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EPA Research
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Characterising the Biological Communities of Rare River Types

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Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
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Characterising the Biological Communities of Rare River Types

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Prepared for the Environmental Protection Agency

by

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The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Contents

List of Figures

List of Tables

Executive Summary

Obligations under the Water Framework Directive (WFD 2000/60/EC) require high water body status to be maintained where it currently exists and all water bodies to achieve at least good status save where derogations have been granted. Surface water status is assigned based on an assessment of the ecological status of the water body against type-specific reference conditions, and compliance with thresholds set for general chemical determinands, priority substances and dangerous substances. Hydromorphology is considered when assigning high status. Before type-specific reference conditions could be defined, EU Member States needed to develop a typology defining the main surface water habitats in the state. The national river typology in Ireland was developed by the RIVTYPE project and accepted by the Environmental Protection Agency (EPA). The typology defined 12 national river types based on geology and slope. During the development of this typology, a number of rare or unusual river types were not adequately represented and so it is not known whether they represent distinct river types or are sufficiently characterised by the current 12 river types. Rare river types in this context are defined as systems that present biota with a distinct combination of naturally challenging or distinct environmental conditions. Four potential rare river types were identified as being poorly represented, and in some cases omitted entirely from the development of the national types: (1) groundwater-dominated rivers; (2) highly calcareous rivers with calcium precipitation; (3) low-conductivity, naturally acidic rivers; and (4) rivers strongly influenced by lakes. This project (RARETYPE) aimed to characterise the macroinvertebrate, macrophyte and phytobenthos communities of rare river types, determine whether or not these rivers, hereafter referred to as “rare types”, fit within the national typology and assess if current water quality assessment methods can adequately assess their condition.

To determine if the rare river types are adequately described by the national typology, five potential reference sites for each river type were selected and surveyed for three biological quality elements (BQEs), macroinvertebrates, macrophytes and phytobenthos, and physico-chemical determinands across seasons. Naturally acid sites were found in acid-sensitive catchments that have igneous/metamorphic geology, peaty soils and low alkalinity (< 10 mg $CaCO_3$ L^{-1}) water. Highly calcareous sites had evidence of calcification and high alkalinity values (> 200 mg $CaCO_3$ L^{-1}), while groundwater-dominated sites had high conductivity and alkalinity values (> 100 mg $CaCO_3$ L^{-1}) and potentially low dissolved oxygen (DO) levels. Lake outlet sites were located, where possible, within 1 km of the lake. The RARETYPE potential reference sites were then analysed alongside the 50 reference sites used to develop the current 12-type typology during the RIVTYPE project. Three impacted sites were also surveyed for each rare river category and used to assess the effectiveness of current assessment metrics.

If these potential rare river types do in fact represent types distinct from the existing 12, then they would be expected to host biological communities significantly different from those of the corresponding national types, e.g. naturally acid sites should have biotic communities distinct from those of national Types 11–14 (100% siliceous geology, hardness < 35 mg $CaCO_3$ L^{-1}) or highly calcareous sites with precipitate should differ from the calcareous Types 31 and 32 (> 25% calcareous geology, hardness > 100 mg $CaCO_3$ L^{-1}). This was not found to be the case for the highly calcareous sites with precipitate and groundwater-dominated sites, which hosted biological communities comparable to the corresponding national types. Further investigation of confined, groundwater-fed streams is recommended. The RARETYPE naturally acid sites had macroinvertebrate and macrophyte communities comparable to those of existing siliceous, soft-water types, although the phytobenthos communities varied significantly. Only the lake outlet sites were sufficiently distinct from their equivalent national sub-type (Type 11) to warrant a new river type. The macroinvertebrates, macrophytes and phytobenthos communities of these sites differed from Type 11 and in some cases from all three siliceous national types.

The EPA *Q*-value rating scheme has been effective in detecting organic/nutrient pollution in Irish rivers. When applied to the rare river types it correctly identified impacted from unimpacted highly calcareous sites in both summer and spring. Similarly, lake outlet sites were correctly designated as either high status or moderate status in spring; however, the distinction between the two was less clear in summer. For groundwater-dominated sites, two out of the three potential reference sites were classed as high status while the third, BLACK, which exhibited low DO levels, was determined as moderate status. These low DO levels may be driven by the input of groundwater low in oxygen and thus the reference condition in such cases may need to be revised to allow good/high status to be assigned in spite of the absence of Class A oxygen-sensitive taxa. However, here again, before this is considered, further investigation of confined, groundwater-fed sites is recommended. Differences in the *Q*-value between potential reference and impacted acid sites were detected in summer but not in spring. In spring, all acid sites scored Q5, although it must be noted, as previously mentioned, that the *Q*-value was not designed to measure the impact of increased acidity.

The Mean Trophic Rank (MTR) was designed to detect nutrient enrichment using macrophyte communities and is intercalibrated for one river type in Ireland. In general, it was found to be ineffective in detecting impacts for all the rare river types, even those where community structure varied significantly between potential reference and impacted sites, as was the case with the groundwater-dominated sites. The inability of the MTR to detect impact in naturally acid sites must be expected because it is designed to detect nutrient enrichment and not the impact of acid inputs. This metric is currently undergoing further testing and refinement by the EPA prior to being used in status assessment. The revised Trophic Diatom Index (TDI) has been successfully intercalibrated for both the Northern and Central Baltic geographical intercallibration groups (GIGs) of which Ireland is part (EU, 2008, 2013). The TDI appeared to correctly classify the majority of sites; however, strict application of the metric means it should only be applied to sites of alkalinity ≤ 150 mg $CaCO_3$ L^{-1}, a threshold breached by all the highly calcareous and groundwater-dominated sites. The importance of selecting the appropriate metrics to detect specific pressures was emphasised by the inability of the metrics above, designed to detect nutrient enrichment, to detect impact in naturally acid sites where acid input is likely to be the main stressor. In this case, the Acid Water Indicator Community species index (AWICsp) invertebrate metric and the Diatom Acidification Metric (DAM) both proved effective in separating impacted from unimpacted acid sites.

Overall, this work provides a solid foundation for making a series of decisions to improve assessment of the true ecological status of sites in rare river types.

1 Introduction

1.1 Background

The Water Framework Directive (WFD 2000/60/EC; EU, 2000) requires Member States to ensure that “high status” is maintained where it currently exists, to prevent deterioration in the existing status and to achieve at least “good status” in all water bodies except where derogations have been granted (2000/60/EC, Annex II). Surface water status is determined by assessing both the ecological and chemical status of the water body. The biological quality elements (BQEs) are assessed against type-specific reference conditions. Before type-specific reference conditions can be established, a typology capable of grouping water bodies based on similar abiotic characteristics must be developed. Two options for defining surface water types were set out in the WFD: System A and System B (EU, 2000). Member States could adopt either approach to develop their national typology. Because of its greater flexibility, Ireland chose the System B approach. The RIVTYPE project tested a number of typologies using 50 high-status sites based on various combinations of physical descriptors (Kelly-Quinn *et al.*, 2005). For a typology to be useful, the types defined must be ecologically meaningful and representative of the surface water bodies present in the state. The RIVTYPE project determined that a 12-category typology based on geology and slope (see Appendix 1) best discriminated the biological elements across all groups (Dodkins *et al.*, 2005; Kelly-Quinn *et al.*, 2005). The typology was accepted by the Environmental Protection Agency (EPA); however, because of scheduling conflicts, the national types were not used in the intercalibration process. Instead, Member States with similar biogeographical water types were placed into geographical intercalibration groups (GIGs) and common intercalibration river types were used for the intercalibration process.

During the development of the existing national typology, a number of rare or unusual river types were not adequately represented and so it is not known whether they represent distinct river types or are sufficiently characterised by the current 12 river types. Kelly-Quinn *et al*. (2009) identified four potential river types that may represent additional river types, as they present biota with naturally challenging combinations of environmental conditions. These include (1) groundwater–dominated rivers; (2) highly calcareous rivers with calcium precipitation; (3) low-conductivity, naturally acidic rivers; and (4) rivers strongly influenced by lakes. Thus, the present project was funded to determine whether or not these rivers, hereafter referred to as “rare types”, fit within the national typology and if current assessment tools can adequately assess their condition.

1.2 Rare River Types

Establishing type-specific reference conditions is further complicated by the difficulty in differentiating natural variability from anthropogenic impact. Rare river types are stretches of river that present naturally challenging combinations of environmental conditions for aquatic biota. A more in-depth review of the literature relating to establishing reference conditions, intercalibration and the biological communities of the rare river types discussed below can be found in Hannigan and Kelly-Quinn (2016).

1.2.1 Groundwater-dominated rivers

Approximately 30% of the annual flow of the majority of Irish rivers is derived from groundwater (Daly, 2009), although the percentage input varies across scale (reach vs catchment) and season (Daly, 2009). Generally, groundwater tends to have a more stable thermal and flow regime than surface waters, including a stable hydrochemical regime reflective of the aquifer geology (Crisp and Westlake, 1982; Sear *et al.*, 1999). Dissolved oxygen (DO) concentrations can vary in groundwater and tend to be low in confined aquifers (Younger, 2009), which could potentially affect the biota. The low DO observed in such groundwaters may influence surface water on a local scale close to the groundwater source but the influence rapidly declines downstream (Sear *et al.*, 1999). Where aquifers are unconfined and can recharge quickly, as is the case for most aquifers in Ireland, DO levels tend to be much higher (Matthew Craig, EPA, October 2015, personal communication). Generally, these rivers can be characterised by low sediment concentrations, a relatively stable thermal and flow regime, and high water clarity (Whiting and Stamm, 1995; Sear *et al.*, 1999). In contrast, Tedd *et al.* (2017) reported that low-vulnerability groundwaters, including some confined aquifers, can have low oxygen levels. Where the underlying aquifer has limestone geology conductivity, hardness and alkalinity will be high. There is a lack of consensus regarding whether groundwater-dominated rivers host distinct invertebrate communities, although the importance of flow permanence and oxygen concentrations on invertebrate community structure is well known (Smith and Wood, 2002; Wood and Armitage, 2004). Conditions presented by groundwater dominance may favour some biological communities, e.g. increased flow stability may favour macrophyte growth, but the effect on invertebrate communities is less clear (Sear *et al.*, 1999) and may not be as important in structuring communities as local-scale factors such as geology (Williams *et al.*, 1997; Cannan and Armitage 1999; Sear *et al.*, 1999).

1.2.2 Highly calcareous rivers with calcium precipitate

A strong groundwater influence in areas with karst limestone bedrock gives rise to highly calcareous river waters, which may lead to precipitation and deposition of $CaCO_3$ on the surrounding substrate, flora and fauna. The degree of deposition can vary from small amounts on flora and fauna to more severe cementing of the substrates (Pentecost, 2005). Substrate compaction or cementing reduces habitat heterogeneity and interstitial spaces in the streambed, thereby impacting two of the most important factors affecting invertebrate structure in a similar way to siltation and sedimentation (Casas and Gessner, 1999; Pentecost, 2005; Rundio, 2009). The loss of microhabitats potentially alters the invertebrate community, which in turn affects food and spawning habitat availability for salmonids (Kelly-Quinn *et al.*, 2003; Pitois *et al.*, 2003; Rundio, 2009). Invertebrate abundance tends to be lower in stream reaches where deposition occurs (Pitois *et al.*, 2003; Álvarez and Pardo, 2007; Rundio, 2009) with burrowing species, in particular, reduced or eliminated from the fauna (Kelly-Quinn *et al.*, 2003; Rundio, 2009). The deposits of $CaCO_3$ can also reduce the decomposition rate of leaves due to impeded activity of decomposers, thus negatively impacting ecosystem functioning (Casas and Gessner, 1999).

1.2.3 Naturally acidic rivers

When the acid-neutralising capacity of a river is low (alkalinity $< 10\,mg\,CaCO_3\,L^{-1}$), the system is susceptible to acidification. This acidity can be due to natural inputs of organic acids (i.e. humic acids) reducing pH for periods (i.e. episodic acidity) or keeping the pH naturally low (Driscoll *et al.*, 1989; Collier *et al.*, 1990). Anthropogenic acidity arises from an influx of inorganic ions (particularly sulfates and nitrates) through atmospheric deposition (Fowler *et al.*, 1989; Kelly-Quinn *et al.*, 1996) or from elevated release of organic acidity (Feeley *et al.*, 2013; Feeley and Kelly-Quinn, 2014). As natural acidity occurs at a much slower rate over a long period of time, organisms can acclimatise and adapt to altered acidity levels and so the effects of natural acidity appear less severe than those associated with anthropogenic acidity (Dangles *et al.*, 2004; Petrin *et al.*, 2008). The role of anthropogenic acidity has complicated the understanding of the invertebrate communities expected in naturally acidic streams; however, these rivers do tend to host communities distinct from circumneutral rivers (Dangles *et al.*, 2004; Kowalik *et al.*, 2007). The nature of the acidity, i.e. natural or anthropogenic, may affect communities more on an individual species level (Kowalik *et al.*, 2007). Although naturally acid rivers host a higher diversity of species than anthropogenically acidified systems, this is likely to be site specific and the importance of local factors other than pH, such as low calcium levels and flow as drivers of community structure, must be considered.

1.2.4 Rivers strongly influenced by lakes (lake outlets)

Lake-fed rivers are transition zones between lacustrine and lotic conditions (Malmqvist and Eriksson, 1995) that are highly productive close to the lake outlet (Hieber *et al.*, 2002). A number of physical and chemical processes in the outflowing river are influenced by proximity to the lake with the effects dissipating within 1–2 km of the lake (Valett and Stanford, 1987; Robinson and Minshall, 1990; Hoffsten, 1999) depending on the size and flow rate of inflowing and outflowing rivers. The macroinvertebrate communities of these water bodies tend to be dominated by filter-feeding taxa such as Simuliidae and Hydropsychidae (Valett and Stanford, 1987; Richardson and Mackay, 1991; Harding, 1992; Hoffsten, 1999), possibly due to the increased transport of phytoplankton and particulate organic matter from the lake (Harding, 1992; Giller and Malmqvist, 1998; Hieber *et al.*, 2002). Filter-feeder densities have been found to decrease sharply with distance from the outlet of lakes of all trophic status (Sheldon and Oswood, 1977; Morin *et al.*, 1988; Robinson and Minshall, 1990), with the exception of oligotrophic Alpine lakes (Maiolini *et al.*, 2006). Lake outlets have been classified as a distinct type in Germany by Brunke (2004).

1.3 Scope of the Project

The objectives of this project were to:

1. characterise the biological communities of rare river types;
2. determine if these rare river types represent separate biological types to those already defined in Ireland (RIVTYPE; Kelly-Quinn *et al.*, 2005); and
3. assess if current water quality assessment methods can adequately assess their condition.

2 Materials and Methods

2.1 Site Descriptors

Four rare river types were included in this project: naturally acid rivers, highly calcareous rivers with calcium precipitation, groundwater-dominated rivers and lake outlet sites. For each type five potential reference sites and five impacted sites were selected for macroinvertebrate, macrophyte and phytobenthos sampling, resulting in a total of 40 sites (Table 2.1a and 2.1b). Naturally acid sites had igneous/metamorphic geology, peaty soils and low alkalinity (< 10 mg $CaCO_3$ L^{-1}) water. Highly calcareous sites had evidence of calcification and high alkalinity values (> 200 mg $CaCO_3$ L^{-1}), while groundwater-dominated sites had high conductivity and alkalinity values (> 100 mg $CaCO_3$ L^{-1}) and potentially low DO levels.

Lake outlet sites were located, where possible, within 1 km of the lake. After the initial summer sampling, some issues were identified regarding the suitability of certain sites. The GLENREE site (bridge near Carrownaglogh), which was suggested as a potential reference site for highly calcareous rivers, exhibited minimal signs of calcification. As a result, it was decided to replace this site with the ABBERT River (bridge at Bullaun) in Galway. The representativeness of the BONET site [Bridge upstream of (u/s) Glenade Lough] as a groundwater-dominated system was queried and replaced by a site on the MOYREE river (bridge u/s Fergus River) in County Clare. The final list of sites surveyed is presented in Table 2.1a (potential reference sites) and Table 2.1b (impacted sites), and their distribution is illustrated in Figure 2.1.

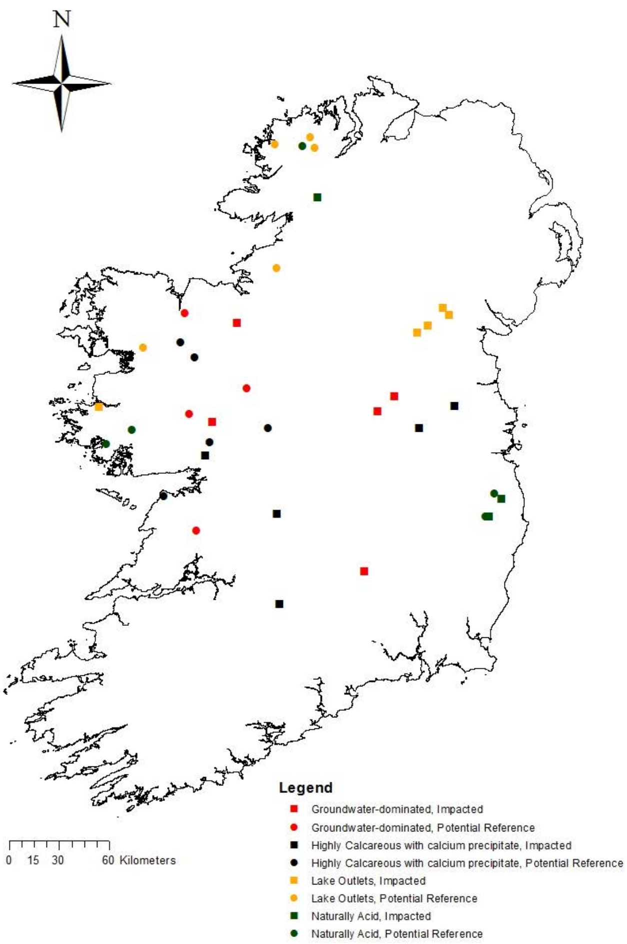

Figure 2.1. Location of all potential reference and impacted sites for the river types surveyed.

