altering land structure by, for example quarrying, building construction and bulldozing present highly significant threats to turlough ecology, these are of rare and isolated occurrence.

Flooding duration

The impact of land drainage on groundwater resources is particularly acute in karst areas owing to the unique characteristics of karst aquifers (Sheehy Skeffington *et al.* 2006) and the hydrological regime of approximately one third of turloughs over 10 hectares have been irreversibly altered by drainage (Coxon 1986). The broad spatial scale of hydrological alterations necessitates good understanding of their ecological consequences. This project has identified that the duration of flooding (hydroperiod) in particular, has major effects on both terrestrial and aquatic communities. Flooding duration strongly influences the distribution of vascular plant species and the zonation of vegetation communities within turlough basins, as well as the seasonal succession of phytoplankton. Hydroperiod is also an important driver of aquatic macroinvertebrate community composition, influencing its abundance and taxon richness. Flooding duration has pronounced influences on all examined ecological components, clearly suggesting that any alteration in flood duration will have important implications for entire turlough ecosystems.

Land drainage shortens the duration of flooding and appears to be the major cause of hydroperiod alterations. Blocking of surface karst features (estavelles, springs) in attempts to increase the availability of agricultural land may reduce the rate of turlough inundation and can be another important factor, albeit less common. Paradoxically, such blocking of karst features may also reduce floodwater recession, thereby prolonging the hydroperiod.

Total phosphorus

Karst catchments are capable of transporting large volumes of water at relatively high velocities, with higher potential for nutrient transport compared with catchments in different geological settings. The problem of nutrient enrichment in freshwaters has been receiving high attention since the early 1980s, yet the eutrophication processes within turloughs is poorly understood. This project identified that, similar to permanent freshwaters, phosphorus is the primary determinant of phytoplankton biomass in turloughs and a key driver of phytoplankton community composition. Despite the ephemeral flooding of turloughs, they develop similar algal biomass as permanent standing freshwaters, hence they likely respond to nutrient enrichment in a similar way to permanent waters. Total phosphorus concentrations in floodwater (as a proxy for trophic conditions) are also important in structuring invertebrate communities, affecting their composition and seasonal patterns. Furthermore, phosphorus concentration in turlough water is a major determinant of vegetation community and plant species distribution. Even though this process is mediated through soil, vegetation patterns are more closely linked to total phosphorus in water than in soils, likely through specific pools of plant-available phosphorus in turlough soils. Parallel to flooding duration, phosphorus concentration influences all examined ecological components suggesting strongly that phosphorus enrichment has implications for entire turlough ecosystems.

Intensification of agriculture leads to nutrient enrichment of waters (e.g. Castillo *et al.* 2000, Cuffney *et al.,* 2000; Haggard *et al.,* 2003). Agricultural practices, such as fertiliser and slurry application or grazing typically entail high risks of phosphorus transmission and are potential contributors of phosphorus enrichment in turloughs. This, however, was not satisfactorily established, likely owing to uncertainty in spatial extent of ZOCs but also lack of precise landuse data (especially stocking densities) at an appropriate scale. The transmission pathway is an important aspect of phosphorus enrichment as it influences the degree of phosphorus attenuation; transport via rapid pathways, such as conduit or overland flow is conducive to lower attenuation compared with diffuse flow.

Grazing

Turloughs are an example of marginal grazing land with Priority Habitat Status (Visser *et al.,* 2007) and grazing regimes within a turlough have been shown to be important for its biodiversity (Ní Bhriain *et al*., 2002, 2003; Sheehy Skeffington *et al.,* 2006). However, little is known about interactive effects of grazing with other pressures. Whereas this study supports the view that grazing regime is an important driver of vegetation communities, its effects appear to depend on trophic conditions. Grazing seems to have little impact on vegetation in the more oligotrophic turloughs, most likely because stocking rates are very low in such turloughs. Sedge-dominated communities, with low palatability and low nutritional value dominate in these turloughs, which therefore are unlikely to support high stocking densities.

Grazing levels in the more nutrient-rich turloughs have more important impacts on vegetation composition and structure. For such turloughs, an appropriate level of grazing is essential for maintaining ecological structure and function, and hence conservation value. Overgrazing reduces community diversity and leads to erosion of vegetation via poaching, and the establishment of weedy annual communities. There is also evidence that greatly reduced grazing in meso- to eutrophic turloughs results in the dominance of tall herb communities and lower community and species diversity. Appropriate grazing levels are 'low' in meso- to eutrophic turloughs, but exact recommendations cannot yet be made due to the lack of required data on stocking levels and timing of grazing on a land parcel basis. Grazing by cattle and horses tends to result in patchy communities, particularly where land parcel boundaries are maintained, increasing ecological diversity in turloughs. There is some evidence that swards can recover following damage caused by excessive grazing levels. However, sheep grazing appears to be especially detrimental, resulting in very shortly cropped swards that are likely to be harmful to ecological functioning and conservation objectives.

There is no evidence that reduced grazing will lead to colonisation of woody vegetation in turloughs, as has been previously suggested. Most woody species are unlikely to be capable of tolerating prolonged flooding (Crawford, 2008) and hence are likely to be restricted to the upper zones of turlough basins. Lack of grazing is likely to lead to the spread of tall herb communities in the more enriched turloughs, while some of the most oligotrophic turloughs are ungrazed by domestic stock with no obvious impact on vegetation.

9.4.1 Further Research

Whereas this project has addressed a number of knowledge gaps relating to turlough functioning, some further questions have emerged along the way. Among them, priority in future research should be given to the uncertainties concerning the key drivers of turlough ecological functioning, and the mechanisms through which they are operating.

Nutrient enrichment by phosphorus is an important driver of turlough ecology. While identifying the ecological state of elevated phosphorus in turlough floodwaters and the impact of elevated phosphorus on biological communities are comparatively straightforward, identifying the particular pressure which drives increased phosphorus input at the turlough level is problematic. Elevated phosphorus can result from a variety of different pressures – for example domestic waste, agricultural waste, fertiliser and slurry application, stock feeding, forestry activities etc. In addition these pressures may be sourced at the local level of the turlough basin and its immediate surrounding, or have a source in the wider zone of groundwater contribution. Effective conservation management from the perspective of regulation of nutrient loading will require detailed evidence of the precise pressure responsible for the biological impacts. This will require specific studies on sources, pathways and receptors, and will likely involve detection of resistant co-migrating chemical compounds specific to different pressures, such as animal growth hormones, antibiotics, etc.

While there would seem to be an intuitive link between agricultural activities (stocking rates in ZOC, intensive agriculture in ZOC) and turlough water quality, such links were not satisfactorily established. Possible reasons for this include the difficulties in distinguishing causative effects of different pressures just mention, lack of appropriate data on stocking rates at the land parcel level, and inadequate definitions of ZOCs. Accurate delineation of turlough ZOCs, and provision of stocking densities at a more appropriate scale (ideally at land parcel scale) would aid management of contamination risks and should be prioritised.

Trophic interactions between algae, aquatic invertebrate grazers and predators in turlough waters, and the relationship of such trophic webs to nutrient cycling, is unclear and would benefit form further research. In addition, fish are likely to have very significant effects on aquatic invertebrate communities. Fish have clearly been deliberately introduced into some turloughs, even large predatory species such as Pike (*Esox lucius*). But juvenile fish and adult three-spined stickleback (*Gasterosteus aculeatus*) have been observed in estavelles during turlough drying – their origin is uncertain in some cases, and it is possible that some might travel via subterranean conduits. Large eels (*Anguilla anguilla*) have also been observed in turloughs, and these could potentially travel overland to reach isolated waterbodies. The impact of fish species on aquatic invertebrates, and their status as deliberate introductions or (semi)natural colonisers requires further study.

Limited experimental evidence suggests that transfer of phosphorus from soil to floodwater is not an important source of available phosphorus in floodwaters. Despite that, there is a close association between vegetation and total phosphorus in water, which suggests a rapid nutrient flux from water through soils to vegetation. The underlying mechanism is poorly understood and requires further research. Furthermore, the close association of vegetation communities with total phosphorus concentration appears conducive to the development of a vegetation index of turlough trophic conditions.

Further research is required on the grazing impacts on turlough vegetation, invertebrate communities and ecological function. This research needs to verify the hypothesised low impact of grazing in oligotrophic communities as being due to the low nutritional value and palatability of the typical sedge-dominated communities of such turloughs, it should also seek to establish appropriate grazing levels across the trophic spectrum of turloughs. However, as noted elsewhere (eg. *Chapter 11, Water Framework Directive Assessments for Turloughs)*, reliable data on the stocking density over time are required at a land parcel level: existing stocking data are far too coarse to provide the information required to develop recommendations on grazing levels to promote the conservation of turlough ecological functioning.

Climate change is anticipated to bring about alteration of rainfall patterns in Ireland, with less precipitation in summer and more in winter (McGrath *et al*., 2005; McElwain & Sweeney, 2006). These changes can potentially alter antecedent rainfall, which is an important determinant of the onset of turlough inundation and their impacts and potential mitigation should be investigated.

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Chapter 10. Conservation Status Assessment

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Potentilla fruticosa growing in flooded limestone pavement, indicating oligotrophic conditions and little modificaton of the upper turlough boundary. *Photo: S. Waldren*

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10.1 Introduction

The Habitats Directive (Council Directive 92/43/EEC) has arguably had one of the greatest impacts on biodiversity conservation in Ireland. Prior to the introduction of the directive and its incorporation into Irish legislation through *Statutory Instrument 94/1997 (European Communities [Natural Habitats] Regulations 1997*, Ireland had one of the lowest percentages of land area designated as protected areas for nature conservation among European Countries (WCMC, 1994).

The Directive essentially requires member states to conserve biodiversity, particularly through the conservation of habitats and species of community interest. Under the definitions of the Directive, a natural habitat is considered to be at favourable conservation status when its natural range and areas it covers within that range are stable or increasing, the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future, and the conservation status of its typical species is favourable.

Article 17 of the Directive requires member states to report on the conservation measures undertaken under the Directive and report on the impacts of these measures on the conservation status of habitats listed under Annex I, and species listed under Annex II, of the Directive and the main results of the surveillance referred to in Article 11. Annex I lists those habitats that require the designation of special areas of conservation (SACs), including Priority Habitat Types. Among the standing freshwater habitats, turloughs (code 3180) are listed as a priority habitat. Priority habitats are defined as those habitats of European

Community interest which are in danger of disappearance and where a large proportion of their range falls within the European territory. Turloughs are known to occur locally in Britain, Estonia, Germany and Slovenia, but with by far the majority occurring within Ireland. Ireland thus has a particular responsibility to protect and conserve this internationally scarce habitat type.

The purpose of this chapter is to report on the conservation status of turloughs with reference to the 2013 round of reporting under Article 17 of the Habitats Directive. The previous Article 17 report for 2007 found that the while the range and surface area of turloughs was favourable, the structure and functions and future prospects were unfavourable – inadequate, leading to an overall conservation assessment of unfavourable – inadequate.

10.2 Methods

The national assessment of turlough conservation status is based on the detailed analysis of the 22 turloughs selected for detailed ecological study. These turloughs were selected to be representative of the range of variation in turloughs in Ireland, while also allowing investigation of a small number of turloughs that are hydrologically linked; for further details on site selection, see *Chapter 2: Site Selection*. The work detailed in this chapter formed a substantial part of the reporting to the EU under Article 17 of the Habitats Directive (Council Directive 92/43/EEC), the methods used were selected to be compatible with the requirements of Article 17; further notes and guidelines on reporting requirements can be found in Evans and Arvela (2011). Article 17 requires reporting under several areas relevant to conservation assessment, the methods used for assessment are described below.

10.2.1 Individual Site Assessments

10.2.1.1 Structure and Functions

The ecological structure and function (see Evans & Arvela, 2011, for definition) was calculated for the 22 study turloughs using a variety of indicators. Structure and function was assessed in three broad categories: hydrological functioning (Function), mean total water phosphorus (Function, see *Chapter 4: Water Chemistry and Algal Biomass*) and biological responses (Structure). As noted by Sheehy Skeffington *et al.* (2006), turloughs are ecologically defined by their hydrological regime, and this is considered the most important ecological driver of turlough function (*Chapter 3: Hydrology*). As turloughs flood from groundwater, groundwater quality plays a major role in ecological functioning, mainly through phosphorus availability (*Chapters 4-9*). Biological responses included algal communities, vegetation communities, and the presence of individual species of vascular plants and aquatic invertebrates. A full list of indicators used is given in tables 10.1-6.

The main pressures affecting the hydrological function of turloughs are likely to be water abstraction and drainage (Table 10.1). Drainage within the turlough zone of groundwater contribution (ZOC) is likely to have a limited effect, and invert of drainage (either blocking of conduits, or drainage) will have proportionally greater effects towards the deeper part of the turlough basin. Water abstraction is only considered significant if for public water supply; small scale abstractions for agricultural use, for example, are likely to have limited impact and water is likely to be returned to the system, albeit with poorer water quality. Abstraction from within the turlough basin was also considered, but in no case was it felt likely to result in a significant impact. Assessment of the indicators was by expert opinion based on detailed field knowledge of the sites. A score for hydrological function was taken as the sum of the indicator scores, with drainage within the ZOC used only when other hydrological indicators were negative; a score of zero indicated 'Good' hydrological functioning, -1 'Intermediate' and -2 or less 'Bad'.

Table 10.1. Hydrological indicators used in the assessment of turlough structure and function

Indicator	*Score*	*Description*
Water abstraction known in zone of contribution	-1	Indicates possible alteration to hydrological regime
Drainage works evident in zone of contribution (ZOC)	-1*	Indicates alteration to hydrological regime, less impact in ZOC
Invert of drainage within in turlough	-1 if at top of flooding zone, ranging to -5 in deepest part of turlough	Indicates alteration to hydrological regime; higher impacts within turlough basal zone, less impact if at top of flooding zone
Any other indication of alteration to the hydrological regime	-1	Any other likely impact on hydrological regime

- only used if other negative indicators occur for a given turlough

Water chemistry was assessed solely by the mean concentration of total phosphorus in the water column (water TP) as this appeared to be the major ecological driver (Table 10.2; see Chapters 4, 5, 6, 7 and 8). A limit of less than 20 µg P l^{-1} was used to imply favourable conservation conditions, based on the value for Irish permanent lakes in McGarrigle *et al.* 2002 and in the 1998 Phosphorus Regulations; 20 µg P l^{-1} was also considered to be the value above which extensive filamentous algal mats were likely to occur (Chapter 5). Mean water TP was calculated from the data of Cunha Pereira (2010, see also Chapter 5). Targets to assess conservation status were set based on mean water TP concentrations. Water TP values of less than 10 µg P l^{-1} were considered to indicate 'Very good' quality, 10 - 20 µg P l^{-1} to indicate 'Good' quality, 20 – 50 µg P l^{-1} to indicate 'Intermediate' quality, and above 50 µg P l^{-1} to indicate 'Bad' quality.

Table 10.2. Water chemistry indicator used in the assessment of turlough structure and function

Indicator	*Score*	*Description*
Mean total phosphorus in water column (water TP)	See text	Indicates P enrichment, which appears to be a major ecological driver

Biological responses were assessed using algal communities, vegetation communities, and vascular plant and aquatic invertebrate indicator species. For the algal communities (Table 10.3), the indicators were the presence of *extensive* algal mats at some stage during the three year monitoring period, and a maximum recorded chlorophyll A concentration of greater than 10 µg CHL l^{-1}. Both indicators are likely to reflect nutrient inputs via groundwater. The values for the two algal indicators were summed to assess conservation status; a total score of zero was considered 'Good', -1 'Intermediate' and -2 'Bad'.

Table 10.3. Biological responses (algal communities) used to assess turlough structure and function

Indicator	*Score*	*Description*
Presence of filamentous algal mats covering at least 2% of turlough area on at least one occasion over three years of observation	-1	Presence of filamentous algal mats likely to be linked to P enrichment, and result in rapid nutrient recycling to soils
Maximum recorded Chlorophyll A greater than 10 µg l-1	-1	OECD Eutrophic or hypertrophic; indicates nutrient enrichment

Both positive and negative vegetation community indicators were used, based on important vegetation communities identified through extensive field survey (see *Chapter 7: Turlough Vegetation: Description Mapping and Ecology*). For assessing vegetation communities, the turloughs were first categorised by major substrate type (see Table 6.4 in *Chapter 6: Turlough Soils and Landuse*): mineral, organic, or marl. This enabled some indicators to be developed specifically for each category, and generally reflected different water nutrient concentrations among these different categories. Whilst this is clearly an over-simplification as a continuous range of variation likely occurs, this approach greatly facilitates the development of appropriate indictors. Some communities were used as positive indicators for some turloughs and negative for others (*Eleocharis acicularis* community, *Filipendula-Potentilla-Viola* community; see Table 10.4).

The presence of several vascular plant species were used as positive indicators (Table 10.5), presence was considered as any occurrence within the turlough, irrespective of abundance. Turloughs with two or more positive indicators were given a score of 2, turloughs with a single positive indicator a score of 1, and those lacking any of the species a score of 0.

The percentage cover of each these vegetation indicator communities were summed for positive and negative indicators applied to each turlough, noting that not all indicators were used in each turlough soil-type category (Table 10.4). A net indicator sum was also calculated as the total percent cover of negative indicators subtracted from the total percent cover of positive indicators. The vegetation community indicators were assessed as showing 'Very good' status (Score of 2) if positive indicators covered at least 50% of the turlough, the status was 'Good' (Score of 1) if the net indicator sum was greater than 20 with less than 50% cover of positive indicators, 'Bad' status (Score -1) was indicated by a negative indictors cover of greater than 50%, with other values assessed as 'Intermediate' (Score 0).

Rumex species (*R. acetosa, R. conglomeratus, R. crispus*) were used to indicate likely fertilisation within the turlough basin, *Rumex* species have been shown to increase in cover following fertiliser application (D. Lynn, S. Murphy & S. Waldren, unpublished data). *Rumex* frequency was calculated as the proportion of relevees in each turlough with any of these *Rumex* species present; frequencies of less than 0.1 were considered 'Good' (Score 1), frequencies between 0.1 and 0.5 were considered 'Intermediate' (Score 0), and frequencies greater than 0.5 considered 'Bad' (Score -1).

Table 10.4. Biological responses (Vegetation communities) used in the assessment of turlough structure and function

Indicator	*Type*	*Description*
Agrostis stolonifera-Glyceria fluitans community	Negative	A community typical of wetter parts of eutrophic turloughs, always grazed (often heavily). Indicates long duration flooding coupled with nutrient enrichment (and usually moderate to high grazing pressure)
Eleocharis acicularis community	Negative for marl turloughs, positive for mineral soils	An ecologically interesting community largely restricted to mesotrophic turloughs on mineral soils; presence in the more oligotrophic turloughs likely to indicate unfavourable nutrient inputs
Filipendula ulmaria-Potentilla erecta-Viola community	Negative for marl, positive for organic and mineral	A community of eutrophic/mesotrophic conditions, associated with grazing. Negative only for marl type turloughs - community to be expected in organic or mineral soil turloughs
Lolium grassland	Negative	Likely to indicate improved grassland, possibly reseeded and fertilized, mostly in the upper zones
Polygonum amphibium community	Negative	A characteristic community of the deeper zones of the more eutrophic turloughs, though note that the species *P. amphibium* occurs widely. Not appropriate for organic or mineral soil turloughs
Poa annua-Plantago major community	Negative	A community found on heavily poached soils, indicating high levels of livestock usage
Eleocharis palustris-Ranunculus flammula	Positive	The typical community of the deeper zones of oligotrophic turloughs, with long duration of flooding. Indicates long duration flooding and absence of nutrient enrichment.
Flooded Pavement	Positive	A diverse array of communities at the upper zone of turloughs indicating a relative lack of disturbance; contains some important turlough species
Limestone grassland	Positive	Indicates unimproved upper margins of the turlough
Molinia caerulea-Carex panicea community	Positive	Sedge-dominated community characteristic of the more oligotrophic turloughs
Schoenus nigricans fen	Positive	Unusual ecological community, restricted to oliotrophic turloughs; appropriate therefore for the organic and marl type turloughs
Woodland/scrub	Positive	Indicates unimproved upper margins of the turlough, and provides important habitat for terrestrial invertebrates during hydroperiod

Table 10.5. Biological responses (vascular plant species) used in the assessment of turlough structure and function

Indicator	*Type*	*Description*
Presence of *Potentilla fruticosa*	Positive	Important/localised species important in turloughs
Presence of *Viola persicifolia*	Positive	Important/localised species important in turloughs
Presence of *Teucrium scordium*	Positive	Important/localised species important in turloughs
Presence of *Limosella aquatica*	Positive	Important/localised species important in turloughs
Presence of *Plantago maritima*	Positive	Unusual ecological habitat for the species; likely a late glacial relict in turloughs, indicating relative lack of disturbance
Presence of *Rorippa islandica*	Positive	A rare species largely restricted to turloughs
Presence of *Frangula alnus*	Positive	The prostrate form of this species is more or less restricted to the upper zones of turloughs, usually associated with limestone outcrops

The presence of selected aquatic (or with at least part of their life cycle spent aquatic) invertebrates was also used as positive indicators in much the same was as vascular plants; any occurrence from any sampling procedure was considered, again irrespective of abundance (Table 10.6). A similar scoring system for aquatic invertebrates was used to that described for vascular plants (see above).

The scores for the various indicators of biological responses (ie. Algal communities, Vegetation, Communities, *Rumex* cover, Vascular plant indicators, Aquatic invertebrate indicators) were then summed to give a total score for biological responses. Turloughs with a score of 5 or greater were assessed as being in 'Very good' biological status, scores of 3 - 5 as 'Good', scores of -1 – 2 as 'Intermediate' and scores of less than -2 as 'Bad'.

Site structure and function assessments considered the hydrological and water chemistry drivers alongside the biological responses (Table 10.7).

Table 10.6. Biological responses (aquatic invertebrate species) used in the assessment of turlough structure and function

Indicator	*Type*	*Description*
Presence of *Alona rustica*	Positive	Restricted to oligotrophic turloughs
Presence of *Alonella exisa*	Positive	Restricted to oligotrophic/mesotrophic turloughs
Presence of *Alonopsis elongata*	Positive	Restricted to oligotrophic turloughs
Presence of *Agabus labiatus* (Coleoptera)	Positive	Part of the so-called "edge-moss-dwelling community" reported to be very susceptible to disturbance by anthropogenic sources such as heavy grazing and nutrient enrichment. Near threatened in Ireland
Presence of *Berosus signaticollis* (Coleoptera)	Positive	Part of the so-called "edge-moss-dwelling community" reported to be very susceptible to disturbance by anthropogenic sources such as heavy grazing and nutrient enrichment. Endangered in Ireland
Presence of *Dryops similaris* (Coleoptera)	Positive	Near threatened in Ireland
Presence of *Graptodytes bilineatus* (Coleoptera)	Positive	Described as most sensitive to disturbances such as nutrient enrichment. Near threatened in Ireland
Presence of *Lestes dryas* (Odonata)	Positive	Rare species characteristic of turloughs
Presence of *Sympetrum sanguineum* (Odonata)	Positive	Rare species characteristic of turloughs
Presence of *Eurycercus glacialis*	Positive	Rare species characteristic of turloughs

Table 10.7. Matrix for assessing individual site structure and function

Status	Targets, based on hydrological function, water chemistry and biological responses
Favourable	No more than one ***Intermediate***, no ***Bad***
Inadequate	Any other value
Bad	Two or more ***Bad,*** or at least one ***Bad*** and no ***Good***

10.2.1.2 Pressures and Threats

Pressures and threats were assessed by expert knowledge of the 22 turloughs based on field survey, and in some cases by data. Pressures and threats were compiled for each turlough from the standard list (http://biodiversity.eionet.europa.eu/article17/reference_portal). The opinion of all project members was sought, along with staff of NPWS. Because of their dependence on groundwater flooding for hydrological and ecological functioning, pressures and threats were considered at the level of the turlough basin, and also the zone of groundwater contribution. The impacts of the pressures and threats were assessed as 'high', 'medium' or 'low' as described in Table 10.8. Quantitative data were used to assess the importance of some of the impacts; for example the number of septic tanks lying in areas of high or extreme pathway susceptibility was used to assess *H02.07 Diffuse groundwater* *pollution due to non-sewered population* within the ZOC. Similarly, the percentage of the turlough grazed and the number of livestock units per land parcel were both used to estimate the impact of *A04.01.01 Intensive cattle grazing*.

Table 10.8. The relative importance of a threat or pressure, after Evans & Arvela (2011)

Code	*Meaning*	*Comment*
H	High importance/impact	Important direct or immediate influence and/or acting over large areas.
M	Medium importance/impact	Medium direct or immediate influence, mainly indirect influence and/or acting over moderate part of the area/acting only regionally.
L	Low importance/impact	Low direct or immediate influence, indirect influence and/or acting over small part of the area/ acting only regionally.

In some cases, the impacts of current pressures were considered as likely to continue as threats into the near future. For many impacts however, the impact of threats was considered differently from current pressures; part of the different impact of threats can be explained by potential agricultural changes due to Ireland's Food Harvest 2020 policy (Department of Agriculture, Fisheries & Food, 2010). Threats such as drainage were considered where calls for future drainage of turloughs are known, and such threats are considered to have a greater impact for turloughs out of the Special Area of Conservation network, or where turloughs are not specifically mentioned as a 'qualifying interest' in the designation of SACs (in this case Brierfield, Carrowreagh and Rathnalulleagh). Finally, several likely threats were considered which are currently not pressures, but which can be expected to have future impacts. Threats of *A02.01 Agricultural intensification* in the ZOC (due to Food Harvest 2020) and *A02.03 Grassland removal for arable land* (mainly the conversion of grassland to maize crops) were considered to have the greatest potential impact as threats in turloughs where the ZOC had the highest percentage of pasture and/or grassland.

Note that several additional pressures/threats such as *E01.03 Dispersed Habitation* could have been used; however, it was considered that the major impact of such dispersed habitation would be via groundwater pollution, and hence the pressure/ threat was coded *as H02.07 Diffuse groundwater pollution due to non-sewered population*.

10.2.1.3 Characteristic Species

For the vegetation communities that were used as positive indicators of turlough structure and function (see above), the synoptic tables given in *Chapter 7: Turlough Vegetation: Description Mapping and Ecology* were used to determine the most frequent species in each community (those with a frequency greater than 40% in <u>all</u> relevés assigned to a community). Species used as indicators in Tables 10.5 and 10.6 (above) were also added to this list. A list of characteristic species is given in Appendix 10.1, though it should be noted that these species are not necessarily characteristic of all turloughs; application of the characteristic species concept is problematic in turloughs due to variation in flooding regime, nutrient status and land use.

10.2.2. Overall National Assessment

10.2.2.1 Range and Area

The consolidated report on turlough distribution in Ireland (Mayes, 2008) was used as a basis for generating maps delimiting the distribution of turloughs within Ireland. Several additional records were available from counties Monaghan, Roscommon, Sligo and Westmeath since Mayes's compilation (Wilson, 2009; Kearney, 2011; Foss & Crushell, 2012); these additional records were checked for duplication (all of the Sligo records and some from Monaghan and Roscommon were already documented by Mayes) before being added to the list. The records compiled by Mayes were scrutinised to determine whether they were likely to be turloughs, or whether the site had been destroyed; some sites, reported in Mayes as 'field ponds', were not used in the mapping of turloughs, as were sites that had obviously been destroyed. Two sites listed by Mayes are considered to have been destroyed since 2000; these are Ballyadam (Co. Cork – filled in) and Doughiska (Co. Galway – site destroyed during construction of a bypass interchange); however, there is no evidence that these sites ever were turloughs. Examination of aerial photographs of Ballyadam suggests a long history of agricultural fields, and no mention of 'liable to flood' on any 6" map; in summary there is little direct evidence to suggest that this was a turlough. Similarly there is no direct evidence that Doughiska was in fact a turlough. A more likely candidate for a turlough is a site at Aghamore (Co. Sligo) which was irrecoverably damaged around 2000 (ie prior to 12 year reporting trend for 2013 report) due to a car salesroom being built on it (which was abandoned when it subsequently flooded, but the habitat is lost); further clarification of the status of this site as a possible turlough is required.

A total of 479 turlough records were used to generate hectad distribution maps, and the range of the turlough habitat was generated using the 'Species and Habitat types Range Tool'. This is an ESRI ArcGIS Ver. 10.0 Tool that *"…seeks to generate grid-based ranges in an automatic and consistent way, using as input the grid-based map of distribution that is derived from the locations of confirmed sightings/occurrences"* (Urda & Maxim, 2012). A buffer of 7 ha, representing the average estimated area, was applied to all turloughs. Turloughs that straddled the 10 km boundary were examined using aerial photography to determine which 10 km^2 was occupied by the turlough.

Of the turloughs reported by Mayes (2008), 129 had surface areas estimated, likely obtained from a variety of sources (not specified). For those turloughs surveyed by Goodwillie (1992) it is known that upper limits of turlough vegetation were used to define area. These were updated with the areas calculated as maximum area of flooding from the 22 turloughs studied in this project (*Chapter 3: Hydrology*); in some cases areas given in Mayes were likely considerable over-estimates (e.g. Carranavoodaun, where it appears that the value for *catchment* rather than *turlough* area reported by Goodwillie has been mistakenly entered). The areas of these turloughs were then used to estimate the surface area of those for which area was not provided in Mayes. It was hypothesised that many of the turloughs over 10 ha would have been already surveyed by Goodwillie (1992); accordingly, 9 out of 10 of the turloughs over 10 ha in area were removed from the set of 129, and the remaining 41 turloughs used to estimate an average area for all other turloughs. Areas were $\log_{10}$ transformed prior to calculating a mean value, and this gave an excellent approximation to a normal distribution. The antilog of the mean value was then used to estimate the surface area of all turloughs of unknown area (value = 7.099 ha). The estimated or known areas of turloughs were used to buffer the grid references (assumed centroids, though this is not always likely to be the case) in order to estimate overlap of turloughs across contiguous hectads; this was determined by examination of 6" maps and aerial photographs. This was used to modify the hectad distribution of turloughs.

10.2.2.2 Favourable Reference Range/Area

For both distribution range area and total surface area of the habitat, the favourable reference value (see Evans & Arvela, 2011, for definitions) was calculated as the current range or area as appropriate, as it is considered that there have been no significant losses of range or area of turloughs in the past 12 years, and certainly no new turlough habitats could have been created. In fact, there is a likely small decline in surface area through drainage reducing the area of flooding, but this is considered minimal in the national context.

10.2.2.3 Structure and Function

The median values for the scores for all 22 turloughs were calculated separately for the hydrological functions, water TP and biological responses, as described above. The median values were then used to define 'Good', 'Inadequate' and 'Bad' scores as for the individual sites; the qualifier 'Very Good' was also used to identify exceptionally good sites though in terms of Article 17 reporting both 'very good' and 'good' can be considered to equate to 'favourable'. The three main indicator areas were then used as described in Table 10.7 to obtain an overall assessment, based on the assumption that the 22 turloughs selected for the detailed study were representative of the range of ecological variation found in turloughs.

10.2.2.4 Pressures and Threats

National level pressures and threats were determined as those that occurred most frequently among the 22 turloughs, with other pressures and threats also considered for other turloughs in addition to the 22 studied in detail. The importance value attached to each pressure and threat (see Tables 10.10, 10.11) took into account the most frequent categories of importance scored in the 22 study turloughs *together* with the frequency of the pressure/threat among these turloughs; additionally, the likely (or in some cases known) impact in additional turloughs nationally was considered.

10.2.2.5 Future prospects

Future prospects were subjectively assessed by consideration of the numbers and magnitude of threats facing individual turloughs. In particular, where the numbers and magnitudes of threats exceeded the current pressures, future prospects were considered to be unfavourable (inadequate or bad, depending on magnitude).

10.3 Results and Discussion

10.3.1 Individual Sites - Summary

The majority of sites had favourable hydrological functioning (Table 10.9). Hydrological function was only considered bad at Kilglassan, although the hydrological function was intermediate at Brierfield, Termon and Tullynafrankagh. The major impact on hydrological function was alteration of drainage within the turlough basin (individual impacts are considered in detail in the individual site assessments below). Hydrological function is considered to be the main ecological driver of turlough habitat function, where flooding from groundwater (seasonal, or other periods of high groundwater charging) result in major constraints to the development and function of biological communities.

Water chemistry was assessed solely by the mean concentration of the total phosphorus pool in the floodwater (water TP), as water TP showed the strongest relationships with algal, vascular plant communities and aquatic invertebrate communities compared to any other chemical variable in the water column or soil (*Chapters 4-8*). Four turloughs had very good water quality, with water TP less than 10 µg P l^{-1}: Lisduff, Knockaunroe, Lough Gealain and Roo West (the latter only just <10; Table 10.9). A further five turloughs had good water quality status with water TP between 10 and 20 µg P l^{-1}, though Brierfield was marginal at 19.8 µg P l^{-1}. Skealoghan was marginal intermediate water quality at 20.4 µg P l^{-1}, and a further ten turloughs had water TP between 20 and 50 µg P l^{-1}. Only two turloughs (Ardkill and Blackrock) had bad water quality, each with water TP greater than 50 µg P l^{-1}; this is an arbitrary figure, but serves to highlight those turloughs where there are significant negative water quality issues. Those turloughs with the lowest water TP are the most oligotrophic turloughs; even modest increases in groundwater TP are likely to have significant negative impacts for these turloughs. Similar increases in water TP in the more mesotrophic turloughs, with intermediate water quality, is likely to have a relatively small biological impact (see *Chapter 4: Water Chemistry and Algal Biomass* and *Chapter 11: Water Framework Directive Risk Assessment*).

The biological status of the turloughs was considered good in eight turloughs, intermediate in 11 and bad in three (Table 10.9). The main reasons for lower biological status tended to be a high cover of negative vegetation indicators; the presence of filamentous algal mats and high chlorophyll contents, and a lack of important plant and aquatic invertebrate species often but by no means always paralleled the vegetation indicators. These were often associated with intermediate or bad water quality status. Some turloughs (e.g. Carrowreagh, Croaghill, Kilglassan) had relatively low coverage of *both* positive and negative indicator communities, they also typically lacked important plant species (but not necessarily important aquatic invertebrates). All of the turloughs with 'very good' water quality had 'good' biological status. Mention should be made of Caranavoodaun and Lough Gealain, both of which had over 90% of the turlough covered with positive vegetation community indicators; Lough Gealain and Garryland were also unique in that they lacked any cover of negative vegetation community indicators.

Table 10.9. Summary of structure and function assessment for the 22 study turloughs, and summary for national assessment; Green = 'Good' (and 'Very Good'), Amber = 'Inadequate' and Red = 'Bad'

Turlough	*Type (based on soil characteristics)**	*Hydrological Functions Assessment*	*Water Quality Assessment*	*Biological Responses Assessment*	*Overall site S&F Assessment*
Blackrock	**MIN**				
Caherglassan	**MIN**				
Carrowreagh	**MIN**				
Coolcam	**MIN**				
Garryland	**MIN**				
Lough Coy	**MIN**				
Rathnalulleagh	**MIN**				
Turloughmore	**MIN**				
Ardkill	**ORG**				
Ballindereen	**ORG**				
Caranavoodaun	**ORG**				
Croaghill	**ORG**				
Kilglassan	**ORG**				
Lisduff	**ORG**				
Lough Aleenaun	**ORG**				
Skealoghan	**ORG**				
Brierfield	**MAR**				
Knockaunroe	**MAR**				
Lough Gealain	**MAR**				
Roo West	**MAR**				
Termon	**MAR**				
Tullaghnafrankagh	**MAR**				
National (median)					

* MIN – predominantly mineral soils, ORG – predominantly organic soils, MAR – predominantly marl-based soils (including peaty marls)

Table 10.10. Main pressures impacting on the study turloughs. The pressure descriptions and their codes are taken from the standard list referred to in Evans & Arvela (2011), in some cases qualifications are given as to whether the pressure is acting at the level of the turlough or within the zone of groundwater contribution (ZOC). Codes highlighted in red are considered to be widespread pressures across turloughs in general; other pressures are more localised. The level of impact is indicated as high, medium or low.

Article 17 Code	*Pressure*	*High*	*Medium*	*Low*	*Overall*
A04.01.01	Intensive cattle grazing	5	10	6	M
H02.06	Diffuse groundwater pollution due to agricultural and forestry activities	4	10	4	M
H02.07	Diffuse groundwater pollution due to non-sewered population (ZOC)	1	3	11	L
A05.02	Stock feeding (=within turlough zone)	0	1	7	L
B01	Forest planting on open ground	0	1	6	L
J02.05	Modification of hydrographic functioning, general (=drainage)	0	1	3	M/L
A08	Fertilisation (within turlough)	0	2	3	M/L
A04.01.02	Intensive sheep grazing	1	1	0	M/H
E02.01	Factory	0	1	0	M
A04.03	Abandonment of pastoral systems, lack of grazing	0	0	1	L
C01.03	Peat extraction	0	0	1	L
J02.07.02	Groundwater abstractions for public water supply	0	0	1	L

The pressures operating on the study turloughs are summarised in Table 10.10 and detailed more fully in for individual sites below (section 10.3.2). Relatively few pressures are considered to have high impacts, and there were considered to be only two pressures that have high impacts in more than one turlough – Intensive cattle grazing and Groundwater pollution from agriculture and forestry. These two pressures, together with groundwater pollution due to non-sewered population (mainly septic tanks) were the only three pressure types that occurred widely in the majority of turloughs. These pressures generally reflect the status of the turlough structure and function, where the major areas of bad or inadequate status occurred through 'Bad' water quality (Table 10.9). Similarly, the generally good hydrological functioning of turloughs is reflected in drainage being a medium or low pressure in only four turloughs. It is also noteworthy that Lough Gealain appeared to have no direct pressures operating at present or in the recent past; interestingly there was a previous threat to this turlough from the highly controversial visitor centre planned for the Burren National Park, which was never built.

Table 10.11. Main threats considered likely to impact on the study turloughs within the next 12 years. The threat descriptions and their codes are taken from the standard list referred to in Evans & Arvela (2011), in some cases qualifications are given as to whether the threat is likely to act at the level of the turlough or within the zone of groundwater contribution (ZOC). Codes highlighted in red are considered to be widespread threats across turloughs in general, other threats are more localised. The level of impact is indicated as hi*gh, medium or low.*

Article 17 Code	*Threat*	*High*	*Medium*	*Low*	*Overall*
A04.01.01	Intensive cattle grazing (in turlough)	1	15	4	M
H02.06	Diffuse groundwater pollution due to agricultural and forestry activities	5	12	5	M
A02.01	Agricultural intensification (in ZOC)	3	8	11	M/L
H02.07	Diffuse groundwater pollution due to non-sewered population	0	3	13	L
M01.03	Flooding and rising precipitations (due to climate change)	0	0	22	L
A10.02	Removal of stone walls and embankments	0	0	21	L
A02.03	Grassland removal for arable land	0	0	11	L
H01.05	Diffuse pollution to surface waters due to agricultural and forestry activities	3	0	0	H
A04.01.02	Intensive sheep grazing	1	1	0	H/M
J02.05	Modification of hydrographic functioning, general (=drainage)	3	3	0	M
A04.03	Abandonment of pastoral systems, lack of grazing	0	1	7	L
J02.07.02	Groundwater abstractions for public water supply	0	1	2	L
A05.02	Stock feeding	0	1	1	M/L
E02.01	Factory	0	1	0	M
D01.02	Roads, motorways		Some		M
M01.07	Sea-level changes			Some	L

'**Some**' in the table refers to turloughs not included in the 22 study turloughs, but where a given threat is likely to occur

The majority of the pressures existing in the study turloughs are likely to continue as threats (Table 10.11). Thus grazing impacts, groundwater pollution from agriculture, forestry and non-sewered housing are considered to be important threats in the next 12 years, for most turloughs with a medium level of impact. The likely threat due to groundwater pollution takes into account the percentage of the ZOC with high and extreme pathway susceptibility; the threat from non-sewered population also takes into account the number of septic tanks per square km of ZOC with extreme pathway susceptibility (see *Chapter 11: Water Framework Directive Risk Assessment*). Agricultural intensification is also considered a threat to many turloughs, mainly through intensification in the ZOC driven by *Food Harvest 2020* (Department of Agriculture, Fisheries & Food, 2010); the impact level of this threat was assessed based on the pasture and grassland cover in the ZOC, with grazing the most prominent agricultural landuse with turlough ZOCs.

In some areas, a threat of conversion from pasture to agricultural maize production (fodder, biofuel) was considered. The impact of this threat is uncertain – if the maize tillage crop replaced intensive improved pasture that is regularly fertilized, ground water pollution from diffuse nutrients may not change, though there may be higher loading of pesticides. However, conversion of unimproved grassland to tillage is likely to result in increased diffuse nutrient enrichment. Reduced levels of grazing, perhaps through abandonment of traditional farming practices, may have a moderate or low impact on vegetation communities, but probably only in the more productive, meso- to eutrophic turloughs; a likely impact would be seen as an increase in the dominance of taller herb and grass communities. Reduced grazing levels in the less-productive, more oligotrophic turloughs is likely to have little or no impact; many of these turloughs are relatively lightly grazed (Lough Gealain appeared to be ungrazed by domestic stock), likely because they are dominated by communities of low productivity and poor nutritional value, being sedge- rather than grass-dominated. Grazing exclosure experiments in an oligotrophic turlough did not result in the establishment of woody plants, but in general resulted in an increase in vegetation height and spread of existing vegetation (D. Lynn, S. Murphy & S. Waldren, unpublished data).

Two threats, neither of which are current pressures, are considered likely to have a low level of impact on many turloughs. These are the degradation of boundary walls within turloughs and alteration of flooding regimes due to climate change. Degradation of boundary walls has been coded as A10.02 *'Removal of stone walls and embankments'*; this reflects a general observation that many of the stone boundary walls within turloughs are under poor repair. With continued degradation, these important boundaries between land parcels will be fragmented, allowing freer movement of grazing animals and hence altering the biological diversity within turloughs through a likely homogenisation of vegetation in adjacent land parcels. Climate change is predicted to increase precipitation in much of the geographical range of turloughs, some predictions suggesting greater seasonality to rainfall (Sweeney & Fealy, 2002), though this is uncertain. Recent modelling exercises suggest the impact of climate change on turloughs is likely to be through increased flooding level and duration (O. Naughton, P. Johnston & L. Gill; unpublished data), with no impact of increased summer drought. This climate-change induced threat has been coded as *M01.03 'Flooding and rising precipitations'*.

A very small number of turloughs, mainly in the Aran Islands, may be threatened by sea-level rise, though this is anticipated to be a more long-term threat. Some turloughs (not among the 22 studied in detail) have been impacted by road development, particularly through the construction of new bypasses and motorways, and this is likely to continue to be a threat to a small number of turloughs (including Coole). The impacts of road development include the impairment of hydrological function, which can be overcome to large degree by incorporation of appropriate culverts, and by water run-off from road surfaces.

Some pressures are considered to decrease in the 22 study turloughs, these include stock feeding and the alteration of hydrological function, mainly through drainage. Turloughs within the SAC network should be immune from these potential threats *provided* the State's SAC network can be effectively protected by appropriate management. Never the less, turloughs within SACs but where turloughs have NOT been identified as a qualifying interest will be at a similar risk to these threats as non-designated turloughs, and, given the likely increased level of flooding brought about by predicted increased future levels of precipitation (see above), these non-designated turloughs may face significant threats due to drainage. In fact there have been calls to reinstate former drainage at Ballinderreen and Kilglassan, while other turloughs outside of the 22 study turloughs also face drainage threats (e.g. the Rahasane complex, the largest known turlough). If drainage only removes the threat of extreme, very occasional high flooding, it may not impact very severely on normal turlough structure and function as flooding will continue to occur within the usual range of variation. However, if attempts are made to drain turloughs to a lower level, this will impact on the normal hydrological functioning of the turlough and also reduce the overall area of turlough communities.

One additional point worthy of mention is that none of the 22 studied turloughs experience pressure from or are threatened by invasive non-native species. This situation is likely to prevail in most other turloughs, although non-native fish have been introduced into some (e.g. pike, *Esox lucius*, and others); this generally favourable condition should be monitored into the future.

The combination of these threats, which in general outweigh the current pressures, generally result in the future prospects of most of the turloughs being unfavourable. There is of course some uncertainty in this. Enrichment of groundwater through diffuse sources is a current pressure and remains a threat, though trends in water quality (both N and P) suggest recent general trends of improvement in groundwater and lakes, though there are fluctuations in general trends which are considered to be due to precipitation levels (McGarrigle *et al*., 2010; EPA, 2012; O'Sullivan, 2012 a, b). Even so, turloughs by their nature occur on areas of karst limestone, often with high proportions of their zones of groundwater contribution in areas of extreme pathway susceptibility. Given that the rural development of domestic housing is likely to continue, and that at least some agricultural intensification is likely driven by *Food Harvest 2020*, we consider the threats identified as being justified. These are likely to have negative impacts on the future structure and function of turloughs. Additional drainage may also reduce the area of turlough habitat slightly, and there is no possibility of creating new turlough habitat. It might be possible to restore or improve the conservation status of some degraded turlough habitat, thereby improving the structure and function of some turloughs and improving the area of turloughs in favourable conservation status. However, given that to date there have been almost no active conservation interventions in turloughs, the prospect of turlough restoration seems distant. For these reasons, the future prospects of turloughs is *unfavourable - inadequate*.

10.3.2 Conservation Condition of the Study Turloughs

Ardkill

Description: Ardkill turlough, one of the smaller study sites (23 ha), is located near Ballinrobe in south County Mayo and is one of a group of five turloughs that occupy hollows in rolling countryside. Skealoghan and Kilglassan turloughs are situated to the west and east of this site, respectively. Steep slopes occur on the south-western side and a low, central limestone cliff is a distinguishing feature of the site. Of the twelve mapped vegetation communities, *Lolium* grassland and *Polygonum amphibium* were the most extensive. Ardkill soils are highly organic and moderately alkaline. The two soil types occurring at the site were 'Fen Peats' and 'Very shallow well-drained organic'. Sixty percent of the site is under rotational grazing. Ardkill generally has a single, long duration flood. It is a moderately deep basin, particularly the south-western end, which holds water for long periods. The turlough has a relatively low drainage capacity and long recession duration. Parts of the turlough are heavily grazed, with consequent poaching and damage to vegetation.

Conservation Condition Summary

Structure & Function	**Bad**
Future Prospects	**Bad**
Site Conservation Condition	**Bad**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: ***Good***	Some drainage work known in the ZOC but not considered to significantly impact on the functioning of the turlough
Water Quality: ***Bad***	82.1 µg P $l^{-1.}$ The highest mean TP recorded.
Biological Responses: ***Bad***	
Algal communities: -2	Extensive algal mats were recorded; high max CHL
Vegetation communities: 0	Moderate cover of both positive and negative indicator communities
Rumex **cover: 0**	12.4% frequency
Important plants: 0	No important species
Important aquatic invertebrates: 0	No important species
Overall Structure & Function: ***Bad***	

Pressures:*

Code	*Impact*	*Notes*
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	H	Very heavy nutrient inputs occur from a local farm, noted as a potential problem by Goodwillie (1992) and now clearly manifest in the groundwater quality
A04.01.01 Intensive cattle grazing (turlough)	M	Locally intensive grazing, evidenced by poaching
A04.01.02 Intensive sheep grazing (turlough)	M	Moderate numbers of sheep graze part of the turlough, but their impact is high: sheep impact in turloughs is greater than that of cattle
A05.02 Stock feeding (within and adjacent to turlough)	L	

*the codes for pressures and threats are those used in EU Habitats Directive Article 17 reporting for 2013

Threats:

Code	Impact	Notes
H01.05 Diffuse pollution to surface waters due to agricultural and forestry activities	H	Agricultural impacts are the result of a farm immediately adjacent to the turlough – they are flagged here as *effectively* directly entering the turlough
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	H	Severe pressures due to enrichment from local sources are likely to continue and have increasing impacts
A04.01.01 Intensive cattle grazing (turlough)	M	Grazing intensity is likely to increase, driven by Food Harvest 2020
A04.01.02 Intensive sheep grazing (turlough)	M	Likely to increase, driven by Food Harvest 2020 due to pasture in ZOC
A02.01 Agricultural intensification (ZOC)	L	Possible intensification in ZOC due to high amount of pasture
A10.02 Removal of stone walls and embankments (in turlough)	L	A general problem in many turloughs, likely to lead to more widespread animal movement and consequently reduced diversity within turloughs
M01.03 Flooding and rising precipitations	L	A potential general problem in turloughs driven by predicted climate change

Future Prospects: **Bad** – Ardkill faces significant ongoing pressures that have already affected the ecological structure and function, though several important vegetation communities remain. These are likely to be at significant risk due to the imminent threats, mainly from groundwater pollution from an adjacent source, and secondarily from intensive grazing.

Overall Assessment: **Bad** – though Ardkill continues to function hydrologically, it is severely impacted by groundwater nutrient enrichment. It still retains some of the important vegetation communities noted by Goodwillie (1992 – who considered Ardkill to be of national conservation importance), but it is likely the main pressures acting on Ardkill are relatively recent and there will likely be further degradation of the vegetation. Ardkill faces considerable threats of medium to high impact, therefore the conservation status is assessed as bad.

Ballindereen

Description: Ballindereen turlough, occurring within the Lough Fingall Complex SAC, is one of the larger turloughs in the study, at 69.5 ha. It is located to the south-east of the village of Ballindereen (Co. Galway), c. 2 km from the coast. It is divided into two by a central laneway. Fourteen vegetation communities were mapped in this turlough; the *Eleocharis palustris-Ranunculus flammula* and *Schoenus nigricans* fen communities were the dominant vegetation types. The soils in Ballindereen are alkaline and organic, with significant amounts of calcium carbonate. There are extensive areas of shallow organic soils. The majority of the turlough (84%) is under rotational grazing. The hydrological data suggest that this turlough is characterised by one major flood event per annum, with a low drainage capacity. There is evidence of previous drainage within the turlough. Vegetation change suggests that grazing pressure has increased since Goodwillie's (survey), and there is evidence of seeding *Lolium* grassland.

Conservation Condition Summary

Structure & Function	**Favourable**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: ***Good***	Drainage has lowered the flood level in the past but is not considered to be currently impacting the ecological function
Water Quality: ***Good***	12.4 µg P l^{-1}
Biological Responses: ***Very Good***	
Algal communities: 0	Although algal mats were recorded they were never extensive, and the maximum CHLa was low
Vegetation communities: 2	High cover of positive indicator communities
Rumex **cover: 0**	3% frequency
Important plants: 2	*Viola persicifolia, Teucrium scordium, Plantago maritima*
Important aquatic invertebrates: 1	*Alona rustica, Alonella exisa*
Overall Structure & Function: ***Good***	

Pressures:*

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing	H	Large proportion of turlough is grazed, some land parcels very heavily grazed
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	M	Moderate number of farms and septic tanks in the ZOC
B01 Forest planting on open ground (ZOC)	L	Limited afforestation in the ZOC
E01.03 Dispersed habitation (ZOC)	L	But impact likely to be via H02.07
J02.05 Modification of hydrographic functioning, general (=drainage in turlough)	L	Drainage has impacted in the past to some degree

Threats:

Code	*Impact*	*Notes*
J02.05 Modification of hydrographic functioning, general (=drainage)	H	Calls for reinstatement of drainage could present a substantial threat
A04.01.01 Intensive cattle grazing (local)	M	Possible intensification of cattle farming within the turlough
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Possible intensification of farming within the ZOC
A02.01 Agricultural intensification (ZOC)	M	Likely driven by Food Harvest 2020 due to pasture in ZOC
A10.02 Removal of stone walls and embankments (in turlough)	L	A general problem in many turloughs, likely to lead to more widespread animal movement and consequently reduced diversity within turloughs
M01.03 Flooding and rising precipitations	L	A potential general problem in turloughs driven by predicted climate change

*the codes for pressures and threats are those used in EU Habitats Directive Article 17 reporting for 2013

Future Prospects: **Inadequate** – several medium impact threats are likely, including increased use for grazing.

Overall Assessment: **Inadequate** – Structure and function is favourable, but future prospects are inadequate due to potential drainage and increasing grazing pressure. These threats need to be mitigated to ensure that they do not impact on the structure and function of this turlough.

Blackrock

Description: Blackrock turlough, also known as Peterswell, is situated to the northwest of Peterswell village (Co. Galway). The turlough extends to 59.3 ha; it has an elongated basin, oriented roughly north-south. The south-eastern edge is steeply sloped and wooded, with another steep slope on the opposite side of the basin, but elsewhere slopes are more gentle. Occasional large rocks are evident throughout the turlough, as well as a number of sink holes in the floor. The turlough is partly fed by the Owenshree river, which enters at the northern end and then sinks within the basin. Ten vegetation types were recorded in Blackrock turlough; the *Potentilla anserina-Potentilla reptans* community was by far the dominant vegetation type, while abundant *Lolium* grassland was also mapped. Blackrock soils are moderately acidic and mineral, with low amounts of calcium carbonate. The majority of the turlough area is composed of very shallow well-drained mineral soil. The entire turlough basin is rotationally grazed. The hydrological data indicate that Blackrock generally experiences a significant annual flooding event, with further flooding occurring occasionally; it is generally a very flashy turlough and has even been recorded dry in mid winter. Of all the turloughs in this study, Blackrock turlough has the deepest floodwater depth (>15 m), largest maximum floodwater volume, fastest daily inflow and largest drainage capacity; the extreme hydrology might have possibly changed the extent of the turlough since Goodwillie's (1992) survey. Some of the limestone grassland mapped by Goodwillie seems to have been lost, probably by increased grazing pressure in the upper margins of the turlough.

Conservation Condition Summary

Structure & Function	**Inadequate**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: *Good*	Some drainage work is known in the ZOC but not considered to significantly impact on the functioning of the turlough
Water Quality: *Bad*	52.4 µg P $l^{-1.}$
Biological Responses: *Intermediate*	Rather mixed responses across categories
Algal communities: 0	No algal mats were recorded, low max CHL; likely due to the highly coloured water due to runoff from the Slieve Aughty forestry activity
Vegetation communities: 0	Moderate cover of both positive and negative indicator communities
***Rumex* cover: -1**	81.1% frequency, very high
Important plants: 1	*Viola persicifolia*
Important aquatic invertebrates: 0	No important species
Overall Structure & Function: *Inadequate*	

Pressures:*

Code	*Impact*	*Notes*
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	H	Pollution due to agriculture and through forestry activity in the Slieve Aughty mountains, also likely from adjacent abattoir
A04.01.01 Intensive cattle grazing (turlough)	M	Moderate grazing within turlough
E02.01 Factory (adjacent to or within turlough)	M	Abattoir adjacent to turlough likely releases nutrient to groundwater
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Relatively low level of habitation in ZOC
B01 Forest planting on open ground (ZOC)	L	Forest planting continuing, but main pressure from forestry is from existing forests via groundwater pollution

*the codes for pressures and threats are those used in EU Habitats Directive Article 17 reporting for 2013

Threats:

Code	*Impact*	*Notes*
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	H	Ongoing significant pressure
A02.01 Agricultural intensification (ZOC)	M	Likely based on the pasture in the lower elevation parts of the ZOC
A04.01.01 Intensive cattle grazing (turlough)	M	Highly productive but extent of grazing likely limited by flashy flooding and extreme depth
E02.01 Factory (adjacent to turlough)	M	Abattoir adjacent to turlough
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	
A04.03 Abandonment of pastoral systems, lack of grazing (ZOC)	L	Removal of grazing from the turlough has the potential to greatly modify the vegetation due to the high productivity
A10.02 Removal of stone walls and embankments (in turlough)	L	A general problem in many turloughs, likely to lead to more widespread animal movement and consequently reduced diversity within turloughs
M01.03 Flooding and rising precipitations	L	A potential general problem in turloughs driven by predicted climate change
A02.03 Grassland removal for arable land (ZOC)	L	Possible shift to maize production locally

Future Prospects: **Inadequate** – there are a relatively high number of medium impact threats likely to further degrade the ecological structure and function; many of these threats are on-going pressures from within the ZOC, chiefly affecting groundwater quality.

Overall Assessment: **Inadequate** – Blackrock is a hydrologically interesting turlough but suffers from high nutrient inputs, likely caused by a combination of agricultural and domestic diffuse pollution, and pollution from forestry activities in the upper elevations of the ZOC. As with other turloughs in the Gort chain, the impact of this forestry on acidic peat soils is evidenced by the highly coloured floodwater, which generally restrict the development of algal communities, and perhaps explains the generally poor aquatic invertebrate communities. Even so, Blackrock retains some important plant communities and several rare or threatened vascular plants.