Table 2.1a(i). Description of potential reference sites surveyed

Site name	County	EPA station	Station location	RARETYPE Site code[c]	IGR
Naturally acid					
CLOGHOGE[a]	Wicklow	10A050005	Just off road side d/s of bridge	CLOG	O14426 09870
DOIRE HOIRBIRT[a]	Galway	30D140290	Maumwee Inflow 1 (Lower)	DOIRE	L97347 48410
OWENVEAGH[a]	Donegal	38O140080	Veagh Cottage	OWVEAGH	C04314 23444
GLENEALO[b]	Wicklow	10G050100	Above miner spoil heaps	GLENO	T08822 96227
OWENGOWLA[b]	Galway	31O020300	Bunnahown Bridge	OGOWL	L81827 39770
Highly calcareous with calcium precipitate					
ABBERT[a]	Galway	30A010500	Bridge at Bullaun	ABBRT	M43625 40783
CAHER[a]	Clare	28C010200	Bridge 2 km d/s Formoyle/Carha Bridge	CAHER	M16315 08251
GLORE[a]	Mayo	34G020200	Glore Bridge	GLORE	M35000 91785
MOY[a]	Mayo	34M020750	At Cuilbaum/Bleanmore	MOY	G26160 00835
SHIVEN[a]	Galway	26S030400	Islandcausk Bridge	SHIVEN	M78709 49360
Groundwater-dominated					
BEHY[a]	Mayo	34B080400	Behy Bridge	BEHY	G28781 18132
BLACK[a]	Galway	30B020100	Bridge at Kilshanvy	BLACK	M31862 57689
ISLAND[a]	Galway	26I030300	Bridge SW Bookalagh	ISLAND	M66216 72970
MOYREE[a]	Clare	27M020700	Bridge u/s Fergus River	MOYREE	R36128 88061
OWENUR	Roscommon	26O060300	Ballyslish Bridge	OWENUR	M89321 87213
Lake outlets					
GWEEDORE[a]	Donegal	38G030100	Bridge E Meenderrynasloe/1.2 km u/s Crolly Bridge	GWEE	C06881 16990
LEANNAN[a]	Donegal	39L010100	Gartan Bridge	LEANN	L98241 48397
OWENCARROW[a]	Donegal	38O030150	Second bridge d/s Lough Veagh	OWCAR	C04314 23444
NEWPORT[b]	Mayo	32N010020	1.25 km d/s Lough Beltra	NEWPORT	M04300 97305
BONET	Leitrim	35B060050	Bridge 1.5 km d/s Glenade Lough	BONET	G84026 44768

Eight of the 10 groundwater sites are regionally important karst aquifers, while Lough Lene–Adeel Stream and the Gaine are locally important karst aquifers.

[a]Indicates sites analysed for all BQEs.

[b]Sites used in analysis of macrophyte and phytobenthos community analysis only.

[c]Codes as applied in Table 5.1 and Figures 5.4 and 5.5.

d/s, downstream; IGR, Irish grid reference.

Table 2.1a(ii). Description of potential reference sites surveyed

Site name	EPA station	Geology	Land use
Naturally acid			
CLOGHOGE[a]	10A050005	Ordovician metasediments	96% bogs; 4% other
DOIRE HOIRBIRT[a]	30D140290	Precambrian quartzite, schist and gneiss	100% moorland
OWENVEAGH[a]	38O140080	Granite	8% forestry; 69% bogs; 23% other
GLENEALO[b]	10G050100	Granite	81% bogs; 19% other
OWENGOWLA[b]	31O020300	Granite	96% bogs; 1% miscellaneous agriculture; 2% water; 1% other
Highly calcareous with calcium precipitate			
ABBERT[a]	30A010500	Dinantian pure bedded limestone	65% pasture; 2% forestry; 15% bogs; 13% miscellaneous agriculture; 5% other
CAHER[a]	28C010200	Dinantian pure bedded limestone	42% pasture; 19% bogs; 17% miscellaneous agriculture; 21% other
GLORE[a]	34G020200	Dinantian pure bedded limestone	42% pasture; 19% bogs; 17% miscellaneous agriculture; 21% other
MOY[a]	34M020750	Precambrian quartzite, schist and gneiss	35% pasture; 1% forestry; 32% bogs; 1% urban; 19% miscellaneous agriculture; 12% other
SHIVEN[a]	26S030400	Dinantian pure bedded limestone	57% pasture; 3% forestry; 22% bogs; 9% miscellaneous agriculture; 9% other
Groundwater-dominated			
BEHY[a]	34B080400	Dinantian pure bedded limestone	33% pasture; 66% bogs; 1% miscellaneous agriculture
BLACK[a]	30B020100	Dinantian pure bedded limestone	92% pasture; 8% miscellaneous agriculture
ISLAND[a]	26I030300	Dinantian pure bedded limestone	56% pasture; 26% bogs; 7% miscellaneous agriculture; 9% other
MOYREE[a]	27M020700	Dinantian pure bedded limestone	38% pasture; 5% forestry; 14% bogs; 14% miscellaneous agriculture; 1% water; 1% other
OWENUR	26O060300	Dinantian pure bedded limestone	84% pasture; 1% urban; 9% miscellaneous agriculture; 1% water; 32% other
Lake outlets			
GWEEDORE[a]	38G030100	Granite	9% pasture; 79% bogs; 1% miscellaneous agriculture; 4% water; 8% other
LEANNAN[a]	39L010100	Precambrian quartzite, schist and gneiss	2% forestry; 59% bogs; 14% miscellaneous agriculture; 4% water; 21% other
OWENCARROW[a]	38O030150	Granite	7% forestry; 54% bogs; 8% water; 32% other
NEWPORT[b]	32N010020	Dinantian sandstone	100% bogs
BONET	35B060050	Dinantian pure bedded limestone	15% pasture; 2% forestry; 55% bogs; 7% miscellaneous agriculture; 4% water; 8% other

Eight of the 10 groundwater sites are regionally important karst aquifers, while Lough Lene–Adeel Stream and the Gaine are locally important karst aquifers.

[a]Indicates sites analysed for all BQEs.

[b]Sites used in analysis of macrophyte and phytobenthos community analysis only.

[c]Codes as applied in Table 5.1 and Figures 5.4 and 5.5.

d/s, downstream; IGR, Irish grid reference.

Table 2.1b(i). Description of impacted sites surveyed

Site name	County	EPA station	Station location	RARETYPE Site code[c]	IGR
Naturally acid					
BUNADOWEN[a]	Donegal	01B010100	Bridge u/s Mourne Beg confluence	BUNOWEN	H08144 87425
LUGDUFF[a]	Wicklow	10L130940	Just d/s of Bridge Pollanass	LUGDUFF	T11060 96135
VARTRY[a]	Wicklow	10K140420	Above Stoney Pass Bridge	VARTRY	O18600 07100
Highly calcareous with calcium precipitate					
BALLYFINBOY[a]	Tipperary	25B020800	Bridge just u/s Lough Derg	BFINBOY	R83804 98048
DEAD[a]	Tipperary	25D010100	Pope's Bridge	DEAD	R85579 43753
SKANE[a]	Meath	07S010600	Dowdstown Bridge	SKANE	N93079 62357
DEEL[b]	Meath	07D010600	Bridge u/s Boyne River confluence	DEEL	N69102 49317
CLARE[b]	Galway	30C011100	Cregmore Bridge	CLARE	M41011 32809
Groundwater-dominated					
NANNY[b]	Galway	30N010100	Bridge NW Loughpark/bridge S of Oakmount	NANNY	M45518 52926
NUENNA[a]	Kilkenny	15N020100	Bridge d/s Clomantagh	NUENNA	S36280 63720
BUNNANADDAN[a]	Sligo	35B080200	Ford NW of Bunnanaddan	BUNADD	G60045 12072
GAINE[b]	Westmeath	26G010100	Bridge 1 km NE of Ballynagall	GAINE	N44578 59286
LOUGH LENE–ADEEL STREAM[b]	Westmeath	07L030040	Bridge u/s Lough Adeel	LENE–ADEEL	N54217 68338
Lake outlets					
ANNALEE[a]	Cavan	36A020150	Second bridge d/s Lough Sillan	ANNA	H68377 06318
KNAPPAGH[a]	Monaghan	36K010200	Bridge u/s Bellatrain Lough	KNAPP	H83430 21440
GENTLE OWEN'S STREAM[a]	Monaghan	06G040100	Bridge 1.5 km d/s Muckno Mill Lough	GOWEN'S	H74468 10701
FANE[b]	Monaghan	06F010300	D/s Lough Muckno	FANE	H87348 16786
CULFIN[b]	Galway	32C040040	Between Lough Fee and Lough Muck	CULFIN	L77868 62129

[a]Indicates sites processed for all BQEs.

[b]Sites used in analysis of macrophyte and phytobenthos community analysis only.

[c]Codes as applied in Table 5.1 and Figures 5.4 and 5.5.

d/s, downstream; IGR, Irish grid reference.

Table 2.1b(ii). Description of impacted sites surveyed

Site name	EPA station	Geology	Land use
Naturally acid			
BUNADOWEN[a]	01B010100	Precambrian quartzite, schist and gneiss	44% forestry; 30% bogs; 26% other
LUGDUFF[a]	10L130940	Ordovician metasediments	~25–33% closed canopy forestry
VARTRY[a]	10K140420	Ordovician metasediments	>30% forestry
Highly calcareous with calcium precipitate			
BALLYFINBOY[a]	25B020800	Dinantian pure bedded limestone	70% pasture; 3% forestry; 4% bogs; 2% urban; 18% miscellaneous agriculture; 3% other
DEAD[a]	25D010100	Dinantian impure limestone	95% pasture; 5% urban
SKANE[a]	07S010600	Dinantian impure limestone	64% pasture; 1% forestry; 2% urban; 34% miscellaneous agriculture
DEEL[b]	07D010600	Dinantian impure limestone	79% pasture; 2% forestry; 5% bogs; 1% urban; 6% miscellaneous agriculture; 2% water; 6% other
CLARE[b]	30C011100	Dinantian pure bedded limestone	63% pasture; 1% forestry; 17% bogs; 1% urban; 15% miscellaneous agriculture; 4% other
Groundwater-dominated			
NANNY[a]	30N010100	Dinantian pure bedded limestone	73% pasture; 15% bogs; 3% urban; 7% miscellaneous agriculture; 2% other
NUENNA[a]	15N020100	Dinantian pure bedded limestone	78% pasture; 3% forestry; 14% miscellaneous agriculture; 5% other
BUNNANADDAN[a]	35B080200	Dinantian pure bedded limestone	89% pasture; 1% bogs; 6% miscellaneous agriculture; 4% other
GAINE[b]	26G010100	Dinantian impure limestone	79% pasture; 10% forestry; 2% bogs; 7% miscellaneous agriculture; 2% water
LOUGH LENE–ADEEL STREAM[b]	07L030040	Dinantian impure limestone	67% pasture; 1% urban; 8% miscellaneous agriculture; 18% water; 6% other
Lake outlets			
ANNALEE[a]	36A020150	Silurian Metasediments	79% pasture; 1% urban; 15% miscellaneous agriculture; 4% water; 28% other
KNAPPAGH[a]	36K010200	Silurian Metasediments	86% pasture; 1% urban; 9% miscellaneous agriculture; 4% water
GENTLE OWEN'S STREAM[a]	06G040100	Silurian Metasediments	100% pasture
FANE[b]	06F010300	Silurian Metasediments	85% pasture; 2% bogs; 25 urban; 6% miscellaneous agriculture; 4% water; 1% other
CULFIN[b]	32C040040	Granite	7% forestry; 65% bogs; 11% water; 17% other

[a]Indicates sites processed for all BQEs.

[b]Sites used in analysis of macrophyte and phytobenthos community analysis only.

[c]Codes as applied in Table 5.1 and Figures 5.4 and 5.5.

d/s, downstream; IGR, Irish grid reference.

2.2 Sampling Methodology

Macroinvertebrate, phytobenthos and physico-chemical samples were collected to represent three seasons: summer (July/August 2014), autumn (October/November 2014) and spring (March/April 2015). Macrophytes were surveyed during the summer period.

2.2.1 *Physico-chemical sampling*

Temperature, conductivity, DO and pH were measured in the field using automatic probes. Water was collected in 1 L polypropylene bottles and sent to the Aquatic Services Unit in University College Cork for analysis. The suite of determinands tested is listed in Table 2.2.

The physical habitat was described in terms of substrate composition, mesohabitat representation (e.g. riffle, glide, run and pool), percentage shading and bank characteristics. The hydromorphological condition was assessed in the summer using the River Hydromorphology Assessment Technique (RHAT) on a 50 m reach (Murphy and Toland, 2014).

As a result of weather conditions, three sites were not sampled during the autumn period (FANE, DEEL and MOYREE), while in spring MOY, GLORE and CLARE could not be sampled until May 2015.

2.2.2 *Macroinvertebrate sampling*

Three replicate, 3-minute, multi-habitat kick samples were taken within a 50 m stretch using a 1 mm mesh kick net as undertaken in the RIVTYPE project (Kelly-Quinn *et al.*, 2005). Hand searches for attached macroinvertebrates were also conducted at each site. Samples were labelled and preserved using 70% industrial methylated spirits.

2.2.2.1 *Laboratory procedures*

In the laboratory, samples for macroinvertebrate analysis were sieved through a 500 µm mesh to ensure no specimens were lost. The washed sample was then transferred to an illuminated white tray where all specimens were removed and stored in labelled tubes in 70% alcohol before being identified to the lowest possible taxonomic level using standard Freshwater Biological Association (FBA) identification

Table 2.2. Standard methods used for hydrochemical analysis

Parameter	Units	Method
Temperature	°C	Electrometric
Conductivity	µS cm^{-1} at 25°C	Electrometric
DO	mg $O_2 L^{-1}$	Electrometric
Oxygen saturation	% Sat.	Electrometric
pH	pH	WTW pH meter 330i
Alkalinity	mg $CaCO_3 L^{-1}$	Titration
Total hardness	mg $CaCO_3 L^{-1}$	Titration
Ammonia	mg N L^{-1}	Automated salicylate method
Nitrate	mg N L^{-1}	Subtraction of measured nitrite from measured TON
Nitrite	mg N L^{-1}	Colorimetric method using Lachat Quikchem 8000
MRP	mg P L^{-1}	Spectrophotometry
Chloride	mg $Cl^- L^{-1}$	Ion chromatography method using Lachat Quikchem 8000
Sulfate	mg $SO_4^{2-} L^{-1}$	Ion chromatography method using Lachat Quikchem 8000
Calcium	mg $Ca^2 L^{-1}$l	Flame atomic absorption spectroscopy
Magnesium	mg $Mg^{2+} L^{-1}$	Flame atomic absorption spectroscopy
Sodium	mg $Na^{2+} L^{-1}$	Flame atomic absorption spectroscopy
Potassium	mg $K^- L^{-1}$	Flame atomic absorption spectroscopy
Aluminium	µg Al L^{-1}	Flame atomic absorption spectroscopy
DOC	mg DOC L^{-1}	High temperature combustion method

DOC, dissolved oxygen carbon; MRP, molybdate reactive phosphorus; TON, total organic nitrates.

keys (Table 2.3). The abundance of each taxon was recorded.

Due to time constraints, samples from only three of the five replicate impacted sites for each river type were processed. In terms of the potential reference sites, samples from five highly calcareous sites, four groundwater-dominated and three naturally acid and lake outlet sites were processed. In order to identify the most representative sites for each category, one sample from each of the 40 sites was processed and the final decision was based on the combined biological, chemical and physico-chemical condition of the sites. Sites used in the analysis of the macroinvertebrate communities are given in Tables 2.1a and 2.1b. The number of macroinvertebrate samples sorted varied across season with all three sorted for the spring period. As little variation was found within sites, two samples were processed for summer, and one from the autumn. The autumn data were not used in the statistical analyses. This is in line with RIVPACS, which uses one 3-minute sample (EU-STAR, 2004).

2.2.3 Phytobenthos sample collection and processing

Benthic diatom samples were collected by brushing the surface of five cobbles at each site using a toothbrush. Where five cobbles of appropriate size were not available, 10 smaller cobbles were used. The sample was rinsed into a Sterilin tube, preserved using Lugol's iodine and wrapped in tinfoil to eliminate light before being sent to Dr Martyn Kelly (Bowburn Consultancy) for expert identification. Following the protocol outlined by Kelly-Quinn *et al.* (2005) and European Committee for Standardization (CEN) guidelines on phytobenthos sampling (CEN, 2003a), the percentage abundance of visible macroalgae was assessed in the field using a six-point abundance estimate scale ranging from occasional (category 1) (< 1%) to dominant (category 6) (> 50%). At each site macroalgal colour, appearance and abundance were detailed. Samples of algae were collected from a 20 m stretch at each site for laboratory identification to genus level using appropriate keys. Macroalgal samples collected during the first round of sampling (summer) were preserved using Lugol's iodine; however, this made identification more difficult and so in subsequent sampling rounds macroalgal samples were identified live. Photographs and measurements were also taken of the various specimens and sent to experts for verification.

Table 2.3. Levels of taxonomic identification

Taxon	Level of identification
Oligochaeta	Class
Hirudinea	Species
Mollusca	Species/genus
Crustacea	Species
Plecoptera	Species
Ephemeroptera	Species
Coleoptera	Species
Trichoptera	Species/genus
Heteroptera	Species/genus
Odonata	Species
Simuliidae	Family
Chironomidae	Sub-family
Other dipteran larvae	Genus/family

2.2.4 Macrophyte sampling

As mentioned above, macrophytes at all sites were surveyed during the summer fieldwork season. At each site, a 50 m stretch was surveyed following CEN standard guidelines and the approach applied in the RIVTYPE project (CEN, 2003b; Kelly-Quinn *et al.*, 2005). Taxa were recorded on site and their abundances were estimated using macrophyte cover categories (0.01% to > 10%) outlined in the CEN (2003b) guidelines. Vouched specimens were collected for taxa that could not be identified in the field and for expert verification.

2.3 Data Analysis

2.3.1 Standardisation of datasets

2.3.1.1 Macroinvertebrate dataset

Macroinvertebrate taxa were identified to various taxonomic levels and were standardised using the approach applied in the RIVTYPE project (Kelly-Quinn *et al.*, 2005) prior to use in multivariate analysis. Rare species, i.e. species occurring in less than 10% of sites, were removed from the dataset for multivariate analysis. The data were subject to log(x + 1) transformation before analysis was carried out, to downplay the role of dominant species that may mask the effect of rare ones.

2.3.1.2 Macrophyte dataset

Data from 18 reference sites (five naturally acid, five highly calcareous, four groundwater-dominated and four lake outlets) and 17 impacted sites from the RARETYPE project were included in the macrophyte analysis (see Tables 2.1a and 2.1b). Macrophyte cover categories were used to estimate macrophyte percentage abundance (Table 2.4). Rare taxa (present in < 10% of sites) were removed prior to analysis. Since the categories already represent an approximate log transformation, species data were not transformed.

2.3.1.3 Phytobenthos data

As with the macrophyte dataset, the phytobenthos dataset included data from 18 reference sites (five naturally acid, five highly calcareous, four groundwater-dominated and four lake outlets) and 17 impacted sites from the RARETYPE project (Table 2.1a and 2.1b). The diatom data collected during this study were converted to percentage relative abundance while visible macroalgae data were also expressed in terms of percentage cover. For analysis relating to objectives 1 and 3 that included only RARETYPE data, the data were square root transformed prior to analysis.

The RARETYPE phytobenthos data were converted to abundance categories to enable them to be merged with the RIVTYPE phytobenthos data (Table 2.5). The two datasets were then harmonised to account for variation between operators and taxonomic names. Data were not transformed. For this BQE rare taxa were defined as those that were present in less than 10% of sites and present in abundances of < 1% (category 1, Table 2.5).

For the comparison of the rare river types and existing river types the current dataset had to be merged with the RIVTYPE data (Kelly-Quinn *et al.*, 2005). Prior to merging the datasets, the abundance data collected in the current study were converted from percentage abundance to the abundance categories in Table 2.5. The two datasets were harmonised to account for variation between operators and taxonomic names. Data were not transformed. For this comparison rare taxa were defined as those present in less than 10% of sites and present in abundances of < 1% (category 1, Table 2.5) and removed prior to analysis.

Table 2.4. Macrophyte abundance categories and the corresponding percentage abundance cover

Abundance category	% Abundance
1	< 0.1
2	0.1–1
3	1.1–5
4	5.1–10
5	> 10

Table 2.5. Phytobenthos abundance categories and the corresponding percentage cover

Abundance category	% Abundance cover
1	< 0.1
2	1.1–5
3	5.01–10
4	10.01–25
5	25.01–50
6	> 50

2.3.2 Statistical methods

2.3.2.1 Comparison of community structure across river types

Variation in community structure, which incorporates taxon abundance, across potential river types and seasons was analysed using multivariate ANOVA (analysis of variance) carried out using the PRIMER 6 and PERMANOVA (permutational multivariate analysis of variance) package (Clarke and Gorley, 2006; Anderson *et al.*, 2008). PRIMER 6 and PERMANOVA are robust statistical packages designed for analysis of ecological data and are capable of dealing with unbalanced designs. The analysis was based on Bray–Curtis dissimilarities and was run using 4999 permutations. Data were subject to $\log(x + 1)$ transformation prior to analysis in order to reduce the role of dominant species that may mask the effect of rare ones (Clarke, 1993). Macroinvertebrate data were subject to taxonomic adjustment as described by Kelly-Quinn *et al.* (2005) and standardised across all datasets (RARETYPE and RIVTYPE). Where community differences were identified, SIMPER (similarity of percentages) analysis was used to indicate the taxa responsible for the detected difference using PRIMER 6. An analysis of similarity (ANOSIM) which tests the similarity between and within groups of objects based on differences between rank similarities was also conducted for site/habitat groupings. Non-metric multidimensional scaling plots were generated to visually display the site/habitat groupings. Additional multivariate analysis was carried out for lake outlets and groundwater-dominated sites to determine if they differed from their equivalent national type in terms of the representation of *Q*-value Group A, Group B, Groups A–D and Groups A–D excluding C macroinvertebrate taxa (pollution-sensitive to pollution-tolerant; see Toner *et al.*, 2005 and section 6.2.1.1).

2.3.2.2 Relationship between biotic and abiotic data

Distance-based linear modelling (DISTLM) was used to model the relationship between multivariate biological data and environmental predictor variables by partitioning data according to a regression/multiple regression model in PRIMER 6 and PERMANOVA (Anderson *et al.*, 2008). A marginal test was conducted in which individual variables were fitted separately to test their relationship with the biological data. This was followed by a forward step-wise selection procedure that builds a sequential model identifying the set of variables responsible for variation in community structure. The variables selected in the model are conditional on those already included in it (Anderson *et al.*, 2008). Both the marginal and conditional tests were based on Bray–Curtis dissimilarities of the untransformed taxon abundance data using 4999 permutations. The environmental variables tested were pH, percentage DO saturation, percentage substrate, total hardness, Na^+, Cl^-, Ca^{2+}, Mg^{2+}, K^+, slope ($m\,m^{-1}$) and percentage of the upstream catchment made up of calcareous geology. Where strong correlations or multicollinearity between variables were detected, one of the parameters was removed. This resulted in six variables being included in the environmental analysis [pH, percentage DO saturation, percentage substrate, total hardness, Cl^-, slope ($m\,m^{-1}$)]. Where variables were removed due to strong correlation with another factor it must be noted that the retained variable may effectively act as a surrogate for the one that was removed. For example, in this case alkalinity was removed, as it was strongly correlated with total hardness, so any variance attributed to total hardness may be the effect of alkalinity. Distance-based redundancy analysis (dbRDA) is a constrained ordination that enables the variation explained by the model built using DISTLM (Anderson *et al.*, 2008) to be visualised.

2.3.2.3 Biological classification and group validation

Two-way indicator species analysis (TWINSPAN) (Hill *et al.*, 1975; Hill, 1994; Hill and Minchin, 1997) is a hierarchical, divisive biological classification method that uses a Gaussian response model to progressively separate sites of varying environmental conditions into smaller groups depending on the frequency and occurrence of indicator species, until the end groups reach the required level of homogeneity. Although robust, TWINSPAN, particularly earlier versions, has been criticised (van Groenewoud, 1992) as the splitting rule it uses may prevent ecologically closely related sites/samples from clustering together.

The end groups produced by TWINSPAN were validated using the TWINEND program, which measures dispersion within the end group as a percentage of the total dispersion within the whole data set (Legendre and Legendre, 1998). A group reaching a dispersion of 50% or less was deemed as adequately homogeneous; however, where data were very variable (i.e. macrophyte and phytobenthos data) a higher dispersion value of 75% was chosen as adequate for end groups.

Multi-response permutation procedures (MRPP), similar to ANOSIM, tests the similarity between and within groups, and was used to determine if each branch created by TWINSPAN was valid. MRPP provides a qualitatively similar test statistic (A) with values close to 1 indicating that sites within a group are identical, i.e. heterogeneity is low, while $A = 0$ indicates that heterogeneity is equal to that expected by chance. Positive A-values and significant P-values ($P < 0.05$) are favourable results when separating groups.

3 Physico-chemical Characteristics of Rare River Types

3.1 Physico-chemical Characteristics of Potential Reference and Impacted Sites

The mean, minimum and maximum physico-chemical results from spring, autumn and summer sampling from all potential reference and impacted sites are presented in Tables 3.1a, 3.1b, 3.1c and 3.1d. The results are compared with the available environmental quality standards (EQSs) although the number of samples was less than that required for setting status. For designation of general physico-chemical status a minimum of 12 samples over a 3-year period is required.

All naturally acid sites, potential reference and impacted, recorded mean pH values between 5.09 and 6.73 (Table 3.1a). The impacted sites were consistently more acidic (pH < 6) than the non-impacted sites. Similarly, though all acid sites had low alkalinity (< 10 mg $CaCO_3$ L^{-1}), the average alkalinity at impacted sites was much lower (< 1.3 mg $CaCO_3$ L^{-1}) than non-impacted sites (Table 3.1a). The mean conductivity of naturally acid sites ranged between 33 and 80 µS/cm for all sites except the OWENGOWLA (106 µS cm^{-1}) (Table 3.1a). It should be noted that sampling in the acidic sites was carried out in low-flow conditions and therefore that the pH minimum values presented may not represent the minimum that these sites experience during flood conditions (see Feeley *et al.*, 2013).

The lake outlets were all fed by soft-water lakes and so generally had relatively low mean alkalinities (2–72 mg $CaCO_3$ L^{-1}). Three of the four potential reference sites were located in Donegal on siliceous geology resulting in mean pH values of between 6 and 6.8, and alkalinity values < 10 mg $CaCO_3$ L^{-1} (Table 3.1b). Four out of the five impacted lake outlets were located in Cavan and Monaghan on Silurian metasediments; these generally had higher mean pH values (6.9–8.19) and alkalinities (48–72 mg $CaCO_3$ L^{-1}). The fifth site (CULFIN) was located in the west on granite, resulting in pH and alkalinity values similar to the potential reference sites. Conductivity was also higher in impacted sites (82–228 µS/cm) than potential reference sites (74–131 µS cm^{-1}) (Table 3.1b).

Alkalinity ranged from 176 to 328 mg $CaCO_3$ L^{-1} in the highly calcareous rivers with precipitate and from 198 to 335 mg $CaCO_3$ L^{-1} in groundwater-dominated sites (Table 3.1c and 3.1d). The average pH for the highly calcareous sites was generally above 8 (7.96–8.27) while pH in groundwater-dominated sites tended to be between 7 and 8 (Table 3.1c and 3.1d) with very little variation between impacted and non-impacted sites. In terms of conductivity, highly calcareous potential reference sites had values ranging from 383 to 596 µS cm^{-1} while the impacted sites had consistently higher values (582–760 µS cm^{-1}) (Table 3.1c). There was little variation in conductivity between potential reference and impacted groundwater-dominated sites, with all sites recording values between 392 and 691 µS cm^{-1} (Table 3.1d).

Generally, mean DO saturation levels fell within the thresholds of 80–120% (Irish Government, 2009); however, temporal variation meant three sites recorded minimum values of between 70% and 80% (Table 3.1a, 3.1b, 3.1c and 3.1d). The highly calcareous MOY had a mean DO saturation value of 77.8% and ranged from a minimum of 64.8% in spring to 97.2% in summer. The BLACK River, a groundwater-dominated site, had a mean DO saturation level of 53.9% with values as low as 35.7% observed in autumn and up to 82% in spring. Similar DO levels have been observed at this site by EPA surveys in the past (2009–2012). The MOYREE was only sampled during the spring and recorded a DO saturation value of 77.9%. Groundwater-dominated sites, both potential reference and impacted sites, recorded DO below 80% saturation, with levels particularly low in autumn and summer. Other sites also recorded values below 80% saturation, though generally this only occurred during the autumn sampling period and values were never as low as those seen in groundwater-dominated sites (Table 3.2).

In terms of nutrients (Table 3.2), the majority of potential reference sites recorded ammonia and molybdate reactive phosphorus (MRP) values

Table 3.1a. Mean, minimum (min.) and maximum (max.) physico-chemical values for all naturally acid sites (potential reference and impacted) based on a single sample from each of three seasons (summer, autumn and spring) in 2014 and 2015

EPA code	Site	No. samples		pH	Temp. (°C)	DO (mg L^{-1})	% DO saturation	Cond. (µS cm^{-1})	Alkalinity (mg $CaCO_3$ L^{-1})	Total hardness (mg $CaCO_3$ L^{-1})	Ca^{2+} (mg L^{-1})	Mg^{2+} (mgL^{-1})	K^{+} (mgL^{-1})	Na^{+} (mgL^{-1})	Cl^{-} (mgL^{-1})	SO_4^{2-} (mgL^{-1})
10A050005	CLOGHOGE	3	Mean	5.44	11.6	11.53	110.4	38	3.83	5.4	1.52	0.62	0.25	4.63	6.18	2.16
			Min.	5.00	7.8	9.39	88.1	33	0	3.9	1.03	0.52	0.18	3.67	5.73	1.34
			Max.	6.88	17.5	15.38	142.0	47	10.4	7.8	2.34	0.77	0.36	5.67	7.02	2.58
30D1400290	DOIRE HOIRBIRT	3	Mean	6.73	10.6	11.88	95.2	80	9.9	10.7	2.97	1.31	0.28	9.75	15.98	3.84
			Min.	6.57	5.4	8.52	73.9	43	6.2	5.8	1.62	0.68	0.11	5.67	7.02	2.74
			Max.	6.91	17.7	17.73	113.4	121	15.1	14.1	3.80	1.84	0.53	14.78	28.07	4.52
38O140080	OWENVEAGH	2	Mean	6.28	8.0	10.81	88.2	64	4.6	7.3	1.82	1.11	0.36	7.95	13.87	2.91
			Min.	6.06	6.3	8.67	76.9	38	3.0	4.4	1.13	0.61	0.31	5.00	7.03	2.89
			Max.	6.76	9.7	12.94	99.4	90	6.2	10.2	2.50	1.6	0.40	10.9	20.7	2.92
10G050100	GLENEALO	3	Mean	6.26	10.0	14.95	123.8	33	3.6	5.3	1.54	0.59	0.26	3.48	5.10	2.53
			Min.	6.08	6.9	10.00	88.6	28	1.7	4.2	1.19	0.48	0.24	3.22	4.28	1.92
			Max.	6.64	14.9	24.40	182.8	37	6.7	7.3	2.20	0.73	0.28	3.78	5.82	2.93
31O020300	OWENGOWLA	3	Mean	6.12	13.4	9.78	92.3	106	3.6	8.9	1.99	1.59	0.51	14.27	26.12	4.13
			Min.	5.84	8.8	8.54	77.9	91	0.7	8.0	1.88	1.32	0.40	12.22	22.00	3.26
			Max.	6.52	20.5	11.40	102.5	133	5.5	10.1	2.10	2.04	0.70	18.00	33.68	4.86
01B010100	BUNADOWEN	3	Mean	5.09	9.7	11.62	103.3	62	0.8	5.4	1.22	0.94	0.39	7.91	12.93	2.52
			Min.	4.80	8.0	10.64	100.1	47	–0.7	3.6	0.88	0.58	0.30	5.78	6.89	2.09
			Max.	5.45	11.2	12.14	106.7	89	2.4	6.8	1.69	1.20	0.54	11.4	22.60	2.8
10L130940	LUGDUFF	3	Mean	5.19	9.6	10.68	95.8	44	–0.3	3.4	0.68	0.67	0.19	5.29	9.00	3.76
			Min.	4.92	7.8	9.99	87.3	44	–0.8	3.2	0.61	0.64	0.18	5.22	8.77	3.17
			Max.	5.77	13.2	11.41	101.5	45	0.4	3.6	0.78	0.68	0.20	5.44	9.19	4.23
N/A	VARTRY	3	Mean	5.68	10.4	11.03	102.8	41	1.3	6.8	1.56	1.14	0.26	6.37	10.96	5.35
			Min.	5.45	8.6	9.54	86.3	36	0.1	6.7	1.54	1.12	0.22	6.22	10.66	4.86
			Max.	6.19	12.7	12.69	121.8	61	3.6	6.8	1.59	1.17	0.29	6.44	11.37	5.63

White line separates potential reference from impacted sites.

Cond, conductivity; N/A, not applicable; temp, temperature.