Brierfield

Description: Brierfield turlough, which is an NHA rather than a SAC, is a relatively large turlough (59 ha) situated to the east of Castleplunket in central Co. Roscommon. The basin is V-shaped, with arms extending to the south-west and north-west (Goodwillie, 1992). Steep ridges occur around the majority of a relatively flat basin floor. Twelve vegetation types were mapped in Brierfield turlough. Very extensive areas of *Carex nigra-Ranunculus flammula* and *Potentilla anserina-Carex nigra* were recorded. Brierfield soils are circumneutral and peaty, with significant amounts of calcium carbonate. 'Alluvial marl with peaty topsoil' was by far the dominant soil type. Approximately half of the turlough area (54%) is under rotational grazing. The hydrological data indicate that Brierfield turlough experiences one significant flood every per year and that the site is relatively slow to flood and drain; there is some evidence from vegetation that the turlough may flood for longer than when surveyed by Goodwillie.

Conservation Condition Summary

Structure & Function	**Inadequate**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: ***Intermediate***	Drainage has altered the flooding regime, and there is also evidence of drainage within the ZOC that may affect the turlough
Water Quality: ***Good (marginal)***	19.8 µg P l^{-1}. Only just in the 'good' category
Biological Responses: ***Intermediate***	
Algal communities: 0	No algal mats recorded (a negligible quantity in 2008), low max CHL
Vegetation communities: 0	Low cover of negative indicators, almost no positive indicator cover
Rumex **cover: 0**	2% frequency
Important plants: 0	None present
Important aquatic invertebrates: 1	*Agabus labiatus, Graptodytes bilineatus*
Overall Structure & Function: ***Inadequate***	

Pressures:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	H	High grazing levels in some land parcels coupled with high percentage of the turlough grazed
A05.02 Stock feeding (within and adjacent to turlough)	M	Some evidence of stock feeding within the turlough
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Low inputs likely from domestic effluent
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	L	Likely inputs due to agriculture and forestry
J02.05 Modification of hydrographic functioning, general (=drainage in turlough)	L	Some evidence of drainage within the turlough
B01 Forest planting on open ground (ZOC)	L	Some afforestation in the ZOC

Threats:

Code	Impact	Notes
A04.01.01 Intensive cattle grazing (turlough)	M	Likely a continuing pressure
J02.05 Modification of hydrographic functioning, general (=drainage in turlough)	M	Not included in an SAC, so potentially at risk from drainage
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Potential impacts due to development of agriculture and forestry in ZOC
A10.02 Removal of stone walls and embankments (in turlough)	L	A general problem in many turloughs, likely to lead to more widespread animal movement and consequently reduced diversity within turloughs
M01.03 Flooding and rising precipitations	L	A potential general problem in turloughs driven by predicted climate change
A02.01 Agricultural intensification (ZOC)	L	Likely to be relatively based on the amount of pasture in ZOC
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	
A02.03 Grassland removal for arable land (ZOC)	L	Possible shift to arable production locally
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	L	

Future Prospects: **Inadequate** – the majority of the threats are of relatively low impact; however the structure and function are already inadequate, with relatively high water TP and some of the biological indicators intermediate. Additionally, there is no potential protection afforded by SAC status.

Overall Assessment: **Inadequate** – due to the combination of inadequate structure and function and future prospects.

Caherglassan

Description: Caherglassan is a large turlough (63 ha) with SAC status located in the Kilmoran townland of south east Co. Galway. Gentle, grassy slopes surround the majority of a semi-permanent lake which rarely dries out. A steep, rocky outcrop area occurs in the north-western section of the basin (Goodwillie, 1992). Nine vegetation types were recorded at this site; *Potentilla anserina-Potentilla-reptans* and woodland/scrub were the distinctly dominant vegetation types. The majority of the turlough area (72.4%) is composed of the 'Shallow, poorly-drained mineral' soil type, with extensive areas (27.6%) of the 'Alluvial mineral' soil type also evident. All of the turlough is rotationally grazed. Caherglassan turlough has a relatively flashy hydrological regime and a high drainage capacity, water levels show a small diurnal influence of tides. The turlough is fairly extensively grazed; even so, there is some evidence of alleviation of grazing pressure since Goodwillie's survey, with perhaps changes in the pattern of grazing across the turlough.

Conservation Condition Summary

Structure & Function	**Inadequate**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: ***Good***	Of note is the fluctuation in water level in response to tidal stage
Water Quality: ***Intermediate***	43.2 µg P l^{-1}. Towards the high end of this category
Biological Responses: ***Intermediate***	Very mixed across categories, some good but others poor
Algal communities: -1	No algal mats recorded, likely due to the highly coloured water due to runoff from the Slieve Aughty forestry activity; however, high max CHL
Vegetation communities: 1	Moderately high cover of positive indicators, mostly due to woodland scrub in upper zones and *Eleocharis acicularis* community in lower muddy areas
Rumex **cover: -1**	89.5% frequency, the highest recorded
Important plants: 1	*Viola persicifolia*
Important aquatic invertebrates: 0	None present
Overall Structure & Function: ***Inadequate***	

Pressures:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	H	High grazing levels in some land parcels coupled with high percentage of the turlough grazed
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	H	Pollution due to agriculture and through forestry activity in the Slieve Aughtey mountains
A08 Fertilisation (within turlough)	M	Turlough known to have had fertiliser application within the turlough basin
B01 Forest planting on open ground (ZOC)	M	Forest planting continuing, but main pressure from forestry is from existing forests via groundwater pollution
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	
A05.02 Stock feeding (within and adjacent to turlough)	L	Some evidence of stock feeding within the turlough

Threats:

Code	Impact	Notes
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	H	Likely a continuing severe pressure
H01.05 Diffuse pollution to surface waters due to agricultural and forestry activities (ZOC)	H	Considered to be a threat due to continued slurry and fertiliser application; flagged up here due to its particularly severe impact
A02.01 Agricultural intensification (ZOC)	M	Likely a moderate threat due to extensive pasture in lower altitude ZOC
A04.01.01 Intensive cattle grazing (turlough)	M	Continuing pressure
A10.02 Removal of stone walls and embankments (in turlough)	L	
M01.03 Flooding and rising precipitations	L	
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	
A04.03 Abandonment of pastoral systems, lack of grazing (ZOC)	L	Likely to be low based on the pasture in the lower elevation parts of the ZOC
A02.03 Grassland removal for arable land (ZOC)	L	

Future Prospects: **Inadequate** – already faces high pressures from nutrient enrichment, both from ZOC and from local inputs into turlough, and these likely to continue.

Overall Assessment: **Inadequate** – structure and functions are already impacted by pressures and these are likely to persist well into the future. However, some of the biological indicators are in good status, and the turlough still contains some important plant species and vegetation communities; there is some evidence of the spread of woodland and scrub since Goodwillie's report of 1992. This suggests that if strong conservation prescriptions could be applied and adhered to, the conservation status might be considerably improved.

Caranavoodaun

Description: Caranavoodaun turlough lies north of Ardrahan, Co. Galway, and occurs within the Castletaylor Complex SAC. The maximum flooded area was recorded as 34.6 ha. The southern part of the basin slopes gently to the base of the turlough, while the northern slopes are steeper. A permanent pool is present in the centre of the basin. Twelve vegetation communities were mapped in Caranavoodaun; the *Eleocharis palustris-Ranunculus flammula* community was the dominant vegetation type, occurring over most of the bottom of the basin. Caranavoodaun soils are alkaline and highly organic, with significant amounts of calcium carbonate; Fen peat was the dominant soil type found. All of the turlough is rotationally grazed. The hydrological data suggest that there is generally one significant flooding event per annum, with smaller fluctuations occurring throughout the year. The vegetation suggests that the turlough may now be wetter in the central part than when surveyed by Goodwillie (1992), with more aquatic communities. There is localised heavy cattle grazing and poaching damage.

Conservation Condition Summary

Structure & Function	**Favourable**
Future Prospects	**Inadequate/Favourable**
Site Conservation Condition	**Inadequate/Favourable**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: ***Good***	Drainage has lowered the flood level in the past but is not considered to be currently impacting the ecological function
Water Quality: ***Good***	11.0 µg P l^{-1}
Biological Responses: ***Very Good***	
Algal communities: 0	No algal mats recorded (negligible quantities in 2008), low max CHL
Vegetation communities: 2	High cover of positive indicator communities typical of oligotrophic turloughs
Rumex **cover: 1**	Absent
Important plants: 1	*Frangula alnus, Plantago maritima*
Important aquatic invertebrates: 2	*Alona rustica, Alonella exisa, Berosus signaticollis, Lestes dryas, Sympetrum sanguineum, Eurycercus glacialis*
Overall Structure & Function: ***Good***	

Pressures:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	M	Moderate cattle grazing within the turlough
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	M	There are a reasonably high number of dwellings in the ZOC, some very close to the turlough; likely contribution to slight nutrient enrichment
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	L(ZOC)	
B01 Forest planting on open ground (ZOC)	L(ZOC)	
E01.03 Dispersed habitation (ZOC)	L(ZOC)	There are a reasonably high number of dwellings in the ZOC, some very close to the turlough, the major impact of these is likely through groundwater pollution

Threats:

Code	Impact	Notes
A02.01 Agricultural intensification (ZOC)	H	Likely to increase due to prevalence of pasture in ZOC
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Likely to increase due to prevalence of pasture in ZOC
A04.01.01 Intensive cattle grazing (turlough)	M	Continuing pressure
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Continuing pressure
A10.02 Removal of stone walls and embankments (in turlough)	L	
M01.03 Flooding and rising precipitations	L	
J02.07.02 Groundwater abstractions for public water supply (ZOC)	L	Possible threat due to demand caused by density of dispersed dwellings in vicinity of turlough

Future Prospects: **Inadequate/Favourable** – borderline: Caranavoodaun is currently in good ecological condition with vegetation and aquatic invertebrate communities and moderate to low pressures, however water quality is poorer than in other oligotrophic turloughs. There are a number of threats likely to impact on this state due to foreseen intensification of agricultural output in the vicinity of and within the turlough, and due to the high frequency of rural dwellings in the ZOC and especially very close to the turlough.

Overall Assessment: **Inadequate/Favourable** – the currently good ecological conditions are potentially compromised by several threats; borderline Inadequate to Favourable. Caranavoodaun is currently in very good conservation status and of probable international significance, all efforts should be taken to mitigate the threats identified.

Carrowreagh

Description: Carrowreagh turlough, which has NHA rather than SAC status, is situated near Castleplunket in central Co. Roscommon, just north of Rathnalluleagh turlough. It is a relatively compact basin (29 ha) with an elongated shape, extending north-west to south east. The turlough is bisected by a road. Eight vegetation types were mapped at this site; the dominant vegetation types were *Agrostis stolonifera-Potentilla-anserina-Festuca rubra*, *Carex nigra-Carex panicea*, *Lolium* grassland and *Potentilla anserina-Carex nigra*. Carrowreagh soils are moderately acidic, with low amounts of calcium carbonate. The soils are comprised of shallow poorly-drained mineral soil types. The majority of the turlough (84%) is under rotational grazing. Hydrological data indicate that the turlough is relatively quick to flood and drain, and that the site typically experiences one major flood event per year. The vegetation communities of the eastern part suggest it remains wetter for longer than during Goodwillie's survey (1992). Goodwillie's limestone grassland has gone, probably due to heavy grazing from sheep and cattle, coupled with nutrient inputs.

Conservation Condition Summary

Structure & Function	**Inadequate**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: ***Good***	
Water Quality: ***Intermediate***	42.8 µg P l^{-1}. Towards the high end of this category
Biological Responses: ***Intermediate***	
Algal communities: -1	Algal mats recorded in 2007 and 2008, but not extensive; maximum (and mean) CHL high.
Vegetation communities: 0	Relatively little of interest
Rumex **cover: 0/-1**	50%, borderline poor
Important plants: 0	None recorded
Important aquatic invertebrates: 0	None recorded
Overall Structure & Function: ***Inadequate***	Relatively little of biological interest, although without impaired hydrological function

Pressures:

Code	*Impact*	*Notes*
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	H	
A04.01.01 Intensive cattle grazing (turlough)	H	
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	

Threats:

Code	Impact	Notes
A02.01 Agricultural intensification (ZOC)	H	Likely to increase significantly due to prevalence of pasture in ZOC
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	H	Likely to increase significantly due to prevalence of pasture in ZOC
A04.01.01 Intensive cattle grazing (turlough)	M	Continuing pressure
J02.05 Modification of hydrographic functioning, general (=drainage in turlough)	M	Likely threat as turlough is not within a designated SAC
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	
M01.03 Flooding and rising precipitations	L	
A04.03 Abandonment of pastoral systems, lack of grazing (ZOC)	L	Possible impact due to high productivity of turlough
A10.02 Removal of stone walls and embankments (in turlough)	L	

Future Prospects: **Inadequate** – ecological structure and function are inadequate, although there are currently relatively few pressures. Threats are predicted to increase, and lack of SAC designation may increase the impact of several threats.

Overall Assessment: **Inadequate** – Carrowreagh has comparatively little biological interest, moderate to poor water quality and several threats of moderate or high impact. It could possibly be assessed as Bad.

Coolcam

Description: Coolcam turlough, which is designated as an SAC, occurs on the border of Co. Roscommon and Co. Galway, just south of Ballinlough, not far from Croaghill turlough. This is one of the larger turloughs included in the study, at 78.1 ha. It consists of two basins separated by a narrow esker; one smaller (known as Coolcam Lough), which dries out every summer, and a larger part which lies to the south east and seems to retain water throughout the year. Fifteen vegetation communities were mapped in Coolcam turlough. The dominant vegetation types mapped were the *Polygonum amphibium* community, the Open water community and the *Eleocharis palustris-Ranunculus flammula* community. Coolcam soils are moderately alkaline and mineral, and the alluvial mineral soil type occurs in almost 95% of the turlough area. Almost half of the turlough area is rotationally grazed. The hydrological data suggest that this turlough experiences one significant flooding event per annum; evidence from vegetation and comments from locals suggest that it dries out much less frequently than 10 years ago.

Conservation Condition Summary

Structure & Function	**Inadequate**
Future Prospects	**Inadequate/Favourable**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: ***Good***	
Water Quality: ***Intermediate***	34.0 µg P l^{-1}.
Biological Responses: ***Intermediate***	
Algal communities: -1	No algal mats have been recorded, but max CHL is high
Vegetation communities: 1	Moderate cover of positive indicators, low cover of negative indicators
Rumex **cover: 1**	3.7%
Important plants: 0	None recorded
Important aquatic invertebrates: 0	None recorded
Overall Structure & Function: ***Inadequate***	Some good aspects to the vegetation despite overall inadequate status

Pressures:

Code	*Impact*	*Notes*
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	
A08 Fertilisation (within turlough)	M	Some evidence of fertiliser input within turlough
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Relatively modest number of dwellings in the ZOC
C01.07 Mining and extraction activities not referred to above (marl, limestone; in turlough)	L	Quarry adjacent to the turlough, likely to have some local impact
A04.01.01 Intensive cattle grazing (turlough)	L	Low grazing impact, slightly less than half of the turlough grazed

Threats:

Code	Impact	Notes
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Pressure likely to continue due to prevalence of pasture in ZOC
A02.01 Agricultural intensification (ZOC)	L	Likely to increase moderately due to prevalence of pasture in ZOC
A10.02 Removal of stone walls and embankments (in turlough)	L	
M01.03 Flooding and rising precipitations	L	
A04.01.01 Intensive cattle grazing (turlough)	L	
A02.03 Grassland removal for arable land (ZOC)	L	

Future Prospects: **Inadequate/Favourable** – relatively low level of threat, but these not likely to improve the intermediate structure and function assessment; borderline case.

Overall Assessment: **Inadequate** – for reasons just outlined. However, some aspects of the structure and function are favourable; if nutrient inputs could be reduced it might be possible to improve the biological status of this turlough, providing improved future prospects and an overall good structure and function.

Croaghill

Description: Croaghill turlough occurs close to the Dunmore-Ballymoe road (Co. Galway), just east of Coolcam turlough, and extends to 38.6 ha. Designated as an SAC, eskers and drift slopes occur along the edges of this turlough. The main body of the turlough is connected to two smaller areas in the north-west by a narrow channel. Eleven vegetation communities were mapped in this turlough; the *Polygonum amphibium* community was the dominant vegetation type, indicating that this turlough is wet. Croaghill soils are moderately acidic and peaty, with low amounts of calcium carbonate. More than 90% of the turlough area is Fen peat, and 76% of the turlough area is rotationally grazed. The hydrological data suggest that Croaghill turlough experiences a single significant flooding event per annum. As with the hydrologically-linked Coolcam, there is evidence that Croaghill has longer duration flooding than at the time of Goodwillie's survey.

Conservation Condition Summary

Structure & Function	**Inadequate**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: *Good*	
Water Quality: *Intermediate*	25.0 µg P l^{-1}. Towards the lower end of this category.
Biological Responses: *Intermediate*	Moderate vegetation interest but contains important aquatic invertebrates
Algal communities: -1	Algal mats were recorded in 2008 but were not extensive; however max CHL is high
Vegetation communities: 0	Low cover of negative indicators, but a complete lack of positive indicators
***Rumex* cover: 0**	17.3%
Important plants: 0	None recorded
Important aquatic invertebrates: 2	*Alona rustica, Alonella exisa, Eurycercus glacialis*
Overall Structure & Function: *Inadequate*	

Pressures:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	M	
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Relatively modest number of dwellings in the ZOC
A05.02 Stock feeding (within and adjacent to turlough)	L	Some evidence of stock feeding within the turlough

Threats:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	M	Continuing pressure
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Pressure likely to continue due to prevalence of pasture in ZOC
A02.01 Agricultural intensification (ZOC)	L	Likely to increase moderately due to prevalence of pasture in ZOC
A10.02 Removal of stone walls and embankments (in turlough)	L	
M01.03 Flooding and rising precipitations	L	
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	
A02.03 Grassland removal for arable land (ZOC)	L	

Future Prospects: **Inadequate** – as with Coolcam, relatively moderate to low threats, but current pressures not likely to be reduced to allow the current inadequate structure and functioning (poorer than Coolcam) to improve.

Overall Assessment: **Inadequate** – for reasons just outlined. Likely to be less easy to restore to favourable status than Coolcam, as very few notable plants or important vegetation communities occur; however, Croaghill contains important aquatic invertebrates, and water chemistry is reasonable. Perhaps a reduction in grazing might allow vegetation to recover over time, and might reduce local nutrient inputs thereby facilitating continued survival of important aquatic invertebrates.

Garryland

Description: Garryland turlough lies near Gort in south-east Co. Galway and within the sprawling Coole-Garryland SAC complex. The turlough is a relatively compact basin (20 ha), surrounded by woodland. The site is characterised by smooth, often steep grassy slopes and a central ridge, which gives the turlough a horseshoe shape (Goodwillie, 1992). Large boulders are scattered throughout the site and a rocky outcrop occurs in the western section of the basin. Only five vegetation communities were recorded at this site, the dominant vegetation type was *Agrostis stolonifera - Ranunculus repens*. Garryland soils are moderately acidic and inorganic, with low amounts of calcium carbonate. The soils are comprised of shallow, poorly-drained mineral soil types. All of the turlough is under rotational grazing. The absence of fencing or stone walls and the presence of very closely cropped vegetation, due to intensive sheep grazing, distinguish this turlough from the other study sites. Hydrological data indicate that the site has an above average drainage capacity and a relatively flashy hydrological regime, with often more than one significant flood event occurring per annum.

Conservation Condition Summary

Structure & Function	**Favourable**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	Comments
Hydrological Function: *Good*	
Water Quality: Intermediate	24.6 µg P l^{-1}.
Biological Responses: *Good*	
Algal communities: -1	Extensive algal mats were recorded in 2008, but max CHL is low (probably due to highly coloured water – as in Blackrock, Caherglassan)
Vegetation communities: 1	Moderate cover of positive indicators, negative indicators absent
***Rumex* cover: 1**	2.4% frequency, very low
Important plants: 2	*Limosella aquatica, Rorippa islandica, Viola persicifolia*
Important aquatic invertebrates: 1	*Alonella exisa*
Overall Structure & Function: *Good*	

Pressures:

Code	Impact	Notes
A04.01.02 Intensive sheep grazing (turlough)	H	The major pressure, due to sheep very closely cropping the sward
A04.01.01 Intensive cattle grazing (turlough)	M	Moderate cattle grazing
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Pollution due to agriculture and through forestry activity in the Slieve Aughtey mountains
B01 Forest planting on open ground (ZOC)	L	Forest planting continuing, but main pressure from forestry is from existing forests via groundwater pollution
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	
C01.07 Mining and extraction activities not referred to above (marl, limestone; in turlough)	L	A small amount of limestone extraction to the north

Threats:

Indicator	Comments	Indicator
A04.01.02 Intensive sheep grazing (turlough)	M	On-going pressure, not likely to have as much impact going forward
A02.01 Agricultural intensification (ZOC)	M	Likely to increase significantly due to prevalence of pasture in ZOC
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Ongoing pressure
A04.01.01 Intensive cattle grazing (turlough)	M	Ongoing pressure
M01.03 Flooding and rising precipitations	L	
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	
A02.03 Grassland removal for arable land (ZOC)	L	Possible increase in maize production
A10.02 Removal of stone walls and embankments (in turlough)	L	

Future Prospects: **Inadequate** – moderate levels of threat suggest that current favourable structure and function may deteriorate, likely through increased pollution loads. Intensive sheep grazing has probably already had a significant impact (especially on sward height) despite the currently good structure and function, the future threat of sheep grazing is not likely to have such a large impact.

Overall Assessment: **Inadequate** – mostly because threats are likely to result in a deterioration of the structure and function. Removal of sheep grazing would likely help improve the sward and may also reduce some local nutrient inputs. A moderate level of cattle grazing would be required to maintain the important mud communities in Garryland, but care should be taken to ensure that grazing levels from cattle are not too excessive.

Kilglassan

Description: Kilglassan turlough occurs near Ballinrobe, south Co. Mayo within the Kilglassan/Cahervoostia SAC complex. Skealoghan and Ardkill turloughs lie to the south-west of this site. Kilglassan turlough has a long, narrow shape and is bisected by a road. The south-eastern basin is significantly larger than the north-western section. The turlough is surrounded by grassy slopes which are often steep. The north-western section has an extensive flat area. Eleven vegetation types were recorded; the dominant vegetation types were *Potentilla anserina-Carex nigra*, *Polygonum amphibium* and *Carex nigra-Carex panicea*. Kilglassan soils are moderately alkaline and peaty, with significant amount of calcium carbonate. The two recorded soil types were ‘Fen peats’ and ‘Very shallow well drained organic’. All of the turlough is under rotational grazing. Kilglassan turlough has a non-flashy hydrological regime and an average drainage capacity.

Conservation Condition Summary

Structure & Function	**Bad**
Future Prospects	**Inadequate**
Site Conservation Condition	**Bad**

Structure and Function Status:

Indicator	***Comments***
Hydrological Function: Bad	Drainage has affected the upper part of the turlough basin, and there is evidence of additional drainage having a potential impact within the ZOC
Water Quality: Intermediate	27.2 µg P l^{-1}.
Biological Responses: Intermediate	
Algal communities: -1	Algal mats were recorded but were not extensive; maximum CHL*a* was high
Vegetation communities: 0	Low cover of positive indicators, moderately low cover of negative indicators
***Rumex* cover: 0**	10.3% frequency, just above the 'good' category
Important plants: 1	*Plantago maritima*
Important aquatic invertebrates: 1	*Alonella exisa*
Overall Structure & Function: Bad	Mostly due to the impacts of drainage; marginal Bad/Inadequate

Pressures:

Code	***Impact***	***Notes***
A04.01.01 Intensive cattle grazing (turlough)	M	Moderate grazing impact, whole turlough is grazed
A08 Fertilisation (within turlough)	M	Evidence of fertiliser inputs directly into turlough
J02.05 Modification of hydrographic functioning, general (=drainage in turlough)	M	Drainage has impacted on turlough structure and function
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC and local)	M	Moderate nutrient enrichment
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	
A05.02 Stock feeding (within and adjacent to turlough)	L	some evidence of stock feeding adjacent to the turlough

Threats:

Code	Impact	Notes
J02.05 Modification of hydrographic functioning, general (=drainage in turlough)	H	On-going pressure, with further drainage likely
H01.05 Diffuse pollution to surface waters due to agricultural and forestry activities (ZOC)	H	Prevalence of slurry spreading adjacent to the turlough
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Ongoing pressure
A04.01.01 Intensive cattle grazing (turlough)	M	Ongoing pressure
M01.03 Flooding and rising precipitations	L	
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Relatively low threat due to low numbers of dwellings
A02.01 Agricultural intensification (ZOC)	L	
A02.03 Grassland removal for arable land (ZOC)	L	Possible increase in maize production
A10.02 Removal of stone walls and embankments (in turlough)	L	

Future Prospects: **Inadequate** – numerous threats of high and moderate impact.

Overall Assessment: **Bad** – structure and function are impaired by current pressures, the impacts of many are likely to increase in magnitude in the future.

Knockaunroe

Description: Knockaunroe turlough occurs in the flat limestone pavement to the south-west of Mullach Mor (Co. Clare), in the East Burren Complex SAC. There is exposed limestone pavement to the north; the southerly end has a thin cover of soil. There are two subsidiary basins; one to the south, and one at the eastern end across the road. Knockaunroe was the largest turlough in this study, with an extent of 78.8 ha. The turlough has a great diversity of vegation communities, sixteen were recorded; the dominant vegetation types were the *Eleocharis palustris-Ranunculus flammula* community and the flooded pavement community. Knockaunroe has circumneutral highly organic soils, and the dominant soil type is peat-marl. This turlough is hardly grazed, with just 1% of the area under rotational grazing, although the lack of fencing means that there is access for wild and feral grazers (e.g. feral goats). The turlough has an above average drainage capacity. Extensive flooding typically occurs once a year although the water level may vary markedly during flooded periods.

Conservation Condition Summary

Structure & Function	**Favourable**
Future Prospects	**Favourable**
Site Conservation Condition	**Favourable**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: *Good*	
Water Quality: *Very Good*	4.2 µg P l^{-1}. Very low, oligotrophic
Biological Responses: *Very Good*	
Algal communities: 0	No algal mats recorded (negligible amounts only in 2009), low max CHL
Vegetation communities: 2	High cover of positive indicator communities typical of oligotrophic turloughs, but some *Lolium* grassland suggesting some local improvement
***Rumex* cover: 0**	Frequency 4.7%
Important plants: 2	*Potentilla fruticosa, Viola persicifolia, Teucrium scordium, Frangula alnus, Plantago maritima*
Important aquatic invertebrates: 1	*Alonella exisa, Sympetrum sanguineum*
Overall Structure & Function: *Good*	A classic oligotrophic turlough in very good ecological condition

Pressures:

Code	*Impact*	*Notes*
A05.02 Stock feeding (within and adjacent to turlough)	L	Some evidence of stock being fed adjacent to the SE of turlough
C01.03 Peat extraction (turlough)	L	Evidence of past peat cutting but likely ceased very long ago

Threats:

Code	*Impact*	*Notes*
A10.02 Removal of stone walls and embankments (in turlough)	L	
M01.03 Flooding and rising precipitations	L	
A02.01 Agricultural intensification (ZOC)	L	Low level intensification possible in part of ZOC
A04.01.01 Intensive cattle grazing (turlough)	L	

Future Prospects: **Favourable** – low impact threats only.

Overall Assessment: **Favourable** – Knockaunroe is a classic oligotrophic turlough, with excellent diverse biological communities and currently very few low impact pressures. However, any change in groundwater nutrient status would put the current excellent ecological status at risk, so there is a need to monitor the situation to enable immediate action to be taken should adverse conditions prevail.

Lisduff

Description: Lisduff turlough, which has SAC status, is situated to the south of Athleague in south-central Co. Roscommon. This medium-sized turlough is shallow and flat and lacks any distinguishing topographic features. Thirteen vegetation communities were recorded; the dominant vegetation types were *Eleocharis palustris-Ranunculus flammula* and *Molinia caerulea-Carex panicea.* Lisduff soils are alkaline and organic with significant amounts of calcium carbonate. The site has extensive areas of 'Fen Peat', with a limited expanse of the 'Shallow poorly-drained organic' soil type. Approximately half of the turlough area (53%) is under rotational grazing. This turlough is relatively slow to fill and drain and typically there is one major flood event per annum. Lisduff shows several characteristics of the more oligotrophic turloughs, which is unusual within its regional setting.

Conservation Condition Summary

Structure & Function	**Favourable**
Future Prospects	**Favourable**
Site Conservation Condition	**Favourable**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: *Good*	Evidence of drainage in the ZOC but unlikely to have much impact
Water Quality: *Very Good*	7.4 µg P l^{-1}
Biological Responses: *Very Good*	
Algal communities: 0	No algal mats recorded, low max CHL
Vegetation communities: 2	High cover of positive indicator communities typical of oligotrophic turloughs, low cover of negative indicators
***Rumex* cover: 0**	Absent
Important plants: 1	*Plantago maritima*; surprisingly few
Important aquatic invertebrates: 2	*Alonella exisa, Agabus labiatus, Berosus signaticollis, Graptodytes bilineatus, Sympetrum sanguineum*
Overall Structure & Function: *Good*	

Pressures:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	L	Low grazing impact, just under 50% of turlough ungrazed
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Fairly low number of dwellings in high susceptibility pathways

Threats:

Code	*Impact*	*Notes*
A10.02 Removal of stone walls and embankments (in turlough)	L	
M01.03 Flooding and rising precipitations	L	
A02.03 Grassland removal for arable land (ZOC)	L	Potential threat in ZOC
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Continuing low impact pressure
A02.01 Agricultural intensification (ZOC)	L	Low level intensification possible in part of ZOC
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	L	Likely a low threat
A04.01.01 Intensive cattle grazing (turlough)	L	Continuing low impact pressure

Future Prospects: **Favourable** – low impact threats unlikely to have a major influence on the current favourable ecological condition of the turlough.

Overall Assessment: **Favourable** – favourable ecological structure and function combined with a low threat level. Would probably benefit from reduced grazing; reduction in grazing does not seem to impact significantly on the more oligotrophic turloughs. Lisduff is remarkable among the Roscommon turloughs in having very low nutrient status and vegetation characteristic of the more oligotrophic turloughs; it is therefore of considerable conservation interest.

Lough Aleenaun

Description: Lough Aleenaun occurs in the East Burren Complex SAC, off the Ballyvaughan-Kilnaboy road. This is one of the smaller turloughs included in the study, at 13.7 ha. A large hollow is evident, presumably a result of collapse. The turlough is surrounded by scrub-covered pavement and drift-filled fields. The northern end of the turlough is bounded by a steep 4m cliff. Only six vegetation communities were mapped in Lough Aleenaun; the *Agrostis stolonifera-Glyceria fluitans* community was the most abundant. Lough Aleenaun soils are moderately alkaline and organic, with significant amounts of calcium carbonate. Fen peat is the dominant soil type (64.9% of the area). Rotational grazing occurs throughout the turlough. The hydrological regime of this turlough is characterised by many flooding events throughout the year, with rapid filling and draining. In addition, it is known that part of the turlough has been bulldozed in the past (Goodwillie, 1992) resulting in highly degraded biological communities.

Conservation Condition Summary

Structure & Function	**Inadequate/Bad**
Future Prospects	**Inadequate**
Site Conservation Condition	**Bad**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: *Good*	
Water Quality: *Intermediate*	30.7 µg P l^{-1}
Biological Responses: *Bad*	
Algal communities: -2	Extensive algal mats were regularly recorded, high max CHL
Vegetation communities: -1	High cover of negative indicator communities, moderate cover of positive indicators
***Rumex* cover: -1**	60.9% frequency
Important plants: 1	*Rorippa islandica*
Important aquatic invertebrates: 0	None present
Overall Structure & Function: *Inadequate/Bad*	

Pressures:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	M	Moderate grazing impact over the whole of the turlough
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	

Threats:

Code	*Impact*	*Notes*
A02.01 Agricultural intensification (ZOC)	M	Likely increase in ZOC
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Continuing medium impact pressure
A04.01.01 Intensive cattle grazing (turlough)	M	Continuing medium impact pressure
A10.02 Removal of stone walls and embankments (in turlough)	L	
M01.03 Flooding and rising precipitations	L	
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	

Future Prospects: **Inadequate** – medium level threats are unlikely to allow any improvement of the highly disturbed biological communities.

Overall Assessment: **Bad** – although hydrologically Lough Aleenaun functions well, its communities are highly disturbed even though there appear to be relatively few pressures; this is the likely result of extreme disturbance within the turlough thought to be due to previous bulldozing of the basin. Conservation status is assessed as Bad given the Inadequate to Bad structure and function and Inadequate future prospects, coupled with highly degraded biological communities. Conservation action should reduce (but not entirely eliminate) the grazing pressure, and also reduce the nutrient inputs; given the apparently good hydrological functioning, this may facilitate recovery of the biological communities in the medium to long term, improving the conservation status.

Lough Coy

Description: Lough Coy is situated within the Shanvally townland near Gort in south-east County Galway. This turlough is one of four study sites within the Gort lowlands turlough complex, the associated three study turloughs within the complex are Blackrock, Caherglassan and Garryland. Lough Coy is a relatively deep, compact (26 ha), bowl-shaped turlough where often steep, grassy slopes surround a semi-permanent lake. Boulders are peppered throughout the site. Eight vegetation types were mapped within the site; the dominant vegetation types were *Filipendula ulmaria-Potentilla erecta-Viola sp.* and *Agrostis stolonifera-Potentilla anserina-Festuca rubra*. Lough Coy soils are moderately acidic and mineral, with low amounts of calcium carbonate. The dominant soil types were 'Very shallow poorly-drained mineral' and 'Alluvial mineral'. All of the turlough is under rotational grazing. The hydrological data indicate that Lough Coy has a flashy hydrological regime, with more than one significant flood event occurring on an annual basis. The site has a high inflow rate and large drainage capacity.

Conservation Condition Summary

Structure & Function	**Inadequate**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: *Good*	Some drainage work evident in the ZOC but unlikely to have significant impact on the turlough hydrology
Water Quality: *Intermediate*	43.3 µg P l^{-1}. Towards the high end of this category
Biological Responses: *intermediate*	
Algal communities: -1	No algal mats recorded, likely due to the highly coloured water due to runoff from the Slieve Aughty forestry activity; however, high max CHL
Vegetation communities: 1	Moderately high cover of positive indicator communities, low cover of negative indicators
***Rumex* cover: 0**	27.3% frequency
Important plants: 1	*Viola persicifolia*
Important aquatic invertebrates: 1	*Alonella excisa*
Overall Structure & Function: *Inadequate*	

Pressures:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	H	All of the turlough grazed, and some land parcels with very high stocking levels
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Agricultural runoff and runoff from forestry in the Slieve Aughty mountains
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Relatively low dwelling number in areas of high and extreme pathway susceptibility
B01 Forest planting on open ground (ZOC)	L	But major impact will be on groundwater nutrient enrichment

Threats:

Code	Impact	Notes
A02.01 Agricultural intensification (ZOC)	M	Agricultural intensification in ZOC likely
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Continuing pressure
A04.01.01 Intensive cattle grazing (turlough)	M	Continuing pressure
A02.03 Grassland removal for arable land (ZOC)	L	Some evidence of shift to maize production locally
A10.02 Removal of stone walls and embankments (in turlough)	L	
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	
M01.03 Flooding and rising precipitations	L	
A04.03 Abandonment of pastoral systems, lack of grazing (ZOC)	L	Possible pressure, given productivity of site

Future Prospects: **Inadequate** – several moderate impacts which are unlikely to improve structure and functions to favourable.

Overall Assessment: **Inadequate** – due to intermediate structure and function and intermediate future prospects.

Lough Gealain

Description: Lough Gealain lies adjacent and to the north of Knockaunroe turlough, close to the base of Mullach Mor, Co. Clare. This turlough extends to 35.8 ha. The basin is very flat and lacks drift deposits, it is extremely calcareous with extensive marl. The northern area of the turlough retains permanent water and turlough area occurs along the southern end of the basin. Nine vegetation communities were mapped in Lough Gealain; the largest area was occupied by open water, and the flooded pavement community was the most abundant vegetation type. Some of the open water communities are dominated by very open *Phragmites australis* stands with a ground cover of *Littorella uniflora*. Stands of *Cladium mariscus* are also frequent. Lough Gealain soils are moderately alkaline and highly organic, with significant amounts of calcium carbonate. There are extensive areas of alluvial marl, and very shallow poorly-drained organic soils occupy the fringing areas. The hydrological data suggest that Lough Gealain has one major flooding event per annum, but many smaller peaks are also evident. This appears to be one of the most pristine turloughs, with no obvious pressures, and little if any nutrient enrichment.

Conservation Condition Summary

Structure & Function	**Favourable**
Future Prospects	**Favourable**
Site Conservation Condition	**Favourable**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: *Good*	
Water Quality: *Very Good*	4.0 µg P l^{-1}. Extremely low mean water TP, bordering on ultra-oligotrophic
Biological Responses: *Very Good*	
Algal communities: 0	No algal mats recorded, low max CHL
Vegetation communities: 2	Exceptionally high cover of positive indictors (over 96%), no negative indicators
***Rumex* cover: 1**	Absent
Important plants: 2	*Potentilla fruticosa, Frangula alnus, Plantago maritima*
Important aquatic invertebrates: 2	*Alonella exisa, Alanopsis elongata, Graptodytes bilineatus*
Overall Structure & Function: *Good*	

Pressures: exceptionally, no recorded pressures were identified for this site. It is not grazed by domestic stock, and has exceptionally good water quality.

Threats:

Code	*Impact*	*Notes*
A02.01 Agricultural intensification (ZOC)	L	possible threat in ZOC, but likely to be very limited
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	L	Likely low impact pressure
M01.03 Flooding and rising precipitations	L	
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Likely low impact pressure

Future Prospects: **Favourable** – some low impact threats are possible, some of these are generic across all turloughs

Overall Assessment: **Favourable** – appears to be in excellent ecological condition and is of outstanding conservation importance, of international significance. However, any increase in groundwater nutrients is likely to affect ecological function and therefore groundwater nutrients should be monitored regularly.

Rathnalulleagh

Description: Rathnalluleagh turlough, which has NHA rather than SAC status, occurs in central Co. Roscommon just south of Carrowreagh and Brierfield turloughs. The flat-floored basin is surrounded by grassy ridges. A narrow arm extends to the north-west from the main basin area. Only six vegetation types were mapped at the site; *Filipendula ulmaria-Potentilla erecta-Viola* sp. was the predominant vegetation type. Rathnalluleagh has extensive areas of mineral soil types. The soils are moderately acidic with low amounts of calcium carbonate. 'Shallow well drained mineral' and 'Shallow poorly drained mineral' were the two dominant soil types. All of the turlough area is under rotational grazing. The hydrological data indicate that this turlough is relatively quick to flood and drain and there may be more than one major flood event per annum. There is evidence of heavy grazing or agricultural improvement having altered the vegetation since Goodwillie's survey (1992).

Conservation Condition Summary

Structure & Function	**Inadequate**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	***Comments***
Hydrological Function: *Good*	
Water Quality: *Intermediate*	44.6 µg P l^{-1}. High within this category, approaching bad status
Biological Responses: *Intermediate*	
Algal communities: -1	Algal mats were recorded only n 207 though they were not extensive, but max CHL was high
Vegetation communities: 1	High cover of positive indictors (mainly the *Filipendula/Potentilla/Viola community*), moderate cover of negative indicators (mostly *Lolium* grassland); relatively uniform
***Rumex* cover: 0**	30.7%
Important plants: 1	*Viola persicifolia*
Important aquatic invertebrates: 0	None recorded
Overall Structure & Function: *Inadequate*	

Pressures:

Code	*Impact*	*Notes*
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Moderate to high nutrient levels in groundwater likely due to agricultural inputs
A04.01.01 Intensive cattle grazing (turlough)	M	Moderate grazing levels over the whole of the turlough
A05.02 Stock feeding (within and adjacent to turlough)	L	Some evidence of stock feeding adjacent to the turlough
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Relatively low level of septic tanks on high vulnerability pathways

Threats:

Code	*Impact*	*Notes*
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Ongoing pressure
A04.01.01 Intensive cattle grazing (turlough)	M	Ongoing pressure
J02.05 Modification of hydrographic functioning, general (=drainage in turlough)	M	Likely threat as Rathnalulleagh not in a designated SAC
A02.03 Grassland removal for arable land (ZOC)	L	Likely threat in the ZOC due to pasture/grassland cover in ZOC
A05.02 Stock feeding (turlough and immediately adjacent)	L	Lack of SAC designation likely means that this will continue
A02.01 Agricultural intensification (ZOC)	L	Likely threat in the ZOC due to pasture/grassland cover in ZOC
M01.03 Flooding and rising precipitations	L	
A10.02 Removal of stone walls and embankments (in turlough)	L	
A04.03 Abandonment of pastoral systems, lack of grazing (ZOC)	L	Possible threat given the high productivity of the system and the communities present; fairly unlikely given the current grazing level

Future Prospects: **Inadequate –** moderate levels of threat. Lack of SAC designation may mean limited mitigation of these threats.

Overall Assessment: **Inadequate** – while the ecological conditions are average, the current pressures are moderate; however, lack of SAC designation means that many pressures will continue or will likely increase. Designation within an SAC and management of grazing and nutrient inputs could help improve the status of the turlough; however, the relative lack of biological interest probably places the site on a lower conservation priority.

Roo West

Description: Roo West turlough occurs in the East Burren SAC, approximately 5km inland from Kinvara, and 5km from Gort (Co. Galway). The turlough is surrounded on all sides by limestone pavement, and the basin forms a neat depression rather than a sprawling complex. Eleven vegetation communities were recorded in the turlough; the *Eleocharis palustris-Ranunculus flammula* community was the most abundant. The soils in Roo West are moderately alkaline and organic. There are extensive areas of alluvial marl, with very shallow well-drained organic soils in the upper slopes. Hydrological data indicate that this site typically experiences one major flood event per annum, however the turlough may not drain to residual pools every year. The site has a relatively low inflow rate and an average drainage capacity.

Conservation Condition Summary

Structure & Function	**Favourable**
Future Prospects	**Favourable/Inadequate**
Site Conservation Condition	**Favourable**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: *Good*	
Water Quality: *Very Good/Good*	9.8 µg P l^{-1}. Borderline good/very good
Biological Responses: *Very Good*	
Algal communities: 0	Although algal mats were recorded they were never extensive, low max CHL
Vegetation communities: 2	High cover of positive indictors, low negative indicator cover
***Rumex* cover: 1**	Absent
Important plants: 1	*Plantago maritima*
Important aquatic invertebrates: 2	*Alona rustica, Alonella exisa, Agabus labiatus, Berosus signaticollis, Graptodytes bilineatus, Sympetrum sanguineum*
Overall Structure & Function: *Good*	

Pressures:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	M	Moderate grazing levels over the whole of the turlough
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities	L	Fairly low water TP but elevated compared to other turloughs surrounded by limestone pavement; may reflect local inputs from grazing in addition to ZOC

Threats:

Code	Impact	Notes
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Ongoing pressure, which might increase due to agricultural intensification
A04.01.01 Intensive cattle grazing (turlough)	M	Ongoing pressure
A02.01 Agricultural intensification (ZOC)	M	Likely threat as the ZOC contains large amount of pasture
M01.03 Flooding and rising precipitations	L	
A10.02 Removal of stone walls and embankments (in turlough)	L	
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Low level threat due to relatively low numbers of septic tanks in ZOC

Future Prospects: **Favourable/Inadequate** – borderline: an increase in some of the current pressures seems likely, the main impacts would be on groundwater quality due to nutrient enrichment. Water quality in Roo already is poorer than in many other Burren turloughs.

Overall Assessment: **Favourable** – only just about in favourable conservation status, but there is a potential problem of grazing compared to other oligotrophic turloughs locally in the Burren region (e.g. Knockaunroe, Lough Gealain). Efforts should be made to determine the relative contributions of nutrient inputs from domestic grazing within the turlough and from the ZOC. A reduction in grazing would be desireable; the more oligotrophic turloughs seem capable of withstanding very low levels of grazing without altering ecological function, probably because of low productivity. Reduced grazing may help lower the nutrient status.

Skealoghan

Description: Skealoghan turlough, which has SAC status, is situated near Ballinrobe, south County Mayo not far from Kilglassan and Ardkill turloughs. This site generally has a broad, flat topography, with limestone out-crops occurring within the central, north and north-eastern areas. Twelve vegetation types were mapped within this site; the most extensive vegetation types were *Potentilla anserina-Carex nigra*, *Carex nigra-Carex-panicea* and *Lolium* grassland. Almost all of the turlough (87%) is under rotational grazing. Skealoghan soils are circumneutral and peaty, with low amounts of calcium carbonate. Skealoghan has extensive areas of 'Fen Peats' throughout the basin floor. 'Very shallow well drained organic soils' occur on the upper slopes. The turlough typically has one major flood event per annum, however the water level can vary markedly during the flooded period.

Conservation Condition Summary

Structure & Function	**Inadequate**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: *Good*	
Water Quality: *Good/Intermediate*	20.4 µg P l^{-1}. Borderline good/intermediate
Biological Responses: *Intermediate*	Mixed – algal communities reflecting enrichment, but otherwise contains important species
Algal communities: -2	Extensive algal mats were recorded, and max CHL is high
Vegetation communities: 0	Relatively low cover of both positive and negative indicators
***Rumex* cover: 1**	6.9%
Important plants: 1	*Plantago maritima*
Important aquatic invertebrates: 1	*Alonella exisa, Eurycercus glacialis*
Overall Structure & Function: *Inadequate*	Rather mixed

Pressures:

Code	*Impact*	*Notes*
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Moderate to high nutrient levels in groundwater likely due to agricultural inputs
A04.01.01 Intensive cattle grazing (turlough)	M	Moderate grazing levels over the majority of the turlough
A05.02 Stock feeding (within and adjacent to turlough)	L	Some evidence of stock feeding adjacent to the turlough
A08 Fertilisation (within turlough)	L	Some evidence of fertilizer inputs directly into the turlough

Threats:

Code	Impact	Notes
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Ongoing pressure, which might increase due to agricultural intensification
A04.01.01 Intensive cattle grazing (turlough)	M	Ongoing pressure
A02.03 Grassland removal for arable land (ZOC)	M	Likely threat as the ZOC contains large amount of pasture
A02.01 Agricultural intensification (ZOC)	L	Potential agricultural intensification in ZOC; major impacts likely to be via groundwater nutrient levels. May counter any attempts to address nutrients within the turlough
M01.03 Flooding and rising precipitations	L	
A10.02 Removal of stone walls and embankments (in turlough)	L	

Future Prospects: **Inadequate** – the main problem is relatively high levels of grazing and agricultural inputs that are likely to persist. Direct fertiliser input to the turlough should cease through effective management of the SAC, but the relative contributions of local and ZOC agricultural inputs needs to be determined in order for effective methods to be devised to mitigate the threats.

Overall Assessment: **Inadequate** – Skealoghan faces pressures which have impacted on the ecological functioning of the turlough and most of which are likely to persist as threats. These impacts are mainly from agriculture both locally and within the ZOC; as mentioned above the relative contributions of these need to be assessed to help devise prescriptive conservation management to improve the conservation status. Despite these impacts, Skealoghan retains consdierable biological interest.

Termon

Description: Termon turlough, a designated SAC, lies to the east of Lough Bunny (Co. Galway). It consists of a relatively flat basin, surrounded by drift-covered slopes and a limestone outcrop to the northern end. The extent of the turlough is 42.0 ha. This turlough rarely dries out, and of the eight vegetation communities mapped here, by far the most dominant was the Reedbed community. Termon soils are alkaline and organic, with significant amounts of calcium carbonate. The dominant soil type is alluvial marl. Rotational grazing is carried out on a small proportion of the turlough (12%). While this turlough does not dry out, the hydrological data show that there is an annual peak in water levels over the winter months, with a gradual lowering of the water level until it starts to slowly rise again.

Conservation Condition Summary

Structure & Function	**Favourable**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate/Favourable**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: ***Intermediate***	There is a drain at the SW end which likely had an affect on the hydrological functioning, but the resulting alteration to ecology has probably by this stage stabilised.
Water Quality: ***Good***	15 µg P l^{-1}.
Biological Responses: ***Good***	
Algal communities: 0	Algal mats were recorded in 2008 but were not extensive, and max CHL is low
Vegetation communities: 1	Relatively low cover of positive indicators, marginally good
Rumex **cover: 1**	Absent
Important plants: 1	*Teucrium scordium*
Important aquatic invertebrates: 2	*Agabus labiatus, Lestes dryas, Sympetrum sanguineum*
Overall Structure & Function: ***Good***	

Pressures:

Code	*Impact*	*Notes*
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Moderately high number of septic tanks in areas with high pathway susceptibility, but likely limited impact
A04.02.03 Non-intensive horse grazing (turlough)	L	Very light grazing by horses
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	L	
E01.03 Dispersed habitation (ZOC)	L	Moderately high number of dwellings in the ZOC. Likely impacts will be through nutrient enrichment of groundwater
J02.05 Modification of hydrographic functioning, general (=drainage in turlough)	L	As mentioned, drainage will have impacted on the hydrological functioning, though the drains were pre-1990; however, the effect of the drains may still be altering the ecology slightly
A04.01.01 Intensive cattle grazing (turlough)	L	Relatively light grazing with a small percentage of the turlough grazed, likely due to the long period of flooding

Threats:

Code	*Impact*	*Notes*
J02.05 Modification of hydrographic functioning, general (=drainage in turlough)	H	The high level of flooding has resulted in increasing calls for further drainage of this turlough
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	L	Ongoing pressure
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	L	Ongoing low level pressure
A04.01.01 Intensive cattle grazing (turlough)	L	
A02.01 Agricultural intensification (ZOC)	L	Likely threat in the ZOC due to pasture/grassland cover in ZOC
M01.03 Flooding and rising precipitations	L	
A10.02 Removal of stone walls and embankments (in turlough)	L	

Future Prospects: **Inadequate** – threats are mostly low impact; however the calls for further drainage of the turlough would have significant negative impacts on the structure and function of this important turlough

Overall Assessment: **Inadequate/Favourable** – Termon has generally good ecological functioning, with limited pressures and interesting biological communities. However, renewed proposals for drainage are a serious threat. Drainage that removed exceptionally high, very occasional flooding would be beneficial to local communities (the turlough is adjacent to a road) while also ensuring that the general ecological functions prevail – all efforts should be made to ensure that any drainage work addresses the extreme and not the regular flooding events in this turlough.

Tullynafrankagh

Description: Tullynafrankagh turlough occurs in the Lough Fingall Complex SAC and lies between Ballindereen turlough and Caranavoodaun turlough (Co. Galway). This was the smallest turlough included in the study, with an extent of just 12.0 ha. The turlough has a fen-like appearance, and the south-western areas retain water throughout the year. Ten vegetation communities were recorded at Tullynafrankagh; the dominant communities were the Reedbed community and the *Molinia caerulea-Carex panicea* community. Tullynafrankagh soils are moderately alkaline and highly organic, with significant amounts of calcium carbonate. There are extensive areas of fen peats and peat-marl soils. Almost 20% of the turlough area is under rotational grazing. Detailed hydrological monitoring was not conducted at this site, but water level data suggest rapid filling and emptying.

Conservation Condition Summary

Structure & Function	**Inadequate**
Future Prospects	**Inadequate**
Site Conservation Condition	**Inadequate**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: ***Intermediate***	Water is abstracted for a private water scheme from a borehole adjacent to the turlough, and is likely to have some impact on the hydrological function.
Water Quality: ***Intermediate***	33 µg P l^{-1}.
Biological Responses: ***Intermediate***	
Algal communities: -1	Algal mats were regularly recorded but were never extensive, however max CHL was high
Vegetation communities: 1	Intermediate cover of positive indicators, moderate cover of negative indicators. Just makes the good category
***Rumex* cover: 1**	Absent
Important plants: 0	None recorded
Important aquatic invertebrates: 0	None recorded
Overall Structure & Function: ***Intermediate***	

Pressures:

Code	*Impact*	*Notes*
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	M	High level of septic tanks in high risk groundwater pathway
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Moderate agricultural activity within ZOC
J02.07.02 Groundwater abstractions for public water supply (ZOC)	L	Water abstraction likely to have an impact on hydrological function, probably fairly limited impacts although amount of abstraction recently increased
A04.03 Abandonment of pastoral systems, lack of grazing (turlough)	L	Possible impact of low grazing density on the prevalence of taller herb type communities, which may be important here given the relatively high nutrient loading
A04.01.01 Intensive cattle grazing (turlough)	L	Relatively low proportion of the turlough is grazed
A08 Fertilisation (within turlough)	L	Some evidence of fertilizer inputs
E01.03 Dispersed habitation (ZOC)	L	Significant dispersed habitation in ZOC, though impacts most likely through groundwater pollution

Threats:

Code	Impact	Notes
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	H	Likely to be a continuing and increasing impact
A02.01 Agricultural intensification (ZOC)	M	Moderate agricultural intensification likely within ZOC and linked with extreme pathway susceptibility
J02.07.02 Groundwater abstractions for public water supply (ZOC)	M	Continuing pressure, possibly with calls to increase abstraction
H02.07 Diffuse groundwater pollution due to non-sewered population (ZOC)	M	Continuing pressure
M01.03 Flooding and rising precipitations	L	
A10.02 Removal of stone walls and embankments (in turlough)	L	
A04.03 Abandonment of pastoral systems, lack of grazing	L	Possibly the grazing level is too low within the turlough, promoting tall and rather uniform vegetation.

Future Prospects: **Inadequate** – several medium and high impact threats suggest that ecological condition is likely to deteriorate

Overall Assessment: **Inadequate** – structure and function not very good, and coupled with poor prospects suggest unfavourable conservation status. The impact of the group water scheme needs to be determined, more to provide evidence to support or refute similar actions in other turloughs. Water quality is moderately poor and likely worsen due to the high number of septic tanks and agricultural inputs, coupled with large area of extreme pathway susceptibility. A slight increase in grazing level may help increase diversity within the turlough, which is currently rather uniform.

Turloughmore

Description: Turloughmore lies along the eastern fringe of the sprawling East Burren SAC complex in north Co. Clare. Surrounding drift ridges distinguish this site from other turloughs within the East Burren complex which are typically surrounded by limestone pavement. The site consists of a long, narrow basin with a gently sloping, undulating topography. Only six vegetation types were recorded at this site; *Lolium grassland* and *Agrostis stolonifera-Potentilla anserina-Festuca rubra* are by far the most extensive. Turloughmore soils are moderately acidic with low amounts of calcium carbonate. The soils are pre-dominantly comprised of the 'Shallow poorly drained mineral' soil type. This turlough has a very flashy hydrological regime, with multiple significant flood events occurring within a single year. The turlough is heavily grazed by sheep and cattle, and there is evidence of agricultural improvement (improved grassland, woodland and scrub clearance) at this site.

Conservation Condition Summary

Structure & Function	**Inadequate/Bad**
Future Prospects	**Bad**
Site Conservation Condition	**Bad**

Structure and Function Status:

Indicator	*Comments*
Hydrological Function: *Good*	
Water Quality: *Good/intermediate*	19.4 µg P l^{-1}. Borderline intermediate
Biological Responses: *Bad*	
Algal communities: -1	No algal mats were recorded, but max CHL was high
Vegetation communities: -1	High cover of negative indicators (mostly *Lolium* grassland), very low cover of positive indicators. Lacking in diversity
***Rumex* cover: -1**	60%
Important plants: 1	*Teucrium scordium*
Important aquatic invertebrates: 0	None recorded
Overall Structure & Function: *Inadequate/Bad*	Rather poor biological condition despite good hydrological function and moderately good water chemistry status

Pressures:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	H	The whole of the turlough is grazed and some land parcels had very heavy livestock use
A02.01 Agricultural intensification	M	Moderate agricultural intensification seems likely to have occurred within the turlough – fertilisation, establishment of rye grass sward, woodland clearance
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Moderate nutrient enrichment in groundwater likely from agriculture as few dwellings in ZOC; might also be influenced by inputs directly into turlough

Threats:

Code	*Impact*	*Notes*
A04.01.01 Intensive cattle grazing (turlough)	H	Continuing pressure
H02.06 Diffuse groundwater pollution due to agricultural and forestry activities (ZOC)	M	Likely to be a continuing and increasing impact
A02.01 Agricultural intensification (ZOC)	M	Moderate agricultural intensification likely within ZOC and linked with extreme pathway susceptibility
M01.03 Flooding and rising precipitations	L	
A10.02 Removal of stone walls and embankments (in turlough	L	

Future Prospects: **Bad** – current pressures are considered to have large impacts, and are likely to continue, and agricultural intensification is likely in the ZOC.

Overall Assessment: **Bad** – Turloughmore has reasonably good hydrological function and water chemistry, but poor biological communities. There are a number of potentially high impact pressures, many linked with agricultural improvement to support grazing. Though no evidence of fertiliser input was found, the high prevalence of *Lolium* grassland suggests reseeding, perhaps facilitated by the comparatively shallow flooding). This supports a relatively high density of cattle grazing, and this in turn may help to explain the fairly high water TP for a Burren turlough. Any fertiliser input to this turlough needs to be stopped, and the grazing pressure reduced; this may in time allow vegetation communities to recover, but this would be a long-term effect and only if the threats identified can be mitigated.