Table 3.1b. Mean, minimum (min.) and maximum (max.) physico-chemical values for all lake outlet sites (potential reference and impacted) based on a single sample from each of three seasons (summer, autumn and spring) in 2014 and 2015

EPA code	Site	No. samples		pH	Temp. (°C)	DO (mg L^{-1})	% DO saturation	Cond. (µS cm^{-1})	Alkalinity (mg $CaCO_3$ L^{-1})	Total hardness (mg $CaCO_3$ L^{-1})	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	K^{+} (mg L^{-1})	Na^{+} (mg L^{-1})	Cl^{-} (mg L^{-1})	SO_4^{2-} (mg L^{-1})
38G030100	GWEEDORE	3	Mean	6.58	12.7	11.05	101.9	94	7.2	11.2	2.99	1.47	0.59	11.44	20.58	4.06
			Min.	6.46	7.9	9.33	99.4	70	7.1	8.9	2.31	1.18	0.42	9.00	14.89	3.72
			Max.	6.75	18.5	11.96	107.0	130	7.3	13.9	3.50	2.00	0.72	16.00	31.6	4.36
39L010100	LEANNAN	3	Mean	6.58	12.7	10.23	96.2	87	9.6	13.2	3.91	1.37	0.57	9.55	16.79	3.63
			Min.	6.43	8.2	9.22	85.3	74	6.4	11.5	3.54	1.06	0.48	7.22	11.43	3.38
			Max.	7.25	19.5	11.4	101.9	110	14.0	14.4	4.39	1.70	0.64	13.00	25.20	3.91
38O030150	OWENCARROW	3	Mean	6.04	12.0	10.65	100.3	74	2.2	6.2	1.33	1.17	0.41	9.43	17.32	3.42
			Min.	5.96	6.5	9.53	96.4	65	0.9	5.4	1.23	0.93	0.38	8.00	13.37	3.29
			Max.	6.18	20.7	11.27	107.1	88	3.9	7.1	1.40	1.50	0.46	11.40	22.3	3.52
32N010020	NEWPORT	3	Mean	7.27	12.2	9.24	87.5	131	19.7	24.9	7.87	2.08	0.71	12.47	22.53	4.29
			Min.	6.95	6.8	7.76	75.5	117	13.3	22.7	6.80	1.96	0.67	10.70	18.58	3.89
			Max.	7.49	18.5	11.48	104.6	144	24.4	27.0	8.80	2.28	0.77	15.70	30.40	4.54
36A020150	ANNALEE	3	Mean	7.61	12.7	9.57	84.6	179	48.7	58.7	19.10	3.13	3.42	8.59	15.56	10.62
			Min.	7.39	5.9	9.09	79.1	175	47.0	53.3	18.10	3.00	3.24	8.11	14.04	9.89
			Max.	7.97	17.6	9.89	90.6	186	52.0	62.0	21.00	3.30	3.62	9.00	16.53	11.95
36K010200	KNAPPAGH	3	Mean	7.96	11.9	9.82	88.6	228	72.4	62.9	20.63	3.37	3.81	16.89	14.83	14.23
			Min.	7.68	4.4	7.64	80.8	207	67.0	57.5	18.30	3.00	3.30	15.44	13.84	11.89
			Max.	8.91	17.3	11.93	95.8	249	80.0	69.3	23.80	3.90	4.34	19.22	15.69	15.63
06G040100	GENTLE OWEN'S STREAM	3	Mean	7.55	10.7	9.25	83.4	202	59.0	70.4	23.43	3.33	4.25	8.96	14.11	12.13
			Min.	7.50	4.7	7.98	74.3	195	55.6	67.3	21.20	3.10	3.76	8.22	11.86	9.54
			Max.	7.60	15.0	11.00	88.7	205	61.0	72.8	25.60	3.50	5.00	9.89	17.45	14.14
32C040040	CULFIN	3	Mean	6.97	13.8	10.22	95.1	82	4.8	8.1	1.99	1.25	0.42	10.58	19.47	3.61
			Min.	6.67	9.6	8.11	78.3	78	2.4	7.9	1.92	1.20	0.40	10.22	18.67	3.28
			Max.	7.08	18.5	13.19	107.5	86	7.0	8.3	2.10	1.32	0.44	11.22	20.88	3.92
06F010300	FANE	2	Mean	7.89	15.3	8.15	81.9	214	59.5	66.4	23.10	3.45	3.57	10.5	17.34	13.39
			Min.	7.74	11.6	8.05	73.8	211	56.0	66.0	22.90	3.40	3.44	9.67	14.81	12.94
			Max.	8.12	19.0	8.25	90.0	216	63.0	66.8	23.30	3.50	3.70	11.33	19.87	13.84

White line separates potential reference from impacted sites.

Cond, conductivity; temp, temperature.

Table 3.1c. Mean, minimum (min.) and maximum (max.) physico-chemical values for all highly calcareous sites with precipitate (potential reference and impacted) based on a single sample from each of three seasons (summer, autumn and spring) in 2014 and 2015

EPA code	Site	No. samples		pH	Temp. (°C)	DO ($mg\,L^{-1}$)	% DO saturation	Cond. ($\mu S\,cm^{-1}$)	Alkalinity ($mg\,CaCO_3\,L^{-1}$)	Total hardness ($mg\,CaCO_3\,L^{-1}$)	Ca^{2+} ($mg\,L^{-1}$)	Mg^{2+} ($mg\,L^{-1}$)	K^+ ($mg\,L^{-1}$)	Na^+ ($mg\,L^{-1}$)	Cl^- ($mg\,L^{-1}$)	SO_4^{2-} ($mg\,L^{-1}$)
30A010500	ABBERT	2	Mean	8.11	10.2	10.51	92.7	596	297.1	313.0	118.20	5.40	2.66	10.10	20.69	8.83
			Min.	8.09	10.2	8.71	75.6	574	286.2	294.0	112.00	5.20	2.40	10.00	19.57	7.71
			Max.	8.28	10.2	12.31	109.7	617	308.0	332.0	124.40	5.60	2.92	10.2	21.80	9.94
28C010200	CAHER	3	Mean	8.21	12.8	10.71	100.0	383	176.4	175.2	67.53	1.73	0.67	12.44	18.47	4.54
			Min.	8.18	8.7	10.16	88.5	325	152.0	141.0	54.80	1.60	0.57	11.00	12.52	4.05
			Max.	8.28	20.4	11.61	113.2	435	196.2	198.0	74.80	2.00	0.78	14.00	29.92	4.80
34G020200	GLORE	3	Mean	8.14	14.1	10.27	95.3	571	282.8	291.7	109.60	5.00	1.85	9.05	18.07	9.18
			Min.	8.04	10.7	9.71	78.1	562	270.7	271.0	103.20	4.60	1.46	8.56	17.49	6.87
			Max.	8.23	18.9	11.25	105.1	587	296.0	320.0	117.20	5.20	2.43	9.60	18.64	11.36
34M020750	MOY	3	Mean	8.21	14.1	7.98	77.8	464	212.9	225.3	83.60	4.73	1.42	10.10	18.45	11.90
			Min.	8.13	10.3	6.94	64.8	441	204.4	209.0	79.00	4.40	1.07	10.00	17.49	8.18
			Max.	8.32	19.4	9.08	97.2	477	217.2	240.0	86.20	5.20	1.64	10.20	19.88	15.53
26S030400	SHIVEN	3	Mean	8.02	12.6	9.54	91.5	510	245.1	258.7	96.90	4.93	2.10	9.57	18.67	8.10
			Min.	7.86	9.9	7.65	79.6	406	189.8	199.0	75.20	4.40	1.82	7.89	14.24	7.08
			Max.	8.25	17.6	10.85	105.3	614	294.0	320.0	118.40	5.60	2.52	10.60	21.71	9.66
25B020800	BALLYFINBOY	3	Mean	8.12	12.6	11.7	106.2	710	326.4	364.7	125.60	12.40	3.36	11.04	24.40	19.84
			Min.	8.01	10.2	11.11	91.0	678	313.0	338.0	121.20	11.20	3.06	10.78	24.03	15.68
			Max.	8.29	15.0	12.13	121.3	737	334.0	380.0	128.00	14.00	3.64	11.22	24.90	25.39
25D010100	DEAD	3	Mean	8.27	13.3	12.19	108.5	648	306.9	335.3	111.50	13.73	2.84	11.52	20.71	21.16
			Min.	8.16	10.2	11.84	93.3	634	303.0	322.0	110.40	12.00	2.18	11.22	20.19	19.70
			Max.	8.48	16.4	12.68	125.1	661	311.0	348.0	113.20	15.60	3.46	11.89	21.30	23.56
07S010600	SKANE	3	Mean	8.15	9.7	11.56	97.0	760	322.0	362.7	135.50	8.27	2.78	10.81	22.79	55.99
			Min.	8.06	5.1	8.99	89.9	732	290.2	319.0	119.20	8.00	1.92	10.44	21.42	42.81
			Max.	8.34	15.8	13.8	108.0	788	340.6	393.0	149.20	8.00	3.98	11.10	24.40	65.96
30C011100	CLARE	3	Mean	8.17	13.9	9.75	94.7	582	260.2	277.3	104.10	4.93	2.84	12.31	23.31	10.48
			Min.	8.14	8.1	8.12	71.1	568	221.3	231.0	88.40	4.00	1.79	10.56	20.40	8.09
			Max.	8.19	19.6	12.72	121.9	602	292.0	320.0	117.40	6.00	3.96	15.80	28.25	14.90
07D010600	DEEL	2	Mean	7.96	14.4	8.04	81.0	698	327.5	371.5	141.00	7.60	2.00	7.67	15.08	32.11
			Min.	7.90	10.7	7.11	81.0	697	325.0	364.0	138.00	7.60	1.86	7.44	14.88	31.80
			Max.	8.02	18.0	8.97	81.0	698	330.0	379.0	144.00	7.60	2.14	7.89	15.27	32.41

White line separates potential reference from impacted sites.

Cond, conductivity; temp, temperature.

Table 3.1d. Mean, minimum (min.) and maximum (max.) physico-chemical values for all groundwater-dominated sites (potential reference and impacted) based on a single sample from each of three seasons (summer, autumn and spring) in 2014 and 2015

EPA code	Site	No. samples		pH	Temp. (°C)	DO (mg/l)	% DO saturation	Cond. (μS cm^{-1})	Alkalinity (mg $CaCO_3$ L^{-1})	Total hardness (mg $CaCO_3$ L^{-1}l)	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	K^+ (mg L^{-1})	Na^+ (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{2-} (mgL^{-1})
34B080400	BEHY	3	Mean	7.90	10.8	8.91	80.3	555	264.4	265.33	94.00	9.33	1.70	11.11	21.21	9.41
			Min.	7.73	8.1	7.38	66.4	533	260.4	244.0	86.00	4.00	1.46	10.9	19.72	8.47
			Max.	8.13	13.6	10.61	92.8	586	270.0	296.0	106.00	12.40	2.02	11.33	24.05	9.90
30B020100	BLACK	3	Mean	7.57	10.7	5.97	53.9	667	318.8	326.0	118.80	8.67	2.01	11.67	22.71	10.46
			Min.	7.34	9	3.92	35.7	580	253.0	272.0	88.40	6.80	1.39	11.00	22.34	8.77
			Max.	7.83	12.4	9.5	82.0	721	354.4	354.0	134.80	11.60	2.52	12.10	23.38	13.48
26I030300	ISLAND	3	Mean	7.88	12.5	10.6	98.7	494	198.1	208.5	76.20	5.20	1.85	10.79	20.29	6.68
			Min.	7.77	9.1	8.68	76.4	389	154.0	174.0	57.80	4.60	1.76	9.11	16.83	5.02
			Max.	8.06	19.1	13.83	120.3	549	245.0	250.0	94.80	5.80	1.92	13.56	27.13	8.63
27M020700	MOYREE	1		8.01	13.5	8.29	77.9	392	260.4	275.0	105.20	4.80	1.72	9.20	19.70	6.38
35B080200	BUNNANADDAN	3	Mean	7.76	11.6	7.65	71.3	552	257.5	264.0	98.13	5.87	2.36	10.83	19.68	8.77
			Min.	7.53	8.6	6.78	63.5	495	223.2	236.0	88.80	4.40	1.71	10.10	18.12	6.14
			Max.	7.98	14.7	8.74	85.7	662	314.0	308.0	115.60	7.60	2.80	11.78	22.38	11.63
30N010100	NANNY	3	Mean	8.06	12.2	9.80	95.4	599	292.3	309.3	117.47	5.60	2.39	9.07	20.71	7.24
			Min.	7.96	8.8	8.00	68.9	565	270.9	289.0	110.00	4.80	2.07	8.44	20.42	5.21
			Max.	8.19	16.8	11.59	116.9	626	321.4	331.0	126.00	6.40	2.92	9.56	21.18	9.45
15N020100	NUENNA	3	Mean	7.91	11.1	12.67	116.8	674	326.9	338.3	116.53	14.67	2.55	6.85	16.10	8.15
			Min.	7.73	9.2	7.99	71.0	657	320.0	306.0	107.20	12.80	2.54	6.67	15.96	7.82
			Max.	8.31	13.7	15.48	140.4	700	335.0	376.0	122.00	16.00	2.58	7.00	16.37	8.32
26G010100	GAINE	3	Mean	7.87	12.3	10.53	97.1	691	335.4	356.3	135.87	6.67	2.17	7.60	15.59	19.74
			Min.	7.8	8.5	9.46	81.2	674	331.2	348.0	133.20	6.00	2.02	7.56	15.13	17.37
			Max.	7.93	15.3	12.63	118.5	705	338.0	362.0	138.00	7.20	2.42	7.67	15.98	23.55
07L030040	LOUGH LENE–ADEEL STREAM	3	Mean	7.80	11.4	8.67	79.7	499	244.7	250.3	89.60	7.33	1.09	6.56	11.28	11.56
			Min.	7.7	8.8	8.53	73.1	444	211.0	216.0	80.00	6.40	1.08	6.22	10.84	9.31
			Max.	8.11	15.8	8.85	87.2	532	274.8	296.0	100.80	8.00	1.10	6.89	11.81	14.34

White line separates potential reference from impacted sites.

Cond, conductivity; temp, temperature.

Table 3.2a. Physico-chemical conditions and nutrient concentrations recorded for potential RARETYPE river sites in all sampling seasons

Rare river type	Status	Site	Summer 2014						Autumn 2014						Spring 2015					
			pH	Ammonia (mg N L^{-1})	MRP (mg P L^{-1})	Nitrate (mg N L^{-1})	Nitrite (mg N L^{-1})	DO% saturation	pH	Ammonia (mg N L^{-1})	MRP (mg P L^{-1})	Nitrate (mg N L^{-1})	Nitrite (mg N L^{-1})	DO% saturation	pH	Ammonia (mg N L^{-1})	MRP (mg P L^{-1})	Nitrate (mg N L^{-1})	Nitrite (mg N L^{-1})	DO% saturation
Naturally acid	Potential reference	CLOGHOGE	6.88	0.023	0.013	0.015	<0.001	101.2	5.00	0.044[a]	0.010	0.036	<0.001	88.1	5.75	0.032	0.005	0.012	<0.001	142.0
		OWENVEAGH							6.06	0.017	0.002	0.029	<0.001	76.9	6.76	0.009	0.001	0.036	<0.001	99.4
		DOIRE HOIRBIRT	6.57	0.019	0.002	0.007	<0.001	98.4	6.91	0.009	<0.001	0.034	<0.001	73.9	6.79	0.008	0.001	0.036	<0.001	113.4
		OWENGOWLA	6.45	0.010	0.001	0.01	<0.001	96.4	6.52	0.010	0.001	0.024	<0.001	77.9	5.84	0.014	0.001	0.014	<0.001	102.5
		GLENEALO	6.64	0.020	0.003	0.068	0.001	99.9	6.08	0.020	0.000	0.090	<0.001	88.6	6.24	0.014	0.002	0.111	0.001	N/A
	Impacted	BUNADOWEN	5.45	0.049[a]	0.030[a]	0.022	<0.001	100.1	5.28	0.041[a]	0.020	0.040	<0.001	103.2	4.80	0.017	0.004	<0.010	<0.001	106.7
		LUGDUFF	5.77	0.007	0.001	0.206	<0.001	101.5	4.92	0.010	<0.001	0.300	<0.001	87.3	5.25	0.009	0.003	0.267	<0.001	98.5
		VARTRY	6.19	0.008	0.001	0.485	<0.001	121.8	5.45	0.010	<0.001	0.700	<0.001	86.3	5.68	0.009	0.001	0.728	<0.001	100.4
Lake outlets	Potential reference	GWEEDORE	6.46	0.020	0.003	0.016	<0.001	99.4	6.57	0.018	0.003	0.064	<0.001	99.4	6.75	0.011	0.002	0.017	<0.001	107.0
		LEANNAN	7.25	0.034	0.001	0.054	<0.001	101.9	6.43	0.021	0.005	0.060	<0.001	85.3	6.82	0.013	0.002	0.028	<0.001	101.3
		OWENCARROW	6.18	0.015	0.001	0.042	<0.001	107.1	5.96	0.024	0.001	0.069	<0.001	96.4	6.01	0.009	0.001	0.045	<0.001	97.4
		NEWPORT	7.12	0.027	0.002	0.082	0.002	82.5	7.49	0.017	0.003	0.107	0.001	75.5	6.95	0.015	0.004	0.107	<0.001	104.6
	Impacted	ANNALEE	7.64	0.040	0.053[b]	0.071	0.010	-	7.39	0.026	0.064[b]	0.775	0.002	79.1	7.97	0.053[a]	0.008	0.538	0.011	90.6
		KNAPPAGH	7.97	0.118[b]	0.053[b]	0.368	0.026	80.8	7.68	0.051[a]	0.061[b]	0.680	0.005	89.3	8.91	0.022	0.016	<0.010	0.001	95.8
		GENTLE OWEN'S STREAM	7.56	0.105[b]	0.068[b]	0.979	0.061	88.7	7.50	0.086[b]	0.053[b]	1.165	0.009	87.1	7.60	0.039	0.017	0.685	0.008	74.3
		CULFIN	6.67	0.011	0.002	0.013	<0.001	99.6	7.08	0.020	0.000	0.050	<0.001	78.3	6.95	0.009	0.002	0.061	<0.001	107.5
		FANE	7.74	0.057[a]	0.008	0.135	0.012	90.0							8.12	0.031	0.005	0.829	0.007	73.8

Shaded cells indicate site was not sampled in that period. One sample was taken per season.

[a]Failed to meet high status EQS threshold but meets good EQS threshold.

[b]Failed to meet good status thresholds outlined in S.I. No. 272 (Irish Government, 2009).

N/A, not applicable (missing value).

Table 3.2b. Physico-chemical conditions and nutrient levels recorded for potential RARETYPE river sites in all sampling seasons

Rare river type	Status	Site	Summer 2014							Autumn 2014							Spring 2015						
			pH	Ammonia (mg N L^{-1})	MRP (mg P L^{-1})	Nitrate (mg N L^{-1})	Nitrite (mg N L^{-1})	DO% saturation	BOD	pH	Ammonia (mg N L^{-1})	MRP (mg P L^{-1})	Nitrate (mg N L^{-1})	Nitrite (mg N L^{-1})	DO% saturation	BOD	pH	Ammonia (mg N L^{-1})	MRP (mg P L^{-1})	Nitrate (mg N L^{-1})	Nitrite (mg N L^{-1})	DO% saturation	BOD
Highly calcareous	Potential reference	ABBERT								8.28	0.016	0.002	0.818	<0.001	75.6		8.09	0.020	0.010	2.037	0.002	109.7	
		CAHER	8.18	0.020	0.001	0.275	0.001	113.2		8.28	0.011	0.001	0.437	<0.001	88.5		8.18	0.010	0.001	0.183	<0.001	98.4	
		GLORE	8.04	0.009	0.002	0.416	0.002	102.6		8.23	0.014	0.004	0.51	0.001	78.1		8.18	0.014	0.002	0.986	0.003	105.1	
		MOY	8.32	0.018	0.004	0.413	<0.001	97.2		8.20	0.022	0.005	0.39	<0.001	71.5		8.13	0.016	0.007	0.422	0.003	64.8	
		SHIVEN	7.86	0.056[a]	0.016	0.226	0.004	79.6		8.25	0.017	0.003	0.277	<0.001	89.5		8.05	0.019	0.014	1.213	0.005	105.3	
	Impacted	BALLYFINBOY	8.29	0.013	0.009	2.606	0.004	121.3		8.01	0.024	0.018	3.836	0.011	91.0		8.10	0.012	0.011	4.050	0.005	106.3	
		DEAD	8.48	0.035	0.077[b]	1.475	0.007	125.1		8.24	0.040	0.059[b]	1.655	0.009	93.3		8.16	0.018	0.043[b]	1.478	0.005	106.7	
		SKANE	8.34	0.044[a]	0.056[b]	1.421	0.018	89.9		8.11	0.022	0.034[a]	2.537	0.008	93.1		8.06	0.018	0.025	2.544	0.007	108.0	
		DEEL	8.02	0.023	0.019	1.204	0.009										7.90	0.032	0.013	1.769	0.011	81.0	
		CLARE	8.14	0.037	0.009	0.579	0.003	91.2		8.18	0.010	0.00	0.82	0.00	71.1		8.19	0.013	0.005	1.108	0.003	121.9	
Groundwater-dominated	Potential reference	BLACK	7.34	0.027	0.013	0.437	0.022	44.1	1.73	7.71	0.012	0.016	0.304	0.002	35.7	0.62	7.83	0.016	0.005	1.331	0.002	82.0	2.41
		BEHY	8.13	0.011	0.005	1.055	0.002	81.7	1.24	7.94	0.010	0.005	0.94	0.002	66.4	2.57	7.73	0.009	0.011	1.237	0.001	92.8	2.81
		ISLAND	7.77	0.039	0.014	0.348	0.01	99.5	0.45	8.06	0.020	0.009	0.269	0.001	76.4	2.94	7.8	0.017	0.005	0.346	0.001	120.3	3.99
		MOYREE															8.01	0.008	0.007	0.845	0.002	77.9	0.99
	Impacted	NANNY	8.07	0.014	0.003	0.529	0.002	100.5	2.40	8.19	0.010	0.000	0.500	0.000	68.90	1.92	7.96	0.014	0.004	1.897	0.003	116.9	3.48
		NUENNA	8.31	0.010	0.010	5.069	0.003	140.4	7.91	7.73	0.020	0.010	5.490	0.000	71.00	1.70	7.88	0.009	0.007	5.825	0.002	138.9	6.17
		BUNNANADDAN	7.98	0.138[b]	0.020	1.407	0.048	85.7	3.67	7.92	0.030	0.020	0.550	0.010	63.50	6.78	7.53	0.012	0.018	0.635	0.002	64.7	1.54
		GAINE	7.93	0.022	0.015	2.654	0.006	91.6	1.35	7.80	0.040	0.030	3.460	0.010	81.20	3.34	7.89	0.020	0.010	3.246	0.007	118.5	5.98
		LOUGH LENE–ADEEL STREAM	8.11	0.010	0.005	0.793	0.005	87.2	3.08	7.70	0.020	0.010	1.174	0.004	73.10	4.19	7.70	0.012	0.002	0.743	0.003	78.8	2.42

Shaded cells indicate site was not sampled in that period. One sample was taken per season.

[a]Failed to meet high status EQS threshold but meets good EQS threshold.

[b]Failed to meet good status thresholds outlined in S.I. No. 272 (Irish Government, 2009).

BOD, biochemical oxygen demand.

equal to or less than the threshold for high status for these nutrients, which are ≤ 0.04 mg N L^{-1} and ≤ 0.025 mg P L^{-1}, respectively (Irish Government, 2009). With the exception of the BLACK, EPA chemistry data show that the potential reference sites in all river types met the thresholds for good status, but not high status, between 2009 and 2012 (EPA data). The BUNADOWEN was the only impacted naturally acid site to fail to meet high status for both ammonia and MRP during the summer sampling period, although it did meet good status. Ammonia was marginally above the high status threshold in the CLOGHOGE River. None of the potential reference lake outlets showed elevated nutrient levels. Concentrations of MRP at three of the impacted lake outlet sites (ANNALEE, KNAPPAGH, GENTLE OWEN'S STREAM) exceeded the threshold for good status in both summer and autumn. Ammonia levels were also high in KNAPPAGH and GENTLE OWEN'S STREAM as well as the FANE (summer). These sites have consistently failed to reach good status in past EPA surveys. The DEAD (highly calcareous) consistently recorded MRP values exceeding the threshold for good status while the SKANE (highly calcareous) had concentrations exceeding the thresholds for good status in summer and high status in autumn (Table 3.2). Both sites also failed to meet good status in past EPA surveys (2009–2011; see Chapter 6, Table 6.3). The only groundwater-dominated site to breach ammonia or MRP thresholds for high or good status was the BUNNANADDAN in summer, when an ammonia value of 0.138 mg N L^{-1} was recorded (Table 3.2).

Nitrate levels were assessed using the criterion set out by Camargo *et al*. (2005) and an EPA document on compliance rules for certain river chemistry determinands, which proposed a surrogate value of 0.9 mg N L^{-1} and 1.8 mg N L^{-1} for high and good status, respectively (EPA, 2011). All naturally acid sites and one of the impacted sites had nitrate values below the threshold for high status, i.e. ≤ 0.9 mg N L^{-1}. All reference lake outlets recorded low nitrate concentrations that would be typical of high-status waters, as did four of the impacted sites. With one exception (ABBERT in spring), the potential reference groundwater-dominated and calcareous sites had nitrate values less than the threshold for good status (≤ 1.8 mg N L^{-1}). Nitrate concentrations in half of the groundwater and highly calcareous impacted sites exceeded 1.8 mg N L^{-1}.

3.2 Hydromorphology

All of the sites were rated at good to high morphological status based on the RHAT, with the exception of the impacted lake outlet sites (Table 3.3). The reduced hydromorphological scores largely related to poor riparian zone condition and some bank instability.

Table 3.3. Results of the RHAT assessment at the RARETYPE sites

Rare river category	Status	Site	Σ RHAT attribute scores	WFD class	HM score
Naturally acidic	Potentially reference	DOIRE HOIRBIRT	28.5	High	0.89
		OWENVEAGH	31.0	High	0.97
		GLENEALO	28.0	High	0.88
		OWENGOWLA	28.5	High	0.89
	Impacted	BUNADOWEN	26.0	High	0.81
		LUGDUFF	24.0	Good	0.75
		VARTRY	26.0	High	0.81
		CLOGHOGE	29.0	High	0.91
Lake outlets	Potentially reference	GWEEDORE	26.0	High	0.81
		LEANNAN	24.5	Good	0.77
		OWENCARROW	29.5	High	0.92
		BONET	25.5	Good	0.80
		NEWPORT	25.5	Good	0.80
	Impacted	ANNALEE	19.0	Moderate	0.59
		CULFIN	27.5	High	0.86
		FANE	17.5	Moderate	0.55
		KNAPPAGH	20.5	Good	0.64
		GENTLE OWEN'S STREAM	18.5	Moderate	0.58
Highly calcareous	Potentially reference	CAHER	26.0	High	0.81
		GLORE	26.0	High	0.81
		MOY	26.0	High	0.81
		SHIVEN	27.5	High	0.86
	Impacted	BALLYFINBOY	24.5	Good	0.77
		DEAD	25.0	Good	0.78
		SKANE	21.0	Good	0.66
		DEEL	25.0	Good	0.78
		CLARE	25.5	Good	0.80
Groundwater-dominated	Potentially reference	BLACK	25.5	Good	0.80
		BEHY	23.5	Good	0.73
		ISLAND	27.5	High	0.86
	Impacted	NANNY	25.5	Good	0.80
		NUENNA	23.0	Good	0.72
		BUNNANADDAN	23.0	Good	0.72
		GAINE	24.5	Good	0.77
		LOUGH LENE–ADEEL STREAM	23.5	Good	0.73

4 Characterising the Biological Communities of Rare River Types

4.1 Macroinvertebrates of Potential Reference Sites

A total of 147 macroinvertebrate taxa representing 17 groups were recorded from the 15 potential reference sites across the four potential rare river types in spring and summer (Table 4.1). The Trichoptera was the most diverse group, with 46 taxa, followed by the Ephemeroptera (18) and Coleoptera (16).

4.1.1 Macroinvertebrate taxon richness and abundance

Taxon richness ranged between 38 and 40 in naturally acid sites, between 42 and 60 across highly calcareous sites, between 22 and 42 in lake outlets and between 38 and 50 in groundwater-dominated sites during spring (Figure 4.1). While richness was generally lower across all sites in summer 2014, this was not statistically significant ($F_{3,20}=4.36$, $P>0.05$) (Figure 4.1a). Lake outlets had significantly lower taxon richness than all other river types ($F_{3,20}=6.94$, $P<0.05$) (Figure 4.1a). In terms of taxon abundance, calcareous and groundwater-dominated rivers had significantly higher values than acid and lake outlets, which recorded similar abundances ($F_{3,20}=16.57$, $P<0.05$) (Figure 4.1b).

Ephemeropteran, plecopteran and trichopteran (EPT) richness was again higher in spring than in summer, presumably due to emergence ($F_{1,20}=13.12$, $P<0.05$), and also varied significantly between potential types ($F_{3,20}=5.19$, $P<0.05$). Perhaps unsurprisingly given their higher alkalinity, highly calcareous sites had higher EPT richness than both the acid and lake outlet sites (Figure 4.2).

Table 4.1. Number of taxa within the macroinvertebrate groups recorded across all 15 potential reference sites

Macroinvertebrate group	No. of taxa
Tricladidae[a]	1
Oligochaeta[a]	1
Hirudinea	5
Gastropoda	11
Bivalvia[a]	3
Crustacea	2
Ephemeroptera	18
Plecoptera	14
Odonata	3
Hemiptera	4
Megaloptera	1
Coleoptera	1
Trichoptera	46
Diptera (excluding Simuliidae and Chironomidae)	14
Diptera: Simuliidae[a]	2
Diptera: Chironomidae[a]	4
Hydracarina[a]	1
Total No. of taxa	**147**

[a]Identified to family level.

4.2 Macrophytes of Potential Reference Sites

4.2.1 Macrophyte community richness and structure

A total of 68 macrophyte taxa were identified across 18 potential reference sites. Taxon richness ranged from as low as 4 in some of the acid sites (GLENEALO) to 23 in the MOYREE, which is a groundwater-dominated site. Naturally acid sites recorded lower taxon richness than all other potential river types, but this was not significant ($F_{3,14}=2.12$, $P>0.05$) (Figure 4.3).

4.3 Phytobenthos of Potential Reference Sites

4.3.1 Phytobenthos richness

A total of 272 diatom taxa were recorded across 18 potential reference sites and all sampling seasons. Diatom richness varied significantly across potential river types ($F_{3,40}=5.68$, $P<0.05$) with naturally acid sites recording significantly lower taxon richness than the other potential types. Richness did not vary significantly across sampling seasons (Figure 4.4).

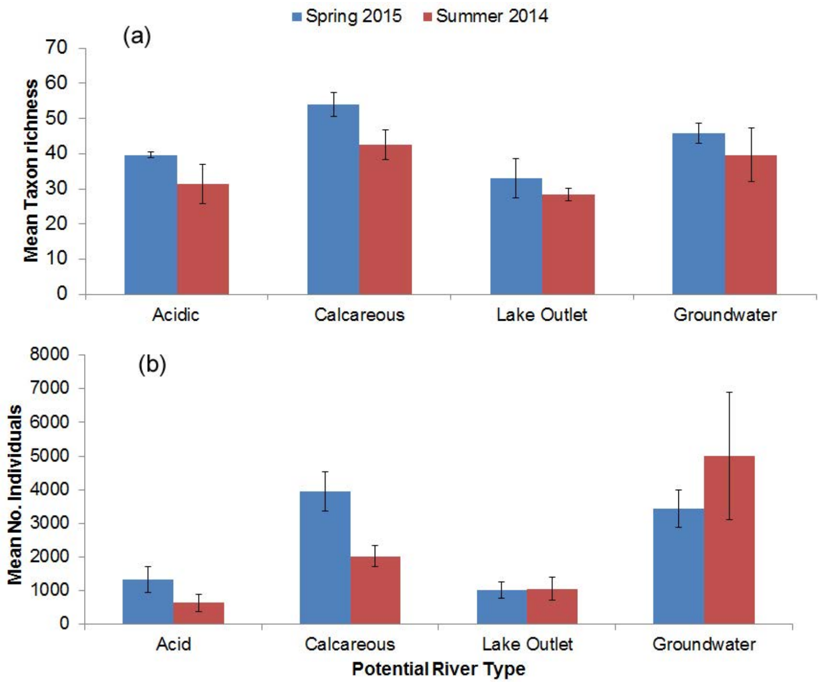

Figure 4.1. Mean [±standard error (SE)] (a) taxon richness and (b) taxon abundance for all potential river types in spring and summer.

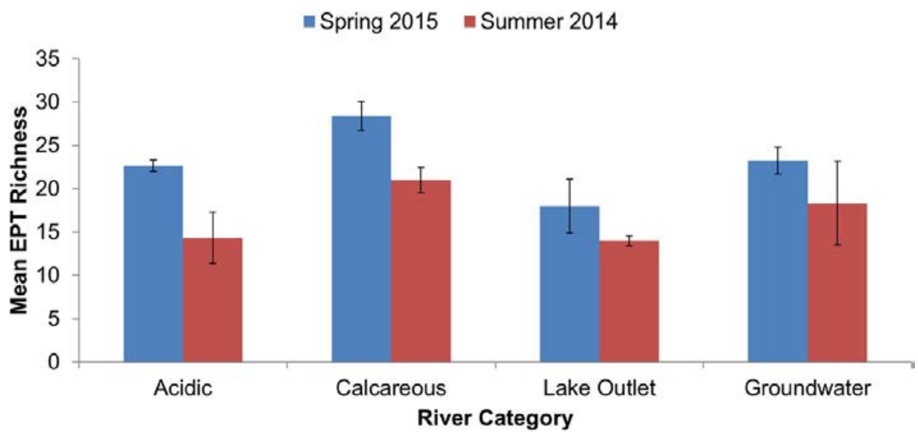

Figure 4.2. Mean (±SE) EPT richness for all potential river types in spring and summer.