10.3.3 Conservation Assessment at National Level

10.3.3.1 Range

The total range occupied in 2013 was 104 hectads, and there are 158 hectads within the range envelope. The range was given as 118 hectads in 2007 report; the difference is due to improved mapping and a different method of calculating the range (range tool) especially in relation to gaps in contiguity, it does NOT represent a real change in the distribution range of turloughs. As there was no direct evidence of range change since the Habitats Directive came into effect, the Favourable Reference Range was taken as the current range of 15800 km^2 (NPWS, 2013).

Turloughs are essentially landforms in karst limestone, so the range is highly unlikely to increase through development of new habitat. Increases in range are only likely through improved knowledge and field survey; this has in fact lead to small increases in range (and hence area of habitat) over the reporting period (e.g. Kearney, 2011; Foss & Crushell, 2012).

J. Ryan (NPWS) reports that part of the turlough at Castlesampson (Co. Roscommon) has been damaged by quarrying, however the extent of the damage and the impact on the ecological and hydrological functioning of the turlough remain unclear.

As noted in the methods section, several sites which may have been turloughs have been lost; however there is no direct evidence that these sites ever were turloughs. All require ground truthing to ascertain the relationship between the location of the degraded area and the location of the potential turloughs. In some cases, even if these could be confirmed as lost turloughs, this would still not alter the distributional range within Ireland. For these reasons, the trend for turlough range is considered to be stable.

10.3.3.2 Area

The total surface area of the turlough habitat was assessed as 68.94 km^2 (Table 12). The surface area reported in 2007 was 81.6 km^2. These differences are not considered to represent a decline in area, but more likely reflect an improved method of calculating area. In 2007, for turloughs where the area was unknown a randomly chosen subset of 25 turloughs of known area were selected. The areas of these 25 turloughs were measured using ArcGIS 9, giving an average area of 0.18 km^2. This value was used together with known turlough areas to provide the national estimate of turloughs at 81.6 km^2; this was considered likely to be a significant overestimate. The average area of 0.18 km^2 per site or 18 ha was also thought likely to be an overestimate, with the majority of the turloughs of unknown area probably being less than 10 ha (Goodwillie, 1992, surveyed turloughs over 10 ha). It is not clear whether the positively skewed distribution of turlough areas was taken into account in 2007;

in 2013 use of log transformed areas avoided this bias and is considered to provide a more reliable estimate of mean area.

Table 10.12. Surface area of turlough habitat

Category	Area (km^2)
Total surface area	68.87
Total area within SACs	38.51
Total area outside of SACs	30.36
Total area within SACs where turloughs mentioned as a qualifying interest	36.59
Total area within SACs where turloughs are NOT mentioned as a qualifying interest	1.92

This lowered Area for 2013 therefore reflects improved estimates of surface area for some turloughs based on hydrological estimation of maximum flood extents, a different method for estimating the surface areas of turloughs where these are not known, improved knowledge of the distribution of turloughs and provision of a database (Mayes, 2008) of collated records for the habitat (see section 2.3.9a, above). The surface area of turloughs is considered stable.

Coxon estimates that over one third of turloughs have been affected by past arterial drainage which may well have reduced the surface area of flooding in turloughs, however these impacts long predate the implementation of the EU Habitats Directive. Less certain is the more recent drainage efforts on some turloughs (e.g. Ballinderreen, Rahasane, Kilglassan) where more recent drainage reduces the level of extreme floods. It is not known whether this predates the implementation of the Habitats Directive, nor is the reduction in extent of flooded area (if any) known. Several turloughs around Clarinbridge (e.g. Tonroe) have been relatively recently affected by drainage to the sea via the Clarin River; they are no longer considered to function as turloughs but again, the drainage work was brought about prior to 1994 and hence does not affect the Area, Favourable Reference Area or trend reporting.

The determination of the surface area of individual turloughs is fraught with difficulty. Different approaches have looked at the extent of maximum flooding, the extent of vegetation influenced by the turlough hydrological regime. Extent of maximum flooding requires continuous monitoring by pressure sensing 'divers' coupled with a detailed topographic survey (as used in TCD survey – *Chapter 3: Hydrology*), or very regular readings from a standard depth scale. Problems associated with using vegetation communities include the gradual shift from wetland to dry land communities which extend beyond the influence of the turlough, and also that the upper less-flooded zones are likely to be subjected to greater modification by various land use practices. One additional difficulty is that occasional extreme flooding events increase the flooded area considerably. For 22 turloughs that have been subject to detailed hydrological investigation (Chapter 3) the surface area was defined by the maximum flooded area over the two years of continuous monitoring in 2007-2009, there was no extreme flooding in this period. Other surface areas are reported by Goodwillie (1992) and are based largely in the extent of turlough vegetation communities; it is probable that most of the areas reported in Mayes (2008) are likely to have been based on Goodwillie's estimations.

Of the total surface area of turloughs, only 55.9% or 38.51 km^2 occurs within designated SACs (Table 10.12), and 1.92 km^2 occurs in SACs where turloughs are NOT specifically mentioned as qualifying interests. In the latter case, turlough habitat may not be guaranteed protection by the SAC designation.

10.3.3.3 Structure and Function

Structure and function was considered unfavourable – inadequate (Table 10.9). Hydrological functions were generally considered favourable: the majority of turloughs continue to show favourable variation in flooding driven by changes in groundwater supply, and this is the major determinant of turlough ecology. However, water quality was poor or intermediate in the majority of turloughs, and this likely reflects the generally intermediate biological responses observed (Table 10.9).

10.3.3.4 Pressures and Threats

Table 10.13. Main pressures and threats, and their importance ranking (following the criteria outlined in Evans & Arvela, 2011)

Article 17 Code	Pressure	High	Medium	Low	Overall
A04.01.01	Intensive cattle grazing	5	10	6	M
H02.06	Diffuse groundwater pollution due to agricultural and forestry activities	4	10	4	M
H02.07	Diffuse groundwater pollution due to non-sewered population (ZOC)	1	3	11	L
	Threat				
A04.01.01	Intensive cattle grazing (in turlough)	1	15	4	M
H02.06	Diffuse groundwater pollution due to agricultural and forestry activities	5	12	5	M
A02.01	Agricultural intensification (in ZOC)	3	8	11	M/L
H02.07	Diffuse groundwater pollution due to non-sewered population	0	3	13	L
M01.03	Flooding and rising precipitations (due to climate change)	0	0	22	L
A10.02	Removal of stone walls and embankments	0	0	21	L

Pressures and threats were assessed by expert knowledge of the 22 turloughs (see above), and by quantitative data generated by this project. Pressures and threats that were most frequently identified among the 22 turloughs were identified as those most significant at the national level, and are listed in Table 10.13. Other pressures and threats known to be operating on additional turloughs (road development, drainage etc.) were also considered, but these were either included in those pressures and threats identified as described, or of too isolated occurrence to be considered at National level. The main pressures are intensive cattle grazing, diffuse groundwater pollution due to agriculture and forestry and due non-sewered dwellings. In addition to these three, the man threats also include agricultural intensification, changes in flooding regimes brought about by climate change, and the degradation of boundary walls leading to greater homogenisation and reduced diversity within turloughs.

10.3.3.5 Future Prospects

As mentioned above, the trends in pressures since the previous reporting period have declined slightly in many turloughs, though in a small number of cases these pressures are known to have increased. In addition, there are renewed calls for drainage of turloughs; if such drainage only removes extreme flood water (e.g. exceptionally high water levels that are likely to occur less frequently than once every decade) it will be unlikely to have significant impact on the conservation status of turloughs, but some suggestions have included lowering of normal flood levels. In addition some turloughs are threatened by adjacent road development, with associated run off as well as disruption of hydrological function. The Irish Government's Food Harvest 2020 (Department of Agriculture, Fisheries & Food, 2010) is likely to lead to some agricultural intensification, potentially placing future pressures on turlough grazing. There is some shift towards conversion of grasslands to maize crops in the zone of groundwater contribution to some turloughs, and if this involves conversion of unimproved pasture there are likely to be groundwater impacts due to fertiliser and pesticide diffuse pollution sources. Thus despite the general trends in slight improvements in groundwater quality (McGarrigle *et al*., 2010; EPA, 2011; O'Sullivan, 2012a, b), there are likely increased threats to turloughs especially as many have considerable areas of high or extreme pathway susceptibility due to the karst nature of the landscape. Turloughs also face threats due to increased precipitation patterns caused by predicted shifts in climate, and also by the lack of maintenance of stone walls and other boundaries within turloughs which may lead to greater homogenisation of land parcels within turloughs. For all these reasons, the future prospects are considered to be Unfavourable (inadequate), although the threats are not considered likely to be of high enough impact to merit the status of Unfavourable (bad).

In 2007 the future prospects were also considered Unfavourable (inadequate), likely reflecting the threats potentially acting on turloughs. One major problem with assessing both pressures and future threats is the lack of previous monitoring to provide reliable baseline data – this situation has now been addressed for the turloughs studied in this project. For those turloughs within the SAC network (and where those SACs have turloughs specifically notes as a qualifying feature), there is reason to assume that turloughs will be protected from alteration of the hydrological regime. However many turloughs (mostly smaller ones, and perhaps those of lower current conservation value – though these might be suitable for restoration) remain outside of the SAC network, and hence are likely more vulnerable to activities which may impair their ecological structure and functioning. There are however some likely increased threats to turloughs generally through probable agricultural intensification as a result of Ireland's Food Harvest 2020; this may lead to increased nutrient inputs into ZOCs and possibly increased grazing in all but the most oligotrophic turloughs. For these reasons, future prospects are considered to be unfavourable – inadequate and declining slightly.

10.3.3.6 Overall Assessment

The overall assessment for turloughs is unfavourable – inadequate; while the range and surface area are considered favourable, the structure and functions (specifically water chemistry and biological responses) were considered unfavourable – inadequate, as were the future prospects (Table 10.14).

Table 10.14. Assessment matrix for turlough conservation status.

Parameter	Conservation Status			
	Favourable ('green')	**Unfavourable – Inadequate ('amber')**	**Unfavourable - Bad ('red')**	***Unknown (insufficient information to make an assessment)***
Range	**Stable**			
Area covered by habitat type within range	**Stable**			
Specific structures and functions (including typical species)		Hydrological functioning generally good, but water quality and biological responses poor in many turloughs		
Future prospects (as regards range, area covered and specific structures and functions)		There are rather numerous threats, mostly of moderate to low impact, but these are greater in number than current pressures		
Overall assessment of CS		One or more 'amber' but no 'red'		

10.4 Conclusions

The national assessment for turloughs for 2013 was overall unfavourable – inadequate, mostly due to continuing pressures from nutrient enrichment in groundwater and intensive cattle grazing. These pressures appear to be having moderate impact on the ecological functioning of turloughs. Five of the 22 sites investigated in detail had unfavourable - bad conservation status overall (Ardkill, Kilglassan, Lough Aleenaun, Tullynafrankagh, Turloughmore), while four turloughs were in good (=favourable) conservation status (Knockaunroe, Lisduff, Lough Gealain, Roo West); all of the latter group could be considered to be oligotrophic, with important biological communities, and hence of considerable national and international importance. All other turloughs were assessed as unfavourable – inadequate, in many cases because future prospects were poor due to the number of threats faced.

The National Assessment in 2007 also suggested a conservation status of unfavourable – inadequate. While the major pressures were the same, it is not considered that these continuing pressures of groundwater enrichment and intensive grazing are resulting in further deterioration of turlough conservation status. The main nutrient driver, phosphorus, is likely to be largely incorporated into soils in the form of highly insoluble ferric and calcium complexes, rendering the phosphorus largely unavailable. Thus while high concentrations of P in groundwater have an impact on biological communities and prevent impacted turloughs from developing more favourable communities, the continued pressure is likely to be stable and not worsening. Similarly, while grazing levels are likely to be high in some turloughs, the ability of vegetation to recover from grazing – as witnessed by comparison of Goodwillie's (1992) vegetation maps with those in *Chapter 7: Turlough Vegetation - Description, Mapping and Ecology* means that the impacts of grazing are on the whole likely to be stable. However, the increased number of potential threats, mainly due to increased rural housing and agricultural intensification due to Harvest 2020 leading to increased nutrient loading, is likely to lead to future deteriorations in turlough habitat quality and conservation status.

Several individual sites have been assessed as having poor conservation status. In many cases this reflects current or recent pressures. Lough Aleenaun is known to have been bulldozed for agricultural improvement and this has seriously modified the ecological functioning. Kilglassan has been modified by drainage. Ardkill seems to be suffering severely from diffuse nutrient inputs from local agricultural sources. Several of these sites were listed as important by Goodwillie (1992); while his survey predates the Habitats Directive, there is evidence of ecological degradation in some sites since his survey. This is particularly true of Ardkill, though Goodwillie does point out the potential likely problems due to agricultural intensification in the vicinity of the turlough; Goodwillie's concerns seem to have been accurate as this site now has the highest loading of groundwater phosphorus. This perhaps illustrates the benefits of repeated and regular monitoring of turloughs.

Also of concern is that some of the sites which are currently of considerable ecological importance have poor future prospects. A particular example is Carranavoodaun, which is one of the more oligotrophic turloughs with important floristic and invertebrate communities characteristic of low nutrient inputs; however the steadily increasing rural housing development in the vicinity of the turlough, and likely future agricultural intensification in the zone of hydrological contribution (and possible increase in grazing pressure within the turlough) point to future degradation of the ecological functioning of this important site. Measures need to be taken now to protect such sites from future degradation. Of particular concern is that fact that only 58% of turloughs are included with areas designated as SACs, and only 53% are included in SACs *and* also mentioned as a qualifying interest in the designation of the SAC. For those turloughs not mentioned as qualifying interests, and for turloughs outside of the SAC network, there is likely to be considerable threats from drainage and agricultural intensification, with reduced protection for these sites.

Bird occurrences were not used in the assessment of conservation status, though many turloughs are known to important sites for both wintering and breeding waders and waterfowl, see Ruttledge (1989), Goodwillie (1992), Buckley (1993), Madden & Heery (1996), Crowe (2005). Some of the more eutrophic turloughs, which often have relatively little floristic or invertebrate interest, may hold interesting and important birds. A good example is Lough Gash, which is strongly eutrophic and has altered plant and likely invertebrate communities, yet attracts several nationally rare or vagrant waterfowl and waders (as during winter 2012/13 – see http://www.irishbirding.com). Future conservation assessments of turlough should incorporate bird survey data; the omission of birds in consideration of conservation status for 2013 was due to lack of consistent data across studied turloughs.

Article 17 reporting requires provision of a list of 'typical' species (Evans & Arvela, 2011). They should be characteristic of a habitat, but this is problematic for turloughs, as many of the characteristic plant species encountered in turloughs also occur in other wetlands, or indeed in well-drained calcareous habitats; what is unique about turlough vegetation is the juxtaposition of ecologically different species along short but strong ecological gradients. Likewise, many of the rare plant and to some extent invertebrate species also occur as rare species in other habitats: they cannot be reliably used to *define* the turlough habitat. Instead, we recommend a series of plant species that indicate key features of the turlough environment: variation in the duration of flooding, and differing nutrient (phosphorus) status. These are discussed further in chapter 13 (Monitoring Methods). Some plant species may be characteristic of a given suite of turloughs (e.g. *Eleocharis acicularis* in the Gort chain) whereas in other turloughs (e.g. the oligotrophic ones) their presence would indicate a considerable deterioration in conditions.

10.5 References

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Appendix 10.1: Characteristic Species

Application of the concept of '*characteristic species*' is problematic in turloughs, as they vary so widely in relation to duration of flooding, nutrient status and landuse. The list below is taken from the 2013 national assessment of habitats for Article 17 reporting (NPWS, 2013); the species below are not characteristic of all turloughs, and lack of any of the species listed below from a given turlough does not necessarily imply poor ecological condition.

Invertebrates

Agabus labiatus
Agabus nebulosus
Agonum lugens
Agonum muelleri
Agonum piceum
Alona affinis
Alona rustica
Alonella exisa
Alonopsis elongata
Bactra furfurana
Badister meridionalis
Badister peltatus
Bagous limosus
Bembidion aeneum
Bembidion clarkii
Berosus signaticollis
Blethisa multipunctata
Carabus granulatus
Chlaenius nigricornis
Chorthippus albomarginatus
Colobaea distinctaIlione albiceta
Deltote uncula
Diaptomus castor
Dryops similaris
Eurycercus glacialis
Graptodytes bilineatus
Haliplus obliquus
Haliplus variegates
Helophorus minutus
Helophorus nanus
Hygrotus impressopunctatus
Laccobius colon
Laccobius minutus
Lestes dryas
Loricera pilicornis
Monochroa lutulentella
Ochthebius minimus
Paraponyx stratiotata
Pelophila borealis
Pherbellia nana

Pherbina coryleti
Philonthus furcifer
Platynus livens
Polycelis nigra
Pterostichus nigrita
Rhantus frontalis
Saldula opacula
Sympetrum sanguineum
Tetrix subulata
Thanatophilus dispar

Plants

Alopecurus aequalis
Callitriche palustris
Carex viridula agg.
Cinclidotus fontinaloides
Drepanocladus sendtneri
Eleocharis acicularis
Frangula alnus
Galium boreale
Limosella aquatica
Ophioglossum vulgatum
Persicaria minor
Plantago maritime
Potentilla fruticosa
Pseudocalliergon lycopodioides
Pseudocalliergon trifarium
Ranunculus repens
Rhamnus cathartica
Riccia cavernosa
Rorippa islandica
Schoenus nigricans
Teucrium scordium
Viola persicifolia

Chapter 11. Water Framework Directive Risk Assessment

K. Irvine, C. Coxon, S. Kimberley, S. Waldren, L. Gill & P. Johnston

The Travaun-Skaghard-Cooloorta complex of turloughs. Set in a landscape of limestone pavement, this oligotrophic complex is likely to have extreme pathway susceptibility to phosphorus enrichment, but only limited sources of enrichment within its zone of groundwater contribution

Photo: S. Waldren

Table of Contents:

11.1 Introduction

11.1.1 Aims and Chapter Layout

This chapter is primarily concerned with assessment of the risk from phosphorus (P) pollution for the turloughs studied in the project. Turloughs are considered as a type of groundwater-dependent terrestrial ecosystem (GWDTE) under the WFD. For a groundwater body (GWB) to achieve good status, groundwater level alterations or pollutants must not result in any significant damage to GWDTEs. GWBs (defined by their hydrological zones of contribution (ZOCs; see 11.1.3)) were initially delineated based on aquifer flow regimes, geological boundaries and flow line boundaries (EPA 2005) during the first River Basin Cycle

(2003-2009). In 2004, GIS-based risk assessments (WFD Working Group on Groundwater, 2004) were applied to 132 GWBs containing GWDTEs as part of the WFD Article V Characterisation and Risk Assessment of River Basin Districts. The work presented in this chapter follows on from, and re-evaluates, the risk assessment for turloughs developed by the Working Group on Groundwater (2004).

The datasets used for the risk assessment work are described in section 11.2. The work undertaken with these datasets falls into three parts. Firstly, the risk assessment GWDTERA2a developed by the WFD Working Group on Groundwater (2004), and a more stringent modified version, was tested for the 22 turloughs (section 11.3). Secondly, regression analysis was used to examine the relationship between phosphorus in turlough waters and the source and pathways in the zones of contribution (section 11.4). Finally, a nutrient export coefficient modelling approach was used in order to predict turlough phosphorus concentrations (section 11.5). The findings from the phosphorus risk assessment work as a whole are discussed in section 11.6.

The WFD requires using chemical and hydrological data to assess status of GWBs at risk of failing to meet WFD objectives for GWDTEs. Groundwater nutrient threshold values are used as part of the chemical status test to identify sites requiring more detailed investigation (Blum *et al*. 2009). This chapter proposes groundwater chemical threshold values for turloughs.

The final part of the chapter (section 11.7) evaluates the current GWDTERA1 risk assessment procedure for pressures of water abstraction on turloughs and the quantitative status of the associated GWB, with suggestion for future modifications.

11.1.2 The Role of Agriculture in Nutrient Enrichment of Water Bodies

The risk assessment framework used by the Working Group on Groundwater (2004) comprises *sources* of nutrients, *pathways* of transfer, and the sensitivity of the *receptors,* in this case the turloughs. This follows the development of models that conceptualise phosphorus movement through landscapes and their focus on critical source areas, and pathways of hydrological movement that link hydrological events to P mobilization (Haygarth *et al*., 2005). Turlough catchments are mostly covered in agricultural grassland, which although managed at generally relatively low intensity, nevertheless provides a potential source of P that can be mobilized as nutrient run-off to waterbodies. Intensification of agriculture relates to nutrient enrichment of water bodies all over the world (e.g. Tsirkunov *et al*., 1992; Castillo *et al*., 2000; Cuffney *et al*., 2000; Haggard *et al*., 2003). A similar link can be expected for turloughs. Livestock, particularly cattle, can have an impact on surface waters at stocking densities considered by agriculturists to be low. For example, in the Lough Melvin catchment with extensive sheep and cattle grazing, about 22% of fields surveyed in the catchment contained high soil phosphorus concentrations despite overall densities of livestock of about 0.5 livestock units ha^{-1}, which would be considered low intensity (Schulte *et al*., 2009). Decline in the water quality in Lough Melvin has been associated with moderate increases in the intensity of cattle farming (Campbell & Foy, 2008). Similarly, relatively modest stocking densities ranging from 0.19-0.81 LU ha^{-1} across a number of case study farms were considered sufficient to pose a risk to water quality, and prompted the development of a risk-assessment model for nutrient export from agriculture to surface waters, groundwaters and groundwater-dependent terrestrial ecosystems, including turloughs (Bartley *et al*., 2009). Cattle densities of about 1 ha^{-1} across 29 catchments in Ireland were associated with eutrophication of lakes studied by Irvine *et al*. (2000).

11.1.3 Nutrient Sources and Pathways in Turlough Zones of Contribution

Assessment of sources of phosphorus for the purpose of this chapter is based on metrics of land use in the Zones of Contribution (ZOC – see *Chapter 3 - Hydrology*). The ZOC for a turlough can be defined in relation to the quantities of water feeding a spring or borehole, and can be considered groundwater catchments. Contributing areas of groundwater to a receptor may not be the same as a surface topographical catchment. Broadly speaking nutrient sources can be considered to be point or diffuse. Diffuse sources are those related to general areas (such as pastures) while point sources are related to more localised and often more concentrated sources of contamination, such as septic tanks or other on-site wastewater treatment systems (OSWTS), or silage, manure or slurry storage areas. Contamination from such point sources can cause intermittent pollution in groundwater and groundwater dependent terrestrial ecosystems such as turloughs (Bartley *et al*., 2009). The risk of nutrient pollution to water increases when high concentrations of sources are connected with the hydrological pathway. This can include movement of nutrients from slurry spreading close to a turlough, or through sinkholes or depressions in the land (dolines) that can provide a ready conduit to the turlough via the groundwater. In karst catchments high concentrations and relatively unrestrained transport of nutrients can be mobilized some distance from the turlough (Kilroy & Coxon, 2005; Holman *et al*., 2008). Assessment of the risk of nutrients reaching a turlough, therefore, depends on knowledge of potential sources and pathways. P from diffuse and point sources may reach turloughs via overland run-off, soil and subsoil throughflow, rivers/streams and groundwater. The nature of groundwater flow within the ZOC influences the transfer of nutrients to turloughs via groundwater. Within-turlough nutrient cycling processes play a major role in determining the ecological impact of P inputs. P tends to accumulate in wetlands via a variety of processes including assimilation into plant tissue and sorption and precipitation of inorganic P with different forms of Fe, Al and Ca (e.g. Reddy & DeLaune, 2008; Mitsch & Gosselink 2000). P cycling in turloughs involes a complex interaction of several physical and chemical processes (Figure 11.1). This complex interplay between nutrient sources and mobilisation is accentuated in turlough catchments because pathways can be rapid, with critical source areas originating some distance from a turlough receptor. The very large areas of some turlough ZOCs provide a large potential for nutrients measured in turloughs to be averaged across extensive volumes of groundwater. Many of the ZOCs themselves are subject to scientific dispute, as ZOCs are extremely difficult to delineate (Naughton, 2011; Tynan *et al*., 2007). Assessment of risk is, therefore, clearly dependent on available data and its spatial resolution.

Figure 11.1 Hypothetical phosphorus cycling in turloughs (adapted from Mitsch & Gosselink 2000). POP = Particulate organic P; SOP = Soluble organic P; PIP = Particulate inorganic P.

11.2 Data Used in the Risk Assessments

11.2.1 Data on Landuse and Nutrient Sources

The project assembled available data from a variety of sources. Zones of groundwater contribution (ZOCs) were defined by a combination of geology/topography, available groundwater tracing and water table data, and expert knowledge that included subjective assessment of confidence in the delineated ZOCs. Detailed site-specific notes on the ZOC delineation process are presented in Appendix 11.1. Land cover data in the ZOCs of the turloughs were extracted from the Teagasc-EPA Soil and Sub-soil Mapping Project (Fealy & Green, 2009) and the CORINE 2000 Project (Bossard *et al*., 2000) geo-referencing databases. Original land cover categories defined in these datasets were aggregated to provide categories relevant for this study (Cunha Pereira, 2011). Despite describing the same areas, the CORINE and *Teagasc* datasets varied in their methods to categorise land cover (Fealy & Green, 2009). The CORINE database discriminates between "improved" and "unimproved" pastures, and was used to differentiate high and low intensity managed grasslands (O'Sullivan, 1994). Its ability to discriminate between grassland categories may be poor (F. Barrett, Forest Service, pers comm.). The *Teagasc*-EPA data were at a higher spatial resolution (1 ha minimum unit size compared with 25 ha) than the CORINE data, and some ground-truthing was undertaken in completing the *Teagasc*-EPA soil maps.

On Site Wastewater Treatment Systems (OSWTS) densities were provided by the ESBi based on the An Post (Postal Office) Directory. Number of dwellings without an official connection to the main sewage system were assumed to use private systems. Data were expressed as the number of septic tanks per square km. The Central Statistics Office (CSO) only provide livestock numbers on an average annual basis across District Electoral Divisions (DEDs), meaning that numbers have to be partitioned on some basis across turlough ZOCs. More accurate data were sourced from the Agricultural Census of 2005, but also only on an average annual basis, and are now a few years out of date. Livestock density was calculated from 2005 data obtained from the Department of Agriculture on the number of livestock (cattle plus sheep) in the DEDs. Cattle and sheep densities were estimated for each turlough ZOC within the DEDs and partitioned according to area of pasture estimated from CORINE. Further distinction was made between grassland based on CORINE and other areas, such that cattle density per hectare of grassland cover could be estimated. More detailed, and relevant data on farm holdings, and associated soil P levels are collected by the Department of Agriculture Food and the Marine (DAFM), but were not available for use here.

11.2.2 Data on Pathway Factors

Likely pathways were based on soil type (acid vs. basic), soil drainage (well drained vs. poorly drained), river channel length and groundwater pathway susceptibility defined in the WFD risk assessment for turloughs (Working Group on Groundwater, 2004). Soil type data were based on maps generated as part of The Irish Forest Soils Project. River channel length was calculated based on 1:50,000 Discovery Maps and drainage density was expressed as total river channel length per square km, although the resolution of the 1:50,000 scale cannot effectively estimate densities of drainage ditches.

11.3 Testing and Modification of the WFD Turlough Risk Assessment Procedures

11.3.1 GIS-Based Risk Assessment Methods

GIS based risk assessments, based on Guidance Document No. GW9 on assessing risks to turloughs from phosphate (Working Group on Groundwater 2004), were done to provide Risk Categories for the 22 turlough ZOCs. The process integrated pathway susceptibilities and pressures to produce Impact Potential maps. The predicted Risk Categories were adjusted with the mean seasonal floodwater turlough TP. Step-by-step details on the approach are outlined below. The WFD approach was revised by the TCD Turlough Research Group (TCD approach) and the two outputs compared for final assessment of risk.

WFD Approach

The preliminary approach followed the methodology outlined in Risk Assessment Sheet GWDTERA2a (Working Group on Groundwater 2004), involving the following steps:

A. Delineation of the ZOC of the turlough (ZOC boundary)
B. Evaluation of pathway susceptibility (Matrix A: *(Datasets; sub-soil depth, Dry/Wet soil categories, aquifer types, karst database)*
C. Evaluation of pressure magnitude *(Datasets; Department of Agriculture database:total livestock units and tillage)*
D. Estimating impact potential by combining pathway susceptibility with pressure magnitude (Matrix B). The Susceptibility and Pressure Magnitude layers were converted into raster files, which are made of 50 m x 50 m pixels. Each pixel has a unique ranking for Pathway Susceptibility (e.g. Extreme, High Moderate orLow), and for each of the Pressure Magnitude layers (e.g. <3%, 3-18%, 18-33% or>33% for tillage).

E. Predicting the risk category (risk of failing to meet WFD environmental objectives) by combining the Receptor Sensitivity, as determined by NPWS using Goodwillie (1992) vegetation data and Ellenberg fertility data for species (Hill *et al*., 1999), with the proportion of the turlough catchment with high and moderate impact potential (Matrix C).
F. Adjustment of risk category using mean seasonal floodwater TP (Matrix D).

Turlough Research Group Approach (TCD Approach)

This approach deviated from the original WFD approach by using a revised Impact Potential matrix (Matrix B) and excluding the turlough area from the process. The revised Impact Potential matrix is presented in Table 11.1. The lowest risk is considered to be 'low' as we consider that in a karst environment the risk can never be considered 'negligible'. Irvine *et al.* (2000) reported a positive association between cattle density and mean total phosphorus (TP) across 29 Irish lakes. LU > 1.5 LU ha^{-1} was associated with mean lake TP > 40 μg l^{-1}, with relatively higher risk among lakes in predominantly peatland catchments and lowest risk in those among calcareous catchment. Adopting the precautionary principle, as built into the Habitats Directive, an LU density of 1.5-2.0 LU $ha^{-1}$is considered a high risk, irrespective of soil type.

Table 11.1 Revised Impact Potential Matrix used for turlough ZOC TCD risk assessment approach.

	Pathway Susceptibility			
	Extreme	*High*	*Moderate*	*Low*
>2.0 LU ha^{-1} or >33% tillage Heavily fertilized forestry on peat* Q value < 4** in surface water	Extreme	Extreme	High	High
1.5-2.0 LU ha^{-1} or 18-33% tillage	High	High	Moderate	Moderate
1.0-1.5 LU ha^{-1} or 3-18% tillage	Moderate	Moderate	Moderate	Low
< 1 LU ha^{-1} or <3% tillage	Moderate	Low	Low	Low

*Heavily fertilized forestry (on peat) corresponds almost completely to sitka spruce. This measure is taken to be a surrogate measure of associated nutrient load from forestry.

**Q value of surface water contributed by poorly productive and/or fissured aquifers and/or of any surface waters within the catchment area. A Q value of ≥4 corresponds to <30μg/l MRP.

The WFD and TCD risk assessment approaches were applied to the Outer ZOC (excluding the turlough area). Nineteen of the turlough boundaries constitute the maximum recorded flood level. The boundaries of Garryland, Coolcam and Tullynafrankagh are based on vegetation as they were only partially surveyed owing to persistent flooding,

11.3.2 GIS-Based Risk Assessment Results

By way of example, pathway susceptibility, pressure and impact potential maps for Caranavoodaun turlough Co. Galway are presented in Figures 11.2-4. The pathway susceptibility map (Figure 11.2) is a critical component of the impact potential map and presents a spatial representation of Extreme, High, Moderate and Low areas of pathway susceptibility, based on horizontal and vertical hydrological connectivity.

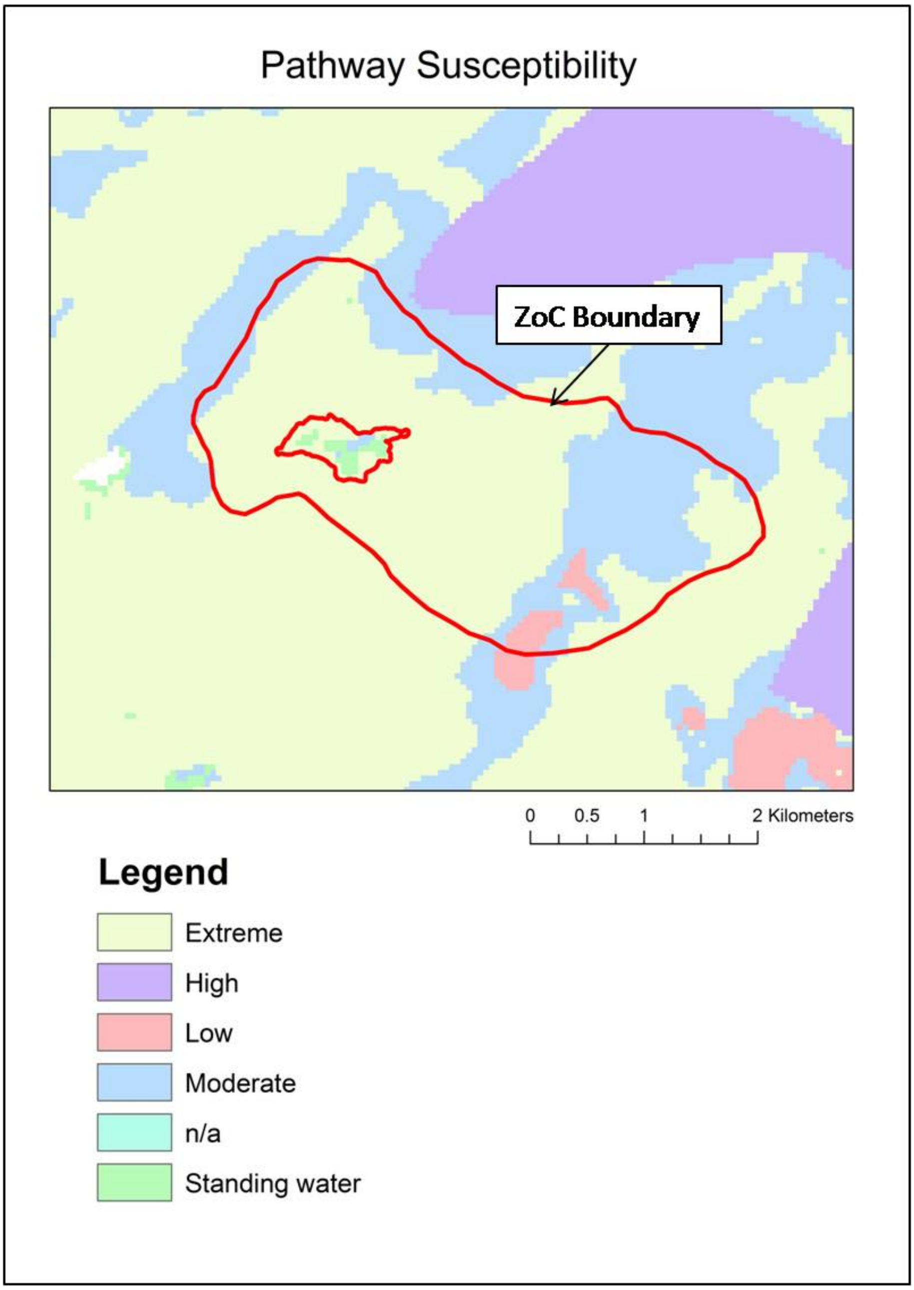

Figure 11.2 Pathway Susceptibility map for Caranavoodaun turlough Co. Galway.

The pressure magnitude map (Figure 11.3) is a critical component of the impact potential maps. It represents Extreme, High, Moderate and Low areas of pressure, based on livestock units and % areas of tillage.

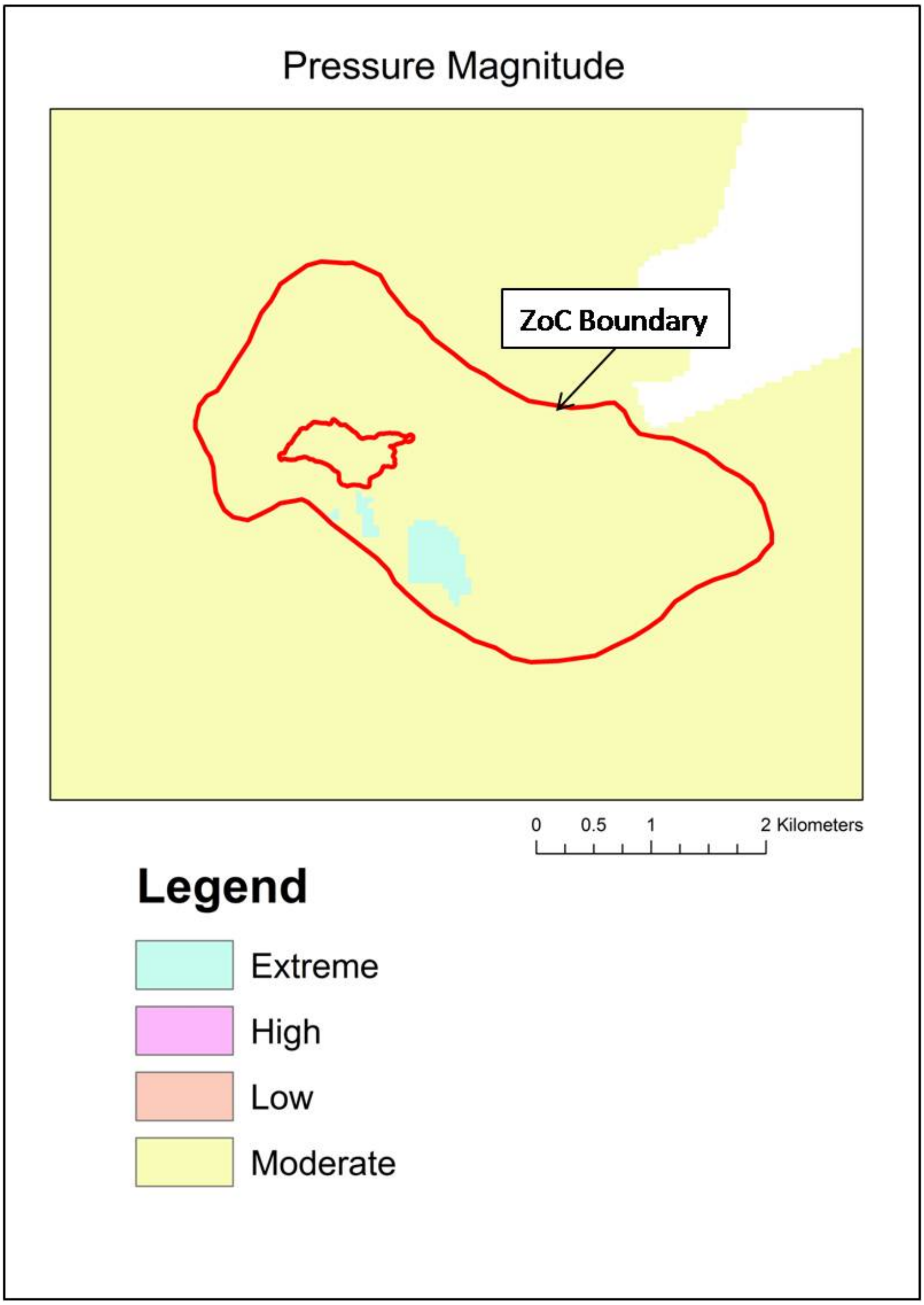

Figure 11.3 Pressure Magnitude map for Caranavoodaun turlough, Co. Galway (pressure magnitudes not generated for unshaded areas).

The impact potential map (Figure 11.4) is a product of Pathway Susceptibility and Pressure Magnitude integration. The proportion of outer ZOC area with Extreme, High, Moderate and Low Impact Potential provides an integrated summary of groundwater P eutrophication potential.

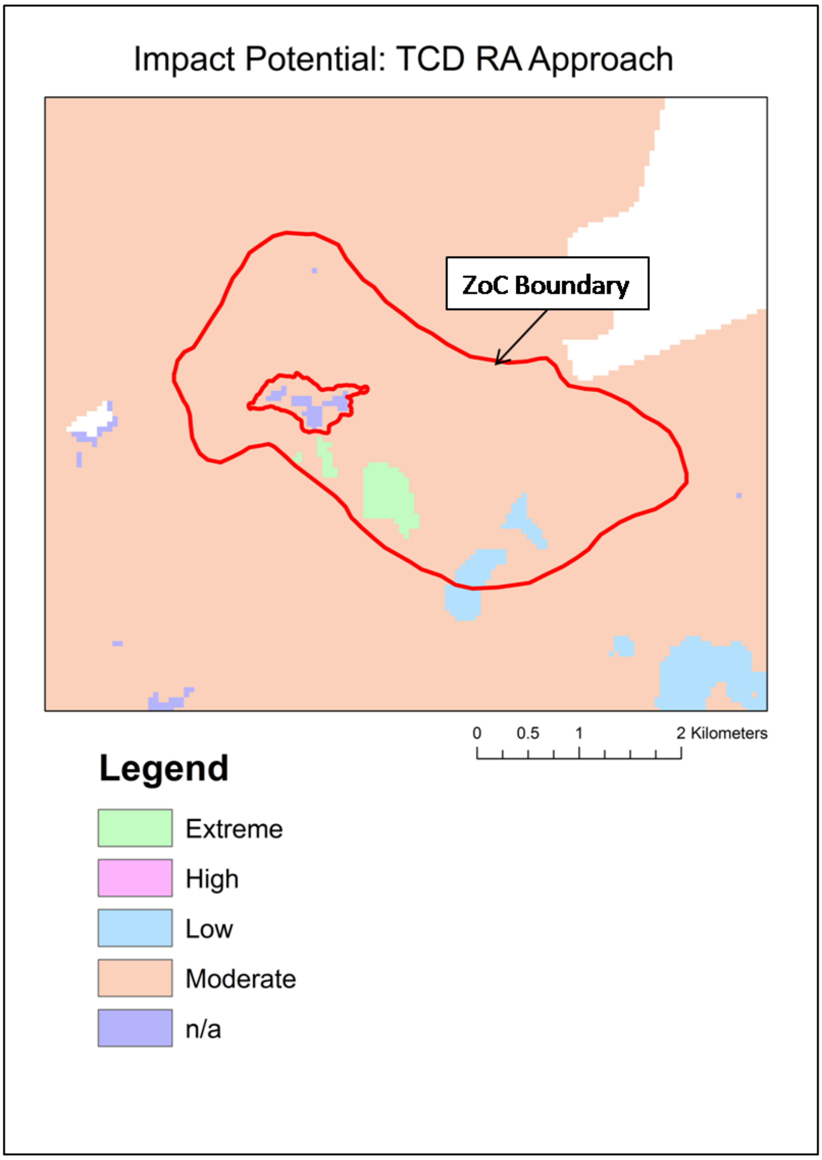

Figure 11.4 Impact Potential map for Caranavoodaun turlough, Co. Galway (impact potential not generated for unshaded area).

Using Matrix C of Guidance Doc. No. GW9, the predicted risk categories were determined by combining data on Impact Potential (WFD and TCD) and Receptor Sensitivity. Guidance Doc. No. GW9, categorises water bodies as *'at risk'* (categories 1a or 1b) or *'not at risk'*. This terminology is that used in the Article 5 WFD Characterisation Report (Government of Ireland, 2005), of water failing to achieve WFD environmental objectives. These risk categories are *1A: at significant risk*; *1B: probably at significant risk*; *2A: Not at significant risk* *(low confidence)*; *2B: Not at significant risk (higher confidence)*. The predicted risk categories were adjusted using Matrix D in Guidance Doc. No. GW9 and mean seasonal floodwater TP (μ l^{-1}) data for each turlough. (Table 11.2). Based on the original WFD approach, Ardkill, Blackrock, Caherglassan, L. Coy and Rathnalulleagh were predicted as *Not at significant risk*. These turloughs however show evidence of significant damage linked to nutrient enrichment from groundwater. The revised TCD RA approach predicted that turloughs showing evidence of a water quality problem were *Probably at significant risk*.

Table 11.2. Outputs from Matrix C (Risk category based on predictive risk assessment) and Matrix D (Risk category of turlough catchment adjusted using available impact data) (Guidance Doc. No. GW9, Working Group on Groundwater, 2004).

Turlough Name	*OECD Trophic Status (TP)*	*Receptor Sensitivity (Goodwillie Vegetation)*	*Predicted WFD Risk Category*	*Predicted TCD Risk Category*	*Adjusted WFD Risk Category*	*Adjusted TCD Risk Category*
Ardkill	Eutrophic	Moderate	2B	1B	1A	1A
Ballindereen	Mesotrophic	Extreme	1B	1B	1A	1A
Blackrock	Eutrophic	Moderate	2A	1B	1A	1A
Brierfield	Mesotrophic	High	1B	1B	1B	1B
Caherglassan	Eutrophic	Moderate	2B	1B	1A	1A
Caranavoodaun	Mesotrophic	Extreme	1B	1B	1A	1A
Carrowreagh	Eutrophic	Moderate	1B	1B	1A	1A
Coolcam	Mesotrophic	High	1B	1B	1A	1A
Croaghill	Mesotrophic	Moderate	2A	1B	1B	1B
Garryland	Mesotrophic	Moderate	2B	1B	1B	1B
Kilglassan	Mesotrophic	Moderate	2A	1B	1B	1B
Knockaunroe	Oligotrophic	Extreme	1B	1B	1B	1B
Lisduff	Oligotrophic	High	1B	1B	1B	1B
Lough Aleenaun	Mesotrophic	Moderate	2B	1B	1A	1A
Lough Coy	Eutrophic	Moderate	2A	1B	1A	1A
Lough Gealain	Oligotrophic	Extreme	1B	1B	1B	1B
Rathnalulleagh	Eutrophic	Moderate	2B	1B	1A	1A
Roo West	Oligotrophic	Extreme	1B	1B	1B	1B
Skealoghan	Mesotrophic	Extreme	1B	1B	1A	1A
Termon	Mesotrophic	Extreme	1B	1B	1A	1A
Tullynafrankagh	Mesotrophic	High	1B	1B	1A	1A
Turloughmore	Mesotrophic	Moderate	1B	1B	1B	1B

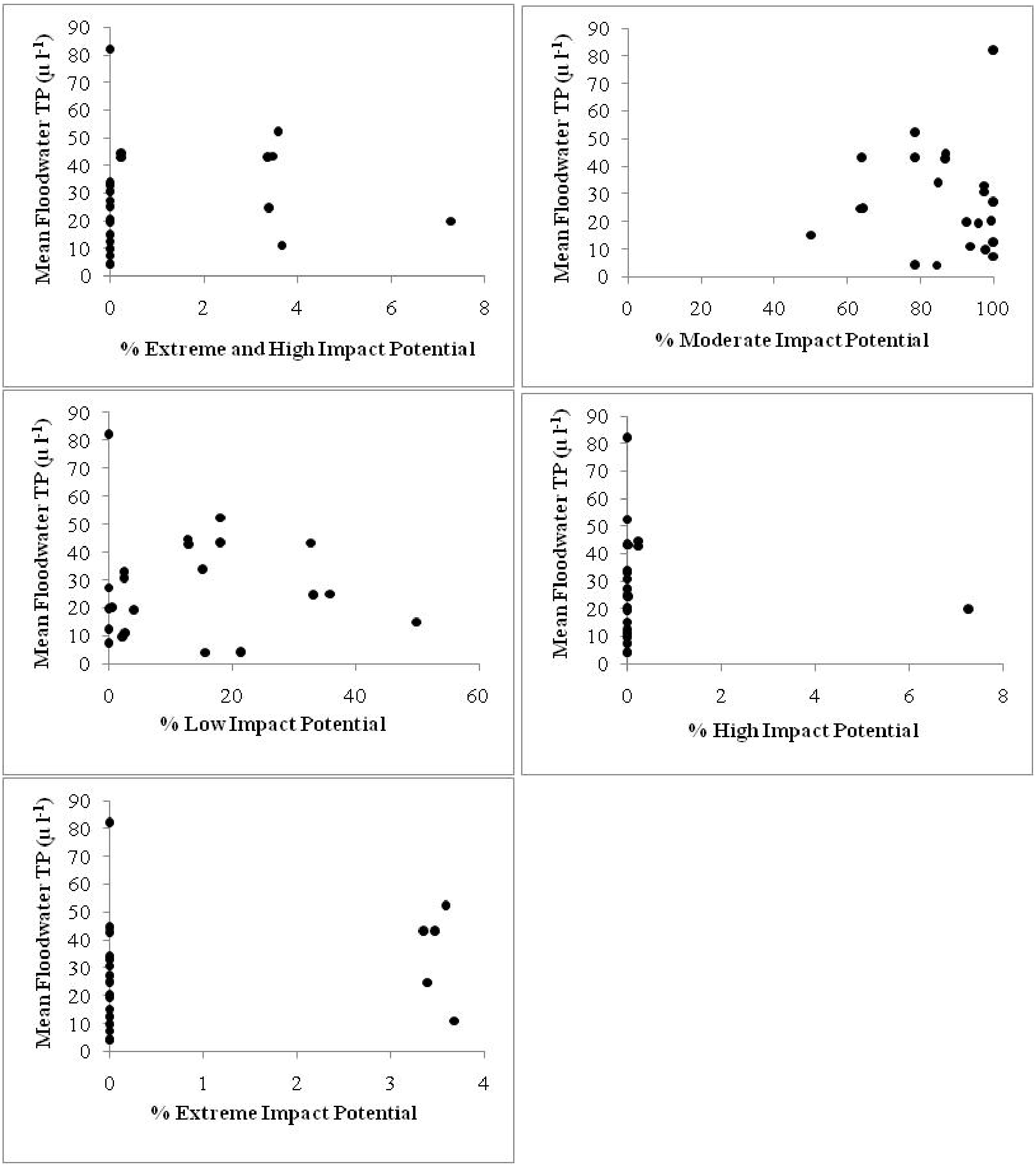

Figure 11.5 Scatter plots of Impact Potential proportions in turlough ZOCs and mean floodwater TP ($\mu g\ l^{-1}$) per turlough (N=22).

Spearman Rank correlation tests found no significant correlations between mean measured TP and any of the impact potential proportions generated from the risk assessment process based on the risk assessment of Matrix B of Guidance Doc. No GW9 (Table 11.3). Scatter plots of the relationships between variables are presented in Figure 11.5. Proportions of Extreme and High Impact Potential are low across sites. The relationship between TP and % Low Impact Potential is perhaps the most informative. Turloughs with predominantly Low Impact Potential in associated ZOCs can have a wide range of TP values. The most oligotrophic sites are not associated with ZOCs dominated by Low Impact Potential. The key point to be made here is that our results show that turlough trophic status cannot be reliably estimated using ZOC Impact Potential proportions.

Table 11.3. Spearman coefficients and p values of correlations between mean seasonal floodwater TP (μg l^{-1}) and Impact Potential proportions (%) in ZOCs (N=22).

Impact Potential category proportions (%)		*Mean Seasonal floodwater Total Phosphorus (μg l^{-1})*
Extreme	coefficient	0.255
	p	0.253
High	coefficient	0.278
	p	0.211
Moderate	coefficient	-0.135
	p	0.548
Low	coefficient	0.097
	p	0.667
Extreme+High	coefficient	0.325
	p	0.140
Extreme+High+ Moderate	coefficient	-0.097
	p	0.667

11.4 Regression Analyses

11.4.1 Regression Methods

The approach taken in this part of the risk assessment work was to examine the relationship between phosphorus in turlough waters and the source and pathway variables in the ZOC described in section 11.2, using Pearson correlation and linear regression.

The dependent variable in the statistical analysis was the mean total phosphorus (TP) as μg l^{-1} measured in each turlough in the 2006-07 flooding season (calculated from nine samples taken between Oct 2006 and June 2007). TP is widely considered to best represent the potential effect of nutrients in standing waters (OECD, 1982) and is a standard method for categorizing phosphorus concentrations. TP correlated well with various characteristics of the vegetation (Chapter 7) and aquatic invertebrate communities (Chapter 8). The initial stage of statistical analysis involved the production of scatter plots and the calculation of Pearson correlation coefficients for the relationships between mean TP and individual pressure and pathway variables.

Scatter plots investigated the relationship across the turloughs. These relationships were examined using both the full dataset of 22 turloughs, and the data set excluding Ardkill. Ardkill was excluded because very high TP concentrations were recorded despite the small ZOC of 3.1 km^2, and the likelihood, from field observations, of the importance of nutrient sources close to the turlough, mobilised by overland or epikarst flow (see Chapter 10:

Conservation Status Assessment). Additionally, vegetation communities of the Ardkill relevees often appear as positive outliers, suggesting higher TP than expected. For these reasons, Ardkill was excluded from further analysis. We have not presented the relationship between mean TP and the number of farms which have received a derogation from the 170 kg ha^{-1} N loading under the Nitrate Directive (European Commission, 2007), because such farms were only present in three ZOCs.

The second stage of statistical analysis involved the combination of the individual ZOC pressure and pathway variables in multiple regressions used to predict turlough mean TP. This was done in two ways. First, logical combinations of variables expected to have a role in determining turlough phosphorus concentrations were examined. Second, the variables with the highest individual correlation coefficients were combined in order to provide multiple regressions that fit the data empirically.

Several turloughs have overlapping or nested ZOCs. The four turloughs of the Gort Lowland grouping (Blackrock, Coy, Garryland and Caherglassan) have nested zones of contribution because they form a sequence along an underground flow path from the Slieve Aughty mountains towards the springs at Kinvarra. The turloughs at the northern end of the distribution in Roscommon also have overlapping ZOCs, with Rathnalulleagh and Carrowreagh sharing an identical ZOC, and with the ZOC of Coolcam turlough lying within that of Croaghill. This nesting of sites means that TP measurements, and ZOC to turlough relationships, are not necessarily independent of each other (see *Chapter 3: Hydrology*, section 3.3 and *Chapter 4: Water Chemistry and Algal Biomass*, section 4.4.1).

11.4.2 Regression Results

From 46 correlations of landscape variables with mean measured TP (excluding Ardkill), 14 showed significant relationships (Table 11.4). Scatterplots of 13 of the significant relationships (omitting number of farms with derogations, as outlined above) are shown in Figure 11.6.

The explanatory power of variables expected to influence TP in turloughs is low (Table 11.4). Some notable examples (as % of variation explained) are Corine All Pasture (10%), Stocking Density as Livestock Units (3%), Corine Improved Pasture (2%), Number of Septic Tanks (1%). Combinations of these variables in multiple regression did not much enhance explanatory power. For example, including stocking density, extreme pathway susceptibility and number of septic tanks, variables that might *a priori* be considered to drive TP in groundwater, explains only 16.3% (based on the adjusted R squared value) of variation in TP (Table 11.5). Greater explanation of the variance of the TP data can be explained by a model using explanatory variables that are significantly correlated with turlough TP (Table 11.4), while minimising collinearity by avoiding highly correlated variables (Table 11.6). Various combinations of Corine Unimproved Pasture, Extreme Pathway Susceptibilty, Acid Soil % and Drainage Density can be used to construct models that explain >70% of variation in turlough TP but such models are highly empirical, reducing statistical validity. A relatively simple model using just Corine Unimproved Pasture and Drainage Density, which are not significantly correlated at p=0.05, explains 72.2% of the variation in turlough TP (Table 11.7), although further investigation would be needed to better understand the mechanisms and validity of this relationship.

Table 11.4. Pearson correlations and r^2 values between catchment variables and measured mean TP in the 21 turloughs (excluding Ardkill). * = significant at p = 0.05.