When the macroalgal taxa were included, taxon richness increased in all potential types but did not vary significantly between seasons (Figure 4.4b). The number of phytobenthos taxa recorded in acid sites ranged from 22 taxa in autumn and spring to 27 in summer. Richness in the lake outlets was lowest in autumn (33) and highest in summer with 51 taxa. The lowest richness recorded across all potential types was 26 in groundwater-dominated rivers and was highest (52) in lake outlets in summer 2014 (Figure 4.4b). The number of algal taxa recorded at each site ranged from none in the ISLAND River (summer and autumn), the SHIVEN (summer) and the MOY (spring), to seven in spring in OWENCARROW, OWENVEAGH and GWEEDORE.

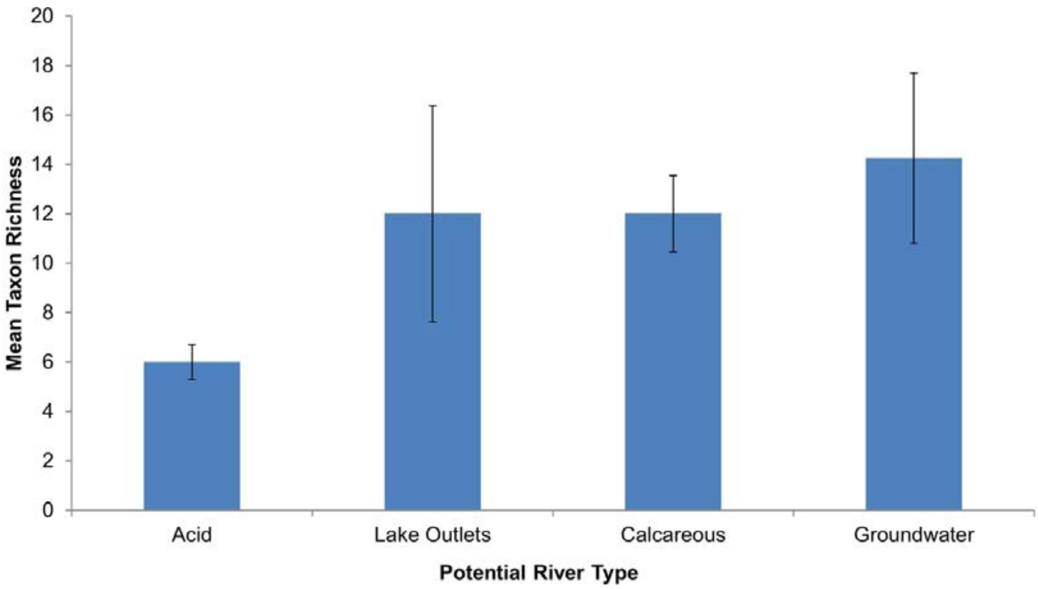

Figure 4.3. Mean taxon richness (±SE) for all potential river types surveyed in summer 2014.

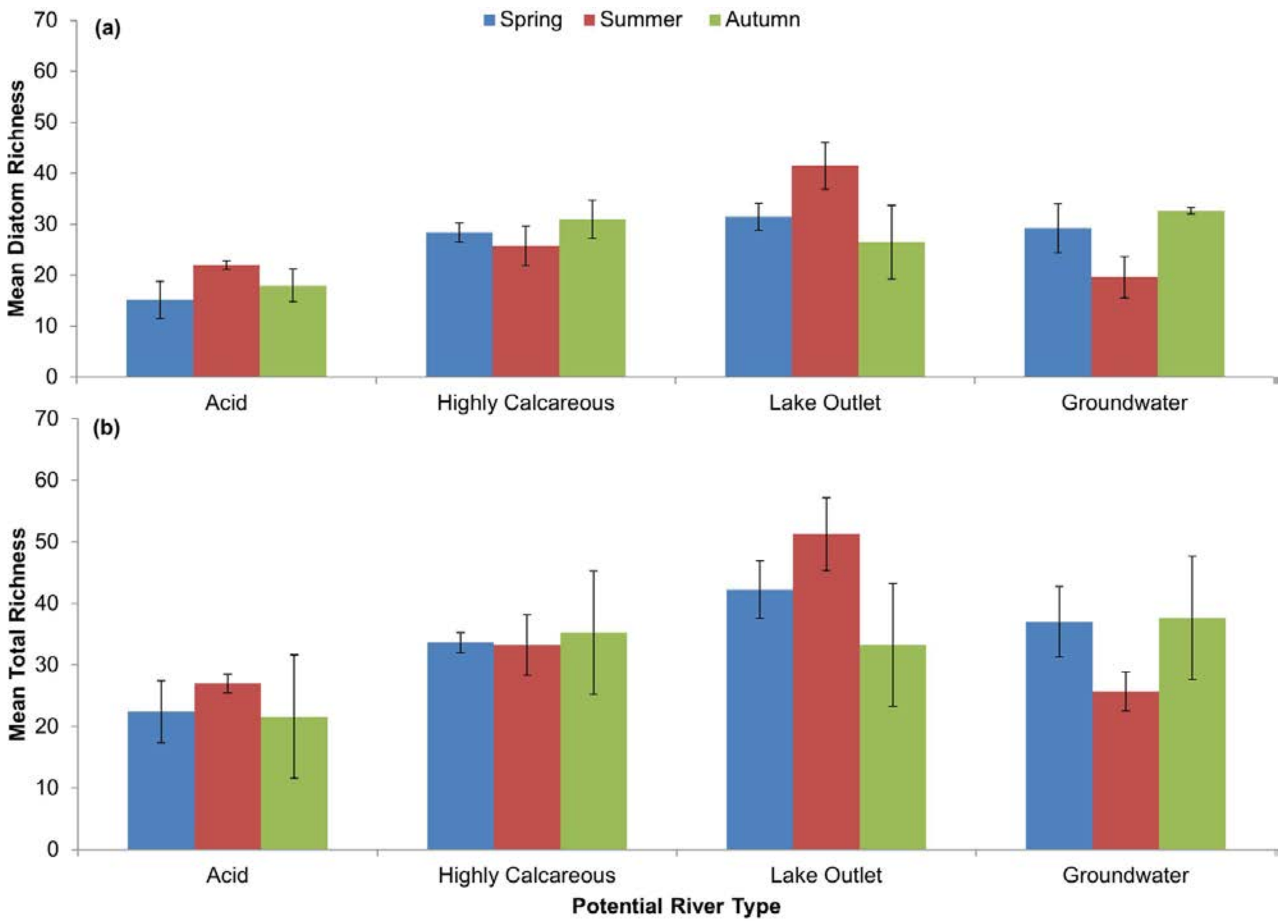

Figure 4.4. Mean (±SE) (a) diatom taxon richness and (b) taxon richness (algae and diatoms) for all potential river types and sampling seasons.

5 Are Rare Type Rivers Different from the Existing National Types?

5.1 National River Types

The national typology describes 12 river types based on geology and slope. There are three geology categories into which rivers are classed: (1) 100% siliceous geology (igneous/metamorphic rock) with total hardness values <35 mg $CaCO_3$ L^{-1}; (2) mixed geology, which refers to sites with between 1% and 25% calcareous geology (hardness values 35–100 mg $CaCO_3$ L^{-1}); and (3) calcareous geology, i.e. >25% calcareous geology and total hardness of >100 mg $CaCO_3$ L^{-1}. After being placed into a geology type, rivers were further split across four slope categories (very low to high slope) (Table 5.1). This typology was developed by the RIVTYPE project (Kelly-Quinn *et al*., 2005) using 50 high-status sites (Appendix 2). Those sites represented 10 of the 12 national types (Table 5.1).

Under the national typology, the potential rare river types would be classified as follows. Naturally acid sites fit into Types 11–14 depending on the slope of a site, as a result of their igneous/metamorphic geology and low alkalinity (<10 mg $CaCO_3$ L^{-1}). Similarly, because of the underlying geology, the soft-water lake outlet sites also fall into this group, specifically Type 11 (Table 5.1). On account of their limestone geology and high hardness/alkalinity values, both the highly calcareous sites with calcium precipitate and groundwater-dominated rivers fit into Types 31–32 (Table 5.1). If these potential rare river types do in fact represent types distinct from the existing 12, then they would be expected to host biological communities significantly different from those of the corresponding national types (Table 5.1), e.g. naturally acid sites would have biotic communities distinct from those of Types 11–14 or highly calcareous sites with precipitate should differ from the calcareous Types 31 and 32. All the potential rare river types would be expected to host communities significantly different from sites in Type 21–24 (mixed geology).

To determine if this is the case, the biological data collected for the 18 RARETYPE potential reference sites were analysed alongside the data collected for the 50 river sites used in the RIVTYPE project to develop the existing national river typology (Kelly-Quinn *et al.*, 2005). The RIVTYPE sites were grouped according to their national river type while RARETYPE sites were labelled by their potential rare river type (Table 5.1). Of the 50 RIVTYPE sites, 19 were Types 11 to 14 (100% siliceous geology), 27 were Types 21 to 24 (mixed geology), while four were Types 31 to 32 (Table 5.1). Types 24 and 31 were each represented by only one site (Table 5.1) and so results for these types should be interpreted with caution. Of the siliceous sites (Type 11–14), 11 had mean alkalinity values ≤10 mg $CaCO_3$ L^{-1}, six had values ≤20 mg $CaCO_3$ L^{-1} and two, OGLIN and LIFFY, had a mean alkalinity of 30 and 40 mg $CaCO_3$ L^{-1}, respectively. Mixed geology sites (Types 21–24) had alkalinities of between 10 and 147 mg $CaCO_3$ L^{-1} with five sites recording values <20 mg $CaCO_3$ L^{-1}. Types 31 and 32 (calcareous geology) sites had alkalinities between 175 and 212 mg $CaCO_3$ L^{-1}. A more detailed description of the RIVTYPE sites is given in Appendix 2.

There was some overlap between the sites surveyed in the current project and those in the RIVTYPE project with the GLENEALO (10G050100), CAHER (28C010200) and MOY (34M020750) surveyed in both studies.

5.2 Macroinvertebrate Communities of Potential Rare River Types Versus Existing National Types

For the macroinvertebrate analysis, it is important to note that 15 potential reference RARETYPE sites were analysed with the 50 sites used in the RIVTYPE project (Table 2.1a).

5.2.1 *Macroinvertebrate community structure*

Spring macroinvertebrate community structure varied significantly across types ($F_{13,51}$ = 2.54, P < 0.05) (Figure 5.1). Both the RARETYPE highly calcareous with precipitate and RARETYPE groundwater-dominated

Table 5.1. Sites used in RIVTYPE project (Kelly-Quinn *et al.*, 2005) assigned to one of the 12 national river types based on their hardness and slope. Sites used in the current RARETYPE project are highlighted in bold

Geology	Hardness values	Slope ($m\,m^{-1}$)			
		1 (≤0.005)	2 (0.005–0.02)	3 (0.02–0.04)	4 (>0.04)
1 (100% siliceous)	<35 mg L^{-1}	BLKWA	CARAG	CBURN	DODDE
		EANYM1	GGARF	GWBAR	LSLAN1
		FINOW	LSLAN2	OMORE	
		FLESK	OGLIN	SWANL	
		GCREE		URRN	
		GNEAL			
		LIFFY			
		OREAG			
		GLENO	**OWVEAGH**	**CLOG**	**DOIRE**
		GWEE			**OWGOWL**
		LEANN			
		OWCAR			
		NEWPORT			
2 (1–25% calcareous) (mixed)	35–100 mg L^{-1}	AILLE	BHALL	BOW	BONET1
		BROAD	BILBO	CLYDA	
		DUNIR	BOLND	DUNNE1	
		EANYW1	CAMCO	KEERG	
		GOURN	DUNNE2		
		GRANE	EANYM2		
		MOY1	FUNSH		
		OWGAR	GDINE		
		SLANY	GOWLA		
		SULLA	NPORT		
			OWBEG		
			OWDAL		
3 (>25% calcareous)	>100 mg L^{-1}	MOY2	BEHYM		
			CAHER		
			SHILL		
		ABBRT			
		CAHER			
		GLORE			
		MOY			
		SHIVEN			
		BEHY			
		BLACK			
		ISLAND			
		MOYREE			

Examples of type codes. The two codes from above are combined in order of geology (first digit) and slope (second digit). e.g. A code of 11 indicates a siliceous low slope site (hardness values <35 mg $CaCO_3L^{-1}$). e.g. A code of 31 indicates a calcareous low-slope (hardness values <35 mg $CaCO_3L^{-1}$). e.g. A code of 23 indicates a mixed geology and high slope between 0.02 and 0.04 m m^{-1} (hardness values 35–100 mg $CaCO_3L^{-1}$). Full RARETYPE site naes are given in Tables 2.1a and 2.1b.

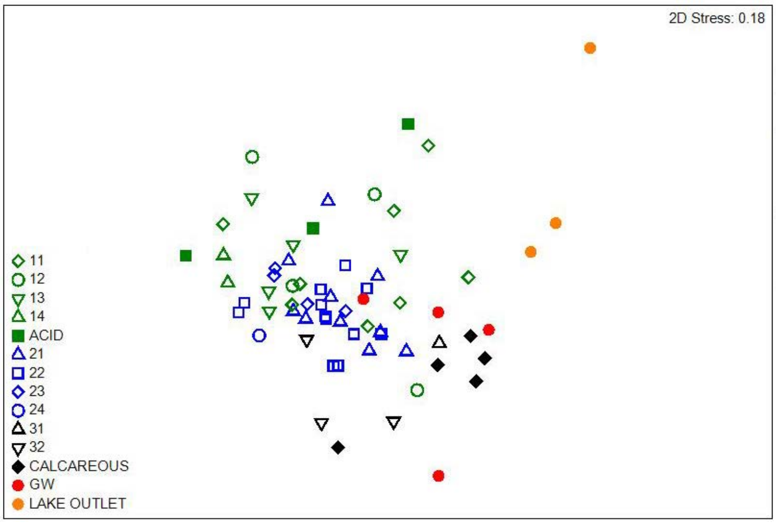

Figure 5.1. Multidimensional scaling plot of macroinvertebrate community structure for potential rare and existing national river types, based on Bray–Curtis similarities of log(x+1) transformed spring taxa abundance data. Open symbols represent RIVTYPE sites categorised by national type, closed symbols represent RARETYPE sites. Green symbols represent 100% siliceous geology, blue symbols mixed geology sites and black symbols represent sites with >25% calcareous geology. The lower outlier groundwater-dominated site is the BLACK River while the lake outlet outlier is the OWENCARROW.

sites hosted communities of similar structure to those of the existing calcareous Type 32 (Figure 5.1). As expected, community structure differed significantly from that of siliceous, low-hardness river types (Types 11–14) and mixed geology types (21–23), which had moderate hardness values and <25% calcareous geology (Figure 5.1). The existing calcareous river Types 31 and 32, RARETYPE groundwater-dominated and highly calcareous with precipitate rivers tended to have higher abundances of the caddisflies *Agapetus* spp., *Potamophylax latipennis* (Curtis) and *Limnephilus* spp., the mayflies *Heptagenia* spp. and *Ephemera danica* (Müller), non-biting midge larvae (Chironominae) and freshwater shrimps (Gammaridae), and lower abundances of the mayflies *Rhithrogena* spp. and *Ecdyonurus* spp., stoneflies (Plecoptera) and blackfly larvae (Simuliidae) than existing siliceous or mixed geology river types.

The RARETYPE naturally acid sites hosted macroinvertebrate communities similar to those found in the 100% siliceous national types (Types 11, 12, 13, 14). The higher abundances of the stoneflies *Leuctra* spp. and *Amphinemura sulcicollis* coupled with the much lower abundances of the mayfly *Rhithrogena* spp., the beetle *Elmis aenea* and species associated with more alkaline conditions, e.g. *Gammarus* spp., separated them from mixed geology and calcareous river types (Type 21–23, 32).

With the exception of Type 31, which, due to lack of replicates, must be viewed with caution, the community structure of the lake outlets differed from all existing river types including the siliceous types. If adequately represented in the national typology, the macroinvertebrate communities of these soft-water lake outlets should be similar to those of existing siliceous Type 11, but for spring communities this was not the case ($P = 0.006$). The main taxa driving the difference in community structure between the types were the bivalve family Sphaeriidae, which were present in significantly higher abundances in the outlets, while the mayflies *Rhithrogena* spp. and *Ecdyonurus* spp. were absent from the outlets in spring. Interestingly, outlets had higher abundances of the filter-feeding caseless caddisfly *Hydropsyche* spp. but Simuliidae were absent from the spring outlet community.

Trends similar to those observed in spring were recorded for summer data with macroinvertebrate community structure varying significantly across types ($F_{13,49} = 2.30$, $P < 0.05$) (Figure 5.2). Here again, the lake outlets' community structure differed from Type

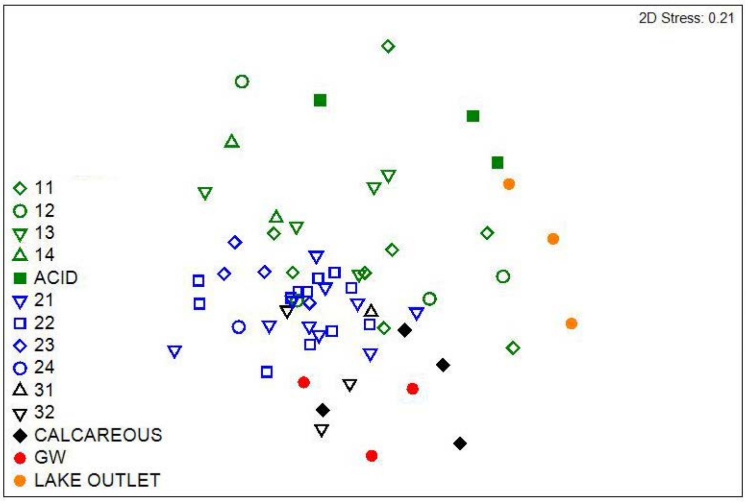

Figure 5.2. Multidimensional scaling plot of macroinvertebrate community structure for rare and national river types, based on Bray–Curtis similarities of log(x+1) transformed summer abundance data. Open symbols represent RIVTYPE sites categorised by national type, closed symbols represent RARETYPE sites. Green symbols represent 100% siliceous geology, blue symbols represent mixed geology sites and black symbols represent sites with >25% calcareous geology.

11 ($P = 0.005$) and was similar only to Type 12. The lake outlets in summer still had higher abundances of Sphaeriidae and the Heptageniidae were absent, while Simuliidae were present but in lower abundances than in national Types 11 to 14. Furthermore, the additional analysis comparing the lake outlets with the national Type 11 sites (based on geology and slope) returned significant results in terms of the abundances of *Q*-value Group A ($F_{7,21} = 1.507$, $P < 0.05$), Group B ($F_{7,21} = 1.847$, $P < 0.05$), Groups A–D taxa ($F_{7,21} = 1.962$, $P < 0.05$) and Groups A–D excluding C ($F_{7,21} = 2.026$, $P < 0.05$) here again driven by differences in the abundances of the aforementioned taxa (Sphaeriidae, Heptageniidae, Hydropsychidae and Simuliidae). The same significant results were observed for spring data. No significant differences in any of these indicator groups were detected between groundwater-dominated sites and national Types 31 and 32.

5.2.2 Relationship between invertebrate communities and environmental variables

A combination of four environmental variables (percentage sand/silt/mud, pH, hardness and slope) were identified using the BEST procedure in PRIMER 6 as being most correlated with the variation observed in spring community structure ($\rho = -0.419$, $P < 0.01$). With the exception of dissolved oxygen, percentage sand and bedrock, all other variables were significantly correlated with invertebrate community structure (Table 5.2) using DISTLM analysis. When fitted sequentially, hardness, pH and slope accounted for 17.2% of the variance observed in community structure in spring. A dbRDA ordination was used to visualise the fitted model generated by the DISTLM routine in multidimensional space (Figure 5.3). The first and second axes account for 12% and 5.2%, respectively, of the total variation. Similar to spring pH, total hardness and slope accounted for 14.5% of the variation in the summer biological data when modelled using DISTLM.

5.2.3 TWINSPAN ordinations of rare and national type data

5.2.3.1 The TWINSPAN classification of spring macroinvertebrates.

The TWINSPAN classification of spring macroinvertebrate taxa included 87 taxa across all RARETYPE and RIVTYPE sites. The TWINSPAN analysis resulted in a dendrogram that identified 15 groupings using the TWINEND 50% dispersion end group (Figure 5.4). Fourteen end groups were validated using MRPP ($A = 0.192$, $P < 0.0001$) with one isolated site (DUNNE2, Dunneill River) (Table 5.3). The first division separated six groups on the

Table 5.2. Results of DISTLM analysis for fitting environmental variables to spring macroinvertebrate community structure data for existing and potential rare river types

Variable	% Variance	*P*-value	% Cumulative
Individual variables[a]			
pH	6.43	**0.001**	
Dissolved oxygen (% saturation)	7.07	**0.001**	
Total hardness (mg $CaCO_3$ L^{-1})	9.56	**0.001**	
Cl^- (mg L^{-1})	7.35	**0.001**	
Bedrock (%)	1.29	0.638	
Boulder (%)	3.39	**0.018**	
Cobble (%)	2.62	0.056	
Gravel (%)	3.48	**0.015**	
Sand/silt/mud (%)	2.29	0.125	
Calcareous geology (%)	8.77	**0.001**	
Slope (m m^{-1})	5.82	**0.001**	
Fitted with other variables[b]			
Total hardness (mg $CaCO_3$ L^{-1})	9.56	**0.001**	9.56
pH	4.50	**0.001**	14.06
Cl^- (mg L^{-1})	4.23	**0.001**	18.29
Slope (m m^{-1})	3.46	**0.002**	**21.75**

Cumulative (%) refers to cumulative percentage of variance. Values in bold indicate a significant correlation.
[a]Variables were tested individually ignoring other factors.
[b]Step-wise selection of variables.

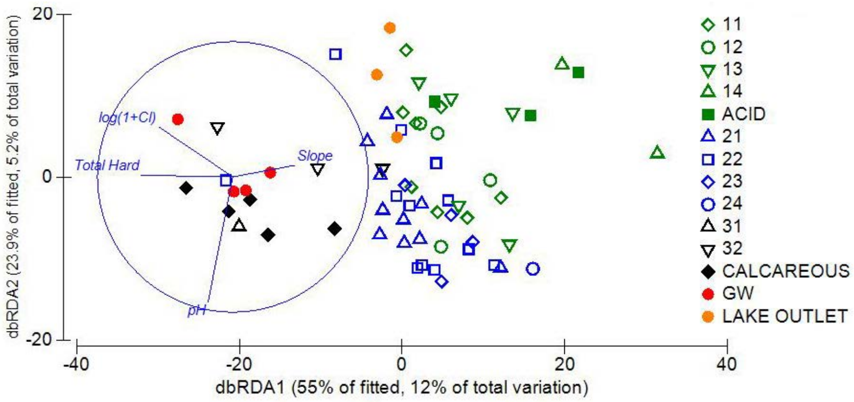

Figure 5.3. Distance-based redundancy analysis (dbRDA) ordination plot of the spring macroinvertebrate abundance data log (*x* + 1) transformed and the predictor variables selected by DISTLM routine using step-wise selection procedure. Open symbols represent RIVTYPE sites categorised by national type, closed symbols represent RARETYPE sites. Green symbols represent 100% siliceous geology, blue symbols represent mixed geology sites and black symbols represent sites with > 25% calcareous geology.

left (34 sites, Groups 1 to 6) from nine groups (31 sites, Groups 7 to 15) on the right. This division was due to high occurrences of the stoneflies *Leuctra inermis* and *Brachyptera risi* in the groups on the left and the higher occurrences of the caddisfly *Athripsodes* spp., mayfly *Heptagenia* spp. and the Glossiphoniidae leech family in the groups on the right. The second division further split the group of 34 sites into 12 and 22 sites with higher occurrences of the mayflies *Baetis* spp., *Heptagenia* spp. and

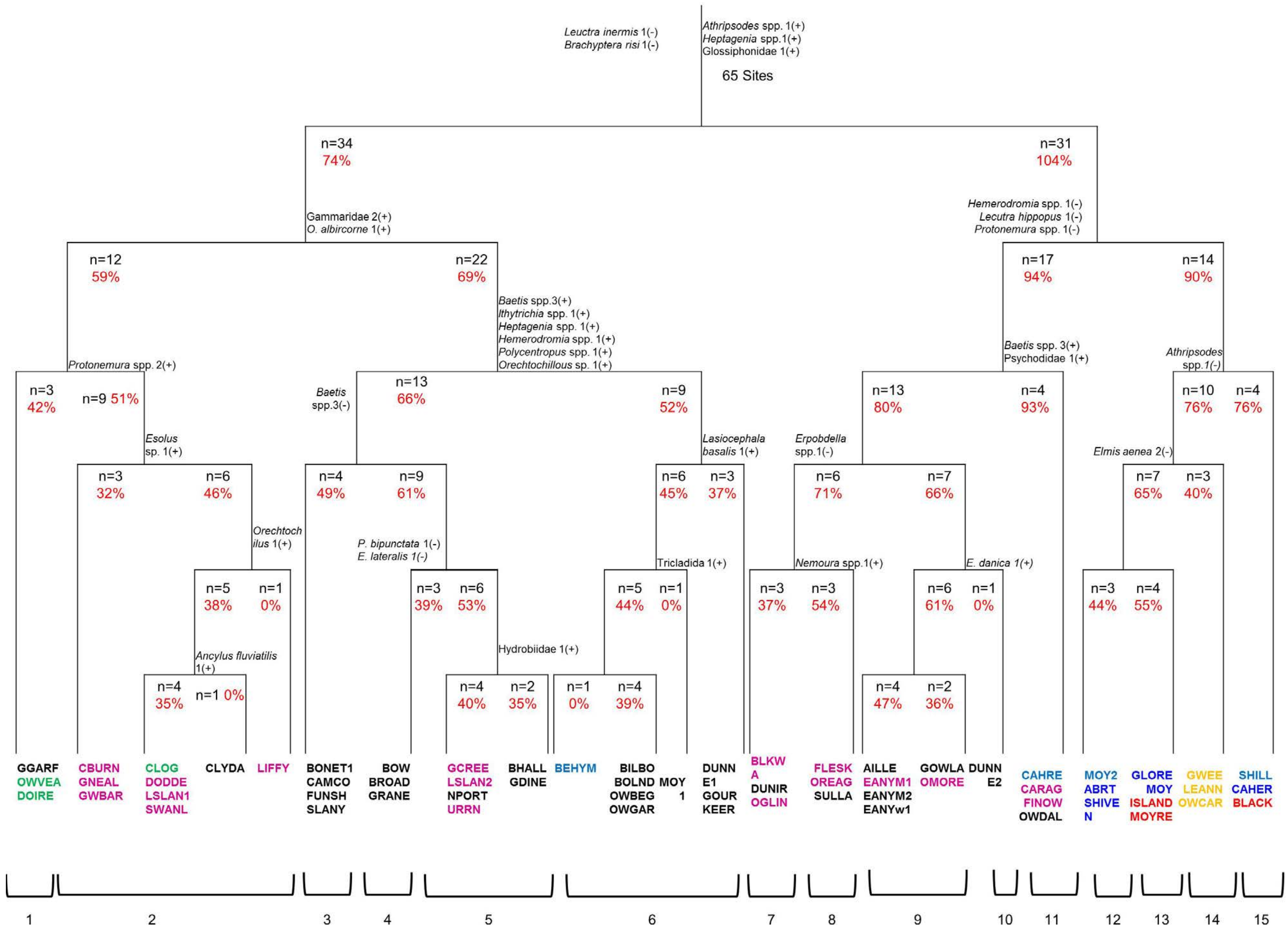

Figure 5.4. TWINSPAN dendrogram for spring macroinvertebrate log(*x*+1) transformed data. The number of sites is denoted by n, while values in red represent the TWINEND percentage dispersion value. Each typology is colour coded as follows: Types 11–14 (purple), naturally acid (green), lake outlets (orange), Types 21–24 (black), Types 31 and 32 (light blue), highly calcareous with precipitate (dark blue), and groundwater-dominated (red).

Table 5.3. TWINSPAN site groupings of spring macroinvertebrate community data using the TWINEND 50% dispersion

Group	TWINEND 50%	National type	Group	TWINEND 50%	National type	Group	TWINEND 50%	National Type
1	GGARF1	12	6	BEHYM1	32	11	CAHRE1	32
	DOIRE	14_Acid		BILBO1	22		CARAG1	12
	OWVEAGH	12_Acid		BOLND1	22		FINOW1	11
2	CBURN1	13		MOY1	21		OWDAL1	22
	GNEAL1	11		OWBEG1	22	12	ABBRT	31_Highly Calcareous
	GWBAR1	13		OWGAR1	21		MOY2	31
	CLOG	13_Acid		DUNNE1	23		SHIVEN	31_Highly Calcareous
	CLYDA1	23		GOURN1	21	13	GLORE	31_Highly Calcareous
	DODDE1	14		KEERG1	23		ISLAND	31_GW
	LIFFY1	11	7	BLKWA1	11		MOY	31_Highly Calcareous
	LSLAN1	14		DUNIR1	21		MOYREE	GW
	SWANL1	13		OGLIN1	12	14	GWEE	11_Lake Outlet
3	BONET1	24	8	FLESK1	11		LEANN	11_Lake Outlet
	CAMCO1	22		OREAG1	11		OWCAR	11_Lake Outlet
	FUNSH1	22		SULLA1	21	15	BEHY	31_GW
	SLANY1	21	9	AILLE1	21		BLACK	31_GW
4	BOW1	23		EANYM1	11		CAHER	31_Highly Calcareous
	BROAD1	21		EANYM2	22		SHILL1	32
	GRANE1	21		EANYW1	21			
5	BHALL1	22		GOWLA1	22			
	GCREE	11		OMORE1	13			
	GDINE1	22	10	DUNNE2	22			
	LSLAN2	12						
	NPORT1	22						
	URRN1	13						

The national type for each RIVTYPE site is included. The national type into which the rare river types would be expected to fall is included in the coding, e.g. DOIRE HOIRBIRT would be Type 14 under the national typology and so is 14_Acid in the table. For river names see Table 2.1.

GW, groundwater-dominated sites.

caseless caddisfly *Polycentropus* spp. in the group of 22 sites. The 31 sites were separated into two groups of 17 sites, with higher occurrences of the stoneflies *Leuctra hippopus and Protonemura* spp., and *Hemerodromia* spp. (fly larvae), and 14 sites (Figure 5.4). Groups 1, 2, 6, 11 and 15 all separated out at the third division. The separation of Groups 1 and 2 was down to higher abundances of *Protonemura* spp. in Group 2. Group 6 split from Groups 4 and 5 because of higher occurrences of *Baetis, Ithytrichia* spp., *Heptagenia* spp., *Hemerodromia, Polycentropus* spp. and *Orechtochilus* spp. Higher occurrences of *Baetis* spp. and Psychodidae (fly larvae) separated Group 11 from Groups 7 to 10, while Group 15 divided from Groups 12 to 14 on account of lower occurrences of the caddisfly *Athripsodes* spp. The fourth division separated out Groups 3 and 14 with the remaining Groups separating in the fifth and sixth divisions.

The naturally acid sites were separated into Groups 1 and 2, which, with the exception of CLYDA1 (Clydagh River), contained sites designated as having 100%

siliceous geology under the national typology, i.e. they were all classified as Types 11–14. Groups 12, 13 and 15 contained all the RARETYPE highly calcareous and groundwater-dominated sites as well as two of the four Type 31 and 32 sites. Group 14 consisted of the three lake outlet sites and separated from 12 and 13 as a result of the low abundance/absence of *Elmis aenea*. When tested using PERMANOVA, the structure of the invertebrate communities varied significantly across the 15 TWINSPAN groupings ($F_{14,50}$ = 4.19, P < 0.05). ANOSIM indicated relatively strong differentiation between the groups (Global-R = 0.705, P < 0.05). As Group 10 contained only one site, it did not show any statistical significance when tested against other groups. Interestingly, Group 14 (lake outlets) hosted a community structure that varied from all other groupings, with the exception of Group 1, which contained two naturally acidic and one Type 12 site. As all of the lake outlet sites drain soft-water lakes and have an underlying siliceous geology, it is not surprising that they host invertebrate communities similar to those found in acid sites. However, their positioning on the TWINSPAN dendrogram would indicate that there is also overlap with more alkaline communities (Figure 5.4). The analysis also found that Groups 12, 13 and 15 hosted similar community structures. This would indicate that naturally acid, highly calcareous, and groundwater-dominated sites are all grouping as would be expected under the national typology (Table 5.3).

5.2.3.2 The TWINSPAN classification of summer macroinvertebrates.

Summer data resulted in 22 TWINSPAN groups, four of which consisted of a single site (Figure 5.5). The 18 groups with more than one site were validated using MRPP (A = 0.192, P < 0.001). The first division split the 63 sites into 41 sites (Groups 1–14) on the left of the dendrogram and 22 sites (Groups 15–22) on the right, because of higher occurrence of the stonefly *Siphonoperla torrentium*, mayfly *Rhithrogena* spp. and beetle *Hydraena* spp. in the left hand sites (Figure 5.5). The second division split the 41 sites into 15 sites that had higher occurrences of the stoneflies *Amphinemura sulcicollis, Protonemura* spp. *and Chloroperla tripunctata* (Scopoli), and 26 sites. Taxa such as *Perla bipunctata* Pictet (stonefly)*,* the caddisfly *Psychomyia pursilla* (Fabricius)*,* beetles Hydrobiidae and freshwater shrimps Gammaridae were more associated with this grouping. Half of the groups (Groups 1, 2, 3, 7, 14, 17–22) separated out at the fourth division (Figure 5.5).