Variable	*Code*	*r*	r^2
Drainage Density (km/km^2)	DrainD	0.76*	0.57
Acid Soils (%)	AcidS	0.74*	0.55
Unimproved Pasture (CORINE) (%)	CUnimP	0.69*	0.48
Basic Soils (%)	BasicS	-0.69*	0.48
Poorly Drained (%)	PoorDr	0.61*	0.37
Derogation Farms (no.)	DerFms	0.60*	0.36
Wet Grasslands (Teagasc) (%)	TWetGr	0.60*	0.36
Well Drained (%)	WellDr	-0.58*	0.34
High Pathway Susceptibility (%)	HighPS	0.56*	0.31
Peat Bogs (CORINE) (%)	CPeat	0.54*	0.3
Bare Rock (CORINE) (%)	CBRock	-0.54*	0.29
Rock (Teagasc) (%)	TRock	-0.53*	0.28
Extreme Pathway Susceptibility (%)	ExtrPS	-0.53*	0.28
Peat Bogs (Teagasc) (%)	TPeat	0.50*	0.25
Septic Tanks >200 m from turlough (no.)	ST>200	0.41	0.17
River channel length (km)	Rivers	0.35	0.12
Phosphorus from animals (kg)	AnP	0.35	0.12
Nitrogen from animals (kg)	AnN	0.35	0.12
Silage (%)	Silage	0.33	0.11
Other (CORINE) (%)	COth	-0.32	0.1
All Pasture (CORINE) (%)	CAllP	0.32	0.1
Forest and Scrub (Teagasc) (%)	TFor	0.31	0.1
Spruce forest (%)	Spruce	0.31	0.09
Population 2006 (no.)	Pop	0.3	0.09
Total Grassland (Teagasc) (%)	TTotGr	0.28	0.08
Tillage (%)	Till	-0.27	0.07
Septic Tanks <100 m from turlough (no.)	ST<100	0.26	0.07
Ratio of turlough area to total area of ZOC	ARatio	-0.25	0.06
Septic Tanks Km^{-2} High Pathway Susceptibility	ST/HPS	0.25	0.06
SAAR Average annual rainfall 1961-1990	Rain	-0.24	0.06
Pasture (%)	Pastur	0.23	0.05
Wastewater Treatment Plants (no.)	WWTs	0.2	0.04
Septic Tanks <200 m from turlough (no.)	ST<200	0.17	0.03
Total Livestock Units (ha^{-1})	LUs	0.17	0.03
Total Livestock Units (ha^{-1} of CORINE 231+243)	LUsCOR	-0.17	0.03
Sheep (ha^{-1} of CORINE 231+243)	ShCOR	-0.15	0.02
Teagasc Dry Grasslands (%)	TDryGr	0.15	0.02
Improved Pasture (CORINE) (%)	CImpP	-0.14	0.02
Septic Tanks (Km^{-2})	STs	0.12	0.01
Extreme+High Pathway Susceptibility (%)	Ex+HPS	-0.11	0.01
Other (Teagasc) (%)	TOth	0.09	0.01
Cattle Ha^{-1} CORINE 231+243	CatCor	-0.09	0.01
Septic Tanks Km^{-2} Extreme Pathway Susceptibility	ST/EPS	0.07	0.01
Water (Teagasc) (%)	TWat	0.03	0
All Natural and Semi-natural areas (CORINE) (%)	CNSA	0.01	0
Other Agricultural Lands (CORINE (%)	COAgL	0	0

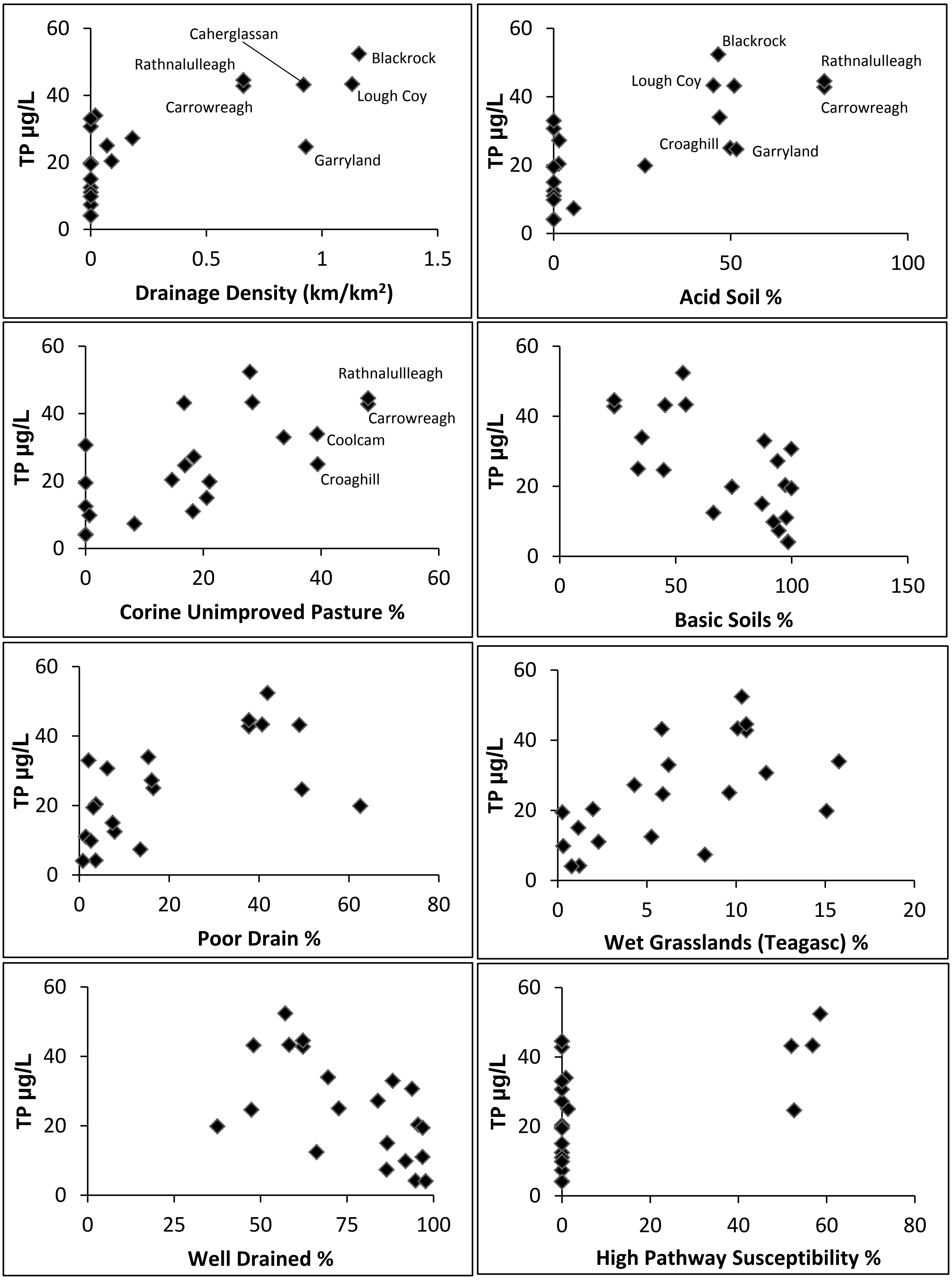

Figure 11.6. Scatterplots showing the relationships between landscape variables and turlough TP in 21 turloughs. Named turloughs are referred to in the text when describing particular figures.

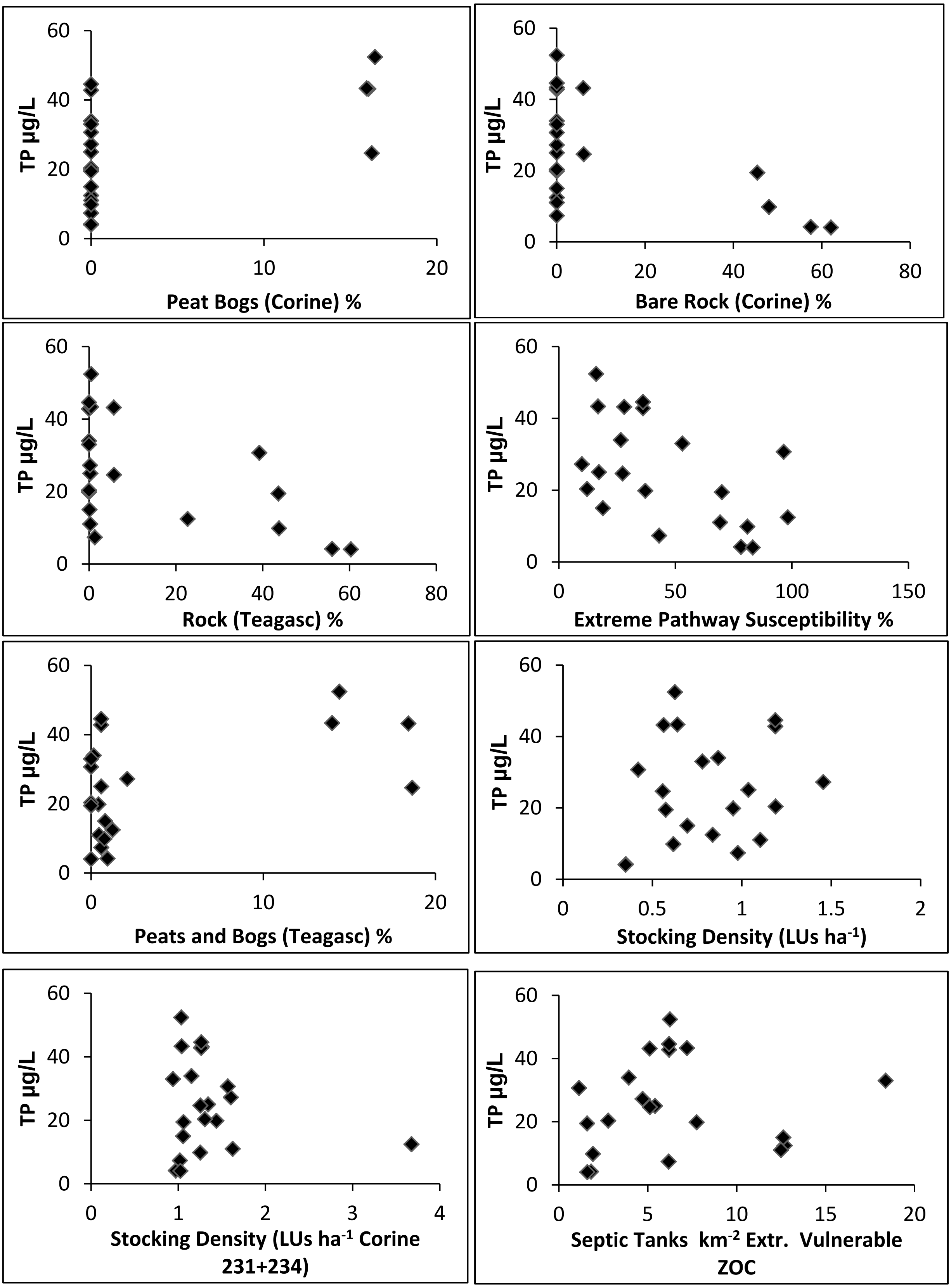

Figure 11.6 (continued).

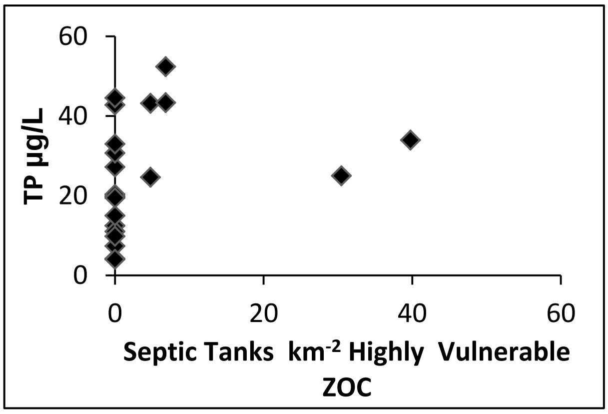

Figure 11.6 (continued).

Table 11.5 Multiple regression of TP and landscape variables predicted to likely drivers of groundwater TP

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	1226.42	3	408.808	2.3
Residual	3019.53	17	177.62	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*probability*
Constant	41.8914	12.99	3.22	0.0050
Total Livestock per ha	-4.81436	11.49	-0.419	0.6804
Extreme pathway susceptibility	-0.28761	0.1164	-2.47	0.0243
No. septic tanks	0.00596691	0.7285	0.00819	0.9936

R squared (adjusted) = 16.3%; s = 13.33 with 21 - 4 = 17 degrees of freedom

Table 11.6 Pearson product-moment correlation coefficients among landscape variables. Codes are explained in Table 11.4.

	CBRock	*CPeat*	*CUnimP*	*TRock*	*TPeat*	*TWetGr*	*ExtrPS*	*HighPS*	*AcidS*	*BasicS*	*WellDr*	*PoorDr*	*DrainD*
CBRock	1.000												
CPeat	-0.178	1.000											
CUnimP	-0.588	0.106	1.000										
TRock	0.893	-0.240	-0.742	1.000									
TPeat	-0.175	0.986	0.077	-0.239	1.000								
TWetGr	-0.604	0.153	0.598	-0.498	0.110	1.000							
ExtrPS	0.543	-0.397	-0.653	0.780	-0.391	-0.317	1.000						
HighPS	-0.184	0.998	0.120	-0.246	0.976	0.169	-0.406	1.000					
AcidS	-0.376	0.458	0.774	-0.484	0.455	0.621	-0.521	0.461	1.000				
BasicS	0.430	-0.391	-0.773	0.502	-0.398	-0.620	0.468	-0.394	-0.954	1.000			
WellDr	0.465	-0.601	-0.472	0.511	-0.621	-0.642	0.455	-0.597	-0.745	0.754	1.000		
PoorDr	-0.399	0.637	0.454	-0.483	0.648	0.600	-0.515	0.631	0.753	-0.662	-0.944	1.000	
DrainD	-0.280	0.883	0.409	-0.365	0.858	0.290	-0.494	0.888	0.725	-0.626	-0.666	0.736	1.000

Table 11.7. Multiple regression of TP with landscape variables showing highest correlations with groundwater TP

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	3183.38	2	1591.69	27
Residual	1062.58	18	59.0323	

Variable	Coefficient	s.e. of Coeff	t-ratio	probability
Constant	11.6226	2.654	4.38	0.0004
Unimproved pasture	0.419044	0.1169	3.58	0.0021
Drainage density	19.3562	4.414	4.39	0.0004

R squared (adjusted) = 72.2%; S=13.33 with 21-4=17 degrees of freedom

11.4.3 Discussion of Regression Results

11.4.3.1 Relationship Between Animal Stocking Densities and TP

The relationship between animal stocking density and TP was not significant ($p>0.05$) and explains only 3 % of the variation in TP. When the stocking densities were applied to appropriate CORINE land cover classes (an approach which was found useful in the WFD Article 5 risk assessments, see Working Group on Groundwater (2005) page 6), the correlation coefficient (-0.17) was also not significant. This is in contrast to studies of relationships between animal stocking densities and TP in Irish rivers and lakes (discussed in section 11.1.2).

An important contributory factor in investigating effects of animal stocking densities on turlough nutrient status is the scale and reliability of the available data. Stocking densities are for DEDs, which do not necessarily have any relation to the turlough ZOCs. Areas of ZOCs ranged between 0.9 and 398 km^{-2}, while those of DEDs ranged from 0.05 to over 500 km^{-2}, and ZOCs and relevant DEDs rarely match in any meaningful way. Especially for smaller turlough ZOCs, the stocking density data are unlikely to reflect the actual stocking density in the ZOC. An adjustment using CORINE land cover classes aimed to apply the stocking density data to relevant land areas did not improve the relationship. Using readily available stocking density data is not, therefore, a useful predictor of turlough TP. Whether TP could be predicted from finer scale stocking densities (e.g. on a farm or land parcel basis) is unresolved, and will remain so until such data are made readily available.

A further issue arising from the coarse resolution of the animal stocking density data is that it was not possible to combine this pressure layer with a pathway layer, e.g. to determine where higher stocking densities coincide with areas high or extreme pathway susceptibility within the zone of contribution. Delivery of P to turloughs from grazing animals or landspreading of animal manures and slurries within the ZOC is most likely to occur where this pressure coincides with a vulnerable pathway, e.g. shallow soil and subsoil or presence of karst features such as dolines and swallow holes. The scale of existing pressure and pathway data do not enable prediction of such risks.

11.4.3.2 Relationship Between OSWTS Density and TP

Unlike the animal stocking density data, the data for onsite wastewater treatment systems (OSWTS) relate to specific locations within the zone of contribution. Therefore, it was possible to examine not only the OSWTS density within the overall ZOC, but also the density of

OSWTS in particular areas within the ZOC. It was anticipated that OSWTS effluent would pose the greatest risk of P transfer to groundwater where the pathway susceptibility was extreme or high. , No significant correlations were found between the density of OSWTS in areas of extreme and high pathway susceptibility within the ZOC and TP (Figure 11.8). This does not rule out the possibility that OSWTS effluent may be of local importance for nutrient emissions, but does suggest that the effect of OSWTS are masked by large ZOCs and influence of other pressures.

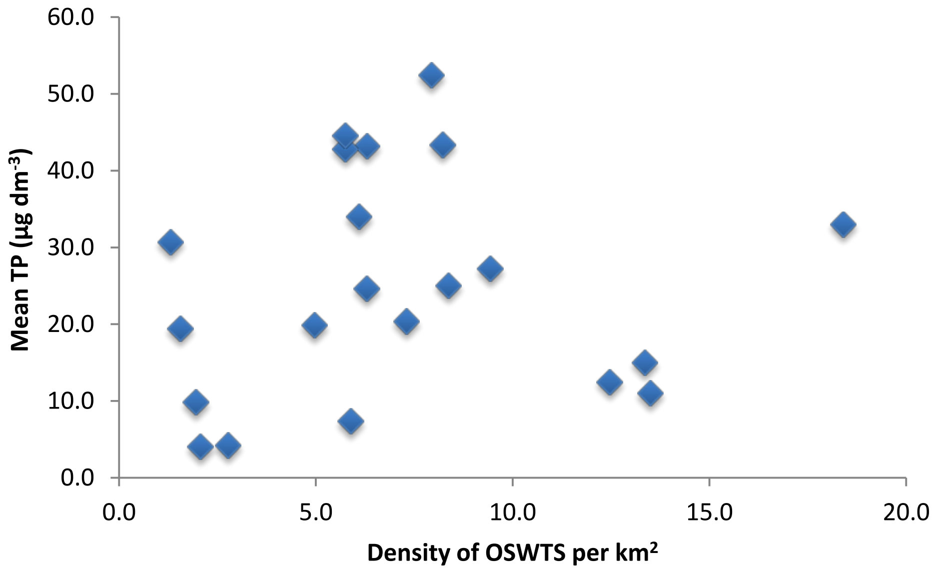

Figure 11.8. Relationship between density of OSWTS and mean TP in 21 turloughs ($r = 0.11$; $p > 0.05$).

11.4.3.3 Relationship Between Land Cover and TP

The two land cover factors showing a significant relationship with TP were pasture (from the CORINE dataset) and percentage of bare rock (from both the Teagasc and CORINE datasets). The highest degree of explanation was provided by the relationship with percentage of unimproved pasture; this showed a positive correlation coefficient of 0.69, explaining 48% of the variation in TP.

The CORINE 2000 dataset divided pasture land into two categories, improved and unimproved. This subdivision of pasture land was introduced in the original Irish CORINE study (O'Sullivan, 1994) because pasture accounts for such a high proportion of Irish land cover. It would be expected that improved pasture would be associated with higher P inputs than unimproved pasture. However, and counter-intuitively, the data show a positive correlation between TP and unimproved pasture, and no significant correlation between TP and improved pasture. There are several possible reasons for this.

Although CORINE 2000 used in the data analysis divided pasture into improved and unimproved, this division was subsequently abandoned as unreliable in the CORINE 2006 dataset. Therefore, the assumption that the improved pasture category in the 2000 CORINE dataset relates to more intensive agriculture may not be valid, and may the CORINE improved pasture category may not be associated with higher P inputs. The correlation of unimproved pasture with TP is among the most significant correlations of all the 46 relationships tested so, nevertheless, merits discussion. The higher correlation of TP with unimproved pasture than with CORINE all pasture (i.e. improved *plus* unimproved), implies that the distinction between unimproved and improved pasture is not meaningless, but has some currently unclear basis that results in higher risk of P transmission from unimproved than from improved pasture. It may be that areas of *'unimproved pasture*' from the CORINE interpretation of satellite imagery actually correspond to land that can support higher stocking densities, or that is more suitable for landspreading of manures and slurries; *ie* it may well *not* be pasture that has not been improved in some way. As discussed below, areas of bare rock and extreme pathway susceptibility are likely to be extremely vulnerable in terms of their pathway (presumably consisting of a patchwork of shallow rendzina soils and rock outcrop), but may have low P inputs, whereas areas of unimproved pasture may correspond to areas with a more complete and deeper soil cover which can sustain more intensive agriculture with higher P inputs. It is worth noting that the correlation of TP with unimproved pasture is higher than the correlation of TP with CORINE all pasture (i.e. improved *plus* unimproved), implying that the distinction between unimproved and improved pasture is not meaningless, but has some currently unclear basis that results in higher risk of P transmission from unimproved than from improved pasture. Perhaps areas of improved pasture coincide with areas of deeper or less permeable subsoil where the risk of P transfer is lower.

From the scatter plot (Fig. 11.6) it can be seen that the turloughs with a high percentage of unimproved pasture and high TP include the Roscommon group: Rathnalulleagh, Carrowreagh, Coolcam and Croaghill. These Roscommon turloughs also have a high percentage of acid soils in their ZOCs. So it is possible that the distinction between improved and unimproved pasture reflects a difference in the underlying soils and subsoils rather than a difference in land use intensity. Thus an alternative explanation of the positive correlation between unimproved pasture and TP may be that the relationship is highly influenced by those ZOCs where a high proportion of unimproved pasture corresponds to areas with more acid soils that are more prone to phosphorus loss. It may be noted that Daly *et al.* (2002), carrying out cluster analysis on 35 Irish river catchments, found that the cluster of catchments with higher molybdate-reactive phosphorus was associated with CORINE low productivity grassland (i.e. the equivalent from the original CORINE 1990 dataset to the CORINE 2000 unimproved pasture used in the present study)., and Ffurther data analysis attributed this relationship to differences in soil hydrology, with the higher P loss being associated with wetter soils.

TP showed a significant negative correlation with the % of bare rock from both the Teagasc and the CORINE land cover datasets. The higher correlation with the Teagasc dataset is explained by the fact that the CORINE dataset misclassified the land cover in the case of two Burren turloughs (Cunha Pereira, 2011). Areas with a high proportion of bare rock would have Extreme groundwater vulnerability and Extreme pathway susceptibility (see below), so might be expected to have a high risk of phosphorus transfer to turlough waters and therefore a positive correlation with TP. However, the negative relationship observed implies that the overriding factor associated with percentage bare rock was the pressure rather than the pathway. Areas with a mosaic of rendzina soil and bare rock are likely to be areas of less intensive agriculture with lower stocking densities, and where slurry spreading is less likely to be undertaken. Therefore the P loading on the land may be lower, resulting in lower P transfers to water regardless of the greater intrinsic vulnerability of such areas.

11.4.3.4 Relationship Between Pathway Susceptibility and TP

Pathway susceptibility is categorised in the WFD Article 5 risk assessment for turloughs (Risk assessment sheet GWTERA2a, discussed in Working Group on Groundwater, 2004) on the basis of soil type and groundwater vulnerability. Areas of Extreme pathway susceptibility includes areas of the ZOC underlain by karst limestone where the groundwater vulnerability is classed as Extreme (i.e. depth to bedrock <3 m) plus areas of the ZOC underlain by other aquifer types which lie within 50 m of a stream channel (on the basis that streams arising in non-limestone areas may sink underground or lose water through their beds on reaching the limestone).

The percentage of the ZOC occupied by areas of Extreme pathway susceptibility had a correlation coefficient of -0.53 and an r^2 of 0.28 (indicating that this ZOC characteristic explained 28% of the variation in TP). However, the negative relationship indicates that the higher the proportion of Extreme pathway susceptibility, the lower the turlough TP, as explained in the previous section. This is the opposite of the relationship expected from the assumptions underlying the WFD risk assessment (Working Group on Groundwater, 2004), where Extreme pathway susceptibility is expected to contribute to higher impact potential.

The reason for this apparent contradiction is presumed to be the fact that Extreme pathway susceptibility will only give rise to phosphorus transfer if it is combined with a phosphorus source. The WFD risk assessment identified the pathway and the pressure as two separate components of the risk assessment, combined in a matrix of impact potential. The analysis of the turlough data suggests that Extreme pathway susceptibility may be linked with lower pressure: as suggested above, it is possible that areas with extreme groundwater vulnerability associated with bare rock have less intensive agriculture with lower P inputs, giving rise to the observed negative correlation between Extreme pathway susceptibility and TP. Thus, turloughs such as Aleenaun, Ballindereen, Gealain, Roo West and Knockaunroe, located in the Burren / Gort lowland area, have a high percentage of Extreme pathway susceptibility in their ZOCs, but low TP because agricultural P loadings are likely to be lower in this region than in areas with a more complete soil cover. The lack of a clear, positive relationship between TP and Extreme+High pathway susceptibility also merits further discussion. The fact that turloughs with elevated TP are not necessarily associated with extensive areas of highly vulnerable pathways suggests that nutrients might be reaching turloughs via other pathways such as over-land flow from adjacent fertilized grassland. In some instances nutrients may also reach turloughs by groundwater input from highly localized high-risk locations that do not account for a significant percentage of the ZOC (e.g. where point sources of contamination such as animal feeders or farm waste stores coincide with point recharge locations such as dolines or swallow holes).

11.4.3.5 Relationship Between Soil Type and TP

The presence of acid versus basic soils in the zone of contribution also showed a relationship with mean TP in the turlough waters: the percentage of acid soils was positively correlated with TP ($r=0.74$, $r^2=0.55$) while the percentage of basic soils was negatively correlated with TP ($r=-0.69$, $r^2 = 0.48$). The scatter plot shows that the turloughs with the highest % of acid soils in their ZOC include four Roscommon sites (Rathnalulleagh, Carrowreagh, Croaghill and Coolcam), followed by turloughs in the Gort Lowland chain (including Blackrock, Coy, Garryland). The majority of acid soils in the ZOCs of the four Roscommon sites are classed by Teagasc as deep, well-drained soils derived from acidic parent material (shown on the subsoil map as glacial till derived from Triassic Dinantian sandstones). The acid soils in the Gort

Lowland turlough ZOCs are more diverse, including blanket peat, poorly drained acid mineral soils with peaty topsoil in addition to deep, well drained acid soils.

Acid peat-rich soils are more prone to phosphorus loss than basic soils derived from limestone glacial till. Daly *et al*. (2001) demonstrated that peaty soils have low P sorption capacities compared with mineral soils, attributed to the blocking or elimination of sorption sites with organic acids. In contrast, calcareous soils retain significant quantities of phosphorus due to both adsorption and precipitation (e.g. Tunesi *et al*., 1999; von Wandruszka, 2006). The interrelationship between acid soils and unimproved pasture (r=0.77, Table 11.6) may also be involved in explaining the higher P loss in these ZOCs. As discussed under land use above, Daly *et al*. (2002) attributed a relationship between higher P loss and unimproved pasture to greater losses from poorly drained soils including gleys, peaty podzols and peats.

11.4.3.6 Relationship Between Drainage Density and TP

A positive relationship between drainage density (in km/km^2) and turlough TP is evident (Table 11.4) though six turloughs with higher drainage densities than the others cluster together (Figure 11.6a). Five of the six are also among the group of turlough ZOCs that have a high % of acid soils (see above). While it is plausible that a high density of drains would increase the efficiency of transfer of nutrients from land to surface waters, drainage density is also highly correlated with % acid soils (r=0.73, Table 11.6) and a number of other catchment variables. Given the extent of project data, it is not possible to separate the effect of drainage density, acid soils and perhaps other variables as predictors of turlough TP.

11.4.3.7 Discussion of Multiple Regressions

Multiple regressions using logical combinations of variables which were expected to have a role in determining turlough phosphorus concentrations (i.e. the pressure variables of animal stocking density, septic tank density and the pathway factor of Extreme pathway susceptibility) provided a very poor degree of explanation of the data (16.3% of the variation in turlough TP explained). This is not unexpected, given the low r values for the individual relationships involved, discussed above. The degree of explanation is insufficient to enable prediction of TP values.

The second approach, whereby the variables with the highest individual correlation coefficients with TP (CORINE unimproved pasture and drainage density) were combined, provided a multiple regression with a much higher degree of explanation of the data (72.2% of the variation in turlough TP). However, as discussed above, the basis of the positive relationship between unimproved pasture and turlough TP is poorly understood. The distinction in CORINE between improved and unimproved pasture is now regarded as unreliable and has been excluded from the more recent CORINE 2006 dataset, and although it would appear from our investigations that there is a real distinction between the two categories, it remains far from clear whether this relates to land use intensity, soil type or some other factor. Although the multiple regression combining unimproved pasture and drainage density provides the best prediction of turlough TP for this dataset of 21 turloughs, the lack of a clear underlying scientific basis for the relationship is not understood makes it a potentially unreliable and makes it an inappropriate predictor for TP at a wider range of turlough sites. Detailed and more refined spatial information on land cover and stocking densities are required than are currently available in order to obtain more meaningful and more widely applicable predictors of P in turlough water; these might include a more specific habitat map of Ireland and readily available LPIS data

11.5 Export Coefficient Modelling

11.5.1 Export Coefficient Modelling Methods

Export coefficients were applied following methodology of Johnes *et al*. (1998) for surface waters, and as applied to Irish catchments by Irvine *et al*. (2001). Sophisticated modelling of nutrient export based on so-called process or semi-process models require much higher resolution of spatial and temporal data, and a knowledge of physical and chemical pathways and chemical transformation. This was not a feasible option given the resources of the project and the crude resolution of the landuse data that the project could access. In any case, complex process modelling would not necessarily provide more reliable model outputs than simpler export coefficient models (Irvine *et al*., 2005).

The lower end of the range of literature values for P export approximates an average emission of 7.7 kg P per head of cattle, and 1.5 kg per head of sheep per year. The Nitrates Regulations (S.I. No 610 of 2010) has provided a legal framework for "Good Agriculture Practice" (GAP). In Table 11.6 (associated with Articles 13 and 30) of these Regulations it is estimated that an adult dairy cow produces 13 kg of P per annum, and a lowland ewe and lambs, 2 kg. Exports of P were calculated based on both of these sets of values to provide a likely minimum to maximum range of nutrients in animal waste. This enables both a direct comparison with the results of Irvine *et al*. (2001) and an estimate that is commensurate with the Nitrates Regulations, which derive from the expert advice of *Teagasc.* Export Coefficients applied to land-use were taken from Johnes et al. (1994, 1996) and used previously for Irish catchments by Irvine et al (2001). For both cattle and sheep an export of 3% of load was used to estimate P loads to the turloughs. The average P load from humans discharged from OSWTS to the subsoil in Ireland was estimated as 2.4 kg P per household per annum (Gill *et al*., 2009). However, the subsoil (in particular calcareous based subsoils) have been shown to provide significant attenuation to such loads in Ireland and so a more realistic human export of 5% of the OSWTS load has been used, based on extensive field data from Gill and co-workers, which suggests 95% attenuation in typical soils less than 1 m thick, to give an annual export of 0.12 kg P per household.

There are clearly many assumptions inherent in an export modelling approach. However, all parameters were derived from published literature. The value of the approach, however, is as much in the trends across data sets as accurate quantification. Export coefficient modelling was tested against the mean measured concentration of TP from the seasonal data set described in Chapter 4. Modelling of mean concentrations of TP in turloughs was based on the empirical model of Foy (1992) derived for Irish lakes, but based on the well-known Vollenweider equation (OECD, 1982). Foy (1992) estimates mean in-lake TP to the mean load:

$$P_{Lake} = 1.118\ P_{input}/(1+\sqrt{\tau w})^{1.135}$$

where τw is lake residence time. For the turloughs the residence time applied to the Foy model was based on a separate modelling procedure described in Cunha Pereira (2011), which gave an "aggregated period coefficient" that accounts for the presence of water in the turlough and effects of inflows from other turloughs in the system. Aggregation periods for 19 turloughs ranged from 15 days (Turloughmore) to 176 days (Termon). Aggregation periods for the other three turloughs were estimated based on similarity of residence time given in days (Cunha Pereira *et al*., 2011).

Modelling of mean turlough TP was done first to provide an *a priori* estimate of loads to turloughs without considering the risk assessment of the Working Group on Groundwater (2004). This provides the *Basic model* taking account of the different livestock inputs*.* Export coefficient modelling is prone to "double accounting" of land use insofar as exports of nutrients from grasslands are inextricably linked with livestock use. This was avoided by considering export from grassland as dependent only on livestock densities. The assumption is that this integrates effects of land management. Export from peatlands, which represented a high percentage of landuse contributing to flow pathways from the Slieve Aughty mountains, was assumed to be accounted for by sheep inputs. Background inputs were assumed to represent a 3% export of average rainfall inputs in Ireland, estimated by Gibson *et al*., (1995) to be of 15 µg l^{-1}. There was an assumption of 3% load through the catchment and 100% (i.e. 15 µg l^{-1}) falling directly onto the turlough. Turlough area for the model was assumed to be 70% of the maximum area measured during the project. Some *post priori* modifications were made based in pathway susceptibilities as described above in section 11.3.1 (TCD approach).

11.5.2 Export Coefficient Modelling Results and Discussion

Input of P in rainfall to turloughs ranged between 0.45-0.55 µg l^{-1}, owing to variations in surface areas of turloughs, that causes a weighted dilution effect between water entering from the ZOC with an assumed coefficient of 3% of input and direct inputs onto the surface of the water with a concentration of 15 µg l^{-1}.

The full model, using a lower range of livestock P input of, respectively, 7.7 and 1.5 kg P for cattle and sheep (Johnes et al, 1994, 196: Irvine et al, 2000, 2001) provided a non-significant relationship ($r = 0.28$; $P > 0.05$) between modelled and measured mean turlough nutrient concentrations (Fig 11.9). Ballindereen was excluded from the analysis as the cattle densities were clearly unusually high, estimated as 4.5 ha^{-1} from the Agriculture 2005 census and corrected to be associated with CORINE grassland categories. This was more than twice the density of all except one of the other ZOCs, ranging from 0.7 (Lisduff) to 2.3 ha^{-1} (Lough Aleenaun). Ardkill, although having the highest recorded measured mean TP, was retained in the model as its concentrations were not strikingly outside the domain of the model results. Modelled TP for the lower livestock export model ranged from 11.4 µg l^{-1} (Lough Gealain) to 59.4 µg l^{-1} (Caranavoodaun). This compared with a range of mean TP measured of 4.0 µg l^{-1} (Lough Gealain) to 82.1 µg l^{-1} (Ardkill). Although the model did not produce a significant correlation with the measured concentrations, it is nevertheless instructive. The three turloughs with the highest modelled TP, but with comparatively low measured values (Caranavoodaun, Kilglassan and Skealoghan) to their cattle densities, and associated with grassland CORINE categories (respectively, 1.9, 1.5 and 1.2 ha^{-1}) in the ZOCs, have greater than 94% of the ZOCs comprising base soils. This suggests a high P attenuation capacity and/or inaccuracies in the cattle density data. The higher livestock model (Fig 11.10) produced, naturally, a similar spread of data points, but with slightly higher modelled values. Intercepts were between 12 and 13 µg l^{-1}, which is implicit of background "reference" state, and close to the value of 13 µg l^{-1} estimated for rainfall by Gibson et al. (1995), although the scatter around this is high.

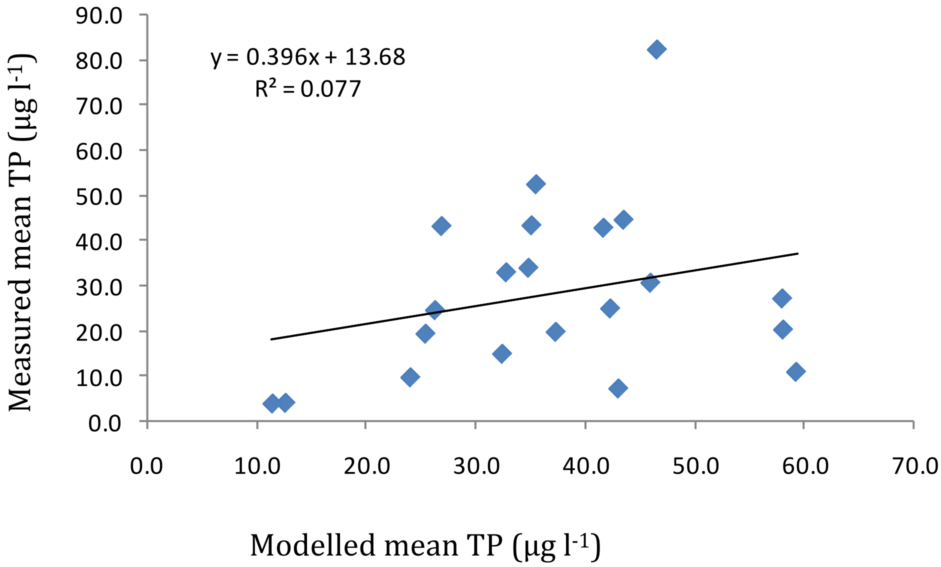

Figure 11.9. The relationship between the modelled and measured TP based on the full model with the lower livestock P inputs, and excluding Ballindereen.

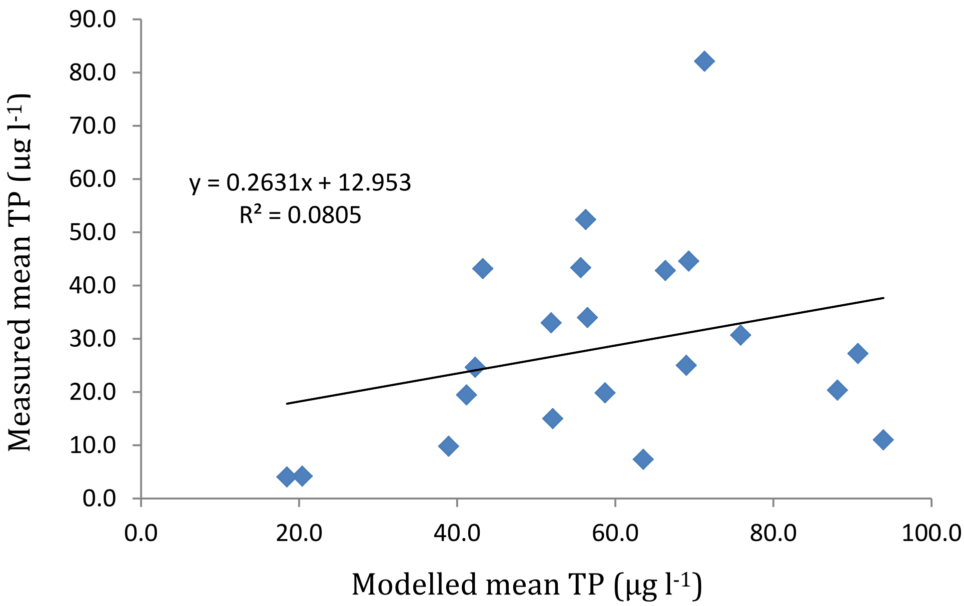

Figure 11.10 The relationship between the modelled and measured TP based on the full model with the higher livestock P inputs, and excluding Ballindereen.

The modelled data were also regressed against the sum of the percentage of the ZOC considered to be of extreme or high vulnerability of nutrient mobility from the surface to the groundwater, as developed by the Groundwater Working Group (GWDTE2a), again excluding Ballindereen. It is striking that there was a significant *inverse* relationship between this estimate of this vulnerability and the modelled TP using the higher P exports (r=-0.54; P< 0.05; n=21; fig 11.11). Using the lower P export estimates gave a slightly stronger relationship (r=-0.56; P<0.01; n=21). There was also a negative curvilinear response of mean measured TP in the turloughs with the Groundwater Working Group percent of ZOC assessed as high and moderate risk categories (Fig. 12; r=0.59; P <0.01; n=22). While the strength of the relationship was modest, it does reflect a gradient of impact on turloughs related to risk categories, but with TP *decreasing* with increasing vulnerability[1].

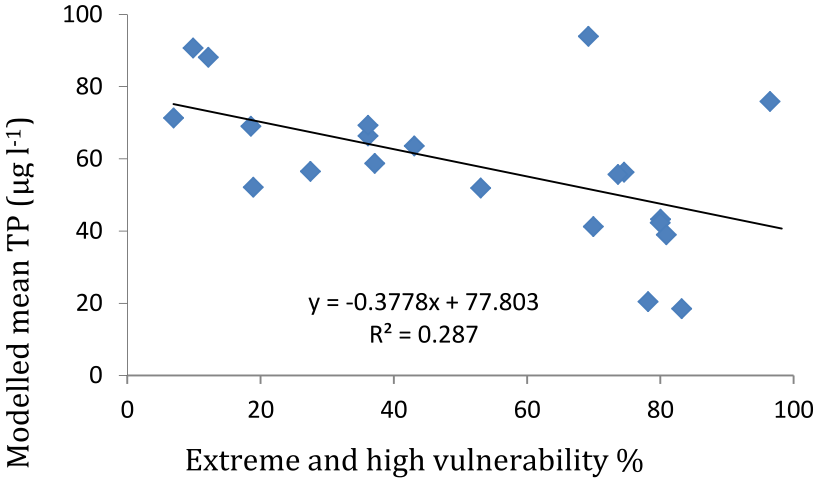

Figure 11.11 Relationship between modelled (high density livestock) mean TP and the percentage of catchment categorised as extreme or high vulnerability to phosphorus transport to groundwater. Ballindereen excluded.

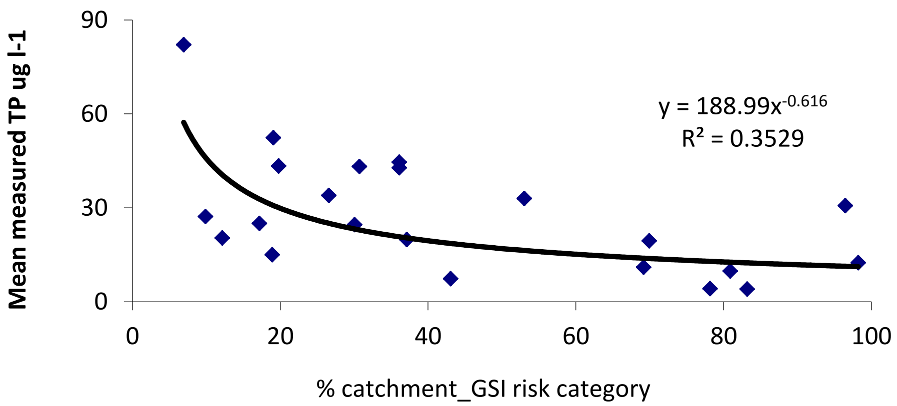

Figure 11.12 The relationship between measured mean TP in the turloughs and the percentage of the ZOC at high to moderate GSI risk category.

Collectively the results indicate lower land use intensity on thinner karst soils, supporting lower stock numbers. These results are supported by the significant negative correlations between measured mean TP and the prevalence of well-drained (r =-0.30 for entire date set and r= -0.58 if Ardkill removed) and base rich soils (r =-0.39 for entire date set and r= -0.69 if Ardkill removed). Shallow karst soils prevent intense cattle stocking unless accompanied by additional feedlots.

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[1] Interestingly, Hynds *et al.* (2012), examining susceptibility of pathogen pollution in private wells, showed that wells in Low vulnerability were more susceptible to pollution that those from Extreme vulnerability. They attributed this to greater surface runoff to the sides of the wells; the implication is that lower subsoil permeability may result in greater lateral transfer of contaminants, whereas in areas of Extreme vulnerability high subsoil permeability results in downward migration of contaminants

Although a positive correlation was found between the number of farms given a derogation under the Nitrates Regulations and the mean TP measured in the turloughs (r = 0.37 for entire date set and r= 0.60 if Ardkill removed), the maximum number of derogated farms in any one catchment was three, and it was not possible to definitively link these with nutrient exports to the turloughs. It does, however, suggest that in more intensively used catchments, the risk of nutrient enrichment of the turloughs increases. Indeed, on a field visit to the Cregduff catchment at the end of January, the potential negative impact of slurry spreading was clearly evident. This was just after the end of the seasonal restrictions on slurry spreading. Hence, farmers maximise their slurry spreading as soon as the period permits. Slurry was spread close to the edge of the turlough, providing an obvious source of enrichment, and emphasising the need for better management.

11.6 Discussion of Phosphorus Risk Assessment Findings

11.6.1 Relationships Between Turlough TP and ZOC Characteristics

11.6.1.1 Relationship Between Landuse Intensity and Turlough TP

The Risk Assessment (RA) procedures and use of simple models appropriate to the resolution of the data illustrates the difficulty of associating landuse with turlough water quality, with no clear relationships found with measured mean TP. The current predictive WFD RA approach cannot be used to effectively target turloughs with water quality issues for further investigation/monitoring. The revised TCD RA approach is an apparent improvement on the original, but the lack of any clear relationships between the Impact Potential proportions and floodwater TP concentrations across turloughs suggests that the current spatial resolution of pressure and pathway data is insufficient to enable reliable prediction of turlough floodwater quality. In light of this and the uncertainties associated with ZOC delineation in karst areas, further catchment modelling work should target turloughs already identifed as having reduced water quality based on floodwater sampling. Such modelling work would benefit from a critical source area approach (Doody et al. 2012), combining catchment and field scale risk assessment to identity critical source areas of nutrient loss.

Overall, useful insights into the relationships between floodwater TP and catchment variables were provided by the risk assessment work. Highly vulnerable ZOCs were associated with *lower* rather than *higher* concentrations of TP, suggesting the inverse relationship between land use intensity and surface to groundwater pathways. This is not surprising given that intensity of use and capacity of use are inextricably linked. This interaction between landscape capacity and landuse intensity greatly confounds catchment (or ZOC) models to predict impact from pressures. The karst landscape of the turloughs provides a highly patchy physical and landuse environment and can, in part, explain the lack of significant relationships between cattle density and turlough water quality. It is, however, important to recognize again the inappropriate scale of the available data. The stocking densities available are for District Electoral Divisions, and may not adequately reflect the stocking density in the ZOC. Using CORINE land cover classes as a surrogate of stocking density did not improve the relationship. It was not possible to use finer scale stocking densities (e.g. on a farm basis), as Government policy maintains these data are confidential.

As noted in section 11.4.3, a further issue arising from the coarse resolution of the animal stocking density data is that it was not possible to combine this pressure layer with a pathway layer to assess higher stocking densities with high or extreme pathway susceptibility within the ZOC. Ideally, data on stocking densities per land parcel over time would be required to more completely investigate pressures related to pathway susceptibility. Such detailed data do not exist at present, and might be difficult to obtain as this would likely place administrative burdens on farmers to report such data. In the meantime, making available the existing data on stocking density per farm (rather than per DED as was available to this project) would be a significant step in allowing a more refined study of pressures and pathway susceptibilities.

Further factors affecting landuse intensity and turlough water quality are possible groundwater dilution effects, and the connectivity of turlough chains. Across a large ZOC the output chemistry may have low to moderate nutrients, as in the case of the Cregduff catchment, while there may be individual turloughs with water quality problems. Separating local from a larger scale of impact remains unresolved.

11.6.1.2 CORINE, Landuse and the Conundrum of the Relationship of Unimproved Pasture on Turlough TP

The most significant relationship found in the correlation analysis was between percentage of unimproved pasture and mean measured TP in the turloughs, which explained 47% of the variation in TP. As discussed in section 11.4.3, a negative correlation between turlough TP and unimproved pasture was anticipated, on the basis that such areas would have lower P inputs, but the data showed a positive correlation. It may be that areas of “unimproved pasture” from the CORINE interpretation of satellite imagery correspond to areas with a more complete soil cover than areas with extreme pathway susceptibility, which can sustain more intensive agriculture with higher P inputs, while areas of improved pasture may coincide with areas of deeper or less permeable subsoil where the risk of P transfer is lower. Alternatively, it is possible that the distinction between improved and unimproved pasture reflects a difference in the underlying soil and subsoil type rather than a difference in land use intensity, most likely explained by areas of unimproved pasture coinciding with areas of more acid soils producing a greater phosphorus loss than through basic soils. The export coefficient modelling indicated that some turloughs with relatively high intensity land use nevertheless had low TP in the turloughs. Owing to sorption and co-precipitation of phosphate with $Fe(OH)_3$ and $CaCO_3$, calcareous systems have a generally high buffering effect to phosphorus pollution. With increasing phosphorus loading, the capacity for calcareous systems to remove phosphorus, either during transport to a water body or within the water body, diminishes. This has been demonstrated in the percolation areas of many septic tanks and OSWTS (Gill *et al*., 2009), and at a larger scale in the calcareous lake Lough Carra which is a marl lake and has many characteristics similar to turloughs (Hobbs *et al*., 2005). In Carra, long-term monitoring, analysis of phosphorus in sediment cores and experimental work on sediment absorption of phosphorus provided supporting information of a gradual decline in lake water quality over approximately the last 40 years (Hobbs *et al*., 2005; Donohue *et al*., 2009).

11.6.1.3 Relationship Between OSWTS Density and Turlough TP:

Because the septic tank data related to specific locations within the ZOC contribution, it was possible to examine not only the septic tank density within the overall ZOC, but also the density of septic tanks in particular areas within the ZOC. The export coefficient modelling approach illustrated that OSWTS may provide only a very small potential contribution to P loads compared with cattle. This was borne out through analysis of the relationship between turlough TP and OSWTS discussed in section 11.4.3. In general, attenuation from OSWTS through less than 1 m of typical glaciated subsoils is greater than 95% (L. Gill *et al*., unpublished data), though discharge into very shallow soils may result in effluent directly entering fissures and hence potentially rapid movement into turlough waters. From the modelling work, it can be concluded that, overall, OSTWS effluent is not currently a major contributor of TP to turloughs in most instances. This does not, of course, rule out the possibility that septic tank effluent may be important in some situations, and OSWTS and their percolation areas need to be properly designed, constructed and operated at the highest standard (EPA, 2009).

11.6.1.4 Relationship Between Pathway Susceptibility and TP

As discussed in section 11.4.3, the percentage of the ZOC occupied by areas of extreme pathway susceptibility showed the second-highest correlation coefficient of the 46 relationships examined, with an r-value of -0.57 and an r^2 of 0.32. However, the negative relationship indicates that the higher the proportion of extreme pathway susceptibility, the lower the turlough TP. The suggested reason for this apparent contradiction is that areas with Extreme groundwater vulnerability associated with bare rock have less intensive agriculture with lower P inputs.

11.6.2 A Reference Phosphorus Concentration for Turloughs

Defining turloughs as GWDTE under the WFD, while for much of the year they exist and function as shallow water bodies, provides difficulties for their effective management. Under the EU Habitats Directive (CEC, 1992), the protection of designated sites (as Special Areas of Conservation (SACs)) requires meeting *favourable conservation status* (FCS). For similar limnetic ecosystems, notably calcareous shallow lakes, failure to meet FCS, would result in designation under the WFD as less than good status. Quoting from paragraph 49 of S.I. No. 272 of 2009, on European Communities Environmental Objectives (Surface Waters) Regulations 2009 (Government of Ireland, 2009): *For the purpose of calculating the ecological status of a body of surface water in accordance with Part IV of these Regulations, the Agency shall, in the case of those surface water bodies which are also protected areas requiring special protection by virtue of standards or objectives arising from specific Community legislation for the protection of water or for the conservation of habitats and species directly dependent on water at European sites, assign a status of less than good ecological status where the standards or objectives for the protected area are not met arising from a failure to meet the required water quality or hydrological standards. Where appropriate, the use of additional site specific biological, microbiological or chemical indicators will be used.*

However, the designation of turloughs as GWDTEs, requires that the groundwater that turlough are dependent on must meet *good status* by merit of chemical and hydrological characteristics that do not cause damage to the GWDTE. Therefore, under the WFD the status condition of the turlough is dependent on the groundwater chemical qualitative and hydrological quantitative status, whereas under the Habitats Directive it is dependent on assessment of physical habitat and ecology. The difficulties in achieving compatibility between the WFD and Habitats Directive are recognized (Irvine, 2009). For turloughs this manifests in their designation as GWDTEs,. Current implementation of the Directives suggests that if under the Habitats Directive they fail to meet FCS, this does not necessarily lead to a less than good status under the WFD. It also confuses the relevance of applying the concept of *reference state* under the WFD because as GWDTE this is not dependent on the structure and function of the biological elements (as defined in Annex V of the WFD), as for other water bodies, but on the physical and chemical characteristics of the groundwater. Addressing these contradictions is clearly necessary to overcome distortions of logic as, in their limnetic phase, the limnology of turloughs is generally similar to shallow lakes (Cunha Pereira, 2011; Cunha Pereira *et al*., 2011).

A further complication in aligning the objectives of the WFD and Habitats Directive for turloughs is the requirement that Member States are required to designate SACs as the best representatives of a particular habitat. For turloughs this would appear to require designation of relatively unimpacted sites. This would logically be those with low nutrient status, and equivalent to a condition of *reference* state under the philosophy of the WFD, but is not a requirement for WFD designation of GWDTEs. Nevertheless, the status of the groundwater supplying the flooded phase of turloughs should not compromise the environmental objectives of GWDTEs and *de facto* cross-compliance with the Habitats Directive.

Article 8 of the WFD, which explicitly incorporates obligations for nature conservation, would strongly suggest a need to implement objectives of the flooded phase of turloughs to be synonymous with high status water bodies as defined by the WFD. As such, applying the principles of a reference state to the flooded phase appears entirely reasonable and in keeping with the spirit of both Directives. Linking this approach with low intensity grazing systems for the terrestrial phase for agreed conservation objectives through management plans is not a contradiction to a reference approach to the flooded phase, merely a traditional and common sense management for nature conservation.

The nutrient and algal dynamics of turloughs have been shown to function in a similar manner to permanent lakes and the current state of knowledge, although limited, provides no compelling reason not to approach an understanding of turlough chemistry in the same way as is done for lakes. For turlough SACs this implies that nutrient status needs to be compatible with the approach and terminology of the WFD, and where reference conditions equate to the upper end of the high status band.

This implies that the chemical status of groundwater bodies that supply any turlough SAC needs to be more stringent than the WFD requirement of *good* chemical status applied to other surface water bodies. Hence, if the nutrient concentrations of the groundwater body provide a high risk of leading to unfavourable conservation condition of the turlough SAC then the ground water body will be less than *good* status. In practical terms, maintaining groundwater nutrient concentrations compatible with surface water reference conditions for relevant shallow lake types provides for the most obvious mechanism for a water supply that does not impact FCS, as discussed above. The question then is what are reference nutrient concentrations for those types of water bodies?

The estimation of background concentrations in all water bodies is problematic as it is unlikely that any waterbody in Ireland has no anthropogenic inputs of phosphorus. Even upland systems receive about 15 µg TP l^{-1} (Gibson *et al*., 1995). In calcareous lakes and most turloughs, however diffuse inputs of this concentration would likely be adsorbed or precipitated in the lakes and surrounding catchment. However direct inputs from springs and stream inflow could results in higher concentrations of TP entering turloughs. A further practical aspect is that many measurements of groundwater, as for rivers, have been of soluble reactive phosphorus, and there is a need to reconcile this in a discussion of groundwater-surface water links in turloughs. Because P in the open-water is rapidly taken up by algae, in standing waters it is assumed that TP represents the best measurement of potential phosphorus availability. In the darkness of the groundwater dissolved P is the better surrogate of nutrient status. Hence to grasp the potential of nutrient status of groundwater to affect turloughs, and to gauge relevant reference nutrient reference state there is a need to consider SRP concentrations in groundwater as potential TP once it is subject to biological uptake and cycling in the open water of turloughs.

The majority of groundwater bodies in the Republic of Ireland have median soluble reactive phosphorus (SRP) <20 µg P l^{-1}. Kilroy (2001), using national data from 1995 to 1997, found a median value of 17 µg P l^{-1} of unfiltered molybdate reactive P in groundwater, but that one quarter of the data were higher than 30 µg l^{-1}. Under the previous EPA lakes classification system (based on OECD, 1982, and assuming as equivalent with TP) this would be considered eutrophic values for standing surface waters.

Background SRP in surface waters within a limestone geology are likely to be <10 µg P l^{-1} (Holman *et al*., 2010). Background soluble phosphate concentrations of 20 µg MRP l^{-1}, based on 149 records from confined Irish aquifers considered to have low anthropogenic impact, were proposed by O'Callaghan Moran & Associates (2007). This value was the 90th percentile of the data, representing the upper limit of natural background conditions, and the mean MRP from the dataset examined by O'Callaghan Moran & Associates (2007), of 6 µg MRP l^{-1}, was judged by Baker *et al*. (2007) to be a better indication of typical natural background conditions. These values are also based on estimates of dissolved phosphorus from unfiltered samples, with the assumption indicated above that dissolved phosphorus in groundwater becomes incorporated into measures of total phosphorus in surface waters. This assumption is made because groundwater lacks light for photosynthetic incorporation of phosphorus into biomass, but it also reflects the use of MRP from unfiltered samples in regulations for river quality, whereas the standard approach for lakes is to measure TP.

11.6.3 The Setting of a Groundwater P Threshold Value for Groundwater Bodies Containing Turloughs

The Groundwater Regulations implementing the EU Groundwater Directive (2006/118/EC) in Ireland (S.I. 9 of 2010) set a threshold value of 35 µg l^{-1} P for MRP (not specified whether filtered or unfiltered). This is based on the criteria for surface waters in the Surface Water Regulations (S.I. 272 of 2009), which include a mean value of <= 35 µg l^{-1} for MRP for good status of river water bodies. When assessing the adverse impacts of chemical inputs of groundwater on associated surface water bodies, poor status of the groundwater body depends on (a) the surface water body failing to achieve good status, and (b) the inputs via groundwater contributing more than 50% of the surface water standard in the surface water body; determination of (b) depends on both the phosphorus concentration in the groundwater body and the groundwater flow contribution to surface water.

Because no phosphorus standard for lakes was set in the Surface Water Regulations, impact on lakes is not taken into account in defining groundwater body status in relation to phosphorus. However, using the above assessment based on the river water body standard, the data for 2007-2009 resulted in 13.3% of the area of Ireland being classed as of poor groundwater body status due to the presence of phosphate in groundwater, and these areas were mainly in the karstified limestone aquifers in the west of Ireland, where mean MRP concentrations were typically >30 µg l^{-1} and more than 60% of stream flows are from groundwater (Daly, 2009). Therefore from 2009 until 2014, many of the karst groundwater bodies containing turloughs were already defined as of poor status because of potential impact of groundwater P on rivers, using the 35 mg l^{-1} MRP threshold. However, it is important to note that examination of the more recent dataset from 2010 to 2012 resulted in a recent (2014/2015) reclassification of these western karstic groundwater bodies to good status (source: EPA online data at http://gis.epa.ie/Envision). Whereas the designation of these groundwater bodies as of poor status because of potential impact of groundwater P on rivers might potentially have resulted in the initiation of additional programmes of measures in relation to phosphorus which would have benefitted turlough water quality, the more recent drop in MRP concentrations in the groundwater monitoring data and the resultant return to good status means that it has become more critical to provide an independent assessment of the chemical status of groundwater bodies associated with turloughs, in order to ensure that sufficient protection is provided for these ecosystems.

As noted in *Chapter 4: Water Chemistry and Algal Biomass*, the mean concentrations of total phosphorus in the 22 turloughs examined in this study ranged between 4.0 and 82.1 µg l^{-1} TP (Table 4.1). A linear relationship was observed between log mean TP and log mean chlorophyll a (a measure of algal biomass), similar to that observed in permanent lakes (Chapter 4; Cunha Pereira *et al*., 2010). This relationship did not show any obvious clusters or break points, and therefore it should be acknowledged that the identification of threshold values for turlough TP involves the division of a continuum rather than the use of any clear natural groupings.

When classifying turlough water quality using TP data, we have attempted two approaches, firstly by treating the turloughs as being comparable to permanent lakes (given the fact that they demonstrate a comparable relationship between TP and algal biomass) and secondly by examining the ecological characteristics of the turloughs themselves:

1. As noted above, the current Surface Water Regulations implementing the Water Framework Directive in Ireland (SI 272 of 2009) do not set any phosphorus standards for lakes. A widely used international classification system for lake trophic status is that of OECD (1982), and the turloughs were classified according to this in Chapter 4. According to the OECD categories based on TP, four of the turloughs are classed as oligotrophic (TP<=10 µg l^{-1}), 12 as mesotrophic (TP >10 and <=35 µg l^{-1}) and six as eutrophic (TP>35 µg l^{-1}) (Table 4.1). However, as noted in Chapter 10, a mean TP value of 20 µg l^{-1} was used for Irish permanent lakes as the boundary between mesotrophic and eutrophic conditions in the 1998 Phosphorus Regulations (SI 258 of 1998) and in McGarrigle *et al*. (2002). Twelve of the 22 turloughs in the present study have a mean TP exceeding 20 µg l^{-1}, while 10 have a mean TP of less than or equal to 20 µg l^{-1}.

2. In Chapter 10, when assessing the conservation status of turloughs for the Habitats Directive, turlough water quality was placed into the following classes using mean water TP concentrations:
    - <=10 µg TP l^{-1} were considered to indicate 'very good' quality (4 of the 22 sites),
    - >10 and <=20 µg TP l^{-1} to indicate 'good' quality (6 of the 22 sites),
    - >20 and <= 50 µg TP l^{-1} to indicate 'intermediate' quality (10 of the 22 sites),
    - >50 µg TP l^{-1} to indicate 'poor' quality (2 of the 22 sites).

The threshold of 20 µg l^{-1} providing the boundary between 'good' and 'intermediate' quality was based on the observation (Chapter 5) that extensive filamentous algal mats were likely to occur in the main body of turloughs with TP above this value.

We propose that the water TP concentrations used for the Conservation Assessment of the turloughs under the Habitats Directive in Chapter 10 should also be adopted for classifying turlough water quality for the Water Framework Directive. As turloughs are by definition intimately connected with groundwater, we consider that the water quality boundaries for turloughs should correspond to the threshold values for groundwater bodies supplying turloughs. Therefore we propose that a key groundwater threshold value for groundwater bodies supplying turloughs should be 20 μg l^{-1} mean TP, and that exceedance of this threshold in either the turlough itself or in the groundwater supplying the turlough should trigger further investigations. As noted above, this threshold value is based not only on turlough characteristics (occurrence of filamentous algal mats) but also on previous Irish lake water quality standards (i.e. the 1998 Phosphorus Regulations), taken in the absence of lake TP standards in the current Surface Water Regulations.

However, we note that use of this single TP threshold would not serve to maintain the water quality of turloughs which are classed as oligotrophic according to the OECD system, or as 'very good' quality according to the turlough water quality classification system above, i.e. sites with a mean TP of 10 μg l^{-1} or less. Although turloughs are classed as groundwater dependent terrestrial ecosystems for Water Framework Directive purposes, rather than as water bodies, it must still be acknowledged that they show a similar relationship between TP and algal biomass as lake water bodies. Therefore, in the same way that lake water bodies of high water quality status must be maintained at high status rather than being permitted to fall to good status, it is reasonable that every effort should be made to maintain turloughs of very good water quality in that condition, rather than setting a single TP threshold value that would allow their water quality to deteriorate. Maximising safeguard for turloughs could involve adopting a reference based approach as for shallow lakes. WFD compliance would not prevent this.

The low mean TP in Lough Gealain and Knockaunroe (both 4.0 μg l^{-1}) indicate a low level of agricultural activity and human habitation in the ZOCs of these turloughs; as such they represent the highest status turloughs that we know of, with the lowest impact of nutrient enrichment. Similarly low levels of TP have been found in Muckross Lake in Co. Kerry which also receives drainage from a relatively unimpacted catchment. It would appear that an average TP of 4.0 μg l^{-1} may be close to the lower limit of what is found in lowland standing waters in Ireland. The concomitant concentration of TN in these two turloughs was 0.5-0.6 mg l^{-1}. Lough Gealain and Knockaunroe may therefore be considered to represent the least impacted turloughs when considering nutrient inputs.

Taking the issue of high quality sites with low impact into account, we propose that in addition to the general groundwater threshold value for groundwater bodies supplying turloughs, of 20 μg l^{-1} TP, a more stringent threshold of 10 μg l^{-1} mean TP should be used in some circumstances. These circumstances need to be obvious to field survey workers and also linked to specific assessments for the more oligotrophic turloughs described in *Chapter 12: Monitoring Methods*. We propose that the majority of potentially oligotrophic turloughs can be predicted from the following criteria:

> Turlough soil type is <u>**not**</u> predominantly mineral or silt-based (i.e. organic or marl based), **and**:
>
> Turlough has limestone pavement within the turlough basin or within 100 m of the turlough, or
>
> Turlough contains the readily identifiable vascular plants *Potentilla fruticosa*, *Frangula alnus* or *Schoenus nigricans*.

We examined a wide range of data, relating to both the turlough itself and the ZOC in drawing up these criteria, and our thinking has been primarily guided by attempting to define criteria that could usefully and pragmatically be applied to a previously unstudied turlough. We abandoned ZOC data due to the great uncertainly in their delimitation, though we kept some wider landscape context in considering turloughs adjacent to limestone pavement; the flooded pavement communities (Chapter 7, and also those of Goodwillie, 1992) correspond well with low TP. Several vegetation communities are also restricted to low TP sites, but the *Potentilla fruticosa/Frangula alnus* and *Schoenus* fen communities have very characteristic species which can be readily identified. Future research may well refine criteria at which lower TP threshold values are applied, through detailed investigation of TP in a larger number of turloughs than were studied here. This combination of soil type, landscape context and a small number of highly characteristic vascular plants identifies all turloughs from the 22 studied in detail that have low TP, or which occur in a context where low TP should be indicated but recent anthropogenic disturbance has resulted in high TP.

Our aim in setting these thresholds and adopting these criteria is to ensure that the very good water quality of oligotrophic sites is maintained.

11.6.4 Prediction Versus Monitoring of Turlough TP

Three different approaches to predicting turlough TP were attempted in this study: modification of the WFD risk assessment methodology (section 11.3), regression analysis of the relationships between turlough TP and source and pathway factors in the zones of contribution (section 11.4), and a nutrient export coefficient modelling approach (section 11.5). While these different approaches added to the conceptual understanding of the relationship between turlough TP and characteristics of the ZOC, several key relationships remain unclear, and the reliability of prediction is greatly hampered by the scale of existing datasets, particularly the DED-scale agricultural data and the karst features providing locations of extreme vulnerability.

These data shortcomings could be overcome by intensive field investigations of the type undertaken in the Cregduff catchment by the Teagasc Agricultural Catchments Programme team (Mellander *et al*., 2012). Mapping of animal stocking densities, fertilizer application rates and soil test phosphorus on a field-by-field basis, combined with intensive mapping of soils, subsoils and karst features, should enable the development of much more reliable models for prediction of turlough TP. However, such investigations are extremely labour intensive, time-consuming and expensive, and they are unlikely to be undertaken in the zones of contribution of a large number of turloughs in the foreseeable future.

Therefore it is proposed that rather than devoting further intensive effort to prediction of turlough TP, a more realistic approach is to carry out annual monitoring of turlough TP. Frequent monitoring of a large number of sampling points within each turlough throughout the flooding season would provide highly reliable TP data, but again this approach would be labour-intensive and expensive. However, as discussed in Chapter 4, section 4.4.7, a reasonable estimate of annual mean TP for each turlough could be provided by a single sample taken in the middle of the flooding season, thereby providing a relatively cost-effective and rapid indication of turlough TP which could be compared with an agreed threshold value.

11.6.5 Management

While estimating critical source areas and pathways of P into turloughs is difficult, it is clear that sufficient precautions need to be in place to minimise the risk. It is also obvious that intensive grassland farming necessitating derogation under the Nitrates Regulations is not compatible with turlough protection if there is risk of nutrient loss to turloughs. Nutrient loss is determined by the coincidence of nutrient sources and transfer pathways. For example, there is a high risk of P loss to turloughs via overland flow from poorly drained soils with elevated P levels. The current policy is that there is no requirement for DAFM to consult with NPWS on possible effects of derogated farms on water quality in water-dependent SACs. More widespread collaboration between DAFM and NPWS is required to provide reliable estimates of livestock densities in turlough ZOCs, to aid the development of more explicit landuse-water quality models going forward. Furthermore, the "Good Agriculture Practice" under S.I. 610 of 2010 is not designed to protect High Status water bodies and is unlikely to even provide adequate protection for Good Status (Irvine & Ní Chuanigh, 2011). Turlough SACs requires the maintenance of *'favourable conservation status'*, which requires appropriate management in both the turlough <u>and</u> immediate surroundings, and for the critical source areas in the wider catchment that may provide a subterranean link with the turlough.

Given the current status quo of land-use policies, and the failure of the Habitats Directive to protect priority habitats and species (e.g. NPWS, 2008) alternative approaches are required for the protection of not only of high conservation value sites (SACs), but of the wider landscape in which they lie. The wider turlough landscape has overlap, and many similarities, with that of the Burren, within which there has been a move to farming for nature under the BurrenLIFE project and Burren Farming for Conservation Programme (BurrenLIFE, 2010). There are lessons to be learnt from this approach that could provide improved protection for turloughs. Such a move would also promote greater cross compliance across European policies and could, for example, be implemented through forthcoming modifications to agri-environment schemes.

11.7 Quantitative Risk Assessment

The following section is based on the review of the Impact Potential Assessment for GWDTEs by Kimberley & Coxon (2013).

Aquifer class and groundwater flow regime will strongly influence the certainty of zone of groundwater contribution (ZOC), recharge and specific yield estimations, and the impact of abstractions on the GWB. Despite this, neither aquifer class nor groundwater flow regime is taken into account in the current Impact Potential Matrix for ZOC abstraction pressures (WFD Working Group on Groundwater, 2004). Eleven aquifer classes are identified in the national aquifer map, grouped into the following four groundwater flow regime types:

1. Karstic,
2. Fissured,
3. Poorly productive, and
4. Intergranular.

The extreme heterogeneity of karstic flow regimes results in lower confidence in ZOC delineation and recharge estimation. For example, Tedd *et al.* (2012) examined three groundwater-level monitoring points in close proximity to one another within a highly karstified sub-catchment of the Nore River Basin, and found considerable variation in hydrograph character, highlighting the complexity on karst flow systems. The GWB flow regime will also affect the susceptibility of the GWB to groundwater abstractions. Differences in specific yield will result in groundwater abstractions as percentages of recharge resulting in a much larger water-level drop in fractured aquifers than in sand and gravel aquifers, because the latter have large intergranular storage available. Assessments of the relative impact of groundwater abstraction thresholds should therefore be more conservative for GWDTEs occurring within karstic and fissured flow regimes than for those with intergranular flow regimes. Poorly productive bedrock aquifers are also likely to be more sensitive to groundwater abstractions than extensive sand and gravel aquifers. Kimberley and Coxon (2013) recommend that consideration should be given to developing a matrix for assessing the potential impact of different abstraction thresholds on different aquifer classes, or the more generalised flow regimes, occurring within ZOCs for the next River Basin Cycle. They further suggest that assessment of the aquifer classes typically occurring within the ZOCs of calcareous fens, turloughs, petrifying springs, machair and groundwater-dependent alluvial forests should be a priority which preceeds the development of such a matrix. An example of the type of matrix that might be developed following assessments of aquifer classes occurring within GWDTE ZOCs is given in table 11.8.

Table 11.8. An example of the type of matrix that might be developed in order to incorporate groundwater body (GWB) flow regime into the quantitative pressure risk assessment process for groundwater-dependent terrestrial ecosystem (GWDTEs). Based on Kimberley & Coxon (2013).

	Impact of abstraction on GWB flow regime (aquifer classes*)			
GWB abstraction as a % of recharge in ZOC of GWDTE	**Karstic (Rkc, Rkd)**	**Fissured (Rf, Lm)**	**Poorly productive**	**Intergranular (Rg, Lg)**
>20%	High	High	High	High
10-20%	High	Moderate	Moderate	Moderate
5-10%	High	Moderate	Moderate	Low
<5%	Moderate	Moderate	Low	Low

Rkc: Regionally Important Karstified Bedrock Aquifer (conduit flow); **Rkd:** Regionally Important Karstified Bedrock Aquifer (diffuse flow); **Rf:** Regionally Important Fissured Bedrock Aquifer; **Lm:** Locally Important Bedrock Aquifer, Generally Moderately Productive; **Rg:** Regionally Important Sand/Gravel Aquifer; **Lg:** Locally Important Sand Gravel Aquifer. ZOC, zone of groundwater contribution.

Development of a matrix as described in table 11.8 could then enable improved assessment of the impact potential of abstraction on the GWDTE types, by combining the impact of abstraction on the GWB with the GWDTE sensitivities to changes in groundwater quantity. The current Impact Potential Matrix for assessing the impact of abstraction on GWDTEs does not include an extreme GWDTE sensitivity category (WFD Working Group on Groundwater, 2004) even though numerous GWDTEs are considered to have an extreme sensitivity to changes in groundwater quantity (WFD Working Group on Groundwater, 2005). Kimberley and Coxon (2013) recommend that this matrix be revised to include an extreme sensitivity category. They also recommend that the current matrix (Table C2 – WFD Working Group on Groundwater, 2004) for assessing the impact of local abstraction and arterial drainage on GWDTEs should similarly be revised to include an extreme 'GWDTE sensitivity to changes in groundwater quantity' category. Finally, Kimberley and Coxon (2013) suggest that this matrix should also be amended to include the statement *'within a 100 m distance that can influence the ZOC'* rather than the current *'within 100 m of boundary'* as a down gradient drain or abstraction may change the position of the ZOC boundary.

Clearly, the current Impact Potential Matrix is not well suited to the assessment of abstraction impacts on turloughs, and a more refined approach is recommended.

11.8 Summary and Conclusions

In this chapter we took three different approaches to assessing risk and estimating P enrichment in turloughs:

- WFD risk assessment procedures based on GWDTTERA2a, examining pathway susceptibility, pressure magnitudes and impact potentials
- Regression of various landscape factors on measured TP in turlough floodwater to assess factors likely to influence TP
- Export coefficient modelling based on predicted P inputs.

The WFD risk assessment approach suggests that of the 22 turloughs studied in detail, 12 were at significant risk (category 1A) and 9 probably at significant risk (category 1B). However, the proportion of the ZOC for each turlough with various impact potentials (extreme, high, moderate, low and any combination of extreme, high and moderate potentials) showed no relationship to measured TP. The most oligotrophic sites were not associated with ZOCs dominated by low impact potential. Difference between risk, and actual P enrichment; for example Lough Gealain has low TP but would be at high risk of damage if factors operating within the ZOC change to result in increased P inputs.

For regression analysis, three factors in the ZOC were considered likely to influence TP recorded in turloughs: the total livestock per ha, the percent of ZOC with extreme pathway susceptibility, and the number of septic tanks. In fact these variables gave a poor explanation of total P, with percent extreme pathway susceptibility surprisingly showing a negative relationship with TP; this was also shown in the export coefficient modelling approach where modelled TP showed a significant negative relationship with the percentage of extreme and high vulnerability in the ZOC. There was a strong positive correlation between the percent of extreme pathway sensitivity and the amount of bare rock in the ZOC; areas with exposed limestone pavement will have extreme pathway susceptibility and hence high risk, but these ZOCs tend to have low habitation and low agricultural usage (eg Knockaunroe, Lough Gealain), which likely explains the low TP.

In fact multiple regression approaches revealed the best predictor of TP was a model with CORINE 2000 *'unimproved'* pasture and drainage channel density, these independent variables explained over 72% of the variation in TP. It is possible that *'unimproved'* pasture is the most likely land classification to carry grazing animals in these turlough ZOCs as a whole, though doubtless there will be individual exceptions to this (for example the relatively few ZOCs which had high percentage of improved and more intensively managed pasture).

While the mechanism underlying our relationship between measured TP and the % unimproved pasture and number of drainage channels remains unclear, this approach appears to reveal the most robust predictors of TP in turloughs. Our model given by

$$TP = (19.4 \times unimproved\ pasture) + (0.419 \times drainage\ density) + 11.6$$

requires verification in an independent sample of turloughs. However, we again stress that a clearer understanding of the impacts of catchment landuse and phosphorus enrichment will be severely hampered until fine scale data on livestock stocking rates (e.g. on a farm basis) are recorded and made widely available for detailed analysis. Finally, we make the point that assessment of risk of P enrichment appears to be unrelated to actual TP concentrations recorded in these turloughs. Because of the difficulty in predicting TP in turloughs from landscape variables, we instead recommend direct measurement of turlough TP during the middle of the flooded phase. This will enable baselines to be set from which future change (positive or negative) may be assessed; increases in TP should trigger more detailed investigations of potential sources and pathways.

11.9 References

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APPENDIX 11.1: TURLOUGH ZOC NOTES

The following contributed to discussion on the delimitation of turlough ZOCs:

ON = Owen Naughton

PJ = Paul Johnston

CC = Catherine Coxon

DD = David Drew

SK = Sarah Kimberley

CH = Caoimhe Hickey

ARDKILL, Co. MAYO (CC, DD)

Topography consists mainly of ridges of glacial till which may have little relevance to groundwater flow but some ridges may be rock-cored. There may be throughflow to the turloughs from surrounding slopes, or perhaps some localised epikarst flow where drift cover is shallow, but the main groundwater flow is independent of topography.

Tracing/Drilling Water sinking in Ardkill traced to Cregduff springs, 5.1 km to the WNW. Greaghans, Kilglassan and borehole H8 between Greaghans and Ardkill also traced to Cregduff springs. Water table map also constructed from water levels in 36 boreholes in c.30 km^2 (see Kilglassan notes). Estimated Ardkill catchment is based on these tracing and water table data. Note however that borehole data south of Ardkill are extremely limited so catchment boundary to S and SE is uncertain.

Geology No obvious constraints

Publications Coxon, C. (1986). *A study of the hydrology and geomorphology of turloughs*, unpublished Ph.D. thesis, Trinity College Dublin (Chapter 6).

Coxon, C.E. & Drew, D.P. (1986). Groundwater flow in the lowland limestone aquifer of eastern Co. Galway and eastern Co. Mayo, western Ireland. In Paterson, K. & Sweeting, M.M. (eds.) *New Directions in Karst*, Norwich, Geo Books, pp. 259-279.

Confidence 70%

Recommendations Existing research findings provide good information on hydrology in the vicinity of Ardkill. However information up hydraulic gradient to the SE is limited. The S and SE catchment boundary could only be more reliably defined by further water table mapping and water tracing to the S and SE of Ardkill.

BALLINDEREEN, Co. GALWAY (DD)

Topography As Tullaghnafrankagh, on watershed therefore a very restricted catchment

Tracing/Drilling No investigations so could drain south, north or west.

Geology No obvious constraints

Publications Mentioned in Gort flood study report

Confidence 70%

Recommendations Needs detailed hydrological investigation and tracing.

BLACKROCK Co. GALWAY (PJ)

Revised by Paul Johnston October 2009, no accompanying notes.

BRIERFIELD, Co. ROSCOMMON (CH, SK)

Topography The boundary is defined principally by topography. In the general region, groundwater flows in a southeasterly direction towards the Shannon River. The six inch maps and aerial photos provide evidence that a spring originates to the east of the boundary in a channel in the Dooneen area. The associated direction of flow is not evident on the six inch map however it seems that water flows in a south easterly direction towards the Scramoge River, therefore justifying the location of the boundary in this region. The north western boundary extends towards Toberelva. A liable to flood area of cutover peat (Subsoils Map), with numerous drains, extends to the NW. This area is likely to drain into the turlough.

Recommendations There are numerous springs at Toberelva. Springs seem to flow towards the turlough but the direction of flow appears to turn SW towards the river and away from the ZOC. The direction of flow should be field investigated to confirm this.

CAHERGLASSAN, Co. GALWAY

Unchanged from WFD, no accompanying notes.

CARANAVOODAUN, Co. GALWAY

Unchanged from WFD, no accompanying notes.

CARROWREAGH and RATHNALULLEAGH, Co. ROSCOMMON (CH, SK)

The hydrological behaviours of Carrowreagh and Rathnalulleagh are extremely similar. This indicates that the turloughs are highly connected and have the same ZOC.

Topography The southern boundary curves around the ZOC of an adjacent turlough (FNUM 1727SWK011). Beyond the southern boundary, stream directional flow is in a southerly direction, also indicated by tracing from Ardlagheen Bog swallow hole to Ballydooley Spring. The south eastern boundary is defined by topography. The Caran Bog lies in close proximity to the south eastern boundary. Flow direction appears to diverge in the south eastern area and the streams feeding Shad Lough were therefore excluded from the ZOC. The ZOC boundary follows the road, which suggests the presence of a ridge, through this area, separating the Carn Bog from the sinking stream feeding Carrowreagh turlough. The northern boundary is defined by a topographic ridge, excluding karst features (1727NWK312 AND 313) which lie on the north easterly side of the ridge. The ZOC boundary curves around Castleplunket Turlough towards the northwest. In this area, tracing evidence suggests north easterly flow, away from the ZOC, from Knockalegan East Swallow Hole to St. Elvias Spring and St. Luke`s Well. Numerous streams rising in the NW of the ZOC feed into Rathnalulleagh turlough. The southwestern boundary is defined purely by topography.

Tracing/Drilling On the southeastern boundary, tracing from Newtown swallow hole to Loughannatryna (KFDB) provides further evidence to support the exclusion of streams feeding Shad Lough.

Geology

Publications

Confidence

Recommendations These karst features adjacent to the northern boundary (1727NWK312 AND 313) should be checked for potential inputs. The karst feature (1727SWK170) in close proximity to the north western boundary should be checked for inputs even though it is unlikely to be part of the ZOC.

COOLCAM, Co. ROSCOMMON (ON, PJ)

Topography Defined by WRBD/SHRBD divide to the west. Recorded water levels indicate west-east flow direction

Tracing/Drilling Tracing from Polleagh Lough to rising stream indicates south-westerly flow direction from Polleagh Lough. Northern boundary limited by positive tracing to Ballybane spring

Geology Extensive faulting to south acting as possible boundary

Publications Coxon, C. & Drew, D. (1999). Groundwater and surface water relationships in a karst terrain. *Proceedings of the Portlaoise Seminar of the IAH Irish Group.*

Confidence 60%

Recommendations Resolve groundwater flow direction from Curragh and Polleagh Loughs

CROAGHILL, Co. GALWAY (ON, PJ)

Topography Reasonable

Geology Extensive faulting to south acting as possible boundary

Publications Coxon, C. & Drew, D. (1999). Groundwater and surface water relationships in a karst terrain. *Proceedings of the Portlaoise Seminar of the IAH Irish Group.*

Confidence 60%

Recommendations Includes Coolcam catchment so same recommendations apply.

GARRYLAND, Co. GALWAY

Unchanged from WFD, no accompanying notes.

KILGLASSAN, Co. MAYO (CC, DD)

Topography consists mainly of ridges of glacial till which may have little relevance to groundwater flow The borehole log from NH5 suggests that the ridge to the east of Kilglassan is not rock-cored (depth to bedrock reported as 21m). There may be throughflow to the turloughs from surrounding slopes (or perhaps some epikarst flow, though unlikely beneath thick calcareous drift), but the main groundwater flow is independent of topography.

Tracing/Drilling Water sinking in Kilglassan traced to Cregduff springs, 5.4 km to the WSW. Greaghans, Ardkill and borehole H8 between Greaghans and Ardkill also traced to Cregduff springs. Water table map also constructed from water levels in 36 boreholes in c.30 km^2 around Kilglassan – Cregduff (see publications for details).

Estimated Kilglassan catchment is based on these tracing and water table data together with limited information to the north-east (i.e. some evidence that Kilrush risings c. 2 km to the north of Kilglassan, like Cregduff, are fed by westwardly flowing groundwater).

Probable catchment of Greaghans turlough has been included in Kilglassan catchment on the precautionary principle, on the basis that groundwater passing under Greaghans may enter Kilglassan.

Geology No obvious constraints

Publications Coxon, C. (1986). *A study of the hydrology and geomorphology of turloughs*, unpublished Ph.D. thesis, Trinity College Dublin (Chapter 6).

Coxon, C.E. & Drew, D.P. (1986) Groundwater flow in the lowland limestone aquifer of eastern Co. Galway and eastern Co. Mayo, western Ireland. In Paterson, K. & Sweeting, M.M. (eds.) *New Directions in Karst*, Norwich, Geo Books, pp. 259-279.

Confidence 60-70%

Recommendations Existing research findings provide good information on hydrology downgradient of Kilglassan but definition of catchment boundary upgradient of Kilglassan depends on extrapolation of water table map and flow directions. It could only be more reliably defined by further water table mapping and water tracing to the east and north-east of Kilglassan.

KNOCKAUNROE, Co. CLARE (DD, ON, PJ)

Topography As Lough Gealain + good data for T5 catchment

Tracing/Drilling Water from Gealain which sinks has been traced to the spring on the north side of Knockaunroe, under high water sinks in Turlough T5 drain to the springs at the southwest of Knockaunroe

Geology No obvious constraints

Publications Report to OPW on tracing from turlough T5, D. Drew 1993

Confidence 50-60%

Recommendations As Gealain + resolve the intermittent contributing area of Turlough T5

LISDUFF, Co. ROSCOMMON (CH, SK)

Topography The south eastern boundary is defined by ridges. The boundary extends beyond the Attiknockan ridge, centrally located in the current ZOC, owing to uncertainty in relation to contribution from a swallow hole and two dolines to the east. The northern boundary is constrained by a ridge and river which flows away from the ZOC area, draining to the River Suck. The western boundary is poorly defined. The turlough basin potentially extends to the west, merging with an adjacent turlough. The connectivity of drainage channels in the western region is unclear from six inch maps. The south western boundary is defined by a river which flows away from the ZOC area. A potential spring is in evidence near the south western boundary which is likely to feed the southern river which drains to the River Suck.

Tracing/Drilling No tracing or drilling has been conducted in this area.

Geology

Publications

Confidence

Recommendations Tracing from the spring in the south eastern area is recommended to investigate potential contribution beyond the Alliknockan Ridge. The connectivity of drainage channels in the western region should also be investigated.

LOUGH COY, Co. GALWAY (PJ)

Revised by Paul Johnston October 2009, no accompanying notes.

LOUGH ALEENAUN, Co. CLARE (DD, ON, PJ)

Topography uncertain especially to east and west

Tracing/Drilling Traced from sinks at Poulawillan (248 002) and Doonyvarden (197 994) under high water conditions

Geology No obvious constraints

Publications Drew, D. (1988). Hydrology of the upper Fergus River catchment. *Proceedings of the University of Bristol Speleologiocal Society,* **18:** 265-77

Confidence 60-70%

Recommendations Resolve difference between large area according to tracing and smaller topographic area – tracing represents high stage overflows?

LOUGH GEALAIN, Co. CLARE (DD, ON, PJ)

Topography Reasonable but tracing suggests a larger area

Tracing/Drilling Sink north of Mullaghmore traced to spring west of Mullaghmore which in turn sinks and rises at the springs on the north side of Gealain

Geology No obvious constraints

Publications Mullan, G (ed.) (2003). *Caves of the Burren and south Co. Galway.* University of Bristol Speleological Society, 31-46.

Confidence 50-60%

Recommendations Resolve difference between large area according to tracing and smaller topographic area + water balance)

RATHNALULLEAGH, Co. ROSCOMMON
See above: linked with Carrowreagh Turlough, Co. Roscommon.

ROO WEST, Co. CLARE/GALWAY

Unchanged from WFD, no accompanying notes.

SKEALOGHAN, Co. MAYO (CC, DD)

Topography consists mainly of ridges of glacial till which may have little relevance to groundwater flow but some ridges may be rock-cored. There may be throughflow to the turloughs from surrounding slopes, or perhaps some localised epikarst flow where drift cover is shallow, but the main groundwater flow is independent of topography.

Tracing/Drilling Four traces from sites east of Skealoghan (Ardkill, Greaghans, Kilglassan and borehole H8 between Greaghans and Ardkill) all traced to Cregduff springs, c.2 km WNW of Skealoghan. Water table map also constructed from water levels in 36 boreholes in c.30 km^2 (see Kilglassan notes), defines water table trough leading to Skealoghan from ESE. Estimated Skealoghan catchment is based on these tracing and water table data. Note however that borehole data south of Skealoghan are rather sparse and catchment boundary to S and SE is somewhat uncertain.

Geology No obvious constraints

Publications Coxon, C. (1986). *A study of the hydrology and geomorphology of turloughs*, unpublished Ph.D. thesis, Trinity College Dublin (Chapter 6).

Coxon, C.E. & Drew, D.P. (1986). Groundwater flow in the lowland limestone aquifer of eastern Co. Galway and eastern Co. Mayo, western Ireland. In: Paterson, K. & Sweeting, M.M. (eds.) *New Directions in Karst*, Norwich, Geo Books, pp. 259-279.

Confidence 70%

Recommendations Existing research findings provide good information on hydrology in the vicinity of Skealoghan. However water table information to the S is somewhat limited: the S and SE catchment boundary could be more reliably defined by further water table mapping and/or water tracing in this area.

TERMON, Co. GALWAY

Unchanged from WFD, no accompanying notes.

TULLAGHNAFRANKAGH , Co. GALWAY (DD)

Topography On surface water and groundwater watershed so topographic catchment can only be small.

Tracing/Drilling Small sink at eastern end of the lough has been traced both south to the Kinvara springs and north to the springs at Kilcolgan (Dunkellin River).

Geology No obvious constraints

Publications Gort flood study report

Confidence 80%

Recommendations Check for input springs. Is it really a turlough?

TURLOUGHMORE, Co. CLARE (ON, PJ)

Topography Western edge defined by the boundary between the Western and Shannon RBD. Eastern edge defined by lower area adjacent to turlough.

Geology No obvious constraints.

Publications None

Confidence 60-70%

Recommendations Further refinement of northern boundary. Possible tracer studies to clarify drainage direction (northeast or southeast flow direction?)

Chapter 12. Monitoring Methods for Turloughs

S. Waldren, N. Allott, C. Coxon, H. Cunha Pereira, L. Gill, K. Irvine, P. Johnston, S. Kimberley, O. Naughton, G. Porst & N. Sharkey

Sorting samples of aquatic invertebrates. *Photo: H. Cunha Pereira*

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12.1 Introduction

12.1.1 Turlough Conservation Context

Turloughs, temporary lakes in karst limestone, are ecologically important habitats. As ecotones they link terrestrial and aquatic habitats (Goodwillie & Reynolds, 2003), the ecological conditions that result from the fluctuating floodwater level poses significant challenges to plant and animal species occupying turloughs (Lynn & Waldren, 2003; Sheehy Skeffington *et al.*, 2006; Sharkey, 2012; Porst, 2009). As a result, some unique assemblages of biota occur with mixes of species characteristic of both terrestrial and aquatic habitats (Goodwillie, 1992; Goodwillie & Reynolds, 2003; Sheehy Skeffington, 2006; *Chapter 7: Turlough Vegetation: Description, Mapping and Ecology*; *Chapter 8: Aquatic Invertebrates*). As groundwater-dependent terrestrial ecosystems, turloughs are mostly restricted to areas of karst limestone, and are therefore geographically restricted; by far the majority of known turloughs occur in Ireland. Ireland therefore has international responsibilities to conserve turloughs within the State. The conservation and ecological value of turloughs is further emphasized by their listing as Priority Habitats of Community Concern in the EU Habitats Directive (Council Directive 92/43/EEC).

12.1.2 Conservation Assessments and Requirements for Monitoring

Appropriate monitoring of turloughs is required under Article 11 of the EU Habitats Directive to assess conservation status, and to inform effective conservation management. Article 17 of the Directive requires regular reporting of the conservation status of annexed species and habitats. Article 17 reporting for habitats requires conservation assessment based on habitat range and area, habitat structure and function and future prospects for the habitat through an analysis of recent and current pressures and predicted future threats, and how these pressures and threats will affect trends in range, area, structure and function of the habitat (Evans & Arvela, 2011). Implicit in this reporting is a requirement for monitoring of ecological status, and also for the collection of baseline data with which to compare trends.

The main natural ecological driver of turlough ecological function is the hydrological regime which results in flooding related to groundwater levels. Various <u>*pressures*</u> influencing the ecological function of turloughs have been identified, as have <u>*threats*</u> which are likely to impact on ecological function in the future. Pressures are likely to influence the ecological and environmental <u>*state*</u> of a turlough, resulting in an <u>*impact*</u> in the turlough biological communities. These pressures result from a number of anthropogenic <u>*drivers*</u>, the most important of which is agriculture; other drivers include resource extraction, climate change, human habitation etc. Nutrient concentrations, particularly of phosphorus, have significant impacts on turlough ecology, however nutrients may enter turloughs locally or from more distant sources through inputs from the zone of groundwater contribution (ZOC). Land use also has a significant impact on the ecological function of turloughs, primarily through the grazing regime on the site but also to a smaller degree through housing development and risk from unsewered effluent in the ZOC. An effective conservation monitoring regime needs to be capable of assessing the state of turlough ecological function through the use of appropriate indicators, and the current pressures and likely future threats. The monitoring regime should provide information required to fulfil obligations for Article 17 reporting, and additionally aid NPWS in devising conservation management for turloughs.

Mayes (2008) compiled a database of actual and potential turloughs, and several additional sites have been subsequently added through field survey. This information is stored in a database maintained by NPWS. Many of these *potential* turloughs have not yet been verified in the field, some may not be classified as turloughs. Verification of potential sites as turloughs or otherwise clearly has implications for assessing the geographic range of turloughs, and the physical area occupied by the habitat.

12.1.3 Problems with Assessing Turlough Conservation Status

One difficulty arises from the fact that turloughs are essentially landforms that contain a variety of different habitats, in some ways analogous to a mountain with cliff, scree, escarpment and plateau forming different habitats. Thus in turloughs estavelles, permanent pools, rock outcrops etc all represent different habitats often with very different biota. Turloughs are set in karst limestone that floods with groundwater, and the resulting ecological gradient in flooding susceptibility results in a variety of vegetation communities which vary spatially along this gradient (Praegar, 1932; *Chapter 7: Vegetation*). These vegetation communities frequently intergrade, hampering definition of 'typical' communities. Vegetation communities typical of other habitats, some of which could be classified as EU Priority Habitats (e.g. Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*: HD code 7210; Limestone Pavement: HD code 8240), can occur at different points along the gradient. In addition, there is great variation among different turloughs, and this leads to particular difficulties in determining characteristic species; some species which might, for example, be characteristic of oligiotrophic turloughs with a long duration of flooding may be absent from other turloughs with different flooding and nutrient regimes. Developing appropriate biological indicators of various pressures and states among this variation is therefore challenging, and compounded by the ecological variation among different turloughs and lack of clear typology (Visser *et al.,* 2006).

Grazing is a key modifier of ecosystem function but impacts vary greatly. Grazing is seasonal, restricted entirely to the dry phase from late spring through summer. While a rapid assessment of grazing pressure is possible through use of appropriate indicators, quantifying grazing pressure to support conservation prescriptions can be difficult due to often numerous landholders being involved or the turlough being managed through commonage. For meso-eutrophic turloughs, an appropriate level of grazing is required – too little and too much will both impact on vegetation structure. Oligotrophic turloughs seem less sensitive to grazing, and can tolerate an absence of domestic grazing; typically these turlough are lightly grazed (a few are ungrazed), probably due to the low nutritional value and low palatability of the typically sedge-dominated vegetation. Meso- and eutrophic turloughs are typically dominated by fewer sedges and more palatable grasses and forbs; an absence of grazing here may result in a relatively uniform tall herb community, reducing ecological diversity.

Finally, one of the key difficulties in assessing turlough conservation status to date has been the lack of consistent baseline data with which to compare change in state as a result of various pressures, and the impact of any change in state on biological communities and hence turlough ecological structure and function. Vegetation surveys have been undertaken at a number of turloughs in the past (see for example MacGowan, 1985; Goodwillie, 1992), but these lack detailed hydrological and nutrient status data, and consistent reporting of pressures and threats. Twenty-two turloughs have been surveyed using a variety of ecological variables, many of which can be used as effective indicators for conservation monitoring. There is clearly a need to expand upon this baseline set of 22 turloughs to ensure a more informed national conservation status assessment is derived for future reporting cycles.

12.1.4. General Monitoring Requirements for Turloughs

An effective monitoring methodology for turloughs needs to assess and set targets for the following broad areas:

- Range and area of the habitat

- Structure and function of the habitat, in particular:
    - Hydrological functioning
    - Nutrient status
    - Status of biological communities
- Pressures and threats that impact on the structure, function, area and range of turloughs

The main purpose of this chapter is to make recommendations for future monitoring of turloughs to provide a basis for Article 17 reporting, but also to provide essential information for National Parks and Wildlife Service (and other stakeholders) to assist in the improved conservation management of turloughs. As noted above, adequate baseline data with which to assess trends in conservation status are lacking for the majority of turloughs, so a key aim is to suggest standardized ways of generating comparable baseline data for a larger number of turloughs.

Reporting under Article 17 requires consideration of the geographic range and habitat area, which requires an understanding of the geographic location of turloughs. A secondary aim of this chapter is, therefore, to suggest a standardized approach to the verification of potential turlough sites.

12.2 Monitoring Approach

This section outlines the suggested monitoring protocol and recommendations for site survey and verification of the habitat as a turlough. We recommend that conservation assessments are based around assessments of condition at a number of sample sites. Three important parameters can be varied in monitoring protocols: **sampling** – the number of sites sampled, **frequency** – the frequency with which sites are monitored (e.g. Article 17 reporting cycle, annual, seasonal etc), and **detail** – the amount of information captured at each monitoring visit. All of these can be varied, but there will be a certain minimum level of detail that will need to be recorded at a certain minimum frequency at a minimum number of sample sites. We use this approach to define a **basic monitoring protocol**, which is designed to fulfil the requirements of Article 17 reporting. We also suggest ways in which this could be expanded for a more **intensive monitoring protocol**, designed to provide more detailed ecological information to help guide conservation management. The intensive monitoring protocol will require greater frequency of sampling (for example to capture seasonal variation), and will capture greater detail (for example full vegetation maps). Elements of the monitoring approach can be adapted for the purposes of any appropriate assessment or environmental impact assessment and to inform conservation measures.

A brief outline of the aims, approaches, indicators required are given for the site verification survey (12.2.1), basic monitoring (12.2.2) and intensive monitoring (12.2.3) protocols, and this is followed by details of the methodology to be employed (section 12.3).

12.2.1 Site Verification

Verification of potential turlough sites is required as these may influence the range and total area of the habitat, important components of reporting requirements for the Habitats Directive. A priority would be verification of those turloughs which may extend the geographic range of the habitat. Field survey missions should focus in a given geographical area to maximize the value returned from costly field work. Prior to field work, relevant remote data sources should be consulted, including aerial photographs, 6” maps, Google Earth and Bing images and, if available, other relevant remote sensing data. Investigations need to determine whether there is a hydrological regime operating that results in seasonal flooding from groundwater, and needs to differentiate this from temporary ponding of surface water or perched water tables; this is most easily determined by consideration of the depth and volume of floodwater in the turlough basin. Being able to detect an obvious flooded and drained phase are important, and therefore a minimum of two visits to each site may be required. Remotely sensed data, if available, may be useful in establishing temporal changes in flooding; while such data are currently scarce, we anticipate that approrpriate data will become increasingly available in the future. A visit during the drained phase can be used to record various vegetation indicators characteristic of long duration flooding.

Aims

The aim is to provide a rapid verification of potential turlough sites based on field visits and supported by desk-based research. The main approach taken is to verify the seasonal and possibly transient flooding of the site from groundwater and the presence of wetland plant communities.

Approach

Areas that are on the periphery of known geographic range of turloughs (see range map from most recent Article 17 reporting and NPWS and Geological Survey of Ireland databases) should be initially targeted, to maximize efficiency and capture any changes to the range of the habitat. Two site visits will be required, one each in the flooded and drained stages of each turlough, except where adequate remotely sensed data can be used to confirm temporal variation in flooding.

Indicators and Evidence Required

Indicators are required to verify significant fluctuation in water level between the wet and dry phase in the absence of surface water outflow; these involve evidence of higher water levels typically at midwinter, and low water level typically in midsummer. Plant community indicators can also be used to suggest long-duration flooding in oligotrophic (*Eleocharis palustris/Ranunculus flammula* community) and meso- to eutrophic turloughs (*Polygonum amphibium* community); descriptions of these commnities are given in Appendix 12.1.

Recommended actions

- Check remote resources – recent aerial photos, information on maps at different scales, Google Earth and other available satellite images if available – to determine if topography/landscape features compare favourably with known turloughs.
- Check whether remotely sensed data are available to determine temporal changes in flooding.
- Check water level fluctuates on a seasonal/transient basis, recording appropriate physical and biological indicators during the flooded (late winter) and drained (mid summer) phases.
- Check presence of selected vegetation communities/plant species.
- Ideally, record other site features – completion of *Site Verification Sheet* (Appendix 12.2).

Justification:

The approach provides a consistent rapid assessment protocol to verify the status of potential turloughs, thereby generating more reliable data on the geographic range of the turlough habitat in Ireland.

12.2.2 Turlough Site Monitoring – Basic Level

This approach will provide a reliable and repeatable protocol to provide the *minimum* amount of data required to assess conservation status under the Habitats Directive Article 17 reporting requirements. This will require basic monitoring of water level, water chemistry, grazing and other landuse impacts, and the assessment of a number of indicators of turlough structure and function. The approach taken will provide an assessment of individual site condition, which will subsequently used to provide an overall conservation assessment of the habitat.

Aim: to provide a minimum level of monitoring to support Habitats Directive Article 17 reporting.

Approach: Continued monitoring of the 22 turloughs studied by TCD as an absolute minimum, although at least 50 turloughs, covering the ecological and hydrological range of variation among turloughs, would provide a more reliable evidence-base for conservation assessments. Some priorities for increasing the coverage include a broader geographic coverage, monitoring of any oligotrophic turloughs outside of the Burren region, monitoring turloughs with coloured water/acid peatlands in ZOC in addition to those in the Gort series (Blackrock, Coy, Coole/Garryland/Newtown, Caherglassan), sites inside and outside the Natura 2000/NHA network. Consideration should also be given to monitoring turloughs which face particular pressures or threats which are not apparent elsewhere. The aim should be to monitor sites which fully cover the range of ecological variation, pressures and threats.

Required Actions:

Basic monitoring will require a combination of desk, laboratory and field-based work.

Desk-based:

- Check distribution and revise if required to enable reporting on range and also area of habitat.
- Incorporate results from field surveys in turlough distribution data, particularly those from any site verification surveys (see above section 12.2.1).
- Select survey sites, suitable site access points, assemble existing baseline data.
- Utilise all appropriate sources of remotely sensed data to construct basic map of observable features and major vegetation units.
- Determine whether any water chemistry analysis is routinely performed in the likely zone of groundwater contribution (ZOC), identify suitable boreholes and stream as potential water sampling locations within the ZOC.
- Analyse water depth, and site topography data.

Field-based:

- Walk site to locate important features/species, to examine features and vegetation units mapped from remotely sensed data, and to stratify the site for a series of recording stops.
- Determine dominant substrate type (Mineral/non-mineral) during dry phase **once** (mid to late summer); repeat survey if changes to substrate are indicated (severe physical damage to the site, inflow of sediment etc.).
- Determine whether limestone pavement occurs within the turlough, or within 100m of the upper upper flooding zone, determine whether any of the following three vascular plant species occur: *Frangula alnus, Potentilla fruticosa, Schoenus nigricans*.
- Employ a series of stops stratified by upper, mid and lower flooding zones to assess indicators of turlough structure and function, and local pressures (grazing, fertilizer inputs) which might impact on the structure and function; record during the dry phase **once per HD reporting cycle** (mid to late summer).
- Record additional pressures, states, likely threats and any significant damage within the turlough during **any site visit** (with a minimum of **once per HD reporting cycle**).
- Install pressure-sensing transducer/loggers (divers) to provide an hourly record of water depth over time. Download data **annually** when floodwater has receded, in mid summer.
- Undertake a dGPS survey of the turlough topography – this only needs to be **undertaken once** per turlough during the dry phase, unless significant changes to the turlough topography are indicated (erosion, deposition, site clearance etc.). Also record notable karst features, any streams in the turlough floor, any potentially permanent pools.
- Map basic broad vegetation units during the dry phase **once per HD reporting cycle** (mid to late summer).
- Collect incidental further records of species (any biota)/communities or features of note or interest, any damage to the turlough **during any site visit**.
- Collect a water sample in the flooded phase (mid-winter) **annually** for water chemistry analysis; also collect water samples from appropriate boreholes or streams within the ZOC identified in desk-based research (above).
- Note any pressures and possible threats in the wider ZOC to the turlough, or with 1 km of the turlough if ZOC is not known, (during *any* site visit, minimum of **once per HD reporting cycle**).
- Complete *Indicator Stop Recording Sheet* (Appendix 12.3) and *Pressures and Threats Recording Sheet* (Appendix 12.4).

Laboratory-based:

- Analysis of water samples from the sample turloughs and their ZOCs: Total P, Total N, pH, alkalinity, colour, and (turlough only) chlorophyll *a.*

Details of the suggested methodology and the indicators required for monitoring are given in section 12.3.

Justification:

This approach would provide the minimum level of monitoring required to complete Article 17 reporting, building upon the baseline information compiled on the 22 turloughs examined in detail. Much of the existing baseline information has been completed to enable changes in pressures, states and impacts to be determined (NB. Tullynafrankagh requires a once-off

GPS-based topographic survey). For additional turloughs, this approach would generate a consistent set of baseline data to determine current pressures, states and impacts, and to facilitate future determination of trends in these.

12.2.3 Turlough Site Monitoring – Intensive Survey

Aim

To provide a comprehensive level of monitoring to support Habitats Directive Article 17, and to provide a detailed understanding of the ecological functioning of different sites to inform site specific conservation management decisions, and to guide environmental impact and appropriate assessment processes.

Approach

More detailed monitoring of a larger, more representative sample of turloughs than in 12.2.2 above. Some priorities include a broader geographic coverage, monitoring of any highly oligotrophic turloughs outside of the Burren region, monitoring turloughs with coloured water/acid peat land in ZOC in addition to those in the Gort series (Blackrock, Coy, Coole/Garryland/Newtown, Caherglassan), sites inside and outside the Natura 2000/NHA network. Ideally 100 verified turloughs which span the range of ecological variation existing in turloughs, and including the 22 studied by TCD, to provide a firm basis for drawing conclusions for conservation assessment and management. However, this approach could also be applied to a small number of sites requiring specific management.

Required Actions:

The actions listed here are additional to those listed under the proposed basic monitoring approach (section 12.2.2 above).

Desk-based:

- Develop a *Site Monitoring Sheet* to accommodate any of the tasks and indicators that are adopted from the intensive survey list. The *Indicator Stop Recording Sheet* could form the framework for developing such a recording sheet.
- Determine an appropriate standard survey methodology for bird surveys, using either fixed point counts or transect counts.

Field-based:

- Collect water samples **annually** in late Autumn (during filling), mid-Winter (fully flooded) and Spring (while drying) for water chemistry analysis to detect seasonal variation.
- Collect samples of aquatic invertebrates at the same time as the water samples for chemical analysis (i.e. autumn, mid-winter, spring), **once per HD reporting cycle.**
- Condition assessment based on water beetle survey, **once per HD reporting cycle** (likely only for oligotrophic and mesotrophic turloughs).
- Record vegetation in releves, **once every second HD reporting cycle**, unless substantial vegetation changes are indicated.
- Map vegetation communities, **once per HD reporting cycle**, unless substantial vegetation changes are indicated.

- Sample terrestrial carabids using pitfall traps throughout the drained period **once per HD reporting cycle.**
- Undertake a bird survey at the same time as annual water (autumn, winter, spring) and vegetation (summer) surveys, with particular emphasis on waterfowl, gulls, terns and waders (Ideally **annually**, minimum **once per HD reporting cycle**).

Note that the frequencies suggested above are relevant for Habitats Directive Article 17 reporting; more frequent monitoring will be required to determine impacts of any specific developments which may impact on turlough structure and functioning, and possibly to support environmental impact assessment or appropriate assessment.

Laboratory-based:

- Analysis of water samples from the sample turloughs and their ZOCs: Total P, Soluble Reactive P, Total N, Total Oxidized N, Total N, pH, alkalinity, colour, and (turlough only) chlorophyll *a.*
- Sorting and identification of aquatic invertebrate samples.
- Sorting and identification of carabid samples.

See section 12.3 for details of methodology

Justification:

In addition to generating data required to complete Article 17 reporting, this approach would provide baseline ecological information from a wide variety of turlough types. It would provide a network of sites for ongoing ecological analysis of turloughs. Trends could be compared against this baseline, generating novel ecological insight to inform conservation management decisions. This approach, or parts of it, could also be used to guide environmental impact assessment and appropriate assessment of turloughs.

12.3 Details of Methodology

This section describes details of the methodology required to undertake the monitoring procedures outlined above. Various field survey sheets are supplied in the Appendices. In all cases it is essential that the field recorders name and a date are recorded on the data sheets.

12.3.1 Site verification

The site verification survey has two main approaches: firstly a desk-based exercise to determine the most appropriate regions for field survey, and secondly a ground truthing survey which will require a minimum of two site visits, if sufficient current or remote sensed data are not available to establish degree of winter flooding. The key aim is to verify that temporal/seasonal changes in flooding occur from groundwater, rather than surface ponding; the volume of water flooding the turlough is critical here: surface ponding is unlikely to be a plausible explanation of the volume of flood water in all but the smallest of turloughs.

12.3.1.1 Site Selection

The main rationale for site verification is to both confirm whether or not sites listed as potential or possible turloughs do in fact qualify as turlough, and to provide greater precision on the range and total area of the turlough habitat. It is therefore recommended to prioritise these investigations to areas on or beyond the periphery of the geographical range of verified turloughs; such areas can be identified by comparing the most recent (at time of writing, 2013) range map generated for Article 17 reporting with the distribution of verified and potential turloughs contained in the database of turloughs maintained by NPWS (Mayes, 2008) and the Geological Survey of Ireland. Once potential turlough sites have been identified that could expand the range of the habitat, other potential turloughs in the vicinity (but possibly within the range of known turloughs) should be identified so that field missions can be planned around visiting potential turloughs that would extend the habitat range while also verifying as many other turloughs in the region as possible.

12.3.1.2 Desk Study

Remotely sensed images – aerial photographs, satellite images, including Google Earth, Bing – can provide important information on landscapes. Some features of turloughs, including estavelles, marl deposits, different winter/summer flooding may all be apparent in this imagery. Potential sites determined as described above should be checked on available imagery for the presence of turlough-like features. This might be best achieved by comparing known turlough sites within the region with the potential turloughs. In some cases this approach has previously revealed destruction of turloughs by development, this should also be checked. Remotely sensed data of high resolution are likely to become increasingly available, in time such data might be capable of providing information which could replace field surveys.

12.3.1.3 Site Visit - Winter

Promising potential sites will need to be verified as turloughs by field visits, unless adequate remotely sensed data are available (likely to be increasingly available in the future). The first visit should be carried out in mid to late winter, likely around early February. However, as the key aim of this visit is to determine a significant level of flooding in the turlough, we caution against being overly prescriptive about the timing of visits to turloughs: timing needs to be related to hydroperiod, which may not always link well with calendar date. For example Blackrock (Co. Galway), a deep turlough with a very flashy regime, has in some years been almost completely drained in mid winter. The advice of rangers or others with relevant knowledge should be sought. Monthly rainfall data might also be utilized to predict likelihood of high groundwater levels.

The main purpose of the winter visit is to determine the extent of flooding in the turlough. The maximum extent of flooding should be recorded in at least four different locations around the flooded periphery, using a hand held GPS receiver (see ‘Equipment’ below). Ideally the GPS receiver should be capable of 1 m accuracy or better with differential post processing. Suitable receivers, including those manufactured by Trimble, may also have computer functionality allowing other attributes to be linked in the field with GPS data, and this may prove an effective tool for data capture in the field. Ordnance Survey Ireland provide RINEX data for differential correction at http://www.osi.ie/Services/GPS-Services/Active-GPS-Station-Data.aspx. The map datum should be set to Ireland 1965 and co-ordinate system to Irish Grid. Characteristically during the flooded phase, various features such as pylons and telegraph posts, fences, walls and trees (at the upper margin) all appear with their bases inundated – presence of these indicators of transient flooding should be noted. If possible, photographs of these features should be taken, and a GPS position taken from the camera location (or, if GPS-enabled, ensure that the camera tags GPS data to digital image) in order to relocate this camera position during the summer visits. Ideally, attach GPS data to EXIF information linked to the digital image data.

If there is a strand line of dead stems (e.g. *Schoenoplectus*, which has large air spaces in dead stems) or other debris that has been rafted up by flooding levels that were higher than those apparent at the time of the visit, the position of these strandlines should be recorded. Note that such strandlines may be lower than the highest regular flood level, as they will form during periods when flood levels are relatively stable and when wind direction is favourable. Waypoints can be recorded directly onto the field sheet, or they can be stored in handheld GPS computers for later download – in this case the file name should be recorded on the data sheet.

Optionally, bird species present should be recorded, particularly waders, gulls and waterfowl; if possible estimate numbers of each species present.

12.3.1.4 Site Visit – Summer

The chief purpose of the second site visit is to verify that the water level has fallen significantly from the winter level. Again, timing should ideally reflect the hydrological regime and would ideally be timed two to four weeks after the flooding has fully subsided: typically this might be from late June to early July.

The partially inundated features recorded during the winter visit should be refound (use winter GPS co-ordinates) – these features should now be entirely above water; another set of photographs should ideally be taken to provide verification. Features indicative of turloughs, submerged during the winter high water visit, may now be obvious and should be recorded. These include estavelles, swallow holes, streams, ponds with aquatic plant species (indicating more permanent water), marl deposits etc. GPS locations of these features should be recorded. Another key feature to note is the presence of the amphibious bryophytes *Cinclidotus fontinaloides* and *Fontinalis antipyretica*, particularly on rocks but sometimes also on trees and shrubs, in zones that are likely to be fully drained in summer but probably submerged during the winter visit; these are likely to be too widespread to merit GPS location, but their presence should never the less be recorded.

The presence of woodland or scrub around the upper margin of the turlough should be noted. Woodland adjacent to turloughs is typically dominated by *Fraxinus excelsior*, *Rhamnus cathartica* and *Crataegus monogyna*, with associated *Salix* species. Scrub may also be present, dominated by *Prunus spinosa*, stunted exmples of the woodland tree species just mentioned, and more locally *Potentilla fruticosa* and prostrate growth forms of *R. cathartica* and *Frangula alnus*.

The lower, more intensively flooded zones of the turlough typically contain characteristic vegetation communities indicative of long duration flooding; several communites occur but in the more oligotrophic turloughs the Eleocharis palustris-Ranunculus flammula community should be obvious, and in meso- and eutrophic turloughs the Polygonum amphibium community dominates. Presence of these two communities should be recorded; synoptic tables of these communities are given in Appendix 12.1 and further details provided in Chapter 7 – Vegetation.

Areas that are heavily poached by cattle are typically dominated by the *Poa annua-Plantago major* community, which contains numerous annual species. The presence of this community should be noted; a synoptic table is given in Appendix 12.1.

The presence of limestone pavement and a small number of vascular plant indicators together with assessment of dominant soil type provides a simple but reliable indication of expected nutrient (phosphorus) availability (*Chapter 11 – Water Framework Directive Risk Assessment*); note that actual nutrient levels may differ considerably as a result of anthropogenic pressures. Turloughs on mineral soils generally have higher total phosphorus in the floodwater. Those turloughs with non-mineral soils (ie. peat or marl based) AND which have limestone pavement in or adjacent to the turlough OR any of three vascular plant indicators (Franula alnus, Potentilla fruticosa, Schoenus nigricans) typically should have very low water TP. The presence of limestone pavement in the turlough or with 100 m of the upper flooding zone of the turlough should be noted, along with the presence of *F. alnus*, *P. fruticosa* and *S. nigricans*.

Soil characteristics should be inspected with the aid of a small trowel to determine whether the predominant soil type is largely organic, mineral or marl-based. Investigations should take place at a number of locations in the turlough basin (minimum of six).

If possible, presence of any waders, waterfowl and gulls should be recorded, noting any that appear to be breeding. Any unusual or interesting plant or animal species should be noted.

A very valuable addition to the Site Verification Sheet (Appendix 12.2) will be information on the most favorable point(s) of access, where to safely leave vehicles, contact information for landowners etc.

Equipment:

The following equipment will be required:

- Handheld GPS Receiver. Ideally the GPS receiver should be capable of 1 m accuracy or better with differential post processing. Rugged units are available that are combined with a small computer, facilitating data storage and subsequent outputting to GIS applications.
- Small hand trowel
- Binoculars (~10 x 50); telescope may be useful for bird counts
- Digital camera; consider a model with GPS capability
- Site verification sheet

12.3.2 Site Categorisation

Some of the indicators used to assess turlough condition apply to only a certain category of turlough, and for some indicators different thresholds apply in different categories of turlough. We define the turlough categories as follows:

The most oligotrophic turloughs typically have organic or marl-based soils, a very low wTP, and specialized vascular plant communities and species present. Our data suggest that these turloughs occur where there is limestone pavement in or adjacent to the turlough, and one or more the following, readily identifiable vascular plant species occurs: *Potentilla fruticosa*, *Frangula alnus* and *Schoenus nigricans*; we use these indicators to categorise **Potentially Oligotrophic turloughs**. Sites which have non-mineral soils, lack limestone pavement in or adjacent to the turlough, and lack the vascular plant indicators of characteristic of oligotrophic turloughs we categorise as **Potentially Mesotrophic turloughs**. However, turloughs on mineral soil typically have a higher total phosphorus (wTP) in floodwater, and some specialized vegetation communities and species not found elsewhere, irrespective of any limestone pavement in the immediate vicinity. They also lack the indicator species *Potentilla fruticosa*, *Frangula alnus* and *Schoenus nigricans*; we categorise these as **Mineral soil turloughs.** Details of these categories and criteria used to define them are given in table 12.1 (see also the worked example in Table 12.7), and an example of the application of this approach to the 22 turloughs studied by the TCD team is given in Appendix 12.5.

Table 12.1. Categories of turlough used in assessment of structure and function indicators, and criteria used to define these categories.

Category	Criteria used to define category
Mineral soil-based	Soils predominantly mineral-based (c.f. organic, marl)
Potentially Oligotrophic	Soils not mineral, AND either: (a) limestone pavement occurring within the turlough basin or with 200 m of it, (b) ANY of *Potentilla fruiticosa*, *Frangula alnus* or *Schoenus nigricans* occurs
Potentially Mesotrophic	Soils not mineral, AND: (a) limestone pavement not occurring within the turlough basin nor with 200 m of it, (b) absence of *Potentilla fruiticosa*, *Frangula alnus* or *Schoenus nigricans*

We point out here that these define *potentially* oligo- or mesotrophic turloughs, based around landscape characteristics and a minimal set of readily identifiable vascular plant species; the actual nutrient status may of course differ as a result of anthropogenic pressures. We avoided using characteristics of the zone of groundwater contribution (ZOC) due to the difficulty in defining ZOCs for most turloughs and certainly for those that have been little studied; we also wanted the absolute minimum of biological attributes to define these categories. This approach seems applicable based on extensive data collected by the TCD team, and also from consideration of the information contained in Goodwillie (1992). With further more detailed ecological study of a greater number of turloughs, it may be possible to refine the criteria used to define these categories, or indeed to define a different and perhaps more appropriate set of categories; for the present, these categories and criteria are based on the best available evidence.

12.3.3 Site Monitoring

This section outlines the methodology used for baseline surveying and monitoring turloughs. We consider that this forms an outline approach: newer and more cost-effective technologies, improved methodologies and more reliable metrics may be developed in the future which may require modification of the approach given here. The basic monitoring approach is intended to provide a minimum level of monitoring consistent with fulfilling the reporting requirements under Article 17 of the EU Habitats Directive. It will ***not*** provide comprehensive data to support conservation management decisions, nor data sufficient for adequate appropriate assessment or to support an accurate environmental impact assessment. In the latter cases, elements for the intensive survey approach are required; see section 12.5.

12.3.3.1 Site Selection

The number of sites monitored will be constrained by available resources to adequately monitor the turlough habitat. The 22 turloughs studied in detail by the TCD turlough ecology and conservation project are an absolute minimum set of turlough for monitoring (*Chapter 2: Site Selection* and Table 12.2). Previous survey of these turloughs has resulted in baseline data that can be used to assess changes in state and impacts, and hence infer changes in pressures operating at the sites.

Table 12.2. Brief details of the 22 turloughs studied in detail by the TCD turlough ecology and conservation project (for further details see *Chapter 2: Site Selection*). Site code numbers givem in italics are NHAs, others are parts of SACs (though not always mentioned as a qualifying feature).

Site name	Townland	County	SAC/NHA code	Easting	Northing
Ardkill	Ardkill	Mayo	000461	127360	262500
Ballindereen	Ballindereen Cartron	Galway	000606	140092	215248
Blackrock	Turloughnacloghdoo	Galway	000318	149780	208130
Brierfield	Brierfield	Roscommon	*000594*	181600	276560
Caherglassaun	Killomoran	Galway	000238	141456	206290
Caranavoodaun	Castletaylor	Galway	000242	145109	215648
Carrowreagh	Carrowreagh	Roscommon	*001624*	178378	275305
Coolcam	Coolcam	Roscommon	000218	157420	271390
Croaghill	Croaghill	Galway	000255	159680	270540
Garryland	Garryland Wood	Galway	000252	141750	204050
Kilglassan	Kilglassan	Mayo	000504	127860	264550
Knockaunroe	Knockaunroe	Clare	001926	130700	193450
Lisduff	Lisduff	Roscommon	000609	184250	255500
Lough Aleenaun	Sheshymore	Clare	001926	124740	195440
Lough Coy	Shanvally	Galway	002117	148927	207255
Lough Gealain	Gortlecka	Clare	001926	131450	194730
Rathnalulleagh	Rathnalulleagh	Roscommon	*000613*	177710	273760
Roo West	Roo	Galway	001926	138627	202214
Skealoghan	Skealoghan	Mayo	000541	124750	262900
Termon	Termon	Galway/Clare	001321	140920	197350
Tullanafrankagh	Caherpeak West	Galway	000606	143208	215339
Turloughmore	Turloughmore	Clare	001926	134700	199800

This minimum number should ideally be expanded to include a wider range of turloughs, and to determine whether some of the 22 turloughs were atypical. For example, including other turloughs, ideally from outside the Burren region, would help to determine whether the very oligitrophic turloughs surrounded by limestone pavement (e.g. Lough Gealain, Knockaunroe) are exceptional in the very low water TP, of typical for this type of turlough. Similarly, efforts should be made to identify other turloughs that are ecologically similar to the Gort chain (Blackrock, Coy, Coole/Garryland/Newtown, Caherglassan), particularly those where groundwater supply originates from peatlands or where the zone of groundwater contribution contains acidic bedrock. A target of at least 50 turloughs covered by the basic monitoring would provide a far more representative conservation assessment for the Habitats Directive. In expanding the number of monitored turloughs, consideration should be give to the following:

- Use the NPWS database of turloughs to determine candidate sites that have been verified (and see 12.3.1 above) as turloughs

- Include some oligotrophic turloughs from outside the Burren region.
- Include some turloughs that have a high percentage of peatlands in the zone of contribution (some around Co. Roscommon for example).
- Ensure that the geographic coverage is broadened
- Include turloughs both inside and outside the range of sites designated as SACs, SPAs or NHAs.
- Include a wide size range.
- Include in as far as possible sites in each River Basin District.

12.3.3.2 Water Sampling

For basic level monitoring we suggest a water sample is taken annually from each turlough in mid winter, when turloughs are likely to be filled and total N in the water is likely to be highest (Cunha Pereira, 2011; *Chapter 4: Water Chemistry and Algal Biomass*). Intensive monitoring would require water samples taken in autumn (when turloughs typically have high water levels but may still be filling), in mid to late winter (to generally coincide with the maximum flooding), and in spring (when water level may still be high, but temperatures have increased and biological activity is higher). Ideally, water samples should also be taken from other points in the zone of groundwater contribution to help estimate where any nutrient pressures are occurring. Suitable locations include boreholes, surface streams and any groundwater monitoring stations already in use by the EPA. A desk-based investigation of potential groundwater monitoring sites should be conducted prior to inititation of site monitoring.

Water samples can be collected from turloughs by throwing a weighted and tethered 5 l plastic bottle from the shore to an area of open water. This potentially may risk sediment disturbance, in which case sampling from 1m depth in the middle of a turlough from a canoe could be considered; it is however recommended that a consistent and repeatable approach to water sample collection is adopted. Locations near springs and swallow holes should be avoided. If replicate samples can be collected, they should be obtained from different locations around the turlough, and retained separately. Sample bottles should be filled as completely as possible and securely stoppered. Water samples for analysis of nitrogen should be returned to the laboratory for analysis as soon as possible. To minimise nitrogen loss and transformation samples should be stored chilled in a cool box with frozen ice packs, or in a portable refrigerator powered, for example, by a car battery or vehicle DC outlet. The location of sampling positions should be recorded using a hand-held GPS receiver; the exact sampling location and its accuracy is usually not of critical importance, but handheld GPS provides a convenient approach to recording location.

A minimum set of analyses should include pH, total nitrogen (TN), total phosphorus (TP), Chlorophyll *a*, pH, colour and alkalinity; this is the minimum requirement for basic level monitoring. For more detailed intensive monitoring additional analysis of Soluble Reactive phosphorus (SRP) and total oxidised nitrogen (TON) should be undertaken. Recommended standard methods are given in Clesceri *et al.* (1989), laboratories undertaking these analyses will likely have minor modifications to these methods. Again, we re-emphasise the importance of timely return of the samples for laboratory analysis, particularly for analyses of nitrogen. Several turloughs could be sampled regionally in one day, maximizing efficiency.

For reference, brief details of the analytical methods used by Pereira (2011) are given here (see also *Chapter 4*). TP concentration was obtained by acidic persulphate digestion of samples at 120°C and subsequent determination of phosphate by colorimetry (Eisenreich *et al*., 1975; Shimadzu UV-1601 Spectrophotometer). SRP was measured in filtered samples

(Whatman GF/C filter) by the colorimetry method used for TP but without digestion. TN was measured after alkaline persulphate digestion of samples at 120°C followed by measuring the resulting nitrate by automated colorimetry (Grasshoff *et al*., 1999; Bran+Luebbe AutoAnalyzer 3). TON was measured on filtered samples using ion chromatography (Dionex Instruments ICS-1500). Chlorophyll a was determined by methanol extraction of Whatman GF/C filters, followed by absorbance measurement of the extract at 665 nm (Chl a peak) and 750 nm for turbidity correction (Standing Committee of Analysts 1980; Shimadzu UV-1601 Spectrophotometer). pH was determined electrometrically (Jenway model 3030) with a glass electrode (resolution 0.1 pH units) and alkalinity was measured by titration to pH 4.5 with 0.01M H_2SO_4 (Eaton *et al*., 2005). Colour was measured spectrophotometrically at 455 nm after filtration of the water sample through a GF/C filter, and expressed as PtCo units or Hazen values (Hach DR/2000 Instrument, Instrument Handbook and Eaton *et al*., 2005). Turbidity was measured nephelometrically on unfiltered homogenised samples (Eaton *et al*., 2005) using a Hach 2100P instrument. For further details see *Chapter 4 – Water Chemistry and Algal Biomass,* and Pereira (2011).

12.3.3.3 Water Level Monitoring

Water levels can be recorded at hourly intervals using pressure sensing 'divers' which measure the pressure of the water and air column above them, and from this the depth of water can be calculated. Divers should be placed at or near the lowest point in a turlough, this is best determined close to the minimum summer flooding. A useful method for anchoring the diver is through use of a concrete paving slab as a platform to contain the diver (Fig 12.1). The diver can be protected by use of Wavin drain pipe (note the inquisitive cattle in Fig. 12.1). A rope securely tied to the platform and with a buoy attached to the other end will facilitate retrieval during times of inundation, should this be necessary; however the set up can be left in place throughout the hydroperiod and data conveniently downloaded when the water has receded.

Figure 12.1. Diver platform, Rathnalulleagh, Co. Roscommon (left), and downloading diver using Reading Unit, Garryland, Co. Galway (right)

In order to determine the water level accurately, compensation for the variation in prevailing air pressure must be made. Met Eireann synoptic station data can be used, or (more appropriately) atmospheric pressure recorded locally. The air pressure readings need to be converted into equivalent water head and this then taken away from the water levels recorded by the Divers. As air pressure varies exponentially with height, the barometric data must be adjusted prior to compensation to allow for the difference in elevation between the local pressure sensor or Met station elevation and that of the Diver on site. Elevations relative to ordnance datum Malin Head (mAOD) can be obtained by using differential GPS surveying techniques, suitable GPS equipment currently includes the Trimble R6 series and higher. In addition to the adjustment of barometric data for differences in site elevations, each Diver record will need to be adjusted for differences in the Diver calibration itself (see *Chapter 2 – Hydrology* and Naughton, 2011 for details).

Suitable apparatus at the time of writing include various Schlumberger Divers® (Marton Geotechnical Ltd, Suffolk, UK). Different models can be employed depending on the depth of the floodwater, those divers that are capable of recording over greater depth (ie. greater pressure ranges) general have slightly lower accuracy and resolution, so consideration needs to be given to the likely maximum depth of flood water in a turlough before deciding on the model to be employed. Some models will also record water temperature and conductivity. A current suitable model for recording atmospheric pressure is the BaroDiver® (DI500). Where there are several turloughs in the local region, a single sensor can be used effectively to record the atmospheric pressure for correction of water depth at several turloughs. Technology is likely to improve, with units becoming more robust, smaller and cheaper, and likely with expanded capabilities in the near future; new models by Reefnet (Sensus Ultra, http://reefnet.ca/products/sensus/) seem cost effective but we have not tested these.

12.3.3.4 Topographic Survey

The elevation of each Diver will need to be surveyed to ensure accurate barometric compensation and adjustment of water level time series data to ordnance datum. Diver elevations can be linked to a temporary bench mark and later adjusted to mAOD. If divers are removed during the hydroperiod the water level must be recorded both before recovery and after redeployment to allow the alignment of the time series before and after recovery. It will be impossible to replace the diver in the exactly the same position if the turlough is flooded.

In order to utlise the water level data to generate ecologically important hydrological variables (based on contour maps, stage–volume and stage–surface area relationships), topographic mapping of the turloughs is required. Differential GPS surveys can be used to develop digital terrain models (DTMs) from which stage/volume/surface area relationships could be defined. The steps involved in the DTM process are shown in the flow chart (Fig 12.2).

A procedure which has been successfully used to carry out GPS surveys in turloughs is outlined in *Chapter 2 – Hydrology* (see also Naughton, 2011). GPS point density will depend upon the terrain variability. Points should be taken at approximately ten to fifteen metre intervals in areas of gentle undulation, though in areas of greater topographic variation (such as estavelles) a spacing of as little as one metre would be more appropriate.

The upper boundary of the survey should be defined by the maximum water level recorded during the monitoring period. Often natural barriers such as woodland or impassable soft marl deposits present within the boundary of the turlough may prevent an area from being surveyed in detail. Areas of open water shallower than 1.5 metres can be surveyed using chest waders or a wetsuit if necessary. A canoe or boat could also be used to sample points in areas of deeper water, though care should be taken inserting a staff into soft sediment which may only be partially visible. When encountering woodland, where GPS accuracy can be significantly reduced, it is recommended that points are taken at breaks in the canopy within the woodland, or transects in clear ground beyond it taken and used to define the upper bound. Typically at least one thousand points should be taken per turlough, this has proved suitable in generating effective digital terrain models for turloughs (*Chapter 2 – Hydrology*, see also Naughton, 2011); this is likely to take 2-3 days per turlough on average.

LIDAR (Light Detection and Ranging) data might in the future be suitable for topographic mapping of turloughs, but currently is too inaccurate to capture the detail required for turlough mapping, with a vertical resolution of 25 cm (OSI 2014). LIDAR mapping from drones flown at low altitude might be feasible if stability of the drone could assure adequate resolution, such future developments may significantly reduce field survey time.

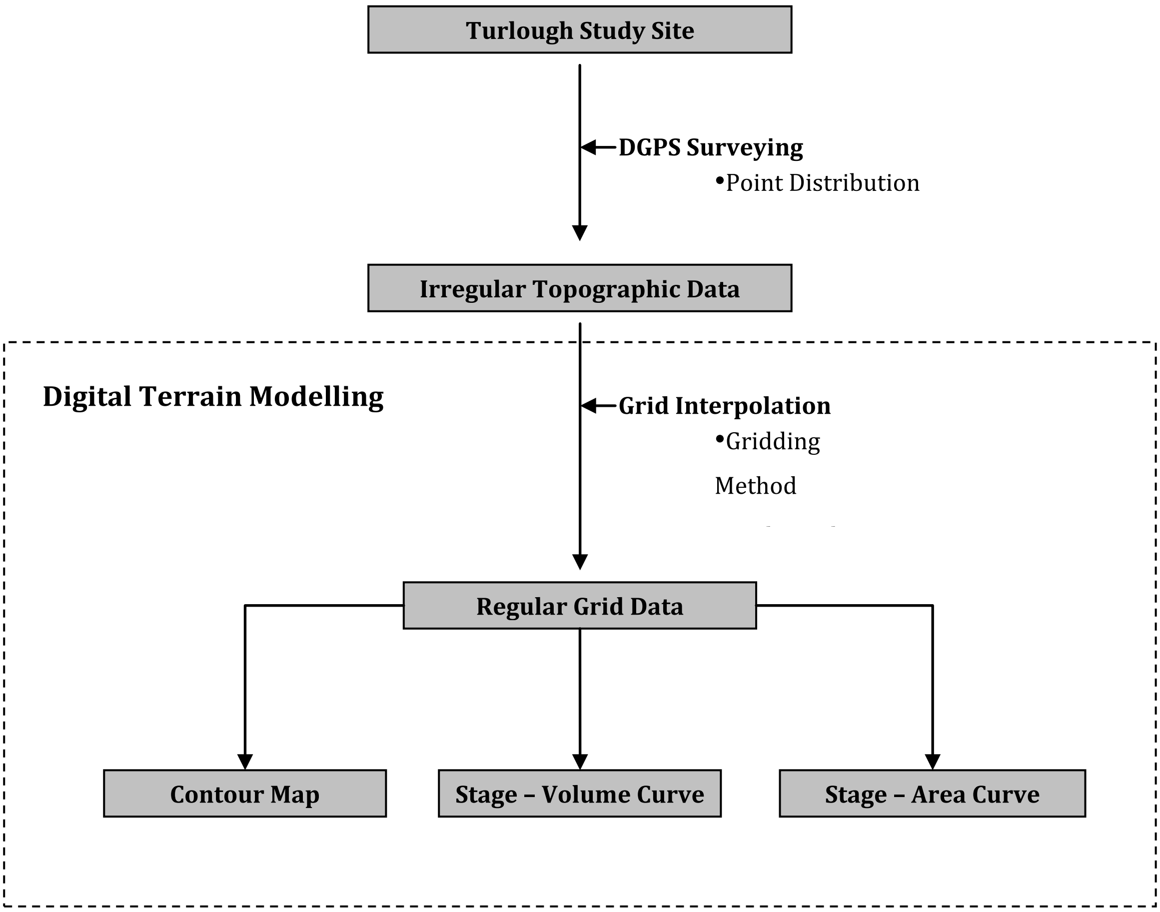

Figure 12.2. Flow diagram of the steps required to develop ecologically relevant hydrological variables from dGPS survey and water level data.

Digital terrain modelling (DTM) provides a means to transform water level data into flooded areas, volumes and the associated flow rates. Ecologically, DTMs aid in the determination and representation of depth, duration and frequency of flooding, factors shown to be of great importance to the diversity and characteristic ecology of turloughs. Construction of DTMs and other relevant outputs (Stage-volume, stage–area curves etc.), including contour maps, should be undertaken by an operator with experience in GIS and spatial modelling.

12.3.3.5 Zone of Groundwater Contribution

Knowing the land area which defines the zone of groundwater contribution (ZOC) to the turlough is important as it can help identify areas remote from the turlough which present pressures which may have impacts on the turlough biological communities. Determination of the ZOC is however fraught with difficulty as surface topography may well not reflect ZOCs, hence tracing may be required.

Identification of ZOCs should be therefore carried out by qualified hydrogeologists. Water table mapping could also be carried out to help estimate catchments. Water level measurements should be made from turloughs, streams, lakes and other surface water bodies using surveys with differential GPS. Water table maps can then be generated using appropriate 3-D visualisation, contouring and surface modelling software; this can help ascertain the regional groundwater flow that can subsequently be used to estimate the extent of the catchment area. For further details see *Chapter 2 – Hydrology*, and Naughton (2011).

12.3.3.6 Vegetation Sampling

The intensive monitoring procedure requires description and mapping of the vegetation communities at each turlough; though desirable this is not required for the basic survey protocol. The basic survey does however require mapping of major vegetation units and some key indicator communities, it also requires a series of stratified stops to record indictors used in the structure and function assessment. However, there is generally no need for repeated remapping of turlough vegetation for conservation assessment at each Habitats Directive reporting cycle, unless significant impacts have occurred or are predicted. Vegetation mapping should also be undertaken for Environmental Impact Asessments or Appropriate Assessments, and possibly also to support Strategic Environmental Assessments. Therefore, even with the adoption of the basic monitoring approach, its is recommended that a process is put in place whereby vegetation mapping is gradually rolled out to previously unsurveyed turloughs, probably initially focusing on those likely to be of most conservation interest. Goodwillie (1992) provides maps for the vegetation of 61 turloughs, some of which are available in digitised form.

Species area curves have previously been used to determine optimum quadrat size (see *Chapter 7: Turlough Vegetation: Description, Mapping and Ecology*). The majority of the vegetation was grassland or short herbaceous vegetation, and a species accumulation curve found 1 x 1 quadrats to be satisfactory; this quadrat size also allows comparison with previous turlough vegetation studies which had used 1 m^2 quadrats (MacGowran, 1985; Caffarra, 2002; Lynn & Waldren, 2003; O'Rourke, 2009; Sharkey, 2012).

Recent aerial photographs (OSI material or Bing), and vegetation maps (Goodwillie, 1992; *Chapter 7*) should be consulted prior to field work, in order to have an initial understanding of the spread and position of vegetation types across the habitat. Various karst features can often be identified from such remotely sensed data, and in addition major vegetation types, such as woodland, flooded pavement, open pools etc can be determined. These broad habitat and vegetation features should be mapped as a desk-based exercise, and later ground truthed (see section 12.3.3.7 below). Vegetation units that should be mapped are woodland, scrub, limestone pavement, reedswamp and open water. Basic vegetation mapping should also include sedge-dominated and herb-forb dominated communities, but these are not likely to be discernable from remote images and will require field mapping.

In the field, each turlough selected for monitoring should be walked over to determine (by eye) the range of vegetation types and habitat variation present. Features of interest, such as estavelles, streams, permanent pools etc, should be noted and mapped using an appropriate GPS receiver. Important plant species, including nationally or regionally rare species, should also be mapped. Ground truthing should be used to refine the vegetation and habitat units previously mapped from remotely sensed sources, and to map sedge-dominated and herb-forb dominated communities. Initial field work should identify the most suitable access points, areas of difficult terrain such as soft marl deposits etc, to facilitate future field work. This initial site walk over should identify a stratification system for subsequent indicator assessment stops and (intensive survey only) releves.

Previous survey work has suggested the most effective approach to sampling the variation in turlough vegetation is to stratify the turlough into upper, middle and lower strata in relation to duration of flooding, and to randomly sample each of these strata. We recommend that this approach be taken for the setting up of the indicator stops and the releves for more intensive monitoring. The releves could usefully be combined with indicator stops in an intensive survey, but data additional to the vegetation releve will need to be sampled; note also that indicator stops are NOT required in some vegetation communities (see below), whereas an intensive vegetation survey should allow description of all communities present. Ideally a similar number of stops/releves should be taken in each strata, however this may not always be either feasible or desirable. In some steeply sloping turloughs, the area covered by the lower communities and habitats is far more limited than the area occupied by the upper and middle zones – in these cases it may be prudent to reduce the number of stops or relevees from lower zones. In other shallow, relatively flat turloughs it may be difficult to determine strong zonation, or there may be a very extensive 'middle' zone. In these cases a departure from even sampling of strata would be reasonable; the sampling effort for each stratum could, for example, reflect the relative area of each. However, it should be born in mind that the approach here is simply to *adequately sample the range of habitat variation within the turlough, avoiding bias*.

For the basic monitoring a series of stops are required for collection of data on a variety of indicators of turlough structure and function, these indicators are listed in table 12.3 along with an explanation. At each stop a series of observations needs to be made in relation vegetation components, grazing pressure, evidence of fertilizer application, a suggested recording sheet is given in Appendix 12.3. Stops should be randomly positioned within each of the turlough zones, but should avoid woodland, reedsamp (dense stands of *Phragmites australis, Cladium mariscus,* or *Schoenoplectus* spp.), limestone pavement or open water as a key role for the stops is to determine the proportion of sedge to grass/herb dominated vegetation. The presence of the vegetation community types referred to in table 12.3 could be recorded at stops to estimate their percentage occurrence, but could also be obtained from mapping of these specific communities; a combination of approaches might be useful. However, the *Eleocharis acicularis* community is likely limited in extent and will be restricted to the muddy bases of mineral soil turloughs, often along streams, and recording at stops is not likely to be effective here. Similarly, woodland, scrub and flooded pavement communities will not be recorded at stops and hence quantitative data on thesese communities should be obtained form mapped area. At each stop, observations should be made within a 2 m radius of the observer, the observations require presence/absence; quantative data (e.g. frequency) for assessment of indicators comes from the summary of all stop data. Note that more than one vegetation type might be present in any stop observation area. The observer should determine whether the vegetation at the stop is dominated by various sedges (*Carex*, *Eleocharis* and *Schoenus nigricans*), or dominated by a mix of grasses and forbs; *Carex* species may occur in grasses/forb communities but will never dominate. Similarly, various herbs may occur with a low cover in Sedge-dominated vegetation, though the only grass likely here is *Agrostis stolonifera*. The aggregate values from the individual stops are used to calculate percentage occurrence, used in the assessment calculations (see section 12.4). It is recommended that at least 20 stops be made in each of the zones within each turlough.

Not all of the vegetation indicators apply in all turloughs; for example, some of the communities which indicate long-duration flooding in oligotrophic communities are replaced by very different communities in mesotrphic turloughs, while some communities appear to be restricted to mineral soil turloughs. Table 12.3 describes which indicators apply to the three turlough types defined in section 12.3.2, see also the worked example of the application of thresholds to indicators in table 12.7.

For more detailed recording of vegetation during intensive monitoring and to provide data for semi-quantitative analysis of vegetation communities, relevés should be placed to obtain a representative sample of each vegetation type. While recording vegetation communities in transects along the flooding gradient will provide fine scale detail of community change in relation to flooding (e.g. Caffara, 2002; O'Rourke, 2009), this will be too time-consuming for conservation monitoring and will result in considerable duplication of information; the transect approach might however prove effective within a given turlough where any potential change in the flooding regime is being monitored (e.g. during an environmental impact assessment). A minimum of five relevés should be recorded in each vegetation type, and at least 50 relevés recorded per turlough. Within each relevé, the vascular plant species present and their cover-abundance should be recorded at 5% intervals, with the following scale applied for cover below 10% to provide extra detail and clarity: 0.1%, 0.3%, 0.5%, 0.7%, 1%, 3%, 5%, 7% (following Perrin *et al.*, 2014). Total cover of bryophytes and charophytes should also be recorded; cover of individual species is likely to be low and time consuming, but should be undertaken if feasible.

Information on the estimated vegetation height within the releve, and the grazing indicators in Table 12.3 within a 2 m radius of the centre of the releve, should also be recorded at the time of the vegetation survey. The location of each relevé should be recorded using a suitable hand-held GPS receiver (ideally to 1 m accuracy).

Identification of turlough vegetation can be problematic; hydrological stresses, shortened growing seasons and sometimes intensive grazing mean that specimens are often stunted (MacGowran, 1985; Goodwillie, 1992; Sharkey, 2012). Particular difficulties arise with *Carex*, *Euphrasia* and *Taraxacum*. Field recorders are advised to acquire relevant identification texts (such as the BSBI Handbooks) and if possible attend any relevant identification training workshops. Identification of *Carex* spp is of particular importance, many species occur most frequently in the more oligotrophic turloughs (e.g. *Carex flacca, C. hostiana, C. panicea*), though some have a wider ecological tolerance (e.g. *C. nigra*) and some occur on more enriched sites (e.g. *C. hirta*). *Viola persicifolia*, a turlough specialist, readily hybridises with *Viola canina*, producing offspring with a range of traits from either parent; identification of non-flowering specimens maybe very difficult. Unknown plant specimens should be placed into labeled zip-lock plastic bags or pressed for later identification.

Table 12.3 Information required to complete basic level assessment of turlough structure and function and to record pressures and threats. Threshold levels, suggested scoring (bolded values in centre columns) and the type of information required (qualitative/quantitative) are given along with suggested assessment level (at whole turlough level or from indicator stops, or calculated from a baseline). This table could form the basis of a spreadsheet to collate the information required to assess site structure and function.

Indicator/Information	Thresholds for turlough types			Information type	Assessment level
	Oligotrophic-type	**Mesotrophic-type**	**Mineral-type**		
1. Hydrological function					
Invert of drainage (any alteration of turlough drainage, either reduction or increase in drainage capacity)	None, or affecting only exceptional flooding: **0**; Affecting flooding in upper part of basin: **1**; affecting flooding in majority of basin: **2**			Qualitative	Whole turlough
Consistent or progressive change in flooding depth/duration/area of flooding (over 12 years, or two HD reporting cycles)	<5% change: **0**; 5-20% change: **1**; >20% change: **2**			Quantitative	Whole turlough/baseline
2. Water quality					
Floodwater TP	< 10 µg l^{-1}: **0**; 10-20 µg l^{-1}: **1**; >20 µg l^{-1}: **2**	< 20 µg l^{-1}: **0**; 20-40 µg l^{-1}: **1**; >40 µg l^{-1}: **2**		Quantitative	Whole turlough
Increase in floodwater TP	> 10% increase: **0**; 10-20%: **1**; >20% increase: **2**			Quantitative	Whole turlough/baseline
Maximum recorded Chl*a*	< 10 µg l^{-1}: **0**; >10 µg l^{-1}: **1**			Quantitative	Whole turlough
Water colour	>30 mg l^{-1} PtCo: **1**, otherwise **0**			Quantitative	Whole turlough
3. Biological responses: terrestrial					
Agrostis stolonifera-Glyceria fluitans community cover	< 5% cover of turlough: **0**; 5-20%: **1**; >20%: **2**			Quantitative	Whole turlough/stops
Cover of Rumex crispus, R. conglomeratus and *R. acetosa* either singly or in combination	cover < 5% of turlough OR frequency < 10% of releves/stops surveyed: **0**; cover >5% cover OR frequency > 10%: **1**			Quantitative	Indicator stops
Lolium grassland cover	< 10% cover of turlough: **0**; 10-20% cover: **1**; >20%: **2**			Quantitative	Whole turlough/stops
Grass-forb dominated community area	< 33% cover of turlough: **0**; > 33% cover **1**		N.A.*	Quantitative	Indicator stops
Filipendula ulmaria-Potentilla erecta-Viola sp. community	< 2% cover of turlough: **0**; 2-10% cover: **1**; >10%: **2**	N.A.	N.A.	Quantitative	Whole turlough/stops
Poa annua-Plantago major community	< 2% cover of turlough: **0**; 2-10% cover: **1**; >10%: **2**			Quantitative	Whole turlough/stops
Polygonum amphibium community	< 2% cover of turlough: **0**; 2-10% cover: **1**; >10%: **2**	N.A.	N.A.	Quantitative	Whole turlough/stops

Eleocharis acicularis community	N.A.	N.A.	No loss: **0**; loss of community: **1**	Quantitative	Whole turlough/baseline
Limestone grassland, Flooded pavement or woodland communities in any combination	>10% of turlough: **0**; <10% of turlough: **1**			Quantitative	Whole turlough
Eleocharis palustris-Ranunculus flammula community	>10% of turlough: **0**; <10% of turlough: **1**		N.A.	Quantitative	Whole turlough/stops
Eleocharis palustris-Ranunculus flammula community	No loss in area: **0**; loss of area: **1**		N.A.	Quantitative	Whole turlough/stops/baseline
Polygonum amphibium community	N.A.	No loss in area: **0**; loss of area: **1**		Quantitative	Whole turlough/stops/baseline
Molinia caerulea-Carex panicea community	cover >2% of turlough: **0**; cover <2%: **1**		N.A.	Quantitative	Whole turlough/stops
Sward height greater than 40 cm	Indicates undergrazing: < 40 cm: **0**; > 40 cm: **1**			Quantitative	Indicator stops
Sward height less than 8 cm	Indicates intensive overgrazing by sheep: > 8 cm: **0**; < 8 cm: **1**			Quantitative	Indicator stops
Notable species (incl. inverts)	No loss: **0**; loss of species: **1**			Qualitative	Whole turlough/baseline
4. Biological responses: aquatic					
Presence of algal paper	< 2% of turlough area: **0**; >2% area: **1**			Quantitative	Whole turlough
Absence of fully aquatic vascular plants	Any species present: **0**, otherwise **1**			Quantitative	Whole turlough
Notable species (incl. inverts)	No loss: **0**; loss of species: **1**			Qualitative	Whole turlough/baseline
5. Other					
Physical damage to turlough (land clearance, resource extraction etc.)	< 5% of turlough area: **0**; 5-20%: **1**; >20%: **2**			Quantitative	Whole turlough
Evidence of feeding rings or other stock feeding in turlough	Any evidence: **1**, otherwise **0**			Qualitative	Whole turlough
Evidence of fertiliser input (pellets etc.)	Any evidence: **1**, otherwise **0**			Qualitative	Whole turlough/Indicator stops
Defoliation of plants	(no threshold, evidence of grazing intensity)**			Quantitative	Indicator stops
Presence of animal dung	(no threshold, evidence of grazing intensity)**			Quantitative	Indicator stops
Presence of grazing animals	(no threshold, evidence of grazing intensity)**			Quantitative	Whole turlough/Indicator stops
Other pressures and threats	(no threshold, evidence of pressures and threats)			Qualitative	Whole turlough

N.A. – Not applicable to this turlough type*　　* use to assess the intensity of grazing unless stocking density data are available*

The time of surveying can also affect vegetation recording; both length of time after last inundation and time within the growing season will affect the presence/absence of certain species. This is a common issue in ecological recording. One way in which this effect can be lessened is to sample at the same time each year. When sampling in the turlough environment, however, it is often necessary to time sampling according to the hydrology of the turlough rather than the calendar. For very intensive monitoring, such as will be required for Environmental Impact Assessments or Appropriate Assessments, it may be necessary to sample vegetation more than once per growing season.

12.3.3.7 Vegetation Mapping

The intensive monitoring approach requires generation of vegetation maps for each turlough. Production of a full vegetation map may only be required every 12 years, but any *changes* to mapped communities should be recorded during each Habitats Directive reporting cycle. The basic monitoring approach requires mapping of broad vegetation units and a small number of vegetation types which are key indicators of turlough structure and function (see below). The methodology below is based on the recommendations given in Smith *et al.* (2011) and *Chapter 7: Turlough Vegetation: Description, Mapping and Ecology*.

Field Preparations

Ordnance Survey (OS) aerial orthorectified photographs and maps, previous vegetation maps (Chapter 7 and digitised maps from Goodwillie, 1992), and topographical contour maps of the site to be mapped in the field should be consulted, when available, prior to field visits. This will provide a general overview of the geographic location, size, topography, and vegetation of a site. Turlough plant community species lists (generated by analysis of relevés recorded as part of the vegetation component of the project) and community identification keys should be printed and laminated for use in the field for identifying turlough vegetation types. Analysis of releve data should be used to refine vegetation communities for mapping. Handheld GPS devices (ideally rugged designs, with fields predefined for recording vegetation and other turlough attributes) should be used for field recording and loaded with georeferenced TIFF images of all available aerial photos, OS maps, any previous vegetation maps, and outline maps of major vegetation types and other features (see section 12.3.3.6 above).

Fieldwork

On arrival at each site, the vegetation should be inspected by walking through the turlough to provide a sample of the general type(s) of vegetation present. Vegetation types present at each site should be identified with the aid of species lists and keys. Vegetation communities can be recorded as point features or polygons, or the boundaries between communities mapped as line features. Mapped features should be supported by notes saved together with the features on the handheld GPS devices. If interpretation of vegetation is made difficult by various factors (phenological, hydrological, disturbance, etc.), this should be noted. It may also be helpful to record a general species list in vegetation units identified by eye (using the DAFOR relative abundance scale).

Boundaries between vegetation types should be recorded as linear features roughly along the centre of the observed zone of transition between two types of community. The frequency of points along a boundary should reflect the site complexity, depending on particular local topography and spatial configuration of vegetation. Diffuse (transition >3m wide) and

Distinct (transition <3m wide) boundaries can be identified separately. Boundaries for vegetation should only be recorded in the field if the area of vegetation in question was above the recommended minimum values (area 400 m^2, width 4 m) for small-scale surveys given in Smith *et al*. (2011).

The basic monitoring protocol requires mapping of broad vegetation units: woodland (any species), scrub (any species), limestone pavement, reedswamp (dominated by any of *Phragmites australis, Cladium mariscus, Schoenoplectus* sp.), open water, sedge-dominated communities, grass-herb dominated communities, *Agrostis stolonifera-Glyceria fluitans* community, *Poa annua-Plantago major* community, *Polygonum amphibium* community, *Eleocharis acicularis* community, *Eleocharis palustris-Ranunculus flammula* community, *Molinia caerulea-Carex panicea* community, *Filipendula ulmaria-Potentilla erecta-Viola* sp. community, limestone grassland (unimproved), *Lolium perenne* grassland. Not all of these communities will be present in each turlough, many of the broader units can probably be mapped from remotely sensed data. Any particularly notable, rare or threatened species should be also be mapped. More intensive monitoring will expand on these mapping requirements for the basic monitoring protocol by mapping all vegetation communities present in each turlough.

Features of general interest at each site should be recorded as points, lines or polygons as appropriate, examples include putative swallow holes, fences, walls, drains, streams, ponds and water level points. These data may be helpful in ground-truthing landscape elements that were represented on aerial photos or OS maps, and will help improve the habitat information available for the surveyed turloughs. Digital photographs taken in the field may also aid interpretation of general topography, vegetation, water levels and various other features of the turlough as surveyed on the day, and can be used subsequently to help improve the confidence of the spatial representations of vegetation.

Post-Field

Data files and digital photographs should be transferred to a computer daily to ensure that field data are backed up and safe. Receiver Independent Exchange Format (RINEX) data can be downloaded from the Ordnance Survey of Ireland website (www.osi.ie) to differentially-correct the field data files and hence help improve positional accuracy (post-processing). Data should be sourced from the nearest appropriate base stations to the surveyed turlough for the time period when fieldwork was carried out. *** *NB. At the time of writing, RINEX data are only made available the following day and for a limited period of time, about one month. Field surveyors **MUST** check up-to-date details from OSI* ***.

Differentially corrected data files should be downloaded into appropriate Geographic Information System (GIS) software for map generation. It is recommended that some training in GIS software should be undertaken by anyone responsible for map production. Details of a general approach to data manipulation, processing and map generation are given in *Chapter 7: Turlough Vegetation: Description, Mapping and Eclogy* (see section 7.4.4).

12.3.2.8 Aquatic Invertebrate Sampling

Macroinvertebrates can be collected from the littoral zone of turloughs using either a box sampler after O'Connor *et al.* (2004), or by sweeping the substrate with a 1 mm mesh sized standard Freshwater Biological Association (FBA) pond net. Single habitat sampling reduces variance and increases power for detecting change among sites (Resh and Jackson, 1993;

Pinel-Alloul *et al.,* 1996; Johnson *et al*., 2004; White and Irvine, 2003; Tolonen *et al*., 2001). However, for the assessment of maximum species diversity a more intensive sampling approach is required (Della Bella *et al.*, 2005).

A box sampler (ideally of dimensions close to 50 cm long x 40 cm wide x 50 cm high) can be easily constructed by cutting out the bottom of a sturdy plastic storage box. The box should be placed over respective sampling sites and organisms trapped within the box removed with a small net with a mesh size of 1mm, sieved, and washed into collection bottles. Box samples should be taken from each available habitat type, and habitat types recorded. Sweep net sampling should also occur in each habitat type, and comprise a 3 minute sampling period divided proportional to each habitat's availability (modified from Biggs *et al*., 1998). Previous analyses have suggested comparable results from turloughs using box and sweep sampling approaches (Porst, 2009).

Samples of "open-water" cladocerans should be collected using a 60 µm mesh size zooplankton net. Three open-water cladoceran zooplankton samples should be taken by horizontal hauls of the net from the shore at three random locations (for further details see Porst, 2009). Open-water cladoceran zooplankton samples should be pooled, washed into collection bottles and preserved with 90% IMS for later identification in the laboratory. Separate sampling for littoral chydorids should be carried out with the use of a perspex tube (for example diameter 5.5 cm, volume 2276 cm^2) after Irvine *et al*. (1989). All available habitats in each turlough should be sampled proportional to their abundance in accessible areas, as for the collection of macroinvertebrate sweep net samples. A total of 25 l should be obtained by rapidly lowering the perspex tube to the substratum, sealing the end with a rubber ball and transferring the content into a container. This sample should then be sieved through a 60 µm mesh size sieve, and subsequently washed into collection bottles. Separate samples of cladoceran zooplankton and chydorids will need to be identified and enumerated in the laboratory using appropriate keys and apparatus. All samples, from littoral or open water need to be preserved *in situ* in 90% IMS.

Lestes dryas and *Sympetrum sanguineum* are important Odonata of turloughs. Several other Odonata occur, but the occurrence of these two species should be checked, most conveniently as adults. Unfortunately there are identification difficulties with adults in both cases: *L. dryas* may be confused with *L. sponsa*, while *S. sanguineum* may be confused with both *S. striolatum* and *S. fonscolombei.* For both genera, it may be necessary to examine adults in the hand for positive identifcation. See Nelson & Thompson (2004) for further details.

Aquatic invertebrate communities will vary throughout the season. We therefore recommend sampling for aquatic invertebrates takes place at the same time as water samples are taken for chemical analysis: <u>a minimum</u> of late spring as water levels begin to recede, autumn during filling and mid-winter also desirable (see 12.3.2.2 above). This will facilitate comparison of aquatic invertebrate communities and species diversity with direct measurements of water quality.

Macroinvertebrates can be identified using the keys by Ashe *et al*. (1998), Brooks and Lewington (1997), Edington and Hildrew (1995), Elliott and Mann (1979), Elliot *et al*. (1988), Fitter and Manuel (1986), Friday (1988), Gledhill *et al*. (1993), Holland (1972), Hynes (1977), Macan (1977), Miller (1996), Nilsson (1997), Reynoldson and Young (2000), Richoux (1982), Savage (1989), Savage (1999) and Wallace *et al*. (2003). Macroinvertebrates were identified to the lowest taxonomic level, generally species. Diptera and Trichoptera pupae, Hydrachnidia, Ostracoda and Oligochaeta were, however, identified to order and all other Diptera and Collembola to family level only. Cladoceran zooplankton and separate chydorid samples were identified using keys by Scourfield and Harding (1966) and Amoros (1984).

Quality of identification should ideally be established by cross-identification of random samples by established experts.

12.3.2.9 Pressure and Threats

Assessment of pressures and threats is an important part of conservation assessment (Evans & Arvela, 2011). Some pressures, such as grazing intensity, can be assessed from data collected during the Indicator Assessment stops (12.3.2.6 above). Many, however, will be qualitatively appraised using expert opinion, and any pressures and potential threats should be documented during any site visits. The likely magnitude of the impact should also be qualitatively assessed, as described in table 12.4. Care should be taken to only consider potentially occurring threats or positive actions (planned drainage, management agreement secured), as opposed to purely aspirational ones (possible road development, possible grazing reduction). Pressures and threats need to be considered at the in the individual site level but also within the ZOC. Determination of the ZOC is often difficult and will be unknown for many turloughs that have not been studied hydrologically; where the ZOC is unknown we recommend consideration be given to pressures and threats within 1 km of the upper flooding zone of each turlough. Pressures and threats should be listed using the standard Article 17 reporting codes, a template for recording pressures and threats based on those previously identified as most likely to occur is given in Appendix 12.4.

Table 12.4. The relative importance of a threat or pressure, after Evans & Arvela (2011)

Code	Meaning	Comment
H	High importance/impact	Important direct or immediate influence and/or acting over large areas.
M	Medium importance/impact	Medium direct or immediate influence, mainly indirect influence and/or acting over moderate part of the area/acting only regionally.
L	Low importance/impact	Low direct or immediate influence, indirect influence and/or acting over small part of the area/ acting only regionally.

12.3.2.10 Terrestrial Carabid Beetle Sampling

Although not studied by the TCD research project, carabid beetles display a high habitat specificity and carabid communities have often been used to assess habitat quality (Lövei and Sunderland, 1996; Cameron and McAdam, 1999). In turloughs, carabid assemblages have been related to grazing, nutrient status and degree of flooding (Ní Bhriain *et al.,* 2002; Moran *et al*., 2012). Carabids can be sampled effectively by using pitfall trap techniques, for relevant applications in turloughs see Ní Bhriain *et al.* (2002) and Moran *et al.* (2012). Because of temporal changes in community structure, carabids should be sampled during the whole of the dry phase, generally from July to September. Traps should contain 1:4 ethylene glycol:water, with a drop of detergent to break surface tension. Traps should be inspected regularly and the contents sieved and preserved in 70% ethanol. Traps contents can later be sorted; in addition to carabids, these traps are also likely to contain spiders which themselves could prove to be useful indicators of environmental quality, and these too should be retained and preserved.

Until carabid communities are more fully understood in turloughs, reliable indicators *per se* cannot be identified. However, changes in *trends* in carabid communities may be important indicators of change. As such, it is important that baseline data are acquired to inform conservation management.

12.3.2.11 Bird Survey

Bird survey and census was not undertaken by the TCD research project. Turloughs may contain several important bird groups, including passage, wintering and breeding waterfowl (Anatidae), waders (Scolopacidae, Charadriidae) and gulls (Laridae). Bird survey can be effectively achieved through timed transects or point counts, where all species observed or heard within a fixed time period are recorded. Distance (or distance class) from the transect or survey point should also be recorded to provide an estimate of detectability – the ability to detect a given species will decline with distance from the observer, an electronic range finder would be useful here. If bird surveys are to be undertaken, a fully standardized, repeatable recording protocol will need to be developed and adhered to by field recorders to maximize data quality. As birds were not surveyed by the TCD research team, development of such a standard protocol is beyond the scope of this project, but should be a priority for future monitoring and impact assessment. Consideration needs to be given to access of either point counts or transects at different stages of the hydroperiod. For further details on designing survey and census approaches, see Bibby (2004) and Gregory *et al*. (2004).

12.3.2.12 Site visits and Scheduling

Selected sites would need to be visited at various times of the year and tasks undertaken with varying frequency. Table 12.5 outlines a schedule of the main tasks of data and sample collection, indicating the time of year that the task should be performed and the frequency with which the task needs to be undertaken (i.e. annually, once per Article 17 reporting cysle, once off). The table also gives an indication of how the timing and frequency of certain tasks should be modified to accommodate Environmental Impact Assessment and monitoring related to potentially damaging developments. In these cases an increased frequency (for example, annual as opposed to once off) and amount (for example monthly as opposed to seasonally) of monitoring effort is required for specifically threatened turloughs to determine the effects of new pressures caused by potentially damaging developments (see also section 12.5).

Table 12.5. Schedule of tasks to be undertaken duirng field visits for turlough conservation monitoring (intensive protocol), showing timing and frequency. For Environmental Impact Assessment, Appropriate Assessment and monitoring of potentially damaging development in specific turloughs, increased frequency and altered timing of monitoring may be required to provide adequate baseline data (indicted by *), but this will depend on the type of proposed development.

Time of year	Tasks	Frequency
Summer	Install divers/download data	Annual
Summer	dGPS survey	Once off
Summer	Determine substrate type	Once off
Summer	Determine proportion of turlough grazed	Annual
Summer	Assess grazing indicators	Annual
Summer	Record vegetation releves	Reporting cycle (*Annual)
Summer	Map vegetation communities	Reporting cycle (*Annual)
Summer	Bird survey	Reporting cycle (*Annual)
Summer (but needs fortnightly visits)	Carabid survey	Reporting cycle (*Annual)
Autumn (*monthly)	Collect water samples	Annual
Autumn	Aquatic invertebrate sampling	Reporting cycle (*Annual)
(*Autumn)	Bird survey	(*Annual)
Winter	Aquatic invertebrate sampling	Reporting cycle (*Annual)
Winter	Bird survey	Reporting cycle (*Annual)
Winter (*monthly)	Collect water samples	Annual
Spring	Aquatic invertebrate sampling	Reporting cycle (*Annual)
Spring	Bird survey	Reporting cycle (*Annual)
Spring (*monthly)	Collect water samples	Annual
(*Spring)	Bird survey	(*Annual)
Any visit	Important species (+ve indicators)	Any visit
Any visit	Physical damage, drainage, natural resource exploitation etc.	Any visit
Any visit	ZOC pressures	Any visit

Equipment list

- Water sampling and storage bottles. Coolbox or portable refrigerator
- Pressure sensing divers, one per turlough. Barodivers for recording atmospheric pressure only.
- Staff-mounted differential GPS receiver capable of 1 cm horizontal accuracy for topographic survey
- Handheld differential GPS receiver capable of sub-metre (ideally 10 cm) horizontal accuracy for habitat mapping
- Quadrat, plant press and polythene bags
- Pitfall traps with suitable covers. Nets for sieving contents in field
- Aquatic invertebrate sampling nets, box sampler, tube sampler
- Various field identification guides to plant and invertebrates
- 30 m measuring tapes
- Small hand trowel
- Binoculars (~10 x 50); telescope also recommended for bird counts
- Digital camera; consider a model with GPS capability

12.4 Conservation Status Assessment and Site Condition Methodology

This section outlines a recommended approach to assessing the conservation status of turloughs for Article 17 reporting. It develops a process to be adopted from the basic monitoring protocol, following on from methods detailed in *Chapter 10: Conservation Assessment*. We regard this very much as a framework for conservation assessment; we have suggested an approach based around the basic survey methods suggested above, but which can be expanded to incorporate new or improved indicators should these become available. With further survey of a wider ecological range of turloughs, better ecological understanding of turlough structure and function will develop. This in turn should lead to improved indicators and metrics for assessment – the draft condition assessment for water bodies based on aquatic beetle survey (Nelson *et al*., in prep) is a good example. In addition, the monitoring protocols suggested here will generate novel baseline data and these can be used in the future to assess trends in pressures, ecological states, and biological impacts.

We have developed the following proposed approach for assessment of individual site condition and overall national assessment based on guidelines set out in Evans and Arvela (2011). As noted by Evans and Arvela, in many areas these guidelines lack specific detail because they have been formulated as a general approach to assessment of a very wide range of species and habitats. We have used some of the examples provided in the guidelines in developing the approach that follows, particularly for the assessment of structure and function and future prospects. We suggest the use of various target and threshold values for use with indicators to assess condition at individual sites, and we also propose thresholds and criteria for generating assessments at national level from individual site condition. Further work may require slight modification of these values, but that should not require alteration of the general approach proposed here.

Article 17 requires conservation status assessment for each biogeographic region in which a habitat occurs. Turloughs can be assessed for the State as a whole, without subdivision into biogeographic units, as Ireland only occurs within the Atlantic biogeographic region.

It is important to note that the habitat needs to be assessed throughout the State, including areas of habitat that are <u>not</u> designated as SACs or cSACs. The methodology proposed below uses both quantitative and qualitative information from a sample of sites which provides site-based conservation condition, these are then combined to provide an overall conservation status assessment for turloughs in the State.

Article 17 requires assessment of the conservation status of listed habitats by consideration of a combination of the *Range*, *Area*, *Structure and Function*, and *Future Prospects* of the habitat (Evans & Arvela, 2011; see also table 12.6). Each parameter is evaluated individually, and these evaluations combined to give an overall assessment. Evaluation of some of these parameters requires the consolidation of individual site evaluations (see for example, Section 12.4.3. Structure and Function, below). Each assessment should be accompanied by a detailed Audit Trail document, which provides supporting evidence and rationale for all decisions and assessments undertaken for Article 17 reporting.

Table 12.6. Assessment parameters for Conservation Status Assessment reporting under Article 17 of the Habitats Directive

Assessment Parameter	Summarised meaning
Habitat Range	The geographic range of the habitat
Habitat Area	The total area occupied by the habitat
Structure and Function	Biological and physical structure, and ecological functioning necessary for the continued existence of the habitat
Future Prospects	Based on consideration of how current pressures and future threats will affect the range, area, and structure and function of the habitat

The range and area occupied by turloughs should be assessed against *favourable reference values*. *Favourable reference range* should encompass the range of variation and distribution of turloughs, and should be at least as large as the range and configuration when the Habitats Directive came into force. In practice, favourable reference range for turloughs has been increased in recent Article 17 Assessments to accommodate new information availale on the distribution of turloughs in Ireland (see *Chapter 10: Conservation Stus Assessment*). Similarly, *Favourable reference area* should encompass the total surface area of the habitat to ensure its long term viability, and must be at least the area of the habitat present when the Habitats Directive came into force. Favourable reference area will, as with favourable reference range, depend on the distribution as further turloughs are discovered through more detailed field survey, but also on the extent to which the turloughs flood; calculation turlough surface area (and hence favourable reference area) is therefore dependent upon the extent of flooding in turloughs AND the methods used to define the upper flooding bound. For further details on the definitions of favourable reference values, see Evans and Arvela (2011).

12.4.1 Range

Changes to the range of turloughs should be recorded with reference to range maps from the most recent Article 17 report for turloughs. Any sites that are lost may reduce the range to below the favourable reference range. However, increases to the range of the habitat will only be due to improved information as a result of further survey (see for example section 12.3.2.1), as turloughs are effectively landforms and cannot be created. If this is the case, the favourable reference range should also be increased to reflect the increased range being the result of improved information. Justification for any change to the favourable reference range should be included in the appropriate Audit Trail document.

Where total range of turloughs decreases below the favourable reference range, the range should be considered unfavourable, following the rules-based approach as outlined in Evans & Arvela (2011).

12.4.2 Area

Changes to the area of the turlough habitat may also occur through similar processes to those described for range: turlough sites could be lost for various reason, or 'new' sites added due to improved information. In addition, the area of any turlough may be reduced by a smaller flooded area, or conversely increased with a larger flooded area. Decreases in maximal (or average) flooded areas may come about through reduced groundwater levels (e.g. through reduced rainfall, abstraction etc.), or by drainage of part of the turlough basin, or by improved mapping of the flooded area. Similarly, increases in flooded area may be due to increased groundwater levels (e.g. due to higher rainfall), or improved mapping. Reasons for any consistent changes in flooded area should be determined. If changes in area are due to improved knowledge (e.g. better survey of turloughs, better mapping of existing turloughs, improved methods of estimating area etc.) then the favourable reference area should be adjusted. Any changes suggested to the favourable reference area must be fully justified in the appropriate Audit Trail document.

The area of the turlough habitat can at present be reliably measured ONLY by reference to hydrological data, such as the median of annual maximum flooded area (which would therefore exclude occasional very high flood levels). This requires accurate modeling of flooding based on site topography and depth of floodwater, such data are only likely to be available for a small number of sites. Estimates of flooded area can be obtained from vegetation maps or the presence of communities restricted to the extreme flooding zone, but these will involve considerable error (for example, compare vegetation mapped by the TCD project with those of Goodwillie – see Site reports) because of the gradual transitions of vegetation communities particularly in the upper flooding zone. In addition, detailed maps of vegetation are available for only a small number of turloughs. For some turloughs, it might be possible to calculate the area of the habitat by remotely sensed data; this approach is likely to become increasingly important in the future, but is currently very limited. In summary, because accurate assessments of area are currently available for a relatively small number of turloughs, reporting some estimation will be required to assess the total area of the habitat for Article 17.

Of the turloughs reported by Mayes (2008), 129 had surface areas estimated, likely obtained from a variety of sources (not specified). Goodwillie (1992) surveyed turloughs greater than 10 ha, and estimated area based on vegetation communities: for the majority of those turloughs surveyed these still remain the most reliable estimate of area. Turloughs less than 10 ha in area are likely to have very little accurate information on area, and this could skew any estimate of the total area of the habitat; this was taken into account in the 2013 conservation assessment by biasing the calculation of an average turlough area towards smaller turloughs: see *Chapter 10 – Conservation Assessment* (section 2) for further details.

Given these varied difficulties, we recommend that the method of determining area of both individual sites AND the estimation of total area within the State be explicitly documented in the relevant Audit Trail document.

Where total area of turloughs decreases below the favourable reference area, the area should be considered unfavourable, following the rules based approach as outlined in Evans & Arvela (2011).

12.4.3 Structure and Function

The structure and function of turloughs should be evaluated by reference to a number of indicators and pressures impacting individual sites; these should be assessed across a range of sample sites (see sections 12.2 and 12.3 above above), and the information combined to provide an overall assessment of structure and function. These individual site assessments can be taken together with site-specific pressures and threats to provide an assessment of individual site condition; this will provide an important tool to guide national conservation priorities and actions and to derive individual site-based conservation objectives.

Indicators have been developed to assess the current structure and function of the turlough habitat and the impacts of pressures (see table 12.3). They have been categorised into five broad areas: *Hydrological Function, Water Quality, Terrestrial Biological Responses, Aquatic Biological Responses*, and *Other Impacts*. Each of these broad areas (apart from Other Impacts) has several indicators, assessment of structure and function at each site is through consideration of each of the combined assessment of indicators within each of these broad areas. The indicators have been defined such that they operate as negative indicators; the sum of indicator values within each broad area is calculated, and divided by the total possible score for those indicators assessed. Thus the minimum score (most favourable) is zero and the maximum score (least favourable) is one within each broad area. This approach has been adopted because it facilitates incorporation of any new indicators into the assessment framework, for example indicators from a more intensive monitoring programme could readily be incorporated into the framework. This approach also makes allowances for any possible missing assessment of indicators for various reasons; some of the vegetation communities used as indicators may not occur in all turloughs, so calculating any loss of cover is meaningless: this can easily be accommodated in the proposed framnework. Some of the indicators suggested include evaluation of changes in value; for example, where wTP increases by more than 10%. At present, very few turloughs can be assessed for this indicator due to lack of a baseline, but this will change in the future as a wider range of baseline data become available for comparison between different reporting periods; we include some such indicators in the expectation that data will be available for their evaluation at the next Article 17 reporting period. Other indicators that indicate changes in state or impact of pressures could readily be incorporated into our evaluation framework. Likewise, with continued monitoring of sites over time, changes in the number and impact of pressures impacting individual sites may change, with decreases in pressures likely to result in improvement while increasing pressures likely to result in a decline of structure and function.

Some of the indicators apply to only a certain category of turlough, and for some indicators different thresholds apply in different categories of turlough; see section 12.3.2 for details.

Assessment of structure and function for each site should be based on whether determination of thresholds for indicators are met for the appropriate turlough category **AND** consideration of the pressures impacting the site, as shown in table 12.7. A worked example based on the 22 turloughs studied in detail by the TCD team is given in Appendix 12.5; this example includes cases where data required to assess a given indicator are not available. For example, changes in water TP is likely to be a very important indicator of site condition, but can only be used after baseline values have been established. Note that for each site, there is an option to alter the assessment of structure and function based on expert opinion, but in such cases justification for deviation from the formula provided MUST be given.

Table 12.7 Turlough structure and function assessment indicators and thresholds, with worked example for three contrasting turloughs.

Turlough name				Caherglassan	Knockaunroe	Skealoghan
Pre-screening A: mineral soil present (=1)				1	0	0
Pre-screening B: flooded pavement community present in turlough (=1)				1	1	0
Pre-screening B: limestone pavement occurs within 200 m of turough (=1)				1	1	0
Pre-screening B: *Potentilla fruticosa* present (=1)				0	1	0
Pre-screening B: *Frangula alnus* present (=1)				0	1	0
Pre-screening B: *Schoenus nigricans* present (=1)				0	1	0
Pre-screening: sum of prescreening criteria B:				2	5	0
ASSESSMENT GROUP [Mineral if A=1; Oligotrophic if A=0 AND B>1; Mesotrophic if A=0 and B=0]				Min	Oligo	Meso
Indicator	**OLIGOTROPHIC GROUP**	**MESOTROPHIC GROUP**	**MINERAL SOIL GROUP**	**Caherglassan**	**Knockaunroe**	**Skealoghan**
1. Hydrological function						
Invert of drainage (any increase or decrease of drainage capacity)	None, or affecting only exceptional flooding:0; Affecting flooding in upper part of basin: 1; affecting flooding in majority of basin 2			**0**	**0**	**0**
Consistent or progressive change in flooding depth/duration/area of flooding (over 6 year HD reporting cycle)	<5% change: 0; 5-20% change: 1; >20% change: 2			**0**	**0**	**0**
Maximum score	**Sum of maximum possible scores for those indicators assessed**			**4**	**4**	**4**
Hydrological function score	Sum of scores divided by maximum possible score (0-0.33 - good; >0.33-0.66: intermediate; > 0.66-1: poor)			**0**	**0**	**0**

2. Water quality	OLIGOTROPHIC GROUP	MESOTROPHIC GROUP	MINERAL SOIL GROUP	Cg	Kn	Sk
Floodwater TP	< 10 µg l^{-1}: 0; 10-20 µg l^{-1}: 1; >20 µg l^{-1}:2	< 20 µg l^{-1}: 0; 20-40 µg l^{-1}: 1; >40 µg l^{-1}: 2		**2**	**0**	**1**
Increase in floodwater TP	> 10% increase: 0; 10-20%: 1; >20% increase: 2			ni	ni	ni
Maximum recorded Chl*a*	< 10 µg l^{-1}: 0; >10 µg l^{-1}:1			**1**	**0**	**1**
Water colour	>30 mg l^{-1} PtCo: 1			ni	ni	ni
Maximum score	**Sum of maximum possible scores for those indicators assessed**			**3**	**3**	**3**
Water quality score	Sum of scores divided by maximum possible score (0-0.33 - good; >0.33-0.66: intermediate; > 0.66-1: poor)			**1**	**0**	**0.67**
3. Biological responses: terrestrial	OLIGOTROPHIC GROUP	MESOTROPHIC GROUP	MINERAL SOIL GROUP	Cg	Kn	Sk
Agrostis stolonifera-Glyceria fluitans community cover	< 5% cover of turlough: 0; 5-20%: 1; >20%: 2			**0**	**0**	**0**
Cover of Rumex crispus, R. conglomeratus and *R. acetosa* either singly or in combination	< 5% cover of turlough OR < 10% of releves surveyed: 0; >5% cover OR 10% releves: 1			**1**	**0**	**0**
Lolium grassland cover	< 10% cover of turlough: 0; 10-20% cover: 1; >20%: 2			**1**	**1**	**1**
Grass-forb dominated community area	< 33% cover of turlough: 0; > 33% cover 1		N.A.	N.A.	**0**	**0**
Filipendula ulmaria-Potentilla erecta-Viola sp. community	< 2% cover of turlough: 0; 2-10% cover: 1; >10%: 2	N.A.	N.A.	N.A.	**0**	N.A.
Poa annua-Plantago major community	< 2% cover of turlough: 0; 2-10% cover: 1; >10%: 2			**0**	**0**	**0**
Polygonum amphibium community	< 2% cover of turlough: 0; 2-10% cover: 1; >10%: 2	N.A.	N.A.	N.A.	**0**	N.A.
Eleocharis acicularis community	N.A.	N.A.	No loss: 0; loss of community: 1	**0**	N.A.	N.A.
Limestone grassland, Flooded pavement or woodland communities in any combination	>10% of turlough: 0; <10% of turlough: 1			**0**	**0**	**1**
Eleocharis palustris-Ranunculus flammula community	>10% of turlough: 0; <10% of turlough: 1		N.A.	N.A.	**0**	**1**
Eleocharis palustris-Ranunculus flammula community	No loss in area: 0; loss of area: 1		N.A.	N.A.	ni	ni
Polygonum amphibium community	N.A.	No loss in area: 0; loss of area: 1		ni	N.A.	ni
Molinia caerulea-Carex panicea community	cover >2% of turlough: 0; cover <2%: 1		N.A.	N.A.	**0**	**0**
Sward height greater than 40 cm (except reedbeds)	Indicates undergrazing: < 40 cm: 0; > 40 cm: 1			**0**	**0**	**0**
Sward height less than 8 cm	Indicates intensive overgrazing by sheep: > 8 cm: 0; < 8 cm: 1			**0**	**0**	**0**
Notable species (incl. inverts)	No loss: 0; loss of species: 1			ni	ni	ni
Maximum score	**Sum of maximum possible scores for those indicators assessed**			**11**	**17**	**13**
Terrestrial biological responses score	Sum of scores divided by maximum possible score (0-0.33 - good; >0.33-0.66: intermediate; > 0.66-1: poor)			**0.18**	**0.06**	**0.23**
4. Biological responses: aquatic	OLIGOTROPHIC GROUP	MESOTROPHIC GROUP	MINERAL SOIL GROUP	Cg	Kn	Sk

Presence of algal paper	< 2% of turlough area: 0; >2% area: 1	**0**	**0**	**1**
Absence of fully aquatic vascular plants	Any species present: 0, otherwise 1	**1**	**0**	**0**
Notable species (incl. inverts)	No loss: 0; loss of species: 1	ni	ni	ni
Maximum score	**Sum of maximum possible scores for <u>those indicators assessed</u>**	**2**	**2**	**2**
Aquatic biological responses score	Sum of scores divided by maximum possible score (0-0.33 - good; >0.33-0.66: intermediate; > 0.66-1: poor)	**0.5**	**0**	**0.5**
5. Other	OLIGOTROPHIC GROUP / MESOTROPHIC GROUP / MINERAL SOIL GROUP	**Cg**	**Kn**	**Sk**
Physical damage to turlough (land clearance, resource extraction etc.)	< 5% of turlough area: 0; 5-20%: 1; >20%: 2	**0**	**0**	**0**
Maximum score	**Sum of maximum possible scores for <u>those indicators assessed</u>**	**2**	**2**	**2**
Other impact score	Sum of scores divided by maximum possible score (0-0.33 - good; >0.33-0.66: intermediate; > 0.66-1: poor)	**0**	**0**	**0**

* N.A. - Indicator not <u>applicable</u> to this assessment group; n.i. – indicator not <u>available</u> at this site

Table 12.7 continued: Summary

SUMMARY		Caherglassan	Knockaunroe	Skealoghan
1. Hydrological function score	Sum of scores divided by maximum score (0-0.33 - good; >0.33-0.66: intermediate;> 0.66-1: poor)	**0**	**0**	**0**
2. Water quality score	Sum of scores divided by maximum score (0-0.33 - good; >0.33-0.66: intermediate;> 0.66-1: poor)	**1**	**0**	**0.67**
3. Terrestrial biological responses score	Sum of scores divided by maximum score (0-0.33 - good; >0.33-0.66: intermediate;> 0.66-1: poor)	**0.18**	**0.06**	**0.23**
4. Aquatic biological responses score	Sum of scores divided by maximum score (0-0.33 - good; >0.33-0.66: intermediate;> 0.66-1: poor)	**0.5**	**0**	**0.5**
5. Other impact score	Sum of scores divided by maximum score (0-0.33 - good; >0.33-0.66: intermediate;> 0.66-1: poor)	**0**	**0**	**0**
COMBINED S&F INDICATORS	Green: no red, no more than 1 amber; Red: Two red, or one red and two or more amber; Amber: any other combination			
PRESSURES				
Number of high impact pressures		2	0	0
Number of medium impact pressures		2	0	2
Number of low impact pressures		2	3	2
OVERALL SITE STRUCTURE & FUNCTION	**GREEN**: S&F Indicators green **AND** no high impact pressure; **RED**: S&F Indicators Red **OR** at least 1 high impact pressure **OR** 1 high impact pressure and at least 3 medium impact pressures			
ADJUSTMENT TO OVERALL ASSESSMENT	Based on expert judgement. Justification for any adjustment **MUST** be given and incorporated into the Article 17 Audit Trail document	**U2**	**Fv**	**U1**

Individual site structure and function condition is given by assessment of the five broad indicator groups (i.e. *Hydrological Function, Water Quality, Terrestrial Biological Responses, Aquatic Biological Responses*, and *Other Impacts*), and assessment of the pressures operating at each site. Scores of less than 0.33 are considered good (Green), 0.33-0.66 intermediate (amber) and scores of greater than 0.66 are considered poor (red). Structure and function for individual sites is considered Favourable when none of the five broad indicator areas are evaluated as poor, or no more than one of the five evaluated as intermediate, **AND** there are no high impact pressures at the site. Structure and function for individual sites is considered Unfavourable (bad) when two or more of the five broad indicator areas are considered poor, **OR** one area is considered bad and at two more considered intermediate, **OR** there is at least one high impact pressure **OR** one high impact pressure and at least 3 medium impact pressures. Structure and function for individual sites is considered Unfavourable (inadequate) in evaluations which fall between these thresholds set for Favourable and Unfavourable (bad). These thresholds for assessing structure and function have been tested on 22 turloughs and appear to be suitable, though further application to a larger number of turloughs may require slight modification of these values. These individual site evaluations of structure and function should reflect the pressures operating at each site; anomalies between structure and function and pressure evaluations might be one reason for expert opinion to adjust the site evaluation, which in itself might be used to trigger a more intensive ecological investigation of those particular sites.

To evaluate overall national Structure and Function, the percentage of the total area assessed as favourable, unfavourable (inadequate) and unfavourable (bad) needs to be calculated from individual site assessments. There are no specific guidelines for achieving this in Evans and Arvela (2011), but examples of two approaches are provided, and these have been used to develop the following proposed system for turloughs. The overall national Structure and Function of turloughs is considered Favourable if Structure and Function in at least 90 % of the total area assessed is considered favourable. The overall national Structure and Function is considered Unfavourable (Bad) if Structure and Function in more than 25% of the area assessed is considered unfavourable (bad); in all other cases the overall national Structure and Function should be considered Unfavourable (Inadequate). An example is given in table 12.8.

Table 12.8 Assessment of national structure and function for turloughs, based on individual site condition assessments (values based on 2013 assessment)

	Area (ha)	Area (% of total)
Total area assessed	905	100%
Total area Favourable	345	38%
Total area Unfavourable (inadequate)	430	47%
Total area Unfavourable (bad)	130	14%
National Structure and Function Assessment	**Unfavourable (inadequate)***	

*Less than 90% of area assessed is Favourable, but not more than 25% is assessed as Unfavourable (bad)

12.4.4 Future Prospects

For each site, all current and recent pressures and predicted future threats should be listed and their likely impact assessed as high, medium or low (see section 12.3.2.9).

The future prospects for turloughs should be based on the current conditions of range, area and structures and function, and the predicted trends in these based on current pressures and likely threats. For assessment, the future prospects of individual sites can be assessed by considering whether threats likely to be operating at the sample sites in the near future (12 years, two reporting cycles) are likely to alter the current area of the turlough (i.e. total area flooded) or its structure and function. Range is unlikely to be affected at local site level unless a site is completely destroyed, though this has happened in exceptional cases in the past. In some cases existing pressures might be predicted to decrease in the future, possibly leading to lower impact threats and hence more favourable conditions. Similarly, some current pressures may become higher impact threats, worsening the conservation condition. Some pressures might be completely eliminated, perhaps by favourable management interventions or other conservation action, improving the future prospects for conservation, in other cases new threats may occur. However, in assessing the impact of pressures on future prospects, some consideration of the duration of the impact should be given. For example, the once off bulldozing of Lough Aleenaun for agricultural improvement has had very long lasting effects which are likely to persist into the future for a considerable time, even though the pressure was impacting for a relatively short period of time and is not considered a future threat. In contrast, recent excessive trampling at Ardkill due to movement of cattle persists as a threat, but the impact is reversible as the vegetation of trampled areas can recover if cattle are moved in and out of the turlough along different routes (see *Chapter 7 – Vegetation: Description, Mapping and Ecology*).

The only likely impacts on trends in area are those that are likely to affect the hydrology of the system, such as changes in rainfall pattern, drainage etc. Most impacts are thus likely to affect the trends in structure and function of a site. Evans & Arvela (2011, page 34) provide a reference matrix for assessing future prospects, and this should be used to guide the assessment, but note that this table mainly refers to favourable reference values; these are relatively easy to apply to range and area but not to structure and function. It is recommended that the numbers of high, medium and low impact pressures and threats be determined for each site, and the predicted trends in current pressures (increase, decrease, stable) assessed, consideration should be given to any planned interventions which should reduce the impact of pressures and threats. The overall impact of trends in pressures and novel threats on site area and structure and function should be assessed in order to obtain future prospects for individual sites. This assessment will be largely based on expert opinion rather than being rules or formula driven; threats be their nature can only be predicted and not measured, and the relative importance of impacts (high, medium, low) is highly subjective. Assessment of trends should be biased to consideration of high impact pressures and threats, while estimation of low impact pressures and threats is important in assessing trends, low impacts are unlikely to have important effects on area or structure and function.

Some guidance for the assessment of future prospects is given in Table 12.9, along with worked examples from three contrasting turloughs. The current area of most individual turloughs is considered good, and most sites there are no pressures or threats likely to significantly alter the area. The current Structure and Function at Ardkill is poor, mainly due to high pressures related to agricultural nutrient input; these are unlikely to diminish in the near future so Future Prospects are assessed as poor. Structure and Function is currently considered good at Caranavoodaun, although nutrient levels are moderately high at this site; pressures from agriculture and from the relatively high density of rural settlement around this turlough result in future Prospects for the site being assessed as intermediate. Lough Gealain has currently no discernable pressures and can be considered one of the most pristine turloughs nationally (and probably globally). The predicted threats are all of low impact and are not considered likely to affect the currently good Structure and Function; the Future Prospects for Lough Gealain are therefore considered to be Good.

Table 12.9. Suggested framework for the estimation of Future Prospects in turloughs, using three contrasting examples.

	Ardkill	Caranavoodaun	Lough Gealain
Number of high impact pressures	1	0	0
Number of medium impact pressures	2	2	0
Number of low impact pressures	1	3	0
Current status of Habitat Area	**Good**	**Good**	**Good**
Current status of Structure and Function	**Poor**	**Good**	**Good**
Number of high impact threats	2	1	0
Number of medium impact threats	2	2	0
Number of low impact threats	3	4	4
Predicted trend in current pressures	Increase	Increase	Stable
Predicted trends in area	Stable	Stable	Stable
Predicted trends in structure and function	Decease	Decrease	Stable
Future prospects	**Poor**	**Intermediate**	**Good**

To obtain the future prospects for the turlough habitat in the country as a whole, we propose using the sampled individual sites to estimate overall prospects in a similar manner to the proposed assessment of overall structure and function (see above). We propose that the overall national Future Prospects of turloughs is considered Favourable if at least 90 % of the total area assessed has favourable prospects. The overall national Future Prospects is considered Unfavourable (Bad) if more than 25% of the area assessed is considered to have Unfavourable (bad) prospects; in all other cases the overall national Future Prospects should be considered Unfavourable (Inadequate). Further work with a larger number of individual turloughs may require some alteration of the thresholds here, but we propose the framework here as there are few specific details given in Evans and Arvela (2011), and our approach for future prospects is consistent with that proposed for structure and function. Expert opinion should be used to verify these overall assessments of future prospects, for example by any information available on likely threats that might be expected for turloughs outside of those sampled for Article 17 reporting.

12.4.5 Overall Conservation Assessment

Overall conservation assessment requires consideration of the habitat range, area, structure and function, and future prospects; the evaluation matrix given in table 12.10 should be used for this assessment.

For overall conservation status to be assessed as **Favourable**, there should be at least three green parameters and no more than one unknown. For conservation status to be assessed as

Unfavourable (inadequate) there should be one or more amber parameters and no red. Conservation status should be assessed as **Unfavourable (bad)** when there are any red parameters.

Table 12.10 General evaluation matrix for assessing habitat conservation status (adapted from Article 17 reporting formats for the period 2007-2012). Conservation status should be assessed as **Unknown** if there are two or more parameters assessed as unknown with no red or amber parameters.

Parameter	Conservation Status		
	Favourable ('green')	Unfavourable – Inadequate ('amber')	Unfavourable – Bad ('red')
Range	Stable (loss and expansion in balance) or increasing ***AND*** not smaller than the 'favourable reference range'	Any other combination	Large decrease: Equivalent to a loss of more than 1% per year within period specified by MS, ***OR*** More than 10% below 'favourable reference range'
Area covered by habitat type within range	Stable (loss and expansion in balance) or increasing ***AND*** not smaller than the 'favourable reference area' ***AND*** without significant changes in distribution pattern within range (if data available)	Any other combination	Large decrease in surface area: Equivalent to a loss of more than 1% per year (indicative value MS may deviate from if duly justified) within period specified by MS ***OR*** With major losses in distribution pattern within range ***OR*** More than 10% below 'favourable reference area'
Specific structures and functions (including typical species)	Structures and functions (including typical species) in good condition and no significant deteriorations / pressures.	Any other combination	More than 25% of the area is unfavourable as regards its specific structures and functions (including typical species)
Future prospects (as regards range, area covered and specific structures and functions)	The habitat's prospects for its future are excellent /good, no significant impact from threats expected; long-term viability assured.	Any other combination	The habitats prospects are bad, severe impact from threats expected; long-term viability not assured.

Parameters should be assessed as *Unknown (insufficient information to make an assessment)* if no or insufficient reliable information is available.

12.5 Application to Environmental Impact Assessment and Appropriate Assessment

The basic monitoring protocol is designed to provide the minimum information that is required for assessment of conservation status under Article 17 reporting for the Habitats Directive. As noted above, the intensive monitoring protocol will provide more detailed ecological information, through monitoring of a wider range of indicators, particularly those which will reflect the broader biological impacts of various pressures, and more precise measurement (cf.

estimation). These more-detailed data can be used to reliably assess trends in pressures, changes in ecological states and resulting biological impacts. As such the components of the intensive survey can also provide the evidence base to support conservation management of turloughs, this includes evidence of the likely impacts of any future developments that may affect turloughs. Many of the indicators proposed could be incorporated into Environmental Impact Assessments and Appropriate Assessments where appropriate, though the exact nature of any proposed development will likely determine the exact suite of indicators and monitoring approaches that should be employed.

We can make some recommendations for future EIA and AA procedures that involve turloughs. As mentioned above (section 12.1.3 above, see also *Chapter 9: Integration and Ecological Function*), while determination of various critical ecological *states* (e.g. flooding, nutrient status) is relatively straightforward, determining the *pressures* that are directly responsible for these ecological states (e.g. reduced flooding, increased total P in floodwater) is far more problematic. Additionally, biological responses to changes in ecological state may be slow to develop, particularly changes in vegetation community (aquatic invertebrate communities may respond faster). As a result, we strongly recommend that EIA or AA for developments which may potentially impact upon the ecological structure and function of ANY turlough should focus particularly on the key ecological processes of flooding regime and nutrient status. This will require assessment of the proposed development on the depth and area of flooding within the turlough, and on the concentrations of total phosphorus in floodwater, and implicit here is a requirement to establish quantitative baseline data for:

1. The area and depth of flooding, by continuous monitoring of water depth using the methodology outlined in section 12.3.2.3, coupled with a full topographic survey of the turlough using the methodology outlined in section 12.3.2.4
2. The concentrations of total phosphorus in water samples taken MONTHLY during the hydroperiod (generally September to May) using the methodology outlined in section 12.3.2.2.
3. The zone of groundwater contribution to the turlough, which must be accurately identified see section 12.3.2.5.
4. Vegetation communities – a vegetation map (mentioned below but needs to be in this list of 'quantitiative baseline data')
5. Baseline survey of species and other communties, particularly those of conservation concern and those that may be impacted by the proposed development or activity

If developments proceed, it should be a requirement that adequate monitoring of vegetation communities, aquatic invertebrate communities, terrestrial carabid communities, breeding/wintering waterfowl, waders and gulls are recorded, where appropriate, for adequate periods prior to and subsequent to the development, so that any impacts on key biological processes can be determined. This may require more frequent monitoring of these communities than proposed for standard intensive monitoring (see Table 12.5); at least annual monitoring of biological communities is required to generate adequate data to determine fine scale responses and trends. For birds, carabids and aquatic invertebrates this will require assessment of seasonal changes (see sections 12.3.2.8, 12.3.2.9 and 12.3.2.10 above). Other indicators, such as those recording physical damage to the site in Table 12.3, should also be recorded at least annually.

One particular development which is likely to be mooted for some turloughs is drainage to relieve flooding. Drainage to reduce extremely high flood levels, which may occur only very sporadically, is unlikely to significantly affect turlough ecological structure and function. Such flooding levels would be considered well above the median levels of annual maximum flooded area – more detailed work may be able to determine percentile ranges of annual maximum flooded area above which biological impacts are minimal. More serious would be any proposed impact that lowered the median value, recorded over at least six years, of the annual maximum flooded area or depth.

12.6 Implementation

The implementation of the monitoring protocols outlined here will be complex and possibly involve a number of actors and agencies. We make some brief observations and recommendations here on possibilities for implementation.

Of paramount importance will be consistency of data collection during monitoring, this will be especially important if different individuals are recording information or taking samples in different parts of the country. We have outlined in detail some of the methodologies that have been developed from the TCD project on turlough ecology and conservation, but we emphasise that appropriate standardized methodology will need to be adopted for features/species/communities not covered by our project (e.g. carabids, birds). It will be essential to ensure consistency of data collection and methods of analysis.

NPWS Rangers could be used to collect some of the data, their expertise will certainly be invaluable in implementing the site verification procedures, and possibly some of the basic monitoring protocol. NPWS should seek engagement with various agencies who could contribute to on-going monitoring:

- *Environmental Protection Agency:* analysis of water samples from turloughs and groundwater in ZOCs
- *Office of Public Works:* acquisition and assessment of water level data
- *Department of Agriculture, Food and the Marine; Teagasc Teoranta*: stocking density and timing of stocking at a land parcel level, both within turloughs and their wider ZOCs

Some of the proposed monitoring work should link in directly with water quality reporting, flood monitoring and stocking rates that are likely to be ongoing with these agencies. However, it should be emphasized that NPWS should ensure that where turlough monitoring requirements outlined in this chapter are incorporated into any other ongoing monitoring programmes, the data appropriate for turlough conservation assessment should meet the standards required in terms of variables measured, timing and frequency of sampling.

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Appendix 12.1: Synoptic Tables of Vegetation Communities That Form Part of the Conservation Assessment

The floristic tables for vegetation communities that form part of the conservation assessment are presented below. The synoptic tables are those derived from Sharkey (2012) and also provided in *Chapter 7 – Vegetation*, based on sample releves from 22 turloughs. These synoptic tables should give an indication of the community, especially the dominant and more abundant species present, but there is likely to be considerable variation among and within turloughs. In the tables that follow 'Frequency' refers the percentage of relevés assigned to the community that contained a given species, and is not related to the abundance of that species in the samples. The frequency classes used in the tables are those used in the UK National Vegetation Classification (Rodwell, 1991a), and are denoted by Roman numerals: I = 1-20% frequency, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%. Following the terminology of the NVC for a given community, species that occur at frequency classes IV to V to are referred to as constants. The other classes are described as: III – common/frequent, II – occasional and I – scarce. In the tables, the species are sorted according to frequency, and then alphabetically.

Agrostis stolonifera-Glyceria fluitans community,

This community is generally aquatic, occurring at the base or near the bottom of the turloughs, in areas that are likely to retain some standing water throughout the season. *Agrostis stolonifera* and *Glyceria fluitans* are constant and dominant species, with frequent *Eleocharis palustris* and *Galium palustre,* several aquatic species occur. The community occurs in areas of nutrient enrichment that are accessible by livestock, though grazing may limited due to the presence of standing water.

Floristic table for the *Agrostis stolonifera-Glyceria fluitans* community.

No. of relevés	28		
No. of species	51		
Agrostis stolonifera	V (3-9)	*Leontodon autumnalis*	I (4)
Glyceria fluitans	IV (4-8)	*Lythrum portula*	I (4)
Eleocharis palustris	III (3-9)	*Molinia caerulea*	I (4)
Galium palustre	III (3-6)	*Oenanthe aquatica*	I (5)
Cardamine flexuosa	II (3-7)	*Polygonum persicaria*	I (4-5)
Equisetum fluviatile	II (4-6)	*Phalaris arundinacea*	I (5-6)
Mentha aquatica	II (3-6)	*Plantago major*	I (1)
Myosotis scorpioides	II (4-7)	*Poa annua*	I (4)
Polygonum amphibium	II (3-8)	*Polygonum aviculare*	I (5)
Ranunculus repens	II (3-6)	*Potentilla anserina*	I (3-5)
Alisma plantago-aquatica	I (3-5)	*Ranunculus flammula*	I (4-5)
Alopecurus geniculatus	I (4)	*Ranunculus trichophyllus*	I (1-5)
Apium inundatum	I (5)	*Rorippa amphibia*	I (4-6)
Apium nodiflorum	I (4-5)	*Rorippa palustris*	I (4-7)
Baldellia ranunculoides	I (4-5)	*Rumex crispus*	I (2)
Callitriche spp.	I (4)	*Rumex obtusifolius*	I (5)
Caltha palustris	I (4)	*Senecio aquaticus*	I (1)
Cardamine pratensis	I (4)	*Sparganium erectum*	I (5-6)
Carex nigra	I (3-5)	*Stellaria media*	I (3-4)
Gnaphalium uliginosum	I (1-2)	*Trifolium repens*	I (4-5)

Juncus acutiflorus	I (4-5)	*Veronica catenata*	I (4)
Juncus articulatus	I (3-4)	*Veronica scutellata*	I (4-5)
Juncus effusus	I (6)	*Zannichellia palustris*	I (4)
Lemna minor	I (3)		

Here and in the following floristic tables, species frequency within the vegetation type is indicated by Roman numeral (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80% and V = 81-100%). The numbers in parentheses indicate the range of Domin scores within the community for each species to give an indication of abundance.

Eleocharis acicularis community

This community forms relatively small patches dominated by *E. acicularis* on drying mud near water, usually at the very base of the turlough, and low water levels will be needed to detect it. The community appears to be restricted to mineral soil turloughs in the vicinity of Gort (Co. Galway) but should be looked for in mineral soil turloughs elsewhere. The sward is very short. *Eleocharis acicularis, Agrostis stolonifera, Rorippa islandica*, *Lythrum portula, Callitriche* sp. and *Ranunculus trichophyllus* are constant, while *Gnaphalium uliginosum, Mentha aquatica, Polygonum hydropiper* and *P. minus* were common. This community seems to consist mostly of annual species that complete their life-cycle while the flooding has subsided.

Floristic table for the *Eleocharis acicularis* community.

No. of relevés	13		
No. of species	27		
Agrostis stolonifera	V (3-6)	*Polygonum persicaria*	II (3-4)
Eleocharis acicularis	V (3-9)	*Polygonum aviculare*	II (4-5)
Callitriche spp.	IV (1-3)	*Potentilla anserina*	II (1-4)
Lythrum portula	IV (1-4)	*Rorippa amphibia*	II (1-2)
Ranunculus trichophyllus	IV (1-4)	*Bellis perennis*	I (1)
Rorippa islandica	IV (1-3)	*Juncus articulatus*	I (2)
Gnaphalium uliginosum	III (1-4)	*Poa annua*	I (3)
Mentha aquatica	III (1-4)	*Polygonum amphibium*	I (3)
Polygonum hydropiper	III (4-5)	*Ranunculus repens*	I (1)
Polygonum minus	III (3-5)	*Sparganium emersum*	I (4)
Eleocharis palustris	II (3-5)	*Trifolium repens*	I (3)
Galium palustre	II (2-3)	*Urtica dioica*	I (2)
Limosella aquatica	II (1-4)		

Eleocharis palustris-Ranunculus flammula community,

This community is dominated by *Mentha aquatica*, *Eleocharis palustris and Ranunculus flammula; Polygonum amphibium* is frequent, along with *Glyceria fluitans, Galium palustre* and *Juncus articulatus*. *Elodea canadensis*, an invasive aquatic alien, is occasionally found in this community. The community is found in the lower zones of mainly oligotrophic turloughs, usually in shallow water. It can form large stands, especially in shallower basins or those with a flat bottom with marl or occasionally silt. It is often subject to poaching by cattle seeking water, and subsequent enrichment through dunging.

Floristic table for the *Eleocharis palustris-Ranunculus flammula* community.

No. of relevés	31		
No. of species	45		
Eleocharis palustris	V (3-9)	*Hippuris vulgaris*	I (4-5)
Mentha aquatica	V (3-7)	*Hydrocotyle vulgaris*	I (3-5)
Ranunculus flammula	IV (2-6)	*Juncus bulbosus*	I (5)
Galium palustre	III (3-5)	*Lemna minor*	I (4)
Glyceria fluitans	III (4-7)	*Littorella uniflora*	I (3-8)
Juncus articulatus	III (3-8)	*Lythrum portula*	I (3)
Polygonum amphibium	III (3-5)	*Myosotis scorpioides*	I (3-4)
Agrostis stolonifera	II (3-7)	*Polygonum persicaria*	I (4)
Alisma plantago-aquatica	II (2-7)	*Phalaris arundinacea*	I (2)
Baldellia ranunculoides	II (3-6)	*Potamogeton gramineus*	I (4-6)
Equisetum fluviatile	II (4-6)	*Potentilla anserina*	I (3)
Oenanthe aquatica	II (4-7)	*Ranunculus repens*	I (3)
Potamogeton natans	II (3-6)	*Ranunculus trichophyllus*	I (3-5)
Apium inundatum	I (3)	*Rorippa amphibia*	I (2-9)
Cardamine flexuosa	I (4)	*Samolus valerandi*	I (3-4)
Carex elata	I (7)	*Schoenoplectus lacustris*	I (9)
Carex viridula	I (4-6)	*Sparganium emersum*	I (3-5)
Carex hostiana	I (4)	*Sparganium erectum*	I (4-5)
Carex nigra	I (3-6)	*Teucrium scordium*	I (3)
Chara species	I (4)	*Veronica beccabunga*	I (4)
Eleocharis multicaulis	I (4)	*Veronica scutellata*	I (4)
Eleogiton fluitans	I (7)	*Zannichellia palustris*	I (6)
Elodea canadensis	I (5-8)		

***Filipendula ulmaria-Potentilla erecta-Viola* sp. community,**

A herb-rich community in which *Viola* sp., *Filipendula ulmaria, Potentilla anserina, Lotus corniculatus* and *Potentilla erecta* are constant. *Carex nigra, Galium palustre* and *Rumex acetosa* are all frequent. This community occurs in the middle of the flooding gradient of nutrient-rich turloughs.

Floristic table for the *Filipendula ulmaria-Potentilla erecta-Viola* community.

No. of relevés	14		
No. of species	30		
Filipendula ulmaria	V (4-7)	*Ranunculus repens*	III (3-4)
Lotus corniculatus	V (4-6)	*Sagina nodosa*	III (0.1-4)
Potentilla anserina	V (4-7)	*Carex panicea*	II (3-4)
Potentilla erecta	V (3-7)	*Cerastium fontanum*	II (0.1-4)
Viola species	V (4-5)	*Juncus bufonius*	II (3)
Carex nigra	IV (4-7)	*Plantago lanceolata*	II (3-4)
Galium palustre	IV (3-5)	*Cardamine pratensis*	I (3)
Plantago media	IV (3-5)	*Festuca rubra*	I (2)
Rumex acetosa	IV (3-4)	*Mentha aquatica*	I (4)
Agrostis stolonifera	III (2-5)	*Ophioglossum vulgatum*	I (2-3)
Galium boreale	III (3-4)	*Plantago major*	I (3-4)
Galium verum	III (4)	*Rhamnus cathartica*	I (0.1)

Leontodon autumnalis	III (3-4)	*Rorippa palustris*	I (2)
Poa annua	III (3-5)	*Rumex crispus*	I (4)
Potentilla reptans	III (4-7)	*Trifolium repens*	I (4)

Limestone grassland

A species-rich vegetation type, with a relatively short sward. *Lotus corniculatus, Potentilla erecta, Plantago lanceolata, Festuca rubra, Carex flacca, Trifolium repens, Succisa pratensis* and *Carex panicea* are constant, while *Leontodon hispidus, Prunella vulgaris, Leontodon autumnalis, Agrostis stolonifera, Molinia caerulea, Galium verum* and *Plantago maritima* are frequent. Limestone grassland occurs on the upper fringes of turloughs with shallow soils, which are generally underlain with limestone; the wide range of calcareous grassland species present generally reflects the transition from turlough to unimproved pasture. The community occurs in a range of turloughs, and is generally lightly grazed, either by livestock or by wild and feral grazers.

Floristic table for the Limestone grassland community.

No. of relevés	57		
No. of species	117		
Festuca rubra	V (4-8)	*Festuca arundinacea*	I (3-7)
Lotus corniculatus	V (4-6)	*Festuca pratensis*	I (5)
Plantago lanceolata	V (1-7)	*Filipendula vulgaris*	I (4-5)
Potentilla erecta	V (3-6)	*Fraxinus excelsior*	I (1-5)
Carex flacca	IV (2-6)	*Galium boreale*	I (4)
Carex panicea	IV (3-7)	*Galium palustre*	I (3)
Succisa pratensis	IV (2-7)	*Geranium sanguineum*	I (4)
Trifolium repens	IV (2-6)	*Geum rivale*	I (5)
Agrostis stolonifera	III (3-8)	*Glechoma hederacea*	I (3)
Galium verum	III (2-6)	*Holcus lanatus*	I (2-5)
Leontodon autumnalis	III (2-7)	*Hydrocotyle vulgaris*	I (1-6)
Leontodon hispidus	III (3-7)	*Hypochoeris radicata*	I (4)
Molinia caerulea	III (3-7)	*Juncus acutiflorus*	I (4)
Plantago maritima	III (4-6)	*Juncus articulatus*	I (3-4)
Prunella vulgaris	III (2-7)	*Knautia arvensis*	I (5)
Bellis perennis	II (1-5)	*Lathyrus pratensis*	I (5)
Carex hostiana	II (3-7)	*Leontodon saxatilis*	I (3-6)
Centaurea nigra	II (3-6)	*Leucanthemum vulgare*	I (2-5)
Danthonia decumbens	II (3-5)	*Linum catharticum*	I (1-5)
Filipendula ulmaria	II (2-6)	*Mentha aquatica*	I (1-3)
Lolium perenne	II (2-5)	*Odontites vernus*	I (2)
Trifolium pratense	II (1-5)	*Parnassia palustris*	I (3-4)
Viola species	II (1-5)	*Phalaris arundinacea*	I (2-5)
Achillea millefolium	I (3-6)	*Phleum bertolonii*	I (3-5)
Achillea ptarmica	I (1-5)	*Phleum pratense*	I (4)
Agrostis capillaris	I (4-6)	*Plantago major*	I (1-2)
Alchemilla spp.	I (5)	*Poa pratensis*	I (4-6)
Alopecurus geniculatus	I (3)	*Poa trivialis*	I (3)
Anagallis tenella	I (2)	*Potentilla anserina*	I (1-8)
Antennaria dioica	I (3-4)	*Potentilla fruticosa*	I (4)
Briza media	I (3-5)	*Potentilla reptans*	I (1-5)
Calluna vulgaris	I (5-7)	*Prunus spinosa*	I (1-4)
Campanula rotundifolia	I (3-4)	*Ranunculus acris*	I (2-5)
Cardamine pratensis	I (1-4)	*Ranunculus flammula*	I (1-4)
Carex hirta	I (4-5)	*Ranunculus repens*	I (1-4)

Carex nigra	I (3-7)	*Rhamnus cathartica*	I (2-3)
Carex pulicaris	I (4)	*Rhinanthus minor*	I (2-4)
Carex viridula agg.	I (3-6)	*Rosa spinosissima*	I (2-3)
Cerastium fontanum	I (1-4)	*Rubus fruticosus* agg.	I (5)
Cirsium arvense	I (3-6)	*Rumex acetosa*	I (3)
Cirsium dissectum	I (1-6)	*Salix repens*	I (5)
Cirsium palustre	I (5)	*Schoenus nigricans*	I (3-5)
Crataegus monogyna	I (1-4)	*Senecio aquaticus*	I (4)
Cynosurus cristatus	I (3-6)	*Stellaria media*	I (3)
Dactylorhiza incarnata	I (1-4)	*Taraxacum officinale* agg.	I (1-5)
Deschampsia cespitosa	I (4-5)	*Thymus polytrichus*	I (3-5)
Elytrigia repens	I (3)	*Veronica serpyllifolia*	I (5)
Equisetum palustre	I (4)	*Vicia cracca*	I (3-5)
Euphrasia spp.	I (2-5)		

Lolium perenne **grassland**

A relatively short (c. 20cm) species-rich sward dominated by *Lolium perenne* and *Trifolium repens*. Other constant species, albeit at generally lower abundance, are *Agrostis stolonifera, Bellis perennis, Cardamine pratense, Festuca rubra, leontodon autumnalis, Plantago lanceolata* and *Prunella vulgaris. Ranunculus acris, Ranunculus repens* and *Taraxacum officinale* agg. are frequent. This community occurs in the upper zones of the turlough basins, generally fringing the turlough, and as such it experiences the least amount of inundation. Some of the species found here, such as *Lolium perenne* and *Trifolium repens* are indicative of semi-improved grassland. These areas are grazed when the flooding level permits. The synoptic table below is based on the *Lolium perenne-Trifolium repens* community (*Chapter 7 – Vegetation*; Sharkey, 2012) to give an indication of the species present, but for conservation assessment all areas dominated by *L. perenne* should be mapped as *Lolium* grassland.

Floristic table for the *Lolium perenne-Trifolium repens* community

No. of relevés	20		
No. of species	62		
Lolium perenne	V (3-7)	*Cirsium vulgare*	I (3-4)
Trifolium repens	V (3-9)	*Danthonia decumbens*	I (3)
Agrostis stolonifera	IV (3-4)	*Elymus repens*	I (4)
Bellis perennis	IV (2-5)	*Festuca arundinacea*	I (3)
Cardamine pratensis	IV (0.1-5)	*Festuca pratensis*	I (4)
Festuca rubra	IV (3-5)	*Filipendula ulmaria*	I (3)
Leontodon autumnalis	IV (3-5)	*Galium palustre*	I (2-3)
Plantago lanceolata	IV (3-6)	*Hydrocotyle vulgaris*	I (4)
Prunella vulgaris	IV (3-5)	*Hypochoeris radicata*	I (2)
Ranunculus acris	III (3-4)	*Juncus acutiflorus*	I (3)
Ranunculus repens	III (2-6)	*Juncus articulatus*	I (4)
Taraxacum officinale agg.	III (2-4)	*Leontodon hispidus*	I (2)
Carex hirta	II (3-4)	*Lotus corniculatus*	I (2-3)
Cerastium fontanum	II (0.1-4)	*Phleum bertolonii*	I (4)
Cirsium arvense	II (0.1-5)	*Phleum pratensis*	I (3-4)
Cynosurus cristatus	II (3-4)	*Poa pratensis*	I (3)
Holcus lanatus	II (2-4)	*Poa trivialis*	I (4)
Plantago major	II (2-4)	*Potentilla anserina*	I (3)
Rumex acetosa	II (2-4)	*Potentilla erecta*	I (3)
Achillea millefolium	I (1-4)	*Potentilla reptans*	I (3-4)

Agrostis capillaris	I (4)	*Rumex crispus*	I (3-4)
Alchemilla filicaulis	I (3)	*Rumex obtusifolius*	I (3)
Carex disticha	I (3)	*Sagina procumbens*	I (2)
Carex flacca	I (3-4)	*Senecio aquaticus*	I (2)
Carex hostiana	I (2)	*Succisa pratensis*	I (3)
Carex nigra	I (2-3)	*Teucrium scordium*	I (2)
Carex panicea	I (3)	*Trifolium pratense*	I (2-4)
Cirsium dissectum	I (4)	*Urtica dioica*	I (3)
Cirsium palustre	I (3-4)	*Veronica serpyllifolia*	I (3)

***Molinia caerulea-Carex panicea* community,**

This community has a relatively short sward (25cm) comprised of a mix of sedges, grasses and forbs. The constant species are *Carex panicea, Molinia caerulea, Carex hostiana* and *Mentha aquatica,* while *Agrostis stolonifera, Carex flacca, Cirsium dissectum, Hydrocotyle vulgaris, Leontodon autumnalis, Lotus corniculatus, Potentilla anserina, Potentilla erecta* and *Ranunculus flammula* are all frequent. The community generally occurs in the middle to the bottom of the flooding gradient in oliogtrophic turloughs, on fen peat or marl.

Floristic table for the *Molinia caerulea-Carex panicea* community.

No. of relevés	44		
No. of species	59		
Carex panicea	V (2-8)	*Galium boreale*	I (3)
Molinia caerulea	V (2-9)	*Hypochoeris radicata*	I (0.1)
Carex hostiana	IV (1-9)	*Juncus acutiflorus*	I (2)
Mentha aquatica	IV (0.1-4)	*Juncus articulatus*	I (1-5)
Agrostis stolonifera	III (1-6)	*Juncus bulbosus*	I (2)
Carex flacca	III (2-5)	*Leontodon hispidus*	I (2)
Cirsium dissectum	III (0.1-5)	*Linum cathartica*	I (2-3)
Hydrocotyle vulgaris	III (0.1-6)	*Lythrum salicaria*	I (2)
Leontodon autumnalis	III (1-4)	*Ophioglossum vulgatum*	I (2)
Lotus corniculatus	III (2-5)	*Parnassia palustris*	I (3)
Potentilla anserina	III (1-7)	*Polygonum amphibium*	I (3)
Potentilla erecta	III (2-5)	*Phalaris arundinacea*	I (1-3)
Ranunculus flammula	III (0.1-4)	*Phleum bertolonii*	I (1-2)
Carex nigra	II (2-8)	*Plantago lanceolata*	I (1-4)
Carex viridula agg.	II (2-7)	*Plantago maritima*	I (2-4)
Galium palustre	II (0.1-4)	*Potentilla reptans*	I (1-4)
Succisa pratensis	II (1-5)	*Prunella vulgaris*	I (4)
Achillea ptarmica	I (1-3)	*Prunus spinosa*	I (0.1-5)
Alopecurus geniculatus	I (2)	*Ranunculus repens*	I (0.1-5)
Anagallis tenella	I (1)	*Salix repens*	I (2-6)
Carex hirta	I (3)	*Samolus valerandi*	I (2)
Cirsium arvense	I (4)	*Schoenus nigricans*	I (0.1-6)
Danthonia decumbens	I (2)	*Teucrium scordium*	I (1-2)
Eleocharis palustris	I (3)	*Trifolium pratense*	I (2)
Elymus repens	I (2)	*Trifolium repens*	I (1-4)
Equisetum fluviatile	I (1)	*Veronica beccabunga*	I (1-2)
Festuca arundinacea	I (3)	*Viola* species	I (0.1-3)
Fraxinus excelsior	I (0.1-3)		

Poa annua-Plantago major community

This community occurs where the integrity of the soil had been damaged through poaching, allowing the large proportion of ruderal species found in this community to colonise; it mostly occurs in the upper zones where livestock movement is concentrated. *Plantago major, Polygonum aviculare, Agrostis stolonifera, Poa annua* and *Matricaria discoidea* are constant, with *Potentilla anserina, Stellaria media* and *Ranunculus repens* frequent. The species list consists of perennials that can rapidly colonise from the surrounding grassland (e.g. *Agrostis stolonifera* and *Potentilla anserina*) and opportunistic ruderals (e.g. *Capsella bursa-pastoris*); the community may also contain the rare *Rorippa islandica*. The vegetation is generally short in stature, with an average height of c. 10cm; bare soil is frequent.

Floristic table for the *Poa annua-Plantago major* community.

No. of relevés	11		
No. of species	33		
Plantago major	V (3-6)	*Festuca arundinacea*	I (4-5)
Polygonum aviculare	V (4-7)	*Gnaphalium uliginosum*	I (4)
Agrostis stolonifera	IV (4-7)	*Juncus articulatus*	I (3)
Matricaria discoidea	IV (2-6)	*Leontodon autumnalis*	I (4)
Poa annua	IV (4-7)	*Lolium perenne*	I (4-5)
Potentilla anserina	III (4-8)	*Polygonum amphibium*	I (3-5)
Ranunculus repens	III (2-5)	*Phalaris arundinacea*	I (2-4)
Stellaria media	III (4-5)	*Poa pratensis*	I (4-5)
Alopecurus geniculatus	II (3-6)	*Polygonum hydropiper*	I (5)
Capsella bursa-pastoris	II (2-4)	*Potentilla reptans*	I (4)
Carex hirta	II (3-5)	*Rorippa islandica*	I (4)
Juncus bufonius	II (3-6)	*Rorippa palustris*	I (5)
Myosotis scorpioides	II (4-5)	*Rumex crispus*	I (3-4)
Polygonum persicaria	II (3-4)	*Rumex obtusifolius*	I (3-5)
Agrostis capillaris	I (5)	*Senecio aquaticus*	I (3)
Cirsium palustre	I (2)	*Trifolium repens*	I (4-5)
Cirsium vulgare	I (2)		

Polygonum amphibium community

Persicaria amphibia, as its name suggests, can tolerate aquatic and damp terrestrial habitats. This community was found in areas that retain shallow water during the summer months, with the emergent vegetation reaching around 35 cm. *P. amphibium, Agrostis stolonifera, Potentilla anserina, Galium palustre, Eleocharis palustris,* and *Ranunculus repens* are the constant species, with frequent *Mentha aquatica* and *Carex nigra.* Note that *P. amphibium* occurs widely in turloughs, but in this community it is consistently the dominant species. It occurs in the middle to lower zones of turloughs with moderate to high nutrient levels that are generally grazed by cattle, where shallow standing water is often retained through the summer. Cattle are likely to water here, resulting in poaching and disturbance.

Floristic table for the *Polygonum amphibium-Eleocharis palustris* community.

No. of relevés	72		
No. of species	76		
Agrostis stolonifera	V (4-9)	*Filipendula ulmaria*	I (2-6)
Eleocharis palustris	IV (2-8)	*Glechoma hederacea*	I (3)

Galium palustre	IV (1-6)	*Hippuris vulgaris*	I (5-7)
Polygonum amphibium	IV (2-9)	*Iris pseudacorus*	I (3-7)
Potentilla anserina	IV (1-8)	*Juncus acutiflorus*	I (3-5)
Ranunculus repens	IV (2-6)	*Juncus bulbosus*	I (3-4)
Carex nigra	III (3-6)	*Juncus inflexus*	I (6)
Mentha aquatica	III (1-7)	*Lemna trisulca*	I (4)
Cardamine pratensis	II (3-6)	*Leontodon autumnalis*	I (5)
Glyceria fluitans	II (2-6)	*Littorella uniflora*	I (6)
Hydrocotyle vulgaris	II (2-9)	*Lolium perenne*	I (4)
Juncus articulatus	II (3-5)	*Lysimachia vulgaris*	I (6)
Myosotis scorpioides	II (2-7)	*Lythrum salicaria*	I (2)
Oenanthe aquatica	II (3-7)	*Ophioglossum vulgatum*	I (3)
Phalaris arundinacea	II (4-7)	*Polygonum persicaria*	I (3-4)
Ranunculus flammula	II (3-7)	*Plantago lanceolata*	I (5)
Rorippa amphibia	II (3-7)	*Polygonum lapathifolium*	I (2)
Agrostis capillaris	I (6)	*Potamogeton gramineus*	I (4-6)
Alisma plantago-aquatica	I (1-5)	*Potentilla reptans*	I (5)
Alopecurus geniculatus	I (3-6)	*Ranunculus lingua*	I (6)
Apium inundatum	I (3-4)	*Ranunculus trichophyllus*	I (3-4)
Apium nodiflorum	I (5)	*Rumex crispus*	I (3-6)
Baldellia ranunculoides	I (3-5)	*Rumex obtusifolius*	I (4-6)
Caltha palustris	I (5-7)	*Senecio aquaticus*	I (1)
Carex disticha	I (4-7)	*Sparganium emersum*	I (5-6)
Carex elata	I (4-6)	*Sparganium erectum*	I (4-5)
Carex flacca	I (4)	*Stellaria media*	I (2-7)
Carex viridula agg.	I (3-5)	*Stellaria palustris*	I (4-5)
Carex hirta	I (4-5)	*Taraxacum officinale* agg.	I (1-4)
Carex hostiana	I (3-7)	*Teucrium scordium*	I (3-5)
Carex rostrata	I (5)	*Trifolium repens*	I (4-5)
Eleogiton fluitans	I (4)	*Veronica beccabunga*	I (1-5)
Equisetum fluviatile	I (2-4)	*Veronica catenata*	I (3)
Festuca arundinacea	I (4)	*Veronica scutellata*	I (1-4)
Festuca rubra	I (4)	*Veronica serpyllifolia*	I (3-5)

Appendix 12.2 Site Verification Recording Sheet

The following pages provide a recording sheet that can be used for site verification

Turlough Site Verification Sheet

Turlough name		Townland	
County		Grid ref.	
Local ranger		Phone no.	

Complete above from NPWS Turlough Database **prior** to field visit

Part 1: General information

Note most suitable site access location, any problems with access etc.:

Part 2: Winter visit

Field Check: GPS receiver set to Ireland 1965 map datum, Irish Grid

Recorder:	Date:

Transient flooding indictors (tick box)

Trees/shrubs		Poles/pylons		Walls/fences		Other (specify)	

Confirm absence of surface water outflow

Enter details of photographs of flooding below:

Photographic image no.	Position	Photographic image no.	Position

Enter GPS positions taken at flood margin below (minimum of 4 – if data stored on mobile GPS computer, state file name below):

Note any wildfowl, waders or gulls present, if possible give approximate numbers:

Record any further comments:

Part 3: Summer visit

Field Check: GPS receiver set to Ireland 1965 map datum, Irish Grid

Recorder:	Date:

Transient flooding indictors (tick box)

Cinclidotus etc. on rocks, trees		Strand line of debris above water level		Winter indicators fully emerged		Other (specify)	

Enter details of photographs taken at same location as winter visit:

Photographic image no.	Position	Photographic image no.	Position

GPS location of perceived lowest point in turlough basin:

Turlough Site Verification Sheet

Has the water level declined since the winter visit?	
Is there a zonation of vegetation types along the elevation gradient?	

Presence of *Eleocharis palustris/Ranunculus flammula* community		Presence of *Polygonum amphibium* community	
Presence of limestone pavement in the turlough, or within 100 m of upper margin		Presence of woodland/scrub on upper margin	

Presence of *Frangula alnus*		Presence of *Potentilla fruticosa*		Presence of *Schoenus nigricans*	

Is the substrate type ***predominantly***:	Mineral?		Organic?		Marl?	

Note any signs of grazing animals present			
Note any signs of poaching or trampling by grazing animals		Note presence of *Poa annua/Plantago major* weedy annual community	

Note positions of any estavelles, swallow holes, streams, ponds with aquatic plant species:

Feature	Position	Feature	Position

Note any wildfowl, waders or gulls which might possibly be breeding:

Note any species of plant or animal of interest:

Do you think this site is a turlough? Give reasons:

Record any signs of damage to ecological structure and functioning:

Record any important features:

Record any further comments:

Appendix 12.3 Indicator Stop Recording Sheet

The following page provides an Indicator Stop Recording Sheet for turlough conservation assessment

Turlough Monitoring Stop Recording Sheet

Turlough Name:	**Recorder:**	**Date:**	**Type:** Mineral - Mesotrophic - Oligotrophic

Zone (**U**pper, **M**id, **L**ower, **O**ther)																									
Indicator	**Stop 1**	**Stop 2**	**Stop 3**	**Stop 4**	**Stop 5**	**Stop 6**	**Stop 7**	**Stop 8**	**Stop 9**	**Stop 10**	**Stop 11**	**Stop 12**	**Stop 13**	**Stop 14**	**Stop 15**	**Stop 16**	**Stop 17**	**Stop 18**	**Stop 19**	**Stop 20**	**Stop 21**	**Stop 22**	**Stop 23**	**Stop 24**	**Stop 25**
Rumex crispus, R. conglomeratus or *R. acetosa* presence	X																								
Dominated by Grass/forbs?	X																								
Dominated by sedges?																									
Average sward height > than 40cm?																									
Average sward height < than 8 cm?																									
Defoliation: **F**requent, **O**ccasional or **A**bsent	O																								
Animal dung present (**C**attle, **S**heep, **H**orse, **O**ther)	C																								
Trampling/poaching	X																								
Direct sign of fertiliser input?																									
Presence of any of the following communities:																									
Agrostis stolonifera-Glyceria fluitans community																									
Eleocharis palustris-Ranunculus flammula community																									
Filipendula ulmaria-Potentilla erecta-Viola sp. community	X																								
Lolium grassland	X																								
Molinia caerulea-Carex panicea community																									
Poa annua-Plantago major community	X																								

Appendix 12.4 Pressures and Threats Recording Sheet

The following pages provide a sheet for recording assessment of pressures and threats at turloughs

Pressures and Threats Recording Sheet for Turloughs

Assessor	Turlough name	County	Grid ref	Date

Code	Level	Description	ZOC	Turlough
A	**1**	**Agriculture**		
A02	2	modification of cultivation practices		
A02.01	3	agricultural intensification		
A02.03	3	grassland removal for arable land		
A04	2	grazing		
A04.01	3	intensive grazing		
A04.01.01	4	intensive cattle grazing (local)		
A04.01.02	4	intensive sheep grazing		
code??	4	intensive horse grazing		
A04.01.05	4	intensive mixed animal grazing		
A04.03	3	abandonment of pastoral systems, lack of grazing		
A05	2	livestock farming and animal breeding (without grazing)		
A05.02	3	stock feeding		
A08	2	Fertilisation		
A10	2	Restructuring agricultural land holding		
A10.01	3	removal of hedges and copses or scrub		
A10.02	3	removal of stone walls and embankments		
B	**1**	**Sylviculture, forestry**		
B01	2	forest planting on open ground		
B02	2	Forest and Plantation management & use		
B05	2	use of fertilizers (forestry)		
C01.03	3	Peat extraction		
C01.07	3	Mining and extraction activities not referred to above		
D	**1**	**Transportation and service corridors**		
D01.02	3	roads, motorways		

Code	Level	Description	ZOC	Turlough
E	**1**	**Urbanisation, residential and commercial development**		
E01	2	Urbanised areas, human habitation		
E01.03	3	dispersed habitation		
E01.04	3	other patterns of habitation		
E02	2	Industrial or commercial areas		
E02.01	3	factory		
H	**1**	**Pollution**		
H01	2	Pollution to surface waters (limnic, terrestrial, marine & brackish)		
H01.05	3	diffuse pollution to surface waters due to agricultural and forestry activities		
H02	2	Pollution to groundwater (point sources and diffuse sources)		
H02.06	3	diffuse groundwater pollution due to agricultural and forestry activities		
H02.07	3	diffuse groundwater pollution due to non-sewered population		
I	**1**	**Invasive species**		
I01	2	invasive non-native species		
J	**1**	**Natural System modifications**		
J02	2	human induced changes in hydraulic conditions		
J02.04.02	4	lack of flooding		
J02.05	3	Modification of hydrographic functioning, general (=drainage)		
J02.07	3	Water abstractions from groundwater		
J02.07.01	4	groundwater abstractions for agriculture		
J02.07.02	4	groundwater abstractions for public water supply		
M	**1**	**Climate change**		
M01	2	Changes in abiotic conditions		
M01.02	3	droughts and less precipitations		
M01.03	3	flooding and rising precipitations		
M01.07	3	sea-level changes		
		Others (list below)		

Appendix 12.5 Structure and Function Assessment Across 22 Turloughs

The table which follows provides an example of the application of the structure and function assessment methodology outlined in this chapter for the 22 turloughs studied in this project. Note that this is different from the structure and function approach used in *Chapter 10: Conservation Assessment* which was used for the 2013 Article 17 reporting (see NPWS 2013).

Appendix 12.5: Structure and function assessment matrix for 22 turloughs; n.i. means indicator was *not available* for that turlough, n.a. means turlough was *not assessed* for that indicator

Turlough name **Prescreening indicator**	**Ardkill**	**Ballindereen**	**Blackrock**	**Brierfield**	**Caherglassaun**	**Caranavoodaun**	**Carrowreagh**	**Coolcam**	**Croaghill**	**Garryland**	**Kilglassan**	**Knockaunroe**	**Lisduff**	**Lough Aleenaun**	**Lough Coy**	**Lough Gealain**	**Rathnalulleagh**	**Roo West**	**Skealoghan**	**Termon**	**Tullaghnafrankagh**	**Turloughmore**
A: mineral soil present (=1)	0	0	1	0	1	0	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1
B: flooded pavement community present in turlough (=1)	0	1	0	0	1	1	0	0	0	0	0	1	0	1	0	1	0	1	0	0	0	0
B: limestone pavement occurs within 200 m of turough (=1)	0	1	0	0	1	1	0	0	0	1	0	1	0	1	0	1	0	1	0	0	0	1
B: *Potentilla fruticosa* present (=1)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
B: *Frangula alnus* present (=1)	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Pre-screening B: *Schoenus nigricans* present (=1)	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	1	0	0	1	0
Pre-screening: sum of prescreening criteria B:	0	3	0	0	2	4	0	0	0	1	0	5	1	2	0	5	0	3	0	0	1	1
ASSESSMENT GROUP [Min if A=1; Oligo if A=0 AND B>1; Meso if A=0 and B=0] Note: Meso/oligo refer to *expected* nutrient status, not measured	Meso	Oligo	Min	Meso	Min	Oligo	Min	Min	Meso	Min	Meso	Oligo	Oligo	Oligo	Min	Oligo	Min	Oligo	Meso	Meso	Oligo	Min

Indicator	Ardkill	Ballindereen	Blackrock	Brierfield	Caherglassaun	Caranavoodaun	Carrowreagh	Coolcam	Croaghill	Garryland	Kilglassan	Knockaunroe	Lisduff	Lough Aleenaun	Lough Coy	Lough Gealain	Rathnalulleagh	Roo West	Skealoghan	Termon	Tullaghnafrankagh	Turloughmore
1. Hydrological function																						
Invert of drainage	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**
Consistent or progressive change in flooding depth/duration/area of flooding (over 6 year HD reporting cycle)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Maximum score	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Hydrological function score	**0**	**0**	**0**	**0.25**	**0**	**0**	**0**	**0**	**0**	**0**	**0.25**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.25**	**0**	**0**
2. Water quality																						
Floodwater TP	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**0**	**0**	**2**	**2**	**0**	**2**	**0**	**1**	**0**	**2**	**0**
Increase in floodwater TP	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni
Maximum recorded Chl*a*	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**1**
Water colour	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni
Maximum score	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Water quality score	**1**	**0.33**	**0.67**	**0.33**	**1**	**0.33**	**1**	**0.67**	**1**	**0.33**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**0.67**	**0**	**1**	**0.33**

3. Biological responses: terrestrial																						
Agrostis stolonifera-Glyceria fluitans community cover	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Cover of Rumex crispus, R. conglomeratus and *R. acetosa* either singly or in combination	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**
Lolium grassland cover	**2**	**1**	**2**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**0**	**2**	**0**	**1**	**0**	**0**	**2**
Grass-forb dominated community area	**1**	**0**	na	**0**	na	**0**	na	na	**1**	na	**1**	**0**	**0**	**1**	na	**0**	na	**0**	**0**	**0**	**0**	na
Filipendula ulmaria-Potentilla erecta-Viola sp. community	na	**0**	na	na	na	**0**	na	na	na	na	na	**0**	**0**	**0**	na	**0**	na	**0**	na	na	**0**	na
Poa annua-Plantago major community	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
Polygonum amphibium community	na	**0**	na	na	na	**0**	na	na	na	na	na	**0**	**0**	**0**	na	**0**	na	**0**	na	na	**1**	na
Eleocharis acicularis community	na	na	**0**	na	**0**	na	no	no	na	**0**	na	na	na	na	**0**	na	no	na	na	na	na	no
Limestone grassland, Flooded pavement or woodland communities in any combination	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**1**	**1**
Eleocharis palustris-Ranunculus flammula community	**1**	**0**	na	**1**	na	**0**	na	na	**1**	na	**1**	**0**	**0**	**1**	na	**0**	na	**0**	**1**	**0**	**1**	na
Eleocharis palustris-Ranunculus flammula community	ni	ni	na	ni	na	ni	na	na	ni	na	ni	ni	ni	ni	na	ni	na	ni	ni	ni	ni	na

Polygonum amphibium community	ni	na	ni	ni	ni	na	ni	ni	ni	ni	ni	na	na	na	ni	na	ni	na	ni	ni	na	ni
Molinia caerulea-Carex panicea community	1	0	na	1	na	0	na	na	1	na	1	0	0	1	na	0	na	0	0	1	0	na
Sward height greater than 40cm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sward height less than 8 cm	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Notable species (incl. inverts)	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni
Maximum score	**13**	**17**	**11**	**13**	**11**	**17**	**10**	**10**	**13**	**11**	**13**	**17**	**17**	**17**	**11**	**17**	**10**	**17**	**13**	**13**	**17**	**10**
Terrestrial biological responses score	**0.62**	**0.06**	**0.45**	**0.23**	**0.18**	**0**	**0.3**	**0.1**	**0.38**	**0**	**0.38**	**0.06**	**0.06**	**0.41**	**0.18**	**0**	**0.4**	**0**	**0.23**	**0.15**	**0.18**	**0.5**
4. Biological responses: aquatic																						
Presence of algal paper	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0
Absence of fully aquatic vascular plants	0	0	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
Notable species (incl. inverts)	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni	ni
Maximum score	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Aquatic biological responses score	**0.5**	**0**	**0.5**	**0.5**	**0.5**	**0**	**0.5**	**0**	**0**	**0.5**	**0**	**0**	**0**	**0.5**	**0.5**	**0**	**0**	**0**	**0.5**	**0**	**0.5**	**0.5**
5. Other																						
Physical damage to turlough (land clearance, resource extraction etc.)	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Maximum score	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Other impact score	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

SUMMARY	Ardkill	Ballindereen	Blackrock	Brierfield	Caherglassaun	Caranavoodaun	Carrowreagh	Coolcam	Croaghill	Garryland	Kilglassan	Knockaunroe	Lisduff	Lough Aleenaun	Lough Coy	Lough Gealain	Rathnalulleagh	Roo West	Skealoghan	Termon	Tullaghnafrankagh	Turloughmore
1. Hydrological function score	0	0	0	0.25	0	0	0	0	0	0	0.25	0	0	0	0	0	0	0	0	0.25	0	0
2. Water quality score	1	0.33	0.67	0.33	1	0.33	1	0.67	1	0.33	1	0	0	1	1	0	1	0	0.67	0	1	0.33
3. Terrestrial biological responses score	0.62	0.06	0.45	0.23	0.18	0	0.3	0.1	0.38	0	0.38	0.06	0.06	0.41	0.18	0	0.4	0	0.23	0.15	0.18	0.5
4. Aquatic biological responses score	0.5	0	0.5	0.5	0.5	0	0.5	0	0	0.5	0	0	0	0.5	0.5	0	0	0	0.5	0	0.5	0.5
5. Other impact score	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
OVERALL S&F INDICATORS																						

PRESSURES																						
Number of high impact pressures	1	1	1	1	2	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1
Number of medium impact pressures	2	1	2	1	2	2	1	1	2	2	4	0	0	2	1	0	2	1	2	1	1	1
Number of low impact pressures	1	3	2	4	2	3	1	4	2	3	2	3	2	0	2	0	2	1	2	5	5	0
OVERALL STRUCTURE AND FUNCTION																						
ADJUSTMENT TO OVERALL ASSESSMENT*	U2	U1	U1	U1	U2	Fv	U2	Fv	U1	U1	U1	Fv	Fv	U2	U1	Fv	U1	Fv	U1	Fv	U1	U1
Area (ha)	22.8	68.4	60.4	59.3	63.3	34.0	29.1	55.7	38.4	20.3	45.5	81.0	53.9	14.3	25.5	36.8	29.5	42.5	33.2	41.6	15.1	34.1

*No adjustments were applied in these turloughs

Chapter 13. Conclusions

S. Waldren, N. Allott, C. Coxon, L. Gill, K. Irvine, P. Johnston & S. Kimberley

Carran turlough, Co. Clare. An exceptionally diverse turlough, not included in the 22 turloughs studied in detail, but of great conservation importance

Photo: S. Waldren

Table of Contents:

13.1 Introduction

This chapter concludes the reporting on the turlough conservation project. The project surveyed indicator taxa and their communities in a group of 22 turloughs, described the hydrological conditions in each turlough and determined the main ecological drivers and constraints operating on the biota. The project aimed to assess the conservation status of turloughs, their risk of pollution, and to devise a monitoring protocol for turloughs that could fulfill State obligations on reporting for the Habitats Directive. However, as turloughs are classified as Groundwater Terrestrial Ecosystems (GWDTE) under the Water Framework Directive (WFD), monitoring protocols for both Directives will intersect to some degree. This involved a multidisciplinary programme of research, elaborated in the preceding chapters and the integration of these findings to explain turlough ecological structure and functioning. This chapter highlights key findings from the project, and makes recommendations for addressing gaps in understanding of turlough ecology, conservation actions, and implementation of monitoring.

13.2 Key Findings – Turlough Ecology

The main ecological drivers that influence structure and functioning of biological communities in turloughs are the hydrological flooding regime (see section 13.2.1) and the phosphorus status (see section 13.2.2) of turloughs.

13.2.1 Hydrology is the Main Ecological Driver

Flooding is driven by groundwater supply, which tends to vary seasonally, in response to cumulative rainfall. Some turloughs show a single long flooding phase peaking over the winter (e.g. Coolcam, Termon), while others show a more ephemeral flooding cycle with rapid filling and emptying in response to shorter periods of cumulative rainfall (e.g. Lough Aleenaun, Turloughmore). A wide range of variation exists between these two extremes, with a number of hydrological variables, such as rate of filling, showing a continuous range of variation (*Chapter 3: Hydrology*; see also Figure 13.1). Superimposed on this mainly seasonal pattern of flooding within turloughs, and the variation among them, are longer term, annual variations in flooding pattern – and perhaps even longer term changes in the flooding regime related to climate change, although observational data are not yet available to investigate the latter possibility in detail. Nonetheless, although turloughs are groundwater driven, the relative rapidity of their flooding response is strongly correlated to the rainfall regime.

Two conceptual models of turloughs were developed that explain hydrological functioning (*Chapter 3: Hydrology*). The flow-through model permits simultaneous inflow and outflow at different points in the turlough, whereas the surcharged-tank model accumulates water depending on the relative pressure heads in the turlough and the underlying karst flow system without simultaneous inflow and outflow. Evidence for the operation of both types of model were found in different turloughs, and many turloughs may operate by a combination of these models. However, both models are based on the overall groundwater-driven nature of turloughs. As turloughs only tend to fill seasonally, they physically reside relatively high in the karstic groundwater profile – that is, there is a significant groundwater storage/flow that has to be satisfied under the turlough before it begins to fill. Hence the turloughs studied each have a particular cumulative rainfall metric as a hydrological characteristic. This overall characterization, coupled with analyses of water balance, has implications for defining the zone of contribution of a turlough which is likely to be much smaller than the conventional topographical definition. Nevertheless, both representations allowed a reliable modeling of the hydrological data based on observed net inflows to a turlough, permitting the derivation of variables that could be used to explain the ecological functioning of turloughs in relation to their biota (*Chapter 3*).

The variations observed in flooding, especially the depth and duration, exert a strong selection pressure on biota inhabiting turlough, influencing the distribution of species and the development and succession of communities (*Chapter 5: Turlough Algae; Chapter 7: Turlough Vegetation - Description, Mapping and Ecology* & *Chapter 8: Aquatic Invertebrate Communities*). As previously noted by Praegar (1932) and others, terrestrial vegetation communities typically occur in zones arranged along the flooding gradient, often with fully aquatic communities in permanent pools at the base of some turloughs. The duration of flooding shows the most consistent relationship with plant species and community distributions in the studied turloughs (*Chapter 7*). Total vegetation cover also changes along the floodwater recession trajectory; while some species are able to maintain photosynthetic leaves and grow in submerged conditions, others redevelop aerial shoots from dormant rhizomes and grow rapidly once the flood level drops. Aquatic invertebrates typically show a succession of communities through the hydroperiod, but this succession may be truncated by variations in the duration of the flooded period (*Chapter 8*). Duration of flooding and the rate of areal reduction in floodwaters were the most influential hydrological variables on aquatic invertebrate community structure. Algal phytoplankton communities also show successional changes through the hydroperiod and seasons in the majority of turloughs which are shallow and have clear water. Turloughs in the Gort-Kinvarra chain (Blackrock, Lough Coy, Garryland

and Caherglassan) are much deeper and have coloured water both of which reduce light penetration and consequently restrict phytoplankton growth. This is the probable reason why these four turloughs had low diversity and biovolume of algae and lacked a seasonal succession.

Hydro-ecological impact is likely to occur if/when the natural frequency-duration of flooding is significantly changed. Thus permanent drainage control is likely to have the most severe and unacceptable impact. There have been calls for drainage of some sites (e.g. Ballindereen, Rahasane, Termon). If the ecology of these turloughs is to be protected, in line with national and international legal requirements, it is essential that any drainage works **only** address the potential negative impacts of extreme flood events (i.e. where there is the least impact on the frequency-duration characteristic). Nevertheless, this will require any such drainage actions to be likely restricted to the very uppermost regions of any turlough and the subject of an Appropriate Assessment. Drainage levels lower in the turlough basin will significantly alter the hydrological regime and damage the ecological communities. Another type of hydrological impact may occur as a result of groundwater abstraction from the same karst system that hosts a turlough. However, unless the scale of the abstraction is found to be a significant fraction of the catchment recharge upgradient of the turlough (as decreed under the WFD), it is unlikely to have an effect on the hydro-ecology of the turlough. As indicated from the study, the net inflows to a turlough are a small fraction of the overall catchment groundwater flow so that unless an abstraction intersects directly with that turlough inflow, it is unlikely to cause an impact.

13.2.2 Phosphorus is the Major Nutrient Driving Turlough Ecology

Of the various nutrients and hydrochemistry investigated, phosphorus showed the strongest relationships with algae (*Chapters 4, 5*), vegetation (*Chapter 7: Turlough Vegetation - Description Mapping and Ecology*) and aquatic invertebrates (*Chapter 8: Aquatic Invertebrate Communities*). Turloughs with phosphorus enrichment had different species complements and communities compared with sites with low phosphorus. Total phosphorus was found to correlate positively with total algal biomass in turloughs (*Chapter 4: Water Chemistry and Algal Biomass*), and appears to drive phytoplankton composition towards higher abundances of green algae in general. Green filamentous algae were found in most nutrient-rich turloughs, except those with coloured water in the Gort-Kinvarra chain. These filamentous communities often formed transient algal mats when floodwater receded, and extensively so in turloughs with total phosphorus in floodwater (water TP) above 20 $\mu g\ l^{-1}$. However, while small areas of filamentous algae occurred in many turloughs, not all of those with water TP above 20 $\mu g\ l^{-1}$ had algal mats every year.

Aquatic algal and invertebrate communities show obvious relationships with water TP (*Chapters 4, 5 & 8*). Terrestrial vegetation might be expected to show a closer relationship to P fractions in soils, but in fact stronger relationships were consistently seen with the floodwater total phosphorus (*Chapter 7*), suggestive of rapid fluxes between water TP, the availability of phosphorus fractions in soils to plants, and plant uptake, but this requires further study.

Vegetation communities in sites with low phosphorus concentrations tended to be dominated by sedges, whereas grasses and forbs were more prevalent where phosphorus concentrations were higher. Most turloughs with low water TP typically occurred in landscapes with abundant exposed limestone pavement, and these shallow soils over karst result in extreme pathway susceptibility to pollution (including nutrient inputs). However, these poor soils only support low intensity agriculture in the zone of groundwater contribution (ZOC), and this probably leads to few sources of phosphorus pollution in the ZOC (*Chapter 11: Water Framework Directive Risk Assessment*), though these potential sources were not investigated in detail by this project. Despite the current very low nutrient status and excellent ecological condition of turloughs such as Lough Gealain and Knockaunroe, the extreme pathway susceptibility of these turloughs places them at serious risk from land any use changes in the ZOC which introduce new sources of P.

The grass-dominated swards of meso- and eutrophic turloughs are probably both more productive (i.e. greater net primary production, not recorded by this project) and more palatable (again, not studied by this project) than the sedge-dominated swards of oligotrophic turloughs, and hence are more intensively grazed. In addition, the meso- and eutrophic turloughs generally occurred in landscapes with less limestone pavement and deeper soils in the wider ZOC, and hence more intensive agriculture within both the turlough and the ZOC than occurs for most oligotrophic turloughs. Although the relationships between various P sources (e.g. livestock, fertilizer and slurry spreading, farmyards, septic tanks, etc., both within and adjacent to turloughs, and from the wider ZOC), pathways and turlough receptors were not part of this project and poorly understood,

Various potential sources can contribute to P inputs to turloughs, these include livestock, slurry and fertilizer spreading, farmyard effluent, septic tank effluent and even, in the case of Blackrock, an abattoir. These sources may occur within the turlough basin or immediately adjacent to it, or in the wider ZOC. Potential sources of P were noted incidentally by the project, but were not the focus of detailed study; the relationships between various sources of P and pathways to turlough receptors – particularly sources in relation to proximity of karst features such as swallow holes, dolines, sinking streams etc – remain poorly understood. Even so, agricultural inputs are likely to be the main sources of P reaching turloughs. Attempts to model turlough P from both regression analysis of landuse and pathway susceptibility, and by nutrient export coefficient modelling (*Chapter 11*) were not satisfactory, and improved models might be developed if finer scale data on farm or land parcel stocking levels and full mapping of karst features were made available to support understanding of turlough ecological functioning.

Not enough has been done in the past to protect turloughs against sources of nutrient enrichment. Examples include direct fertilizer application or slurry spreading in or adjacent to the turlough (Caherglassan and several others), washing out of slurry tankers and direct input of sewage to sites (Lough Gash, Glanamaddy). Much can be done to prevent this from happening, for example by improving the enforcement of the *Good Agricultural and Environmental Condition* regulations to ensure cross compliance, particularly for the statutory management requirements for *Protection of Groundwater* and *Conservation of Natural habitats of Wild Flora and Fauna* under the single farm payment scheme[1]. Issues surrounding the discharge of domestic sewage into the karst and turloughs are already recognized (e.g. by Irish Water) but appropriate methods of wastewater treatment need to be implemented as soon as possible. The Programmes of Measures developed under the Water Framework Directive to ensure good water quality should limit P inputs to groundwater (see section 13.4.5 below), although it is unclear whether these measures are in fact being fully applied.

[1]see http://www.agriculture.gov.ie/farmerschemespayments/crosscompliance/statutorymanagementrequirementssmrs/

13.2.3 Grazing and Landuse Impacts

Grazing is the main landuse of turloughs, and grazing intensity varied considerably, both among the studied turloughs and also within individual turlough basins (*Chapter 6: Soils and Landuse*). Some oligotrophic turloughs (as identified by floodwater total phosphorus) had very low levels of grazing, probably due to the low nutritional value and low palatability of sedge-dominated vegetation in these turloughs as noted above. Meso- and eutrophic sites were likely to be more productive and more intensively grazed, though grazing intensity could also influence the site nutrient status through dung and urine inputs and consequent alteration of nutrient cycling (e.g. van der Waal *et al*., 2011), although this was not studied during this project. Meso- and eutrophic sites with low grazing intensity typically had a more uniform vegetation of taller herbs and grasses, of lower biological interest (e.g. Tullynafrankagh) when compared with sites of similar trophic status but with higher grazing intensity. Over-grazing was a problem in some nutrient-rich turloughs (e.g. Turloughmore), resulting in low diversity swards with little ecological or conservation interest. In contrast, in oligotrophic sites with very low grazing intensity (e.g. Knockaunroe), or even an absence of grazing (e.g. Lough Gealain), did not appear to have reduced biological interest, and the examples just given were in excellent ecological condition. Intensive grazing by sheep, as for example at Garryland, resulted in a very short sward and appeared to have a greater impact than cattle grazing, but it is not clear if this leads to a permanent reduction in diversity. Our findings suggest that both under- or over-grazing in the more nutrient-rich, productive sites may be detrimental to conservation interests (see also Moran *et al*., 2008), whereas in more oligotrophic turloughs very low levels of grazing would seem to be optimal.

Intensive grazing not only removes plant biomass, but may also lead to localized trampling and poaching of soils, particularly in areas adjacent to water and where stock move into and out of land parcels. This may lead to the development of weedy terrestrial vegetation in locally damaged areas. However, comparison with vegetation mapped by this project and that by Goodwillie (1992) suggests that vegetation can recover from localised intensive grazing if livestock movement in turloughs is appropriately managed, indicating the basic resilience of turlough ecology. This was seen at Ardkill, for example, where patterns of stock movement into the turlough appear to have changed since Goodwillie's survey and damaged areas where he recorded weedy ruderal vegetation appeared to have recovered.

The study has confirmed that grazing and its associated agricultural activities is the complicating factor in the maintenance of turlough conservation status. Stocking density alone is a poor metric at the scale of a turlough as longer term flooding and/or the temporary location of feeding points can result in abnormal concentrations of animals with consequent nutrient inputs in a turlough basin. To a limited extent there is a feedback effect in terms of nutrient input as biodiversity increases with grazing intensity (in agreement with previous studies such as Moran *et al*., 2008). However, given the range of turlough behaviour, optimum grazing levels have yet to be determined, as they will vary with trophic status and hydrological regime. Nevertheless, it is appropriate to avoid mechanisms that concentrate grazing animals in a turlough – for example, by avoiding feeding points in the relevant ZOC or applications of artificial fertilizer, and by provision of alternative watering points at low turlough water levels if these are prolonged.

One identified threat to turlough structure and function is the lack of maintenance of field boundaries and walls in several turloughs, perhaps due to reduced grazing and gradual abandonment, removing restrictions to animal movements. This is likely to reduce patch diversity within affected turloughs. Abandonment, however, is unlikely to result in development of trees, which are rare in turloughs and will be ecophysiologically constrained by flooding. Smaller shrubs, such as *Salix repens*, *Frangula alnus*, *Rhamnus catharticus*, may increase as grazing pressure is relaxed, but these species tend to occur in lower nutrient sites. Land abandonment is however of conservation concern, particularly in meso- and eutrophic turloughs, and efforts should be made to maintain an appropriate level of grazing on a site by site basis.

13.2.4 Turloughs Exist as a Hydrological Continuum

Hydrological evidence suggests that a continuum of variation exists in the flooding regime of turloughs (*Chapter 3: Hydrology*). At one extreme are those turloughs that fill and empty rapidly, often in response to short term rainfall events (e.g. Lough Aleenaun, Turloughmore). At the other extreme, some turloughs have a slow inflow and outflow, and hence a single long hydroperiod (e.g. Coolcam, Termon). Figure 13.1 replots a number of hydrological variables calculated in Chapter 3 as ranked series, each shows a more or less continuous range. Some groups of turloughs may have very similar hydrological response, but these are often hydraulically linked: such as the Gort-Kinvarra chain mentioned above, and to which could be added Coole, Newtown and Hawkhill. These all form part of a conduit-driven network, and their hydrological behaviour is strongly correlated. Other smaller groups of turloughs were identified by this project as being hydrologically linked – Knockaunroe and Lough Gealain, Coolcam and Croaghhill, Carrowreagh and Rathnalulleagh (and possibly Briefield) – though it is not clear whether any other large group of hydrologically linked turloughs exists outside the Gort-Kinvarra chain. Nevertheless, all the turlough characteristic responses are linked to the regional karst groundwater responding to the seasonal rainfall regime.

Figure 13.1 also shows a continuous range of variation in chlorophyll *a* (as a measure of phytoplankton biomass), and of water TP, noted above as another key ecological determinant of biological communities. These biological communities also show a gradation among turloughs, which makes classification (and field identification) of communities difficult.

Visser *et al.* (2006) suggested a continuum existed from wet to dry turloughs, based on ordination of a number of data sets. Our data provide support for the continuum concept, in this case through direct examination of both hydrological and ecological variables. As Visser *et al.* pointed out, basing conservation policies on arbitrarily defined types may be flawed. The implication of this is that conservation assessment and management prescriptions need to be determined on a site-by-site basis and on specific hydroecological metrics, rather than based on generalities.

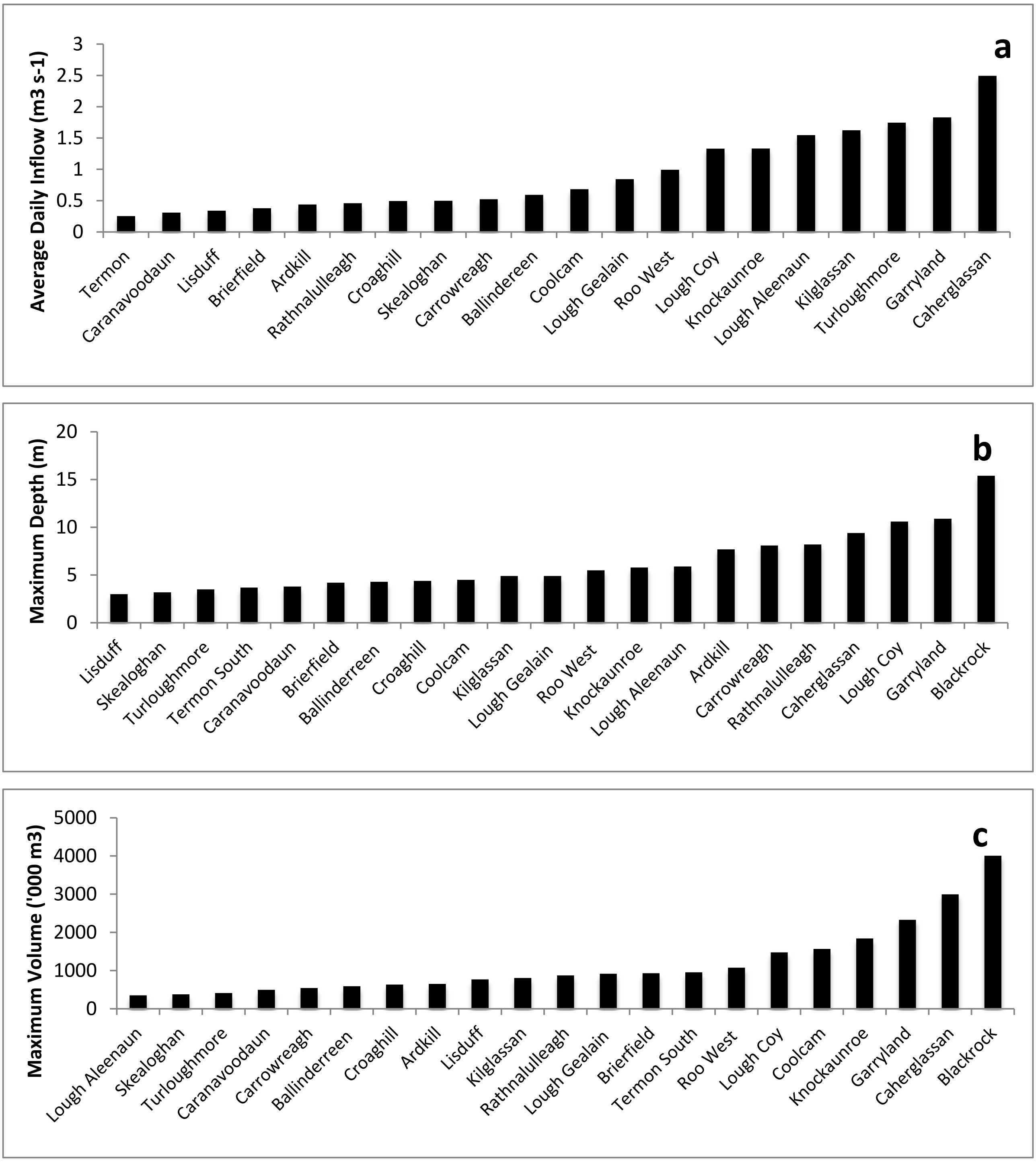

Figure 13.1 Ranked hydrological and ecological variables by turlough: average daily inflow (a), maximum flood depth (b), maximum flood volume (c), recession duration (d), mean Chlorophyll a (e) and total floodwater phosphorus (f). Blackrock omitted from **a** due to large outlying value, Tullynafrankagh omitted from **a-d** due to lack of topographical data. Data are replotted from *Chapter 3: Hydrology* and *Chapter 4: Water Chemistry and Algal Biomass*

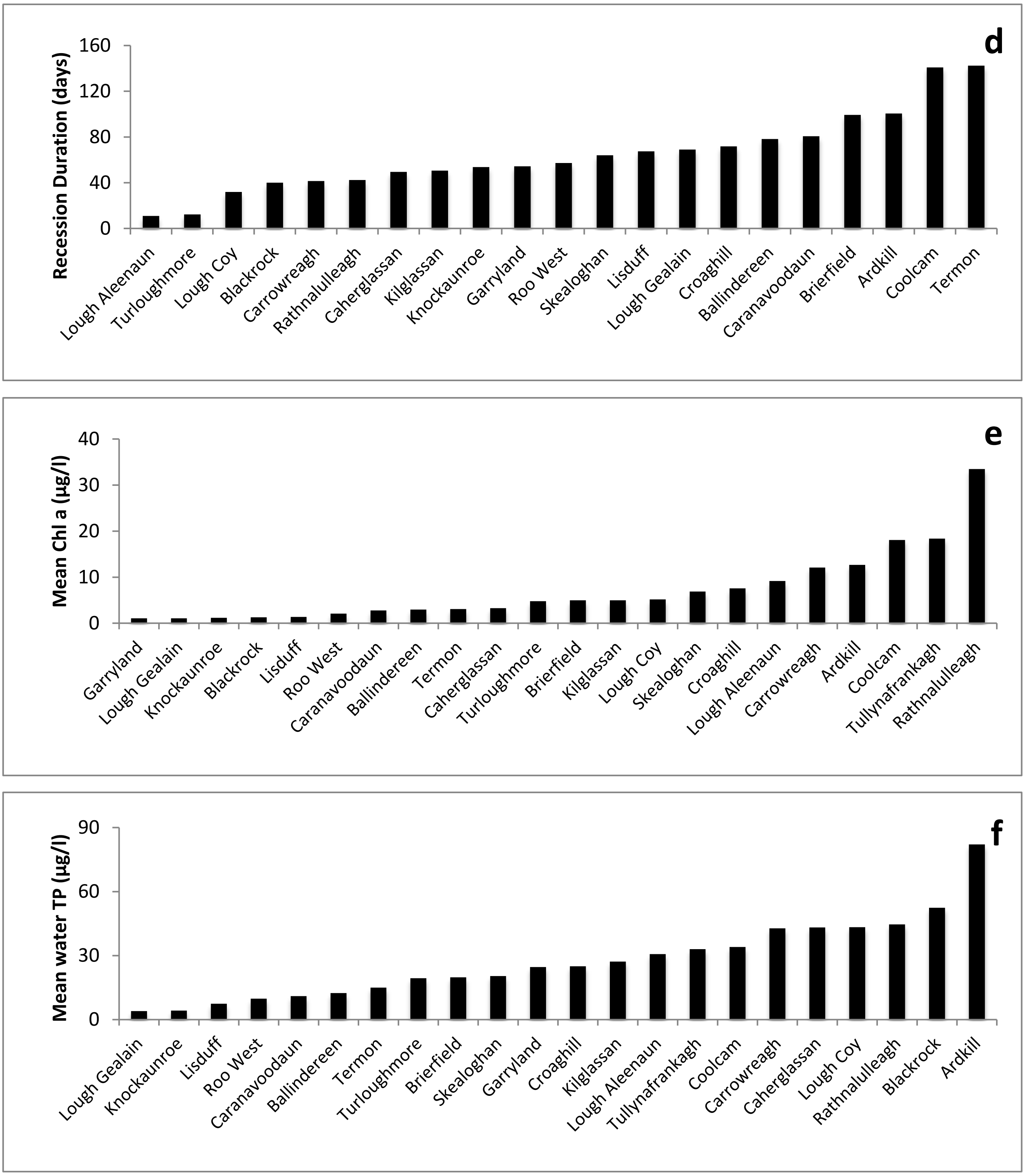

Figure 13.1 Continued

13.3 Conservation Assessment

The national assessment for turloughs for the 2007-2012 Article 17 reporting cycle for the Habitats Directive was unfavourable – *inadequate*. This was mostly due to continuing pressures from nutrient enrichment of groundwater (particularly by phosphorus) and from intensive cattle grazing. Disturbance of the hydrological functioning has not been significant since the Habitats Directive came into force, although earlier phases of drainage implementation are known to have affected turloughs (Coxon, 1986). The future prospects of turloughs was also considered unfavourable – *inadequate*. Four of the 22 turloughs examined in detail appeared in good individual site condition (Knockaunroe, Lisduff, Lough Gealain and Roo West), while five were in bad condition (Ardkill, Kilglassan, Lough Aleenaun, Tullynafrankagh and Turloughmore). The former four were all found to be oligotrophic, and had important biological communities. Most of these turloughs, and likely other similarly oligotrophic sites, are centred around the eastern part of the Burren in Counties Clare and Galway, though Lisduff is in County Roscommon. As these sites represent the least impacted, and perhaps some of the most biologically interesting turloughs, they require special conservation measures to ensure that their current good site conservation status prevails in the future. For the 2007-12 Habitats Directive Article 17 reporting period, almost 66% of the area of turloughs reported to the EU was from Ireland (European Topic Centre on Biodiversity, 2015). Given the restricted distribution of turloughs globally, these oligotrophic turloughs of high conservation status are of major international importance.

Many of these highly oligotrophic turloughs occur in landscapes dominated by exposed limestone pavement and very shallow rendzina soils. These shallow soils and an abundance of fissured limestone result in potentially very high risk of nutrient contamination to groundwater in the zones of groundwater contribution to these sites. However, these shallow soils on karst with extreme pathway susceptibility are in fact likely to have low P sources, as the landscape supports limited grazing and agricultural development, and this may explain the low concentrations of total P in the floodwaters of these turloughs (*Chapter 4: Turlough Water Chemistry and Algal Biomass*; *Chapter 11: Water Framework Directive Risk Assessment*). However, change in landuse could pose a very serious risk to the water quality of important turloughs such as Lough Gealain and Knockaunroe, as the pathway is likely to result in rapid movement of nutrients from sources, with little possibility of attenuation.

The conservation assessment reported in *Chapter 10: Conservation Status Assessment* was made through consideration of a series of indicators for hydrology, nutrient inputs, and the presence of particular species and communities. Despite the suggestions made in section 13.2.4 above that turloughs could not be categorized into types, turlough indicators were nevertheless applied to turloughs grouped by the different soil types which dominated the turlough (*Chapters 6: Soils and Landuse*, see *Chapter 10* for details). This was a matter of expediency to group indicators in the absence of existing site data, and has been carried over into the proposed monitoring programme for turloughs (*Chapter 12: Monitoring Methods for Turloughs*). In addition, scoring for the main water chemistry indicator, total phosphorus in the floodwater, was also categorical: again a result of expediency even though there is a continuous range of water TP (Fig. 13.1 f). This is somewhat unsatisfactory, with some turloughs falling one or other side of a category boundary (e.g. Skealoghan, where the mean water TP of 20.4 $\mu g\ l^{-1}$ was borderline good/intermediate).

The conservation assessment approach proposed for the future (*Chapter 12*) also uses indicators, but individual site assessments can be carried out with a variable number of indicators being assessed. By definition, this facilitates the inclusion of new indicators (and exclusion of those proposed), and it is hoped that once baseline data have been established, as for the 22 turloughs surveyed in this project, that indicators involving *__the degree of change__* in a measurement over time could increasingly be employed. For example, a small increase of 4 $\mu g\ l^{-1}$ of water TP would indicate a small impact on, for example Skealoghan (mean water TP recorded was 20.4 $\mu g\ l^{-1}$), while the same increase in Lough Gealain (mean water TP: 4.0 $\mu g\ l^{-1}$) would indicate a very significant deterioration in water quality, even though a total of 8 $\mu g\ l^{-1}$ would still indicate good water quality. Similarly, a decrease in water TP at Ardkill from the 82.2 $\mu g\ l^{-1}$ recorded by this project to, for example, 60 $\mu g\ l^{-1}$ would suggest an improvement in water quality even though water TP would still remain high. Once effective baselines can be set for sites, this opens up important opportunities for more site-specific assessments to be made in the future. We believe this will generate real ecological insight to help inform and develop site-specific conservation actions in the future.

13.4 Recommendations: Conservation Actions

13.4.1 Monitoring

The points just made in the previous section emphasise the critical importance of on-going monitoring of turlough hydrology and ecology. Firstly there are clear requirements and obligations under the EU Habitats and Water Framework Directives. Secondly, monitoring will form a key part of deepening hydro-ecological understanding of turloughs to develop relevant national conservation prescriptions to safeguard that habitat.

We have suggested a protocol for monitoring turloughs in *Chapter 12: Monitoring Methods for Turloughs* that will not only fulfill obligations under the Habitats Directive, but will further develop ecological understanding of turloughs. A key point is that field monitoring missions need to be timed around the flooding cycle and not by calendar date, as development of aquatic and terrestrial communities will be largely governed by the hydroperiod. Monitoring needs a flexible approach, geared towards flooding regimes that likely vary with time. As previously mentioned, monitoring strategies should be driven by the need to derive and temporally expand upon baseline data. Because several of the key indicator variables that need to be recorded – including water nutrient concentrations, aquatic invertebrate communities – will vary over time, field sampling missions should be timed to adequately capture this variation as well as any significant spatial variability.

As mentioned in section 13.2.2, water TP is the most important nutrient affecting turlough ecology and P enrichment from groundwater (and directly into the turlough) represents a significant pressure to ecological functioning and risk to water quality. Attempts at modeling water TP for the purposes of the Water Framework Directive were not entirely satisfactory for a number of reasons (*Chapter 11: Water Framework Directive Risk Assessment*). In *Chapter 7* we developed a simple and practical index based on vegetation that can predict water TP more accurately than the Ellenberg Fertility indices used previously in Water Framework Directive risk assessment (Working Group on Groundwater, 2004). However, given that vegetation will respond slowly to changes in TP, possibly over several growing seasons, a far more effective approach would be to regularly monitor water TP in turloughs and potential groundwater sources. This could, for example, form part of the regular EPA water quality monitoring. Because water TP varies seasonally (*Chapter 4: Water Chemistry and Algal Biomass*), we recommend that water TP be monitored annually in the early, mid and late hydroperiod phases of the flooding cycle, with a minimum of an annual late winter sample monitoring. If undertaken by the EPA, the timing and frequency of turlough water quality monitoring should be undertaken to deliver the data required to support turlough conservation (and hence needs to be determined by hydroperiod), rather than made fit with any pre-existing sampling regime which may have different priorities.

Inextricably linked to the monitoring of water quality is the need for synchronous hydrological monitoring. As for other GWDTEs, hydrological monitoring needs to be established in a turlough as well as in the ZOC connected to it. Pragmatically, a selection of turloughs needs to be made on the basis of trophic status and regional hydrogeology (and linked to the needs of P monitoring above) for which permanent groundwater monitoring stations should be established. Water levels need to be recorded on at least a daily basis, depending on the characteristic response of the turlough. The project developed practical techniques for such water level monitoring in the unique conditions of a turlough. However, such stations need to be installed for the long term, particularly to address the needs of assessing the effects of climate change.

13.4.2 Oligotrophic Turloughs and their Importance

The more oligotrophic turloughs, with water TP below 10 $\mu g\ l^{-1}$, are likely to be of greatest conservation importance (section 13.3). As mentioned, these turloughs have low sources of phosphorus inputs in their ZOCs, but have extreme pathway susceptibility to nutrient enrichment. At a bare minimum, it is important that water quality be monitored in these turloughs on at least three occasions over the duration of the hydroperiod (see section 13.4.1). As these turloughs also require on-going conservation management, they would be useful candidate sites to develop management plans in consultation with local landowners. Implementation of these plans would help secure their great biological interest and excellent water quality, and should lead to the development of management plans for other less-sensitive turloughs.

13.4.3 Investigate Other Important Turloughs

Our project investigated 22 turloughs which spanned a wide range of hydrological and ecological variation (*Chapter 2: Site Selection*; *Chapter 3: Hydrology*). Nevertheless, several questions come out of this work that suggest studies be undertaken to investigate the comparability of these sites to others:

- Are there other riverine conduit systems with several turloughs, similar to the Gort-Kinvarra chain? Any such system (e.g. Rahasane) is likely to be of both hydrological and biological interest.
- Are there other non-Burren oligotrophic sites comparable to Lisduff and Caranavoodaun? As mentioned previously, oligotrophic turloughs are likely to be of particular biological interest.

Any sites of this sort should be added to a monitoring scheme for turlough reporting (*Chapter 12: Monitoring Methods for Turloughs).* Other important sites should also be considered for inclusion. One such candidate site is Carran, Co. Clare, which has two large basins connected by a sinking stream, and a series of flushes and springs in the north eastern part that hold exceptional botanical interest (Hanley, 2014), and appears to be oligotrophic (Ní Dhonnchadha, 2014). Carran was also mentioned by Goodwillie (1992) as of international importance because of its biological diversity. Given its potential importance, this site should also be incorporated into ongoing monitoring and conservation management schemes.

13.4.4 Trial Rehabilitation of Degraded Turloughs

Several turloughs were assessed as being in bad ecological condition (*Chapter 10: Conservation Status Assessment*). Some of these, such as Ardkill and Lough Aleenaun, should be considered for possible rehabilitation. Ardkill had the highest recorded water TP (Chapter 4) and this eutrophication, thought to be from sources adjacent to the turlough, was having an impact on biological communities (*Chapter 7: Turlough Vegetation - Description Mapping and Ecology*; see also Goodwillie, 1992). There is some indication that water TP concentrations have improved very recently (N. Allott, unpublished data). If local farmers could be brought into a management agreement, it may be possible to further improve the water quality of this site, which would help to maintain the large diversity of vegetation types present (*Chapter 7*; see also Goodwillie, 1992).

Lough Aleenaun has moderate water quality, but the biological communities have been greatly disturbed by bulldozing for rock clearance on the site. If the landowners were amenable, it would be worthwhile attempting to manage stocking densities in an attempt to improve the vegetation communities at this site, and perhaps thereby improve the ecological functioning. A reduction in water TP would also help to improve ecological condition, but this would first require determination of the source of phosphorus enrichment.

In both these cases, developing management agreements and other actions in an attempt to improve the ecological condition of these sites would prove useful case studies of turlough restoration approaches. Lessons leaned here might prove useful in the conservation of other turloughs.

13.4.5 Develop Conservation Management Prescriptions for Turloughs

Much of the national effort in turlough conservation seems to have been driven by site designation and the requirements of Article 17 reporting for the Habitats Directive, and through response to a variety of EU and national regulations. Much of this is *reactive*: far more needs to be done to protect turloughs *proactively* by direct conservation action, particularly those sites of international conservation importance. Conservation goals should be developed through engagement with landowners to ensure that livelihoods can be sustained while ensuring site conservation, this will be challenging give that pressures may come from the wider ZOC. The Water Framework Directive requires that water quality in water dependent ecosystems of European Community importance should be determined by their conservation requirements. The Environmental Protection Agency (EPA) is now responsible for leading the development of *Programmes of Measures* to implement the Water Framework Directive in Ireland, Under the European Union (Water Policy) Regulations 2014 (S.I. NO. 350 of 2014). Programmes of Measures were identified at a national scale in 2008 for implementation of the WFD and these could potentially facilitate conservation of turloughs, for example by controlling point and diffuse source discharges, by measures to protect and restore sensitive habitats and species, and specific measures for High Status Sites such as the highly oligotrophic turloughs mentioned above (section 13.2.2). However, it is not clear to what extent these Programmes of Measures have been implemented, particularly as they will need to be applied to the ZOC. Karst features in ZOCs which link directly into the conduit network, and hence form important pathways for pollutant ingress to turloughs, should be identified and given special protection from potential pollution sources. Such an approach has been used by the Geological Survey of Ireland to define protection zones for water resources, and also through the EPA's Code of Practice for on-site septic tanks and treatment systems (EPA, 2009), which must be at least 15 m from a karst feature. Future research is needed to determine the relative contributions of local and wider ZOC pressures on turloughs especially as the need to manage groundwater quality in a linked GWDTE is a key requirement of the WFD (see next section).

13.5 Recommendations: Future Research on Turloughs

The aim of the research suggested in this section is to fill current gaps in knowledge which have been identified during the course of this project, and to deepen ecological understanding of turlough functioning. Many of the chapters in the report suggest future research work: here we outline what we consider to be the key research priorities to provide the information required for effective conservation of turloughs.

13.5.1 Determine and Refine Zones of Groundwater Contribution (ZOC) to Turloughs

Understanding the ZOC of turloughs is fraught with problems (*Chapter 3: Hydrology; Chapter 11: Water Framework Directive Risk Assessment*). Notably, the ZOC may well not correspond to surface topography, and the ZOC for a given turlough will vary depending upon groundwater levels. This project has shown a huge range in estimated individual turlough ZOCs. Many of the pressures and potential threats identified as impacting or likely to impact on turloughs operate over the wider ZOC/catchment. Given that the real ZOC affecting a turlough may be considerably less than the upgradient topographic area, the results of defining the real ZOC will have a significant impact on landuse management plans. Hence, a deeper understanding of the ZOC for turloughs, perhaps initially for those of highest conservation value, would greatly aid interpretation of pressures and threats, and also provide greater knowledge of turlough ecological functioning. This could be achieved through a combination of tracer studies and geochemical fingerprinting studies, combined with numerical modeling.

13.5.2 Understand Nutrient Sources Contributing to Phosphorus Concentrations in Turloughs

There are several possible sources of phosphorus that could contribute to the observed water TP concentration (see section 13.2.2 above): these include sources in the wider ZOC (though the extent of ZOCs may vary, see above), in the immediate vicinity of the turlough, and directly within the turlough basin. Such sources are mainly related to agriculture (e.g. slurry spreading, stock feeding, fertilizer application and farmyard effluents) but may include wastewater disposal and forestry-related activities. Understanding the relative contributions of these various sources would be an important first step in being able to mitigate high phosphorus loadings to turloughs. This work could be done as part of the work of the WFD, which has to develop catchment (=ZOC) plans where necessary for the protection of water-dependent wetlands. However, corrective action needs to be taken immediately where there is a significant probability of an adverse impact, and not be dependent on long-term studies. This especially applies to nutrient sources adjacent to turloughs. One project to examine the effect of septic tank effluent into karst systems has recently begun under the supervision of Laurence Gill.

13.5.3 Quantify the Relationships Between Livestock Grazing Intensity and Landuse in the Wider ZOC and Water TP Concentrations

Chapter 11: Water Framework Directive Risk Assessment showed poor relationships between various forms of landuse in the ZOC and the concentrations of total phosphorus in floodwater. This may partly be because the delineation of the relevant turlough ZOC is poorly understood. The main form of agricultural activity in turlough ZOCs is stock rearing, and this is expected to be the major source of P to turlough. While there are problems in identifying the likely sources of P in turlough waters (see section 13.6.2), acquiring data on activities such as fertilizer inputs, slurry spreading and farmyard effluent may prove difficult. Stocking density coupled with land parcel area could prove to be a useful predictor of potential sources of P from agriculture, and although such data already exist the available data on livestock densities are currently only available at an unsuitable resolution (that of District Electoral Divisions) to provide any meaningful modeling of P sources on receptors. In addition, Corine data sets are also likely to be of limited use in predicting phosphorus impacts. Data at finer spatial resolution are required: stocking densities at farm or ideally land parcel scale, and soils and habitat descriptions to a similar level of resolution should be made available or acquired to facilitate a deeper understanding of the inter-relationships between phosphorus sources, pathways and receptors to be developed. Combined with 13.5.2, this would enable real insight into the risks of the different phosphorus sources and pathways to turloughs, and help suggest ways to reduce phosphorus loading going forward. However, the priority for point sources within or adjacent to a turlough (e.g .farmyard operations) is immediate management.

13.5.4 Investigate the Nutrient Transfers Between Floodwater, Soils and Vegetation

Terrestrial vegetation, including distributions both of species and vegetation communities, was more closely related to water TP than soil phosphorus (Chapter 6, 7). However, its clear that uptake of P to terrestrial vegetation will be predominantly from soils, and not the water column. Research needs to be undertaken to specifically investigate the fluxes of P between the water column, various fractions of P in the substrate, and within terrestrial vegetation. It is likely that total soil P reflects very little of the P that is available to plants, especially due to the formation of relatively insoluble complexes between phosphate and reduced iron and calcium ions in these base-rich flooded soils.

13.5.5 Develop Models Linking Hydrological Data to Terrestrial Vegetation and Aquatic Invertebrate Communities

The flow through and surcharge tank models of hydrological functioning provide very good descriptors for turlough hydrology based on cumulative rainwater inputs to groundwater (*Chapter 3: Hydrology*). Clear links between hydrological variables and terrestrial vegetation (*Chapter 7: Turlough Vegetation: Description, Mapping and Ecology*) and aquatic invertebrate (*Chapter 8: Aquatic Invertebrate Communities*) communities have been developed. This work needs to be further expanded to link parameters of the long-term hydrological regime to ecological response in a way that will enable accurate prediction of how changes in hydrology (such as climate change, drainage) will drive changes in biological communities. While this requires long term hydrological monitoring, the approach initially is to develop further a rainfall-turlough water level response model. This forms the basis for using the existing rainfall record to generate an ecological response model for a turlough in terms of its pattern of vegetation and invertebrate communities.

13.5.6 Study of Turlough Birds, Fish and Amphibians

Turloughs may contain several important bird groups, including passage, wintering and breeding waterfowl (Anatidae), waders (Scolopacidae, Charadriidae) and gulls (Laridae), some in what are likely to be significant numbers (for example, see Goodwillie, 1992). There is some indication that rare or otherwise important birds may occur on even the most degraded turloughs; for example, several rare species have been recorded from Lough Gash in Co. Clare (Irish Birding: www.irishbirding.com/birds/web), which has such high pollution levels that field workers felt unsafe sampling there (V. Böhm, pers. comm.). Studies of turlough birds were not undertaken during the project reported here; as birds have been widely studied and used as ecological indicators, research into use of turloughs by birds, particularly in relation to turlough trophic status, would be beneficial.

Where fish exist in turloughs they are likely to be major predators of aquatic invertebrates and hence shape invertebrate communities. Various species of fish may occur naturally in turloughs, or have been introduced: a local landowner reported (Pers. comm. to S. Waldren & D. Lynn) introducing Pike (*Esox lucius*) to Hawkhill turlough for sport and food; Pike have also been reported in Garryland. Large Eels (*Anguilla anguilla*) have been observed at a depth of 6 m in a small turlough at Gortlecka that completely dries in summer (S. Waldren & S. Murphy, unpublished observations using SCUBA). Juvenile fish of unknown species have observed in estavelles in the same turlough, and there exists the possibility that fish might be able to move between turloughs in karst conduits in some cases. A small-scale survey of fish and in turloughs would be useful to indicate their frequency and movement, given their potentially large impact on aquatic invertebrate communities.

Several turloughs contain Common Frog (*Rana temporaria*) and Smooth Newt (*Lissotriton vulgaris*) populations, and some of these populations may be of conservation importance. Amphibian tadpoles may be important predators of aquatic invertebrates. As with fish, a small-scale survey of their frequency and abundance in turloughs would be beneficial.

13.5.7 Terrestrial Invertebrates

The terrestrial invertebrates of turloughs have received comparatively little attention, and were not studied during this project. Carabid beetles are important terrestrial predators, and turlough carabid assemblages have been related to grazing, nutrient status and degree of flooding (Ní Bhriain *et al*., 2002; Moran *et al*. 2012). Further study of this group over a wider range of turloughs would be useful to determine their potential for use as indicators of turlough ecological condition.

13.6 Concluding Statement

In conclusion, turloughs are of immense hydrological and ecological interest. They span the interface between terrestrial and aquatic ecosystems, and their ecology is primarily driven by fluctuations in groundwater in karst landscapes. Given their limited global distribution, with the vast majority being identified from Ireland, the State has particular responsibilities to ensure their conservation. Some Irish turloughs are in excellent conservation condition, and are of international significance. However, many others are subjected to a variety of pressures, and the future prospects of many are poor; overall the conservation was assessed as Unfavourable (inadequate). Conservation of turloughs remains challenging due to the impacts from pressures acting both locally and within the wider groundwater catchment, particularly due to the karst terrain in which turloughs occur. Even so, the State needs to ensure turloughs receive adequate conservation in order to fulfill various national conservation objectives and its obligations to the European Union, particularly under the Habitats and Water Framework Directives. Attempts to restore a small number of degraded turloughs could provide deeper understanding of pragmatic conservation approaches that could be adopted more widely, safeguarding the unique ecology of these important ecosystems.

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Annex 2: Site Reports

This annex collates the information gathered during the project on a site by site basis, including information on hydrology, biological communities, water chemistry, soils, conservation status and various maps.