Similar to the trend observed in spring, the highly calcareous with precipitate and groundwater-dominated sites generally grouped together with Types 31 and 32 (Table 5.4). Unlike in spring, however, the naturally acid sites were split with the CLOGHOGE grouping with siliceous sites, while the OWENVEAGH and DOIRE HOIRBIRT grouped on their own on the other side of the dendrogram. Again, lake outlets grouped together but one highly calcareous site (SHIVEN) also grouped with the outlets (Table 5.4) as a result of the absence of the caddisfly *Agapetus* spp. (Figure 5.5). This is unusual given the ecological difference between the sites; however, as noted in section 2.3.2.3, a criticism of the TWINSPAN analysis is that the splitting rule used by the program may sometimes prevent ecologically closely related sites/samples clustering together. Generally, there was no clear separation between the national types, with most groups containing a mixture of siliceous and mixed geology sites. The pattern of separation indicative of geology was much less clear in summer than in spring. This is most likely due to the low occurrence or absence of some Ephemeroptera, during the summer months, due to emergence of adults in May and June. PERMANOVA analysis found that community structure varied significantly across the TWINSPAN groups ($F_{1,41}$ = 3.12, P < 0.05), although there was no clear pattern.

5.3 Macrophyte Communities of Rare Types Versus National River Types

5.3.1 Macrophyte community structure excluding macroalgae

All 18 RARETYPE reference sites were included in the macrophyte analysis. Macrophyte community structure of both the highly calcareous sites with precipitate and groundwater-dominated sites was similar to that of existing calcareous Types 31 and 32, a result also observed in the macroinvertebrate communities (Figure 5.6). As expected, the macrophyte communities of the calcareous types, both existing types and potentially rare types, varied significantly from those with siliceous (existing

Table 5.4. TWINSPAN site groupings of summer macroinvertebrate community data using the TWINEND 50% dispersion

Group	TWINEND 50%	National type	Group	TWINEND 50%	National type	Group	TWINEND 50%	National type
1	CLOG	13_Acid	9	BEHYM1	32	15	CARAG1	12
	DODDE	14		BILBO1	22		EANYM1	11
	URRN1	13		DUNNE1	23	16	EANYW1	21
2	CBURN1	13		NPORT1	22		FINOW1	11
	GNEAL1	11		OMORE1	13		FLESK1	11
	GWBAR1	13		SLANY1	21		OREAG1	11
	LIFFY1	11	10	BOW1	23	17	AILLE1	21
3	GGARF1	12		GRANE1	21		MOY	31_Highly Calcareous
4	CAMCO1	22	11	BLKWA1	11		MOY2	31
	FUNSH1	22		SULLA1	21	18	OGLIN1	12
	GCREE1	11		BOLND1	22	19	BEHY	31_GW
5	LSLAN1	14	12	EANYM2	22		GLORE	31_Highly Calcareous
	LSLAN2	12		GOURN1	21	20	BLACK	31_GW
	SWANL1	13		MOY1	21		CAHER	31_Highly Calcareous
6	BONET1	24		OWBEG1	22		ISLAND	31_GW
7	BROAD1	21		OWDAL1	22		SHILL1	32
	KEERG1	23		OWGAR1	21	21	GWEE	11_Lake Outlet
8	CLYDA1	23	13	BHALL1	22		LEANN	11_Lake Outlet
	GOWLA1	22		DUNIR1	21		OWCAR	11_Lake Outlet
				DUNNE2	22		SHIVEN	31_Highly Calcareous
				GDINE1	22	22	DOIRE	14_Acid
			14	CAHRE1	32		OWVEAGH	12_Acid

The national type for each RIVTYPE site is included. The national type into which the rare river types would be expected to fall is included in the coding, e.g. DOIRE HOIRBIRT would be Type 14 under the national typology and so is 14_Acid in the table.

GW, groundwater-dominated sites.

Types 11, 12, 13) and mixed geology types (existing Types 21, 22, 23) ($F_{13,67}$=2.45, P<0.05) (Figure 5.6). Calcareous types had consistently higher abundances of *Schoenoplectus lacustris* (club rush), *Apium nodiflorum* (fool's-water-cress), *Phalaris arundinacea* (reed canary grass), *Mentha aquatic* (mint) and *Amblystegium riparium* (moss) compared with siliceous or mixed geology types. *Oenanthe crocata* (hemlock water-dropwort), which shows in the present study a general preference for more acid sites, was absent from all calcareous types, both RARETYPE and Type 32 sites.

The only existing types to host macrophyte community structure similar to the lake outlets were siliceous Types 12 and 14. Taxa such as *Racomitrium aciculare* (moss), *Myriophyllum alternifolium* (water-millfoil), *Juncus bulbosus* (rush) and *Fissidens* spp. (moss) were consistently found in higher abundances in lake outlets, while *Marsupella emarginata* (liverwort) was only found in the outlet sites. Both *Racomitrium aciculare* (moss) *and Marsupella* spp. prefer acid conditions. The opposite was true for species including the bryophytes *Platyhipnidium riparioides, Conocephalum conicum* (L.) Lindb*, Thamnobryum*

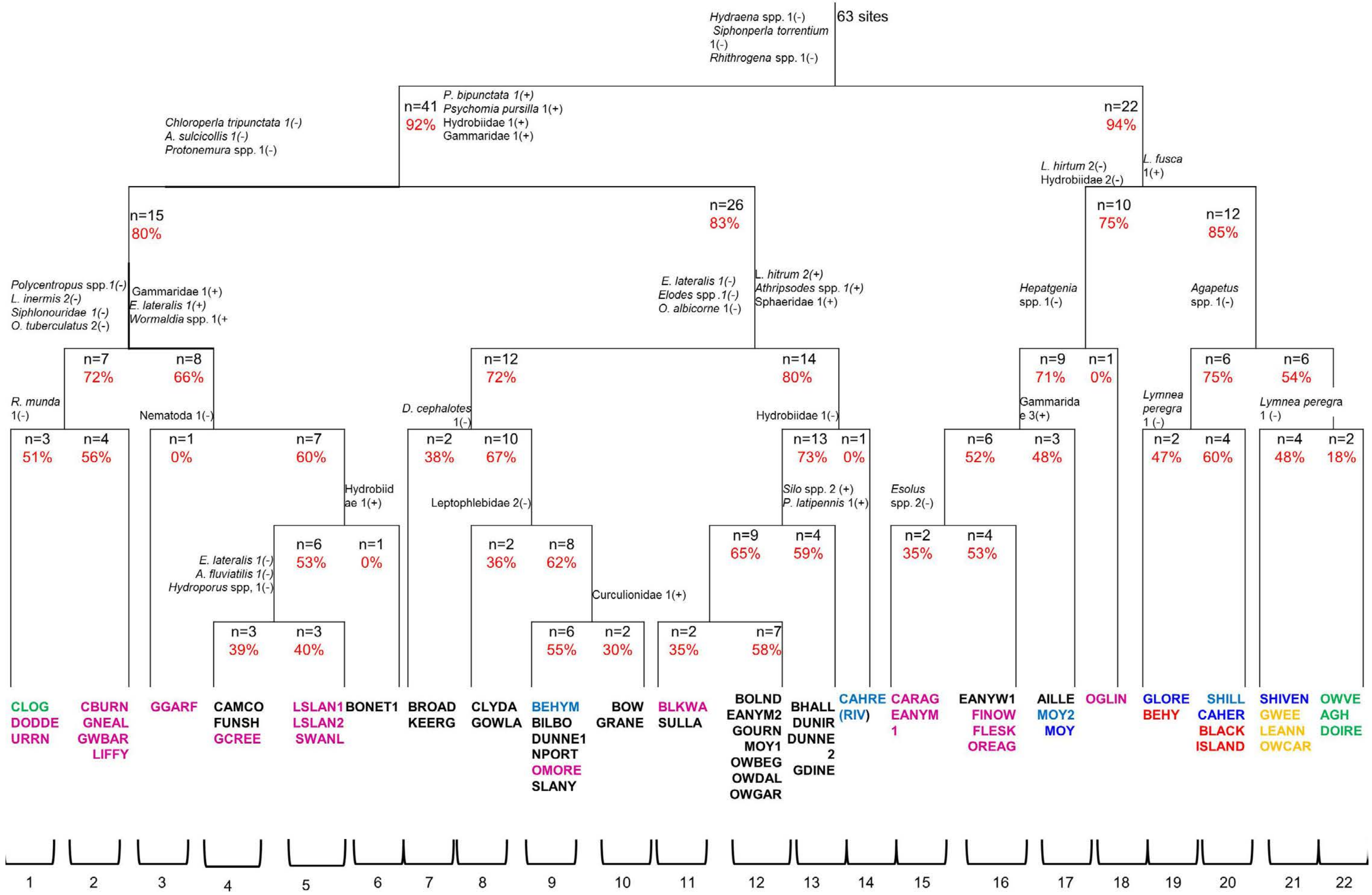

Figure 5.5. TWINSPAN dendrogram for summer macroinvertebrate log(x+1) transformed data. The number of sites is denoted by n, while values in red represent the TWINEND 50% dispersion value. Each typology is colour coded as follows: Types 11–14 (purple), naturally acid (green), lake outlets (orange), Type 21–24 (black), Type 31 and 32 (light blue), highly calcareous with precipitate (blue), and groundwater-dominated (red).

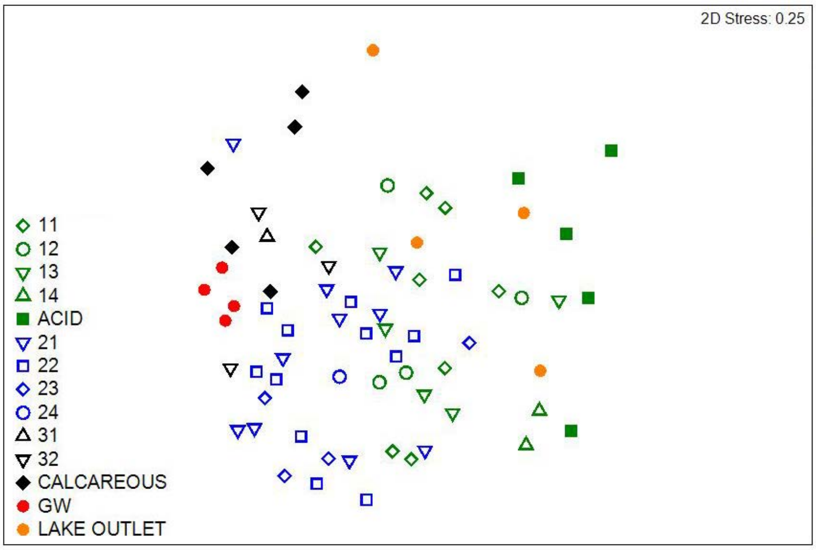

Figure 5.6. Multidimensional scaling plot of macrophyte community structure based on Bray–Curtis similarities of abundance data. Open symbols represent RIVTYPE sites categorised by national type, closed symbols represent RARETYPE sites. Green symbols represent 100% siliceous geology, blue symbols represent mixed geology sites and black symbols denote >25% calcareous geology. The upper outlier is the NEWPORT lake outlet.

spp. and *Chiloscyphus polyanthos,* which are either generalist mosses associated with all water types or prefer more neutral conditions, like the macrophytes *Oenanthe crocata* and *Ranunculus peltatus/pencillatus* (water-crowfoot), which were absent from lake outlet communities. However, the community structure of lake outlets differed from their corresponding national siliceous Type 11.

Under the national typology, the five RARETYPE naturally acid sites fall across all four siliceous geology types (Types 11–14). It is unsurprising then that macrophyte community structure of these potentially rare types was similar to Types 13 and 14 (on siliceous geology), but differed significantly from Types 11 and 12. Similar to lake outlets, bryophytes (mosses) with a preference for neutral conditions or more generalist taxa such as *Platyhipnidium riparioides, Conocephalum conicum, Thamnobryum* spp. and *Chiloscyphus polyanthos* were absent from the RARETYPE acid sites and Type 14. So too were the macrophytes *Oenanthe crocata* and *Ranunculus peltatus/pencillatus.* These sites supported a low number of taxa (11), six of which were bryophytes with a preference for acid/neutral conditions. The liverworts *Pellia* sp. and *Scapania unudulata* (L.) Dum., along with *Ranunculus flammula* (lesser spearwort) and *Juncus bulbosus* (rush), were also present in higher abundances than in other types.

None of the rare types was significantly different in structure to Types 24 and 31, but this may be because each of these types consisted of a single replicate and so could not be accurately tested.

When macroalgal taxa were included in the analysis, communities showed similar patterns to those outlined above ($F_{13,52}=2.22$, $P<0.05$).

5.3.2 Relationship between macrophyte communities and environmental variables

The environmental variables identified using BEST analysis as most correlated with the observed variation in the biological data were pH, hardness and slope ($\rho=0.327$, $P<0.01$). Though significant, there was only a moderate correlation between the environmental variables and the biota. As there was no summer chemistry data available for three sites (OWENVEAGH, ABBERT and MOYREE), they were removed from the analysis prior to running DISTLM. With the exception of percentage bedrock, cobble and sand/silt/mud, all the environmental variables tested were significantly correlated with the biota when tested individually (Table 5.5). When fitted sequentially, total hardness and pH accounted for 12% of the observed variation in community structure between river types.

5.3.3 TWINSPAN ordination of summer macrophyte data

TWINSPAN analysis was completed for the macrophyte data though no discernible pattern could be defined.

5.4 Phytobenthos Assemblages of Rare Types Versus National River Types

5.4.1 Phytobenthos assemblage structure

Prior to analysis, the RARETYPE and RIVTYPE databases had to be harmonised to reduce variation due to operator identification and changes in taxonomy that may have occurred in the 10 years between the development of the two databases. Untransformed abundance data (6-category scale; see Table 2.5) were used in the analysis with rare taxa, i.e. taxa present in less than 10% of sites (6 sites) and never in abundances > 1% were removed prior to analysis.

The structure of the phytobenthos assemblage varied significantly across seasons ($F_{2,150}=4.223$, $P<0.05$) (Figure 5.7). As a result of this temporal variation, each season was analysed separately.

Outliers had to be removed prior to analysis, therefore CAHRE (RIVTYPE), GDINE and CLOGHOGE were removed from the spring dataset, while AILLE was removed from the summer dataset. On account of weather conditions, a number of sites were not sampled during the autumn/winter season resulting in a reduced dataset for this sampling period.

Because of the seasonal variation observed in communities, the analysis of variation between types was undertaken separately for each season (Figure 5.8). Assemblage structure varied significantly across river types in spring ($F_{13,64}=2.905$, $P<0.05$) (Figure 5.8a), summer ($F_{13,64}=2.685$, $P<0.05$) (Figure 5.8b) and autumn ($F_{11,56}=3.169$, $P<0.05$) (Figure 5.8c). Naturally acid sites hosted assemblages that differed from all types, including the existing siliceous types (Types 11 to 13) in spring and autumn and Types 11 to 14 in summer. The phytobenthos assemblage structure of the lake outlets also varied significantly from the equivalent national river types (Types 11 to 14) in spring, and Types 11 to 13 in summer and autumn. Both the highly calcareous sites with

Table 5.5. Results of DISTLM analysis for fitting environmental variables to summer macrophyte community structure data for national and rare river types

Variable	% Variance	*P*-value	% Cumulative
Individual variables[a]			
pH	6.97	**0.001**	
Total hardness (mg $CaCO_3$ L^{-1})	8.15	**0.001**	
Cl^- (mg L^{-1})	3.43	**0.006**	
Bedrock (%)	1.58	0.423	
Boulder (%)	3.79	**0.002**	
Cobble (%)	2.62	0.062	
Gravel (%)	2.68	**0.033**	
Sand/silt/mud (%)	2.05	0.174	
Calcareous geology (%)	6.29	**0.001**	
Slope (m m^{-1})	4.21	**0.001**	
Fitted with other variables[b]			
Total hardness (mg $CaCO_3$ L^{-1})	8.15	**0.001**	8.15
pH	3.88	**0.001**	**12.00**

Cumulative (%) refers to cumulative percentage of variance. Values in bold indicate a significant correlation.
[a]Variables were tested individually ignoring other factors.
[b]Step-wise selection of variables.

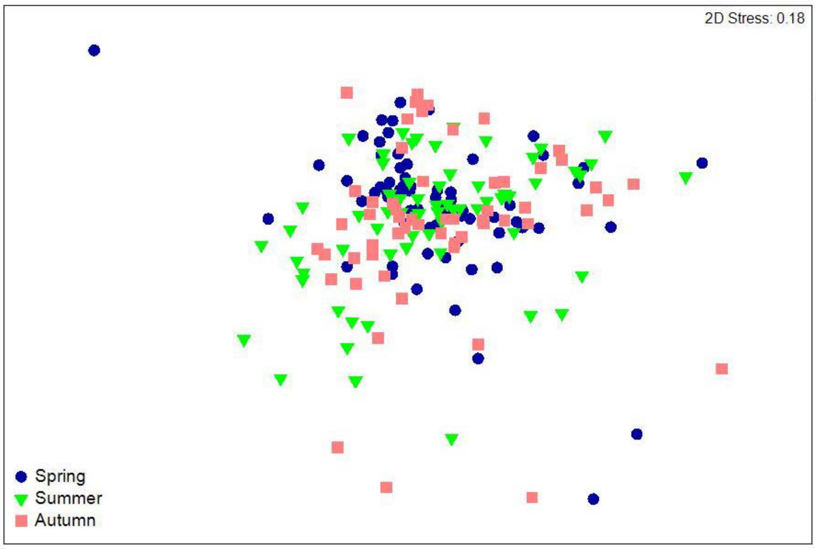

Figure 5.7. Multidimensional scaling plot of phytobenthos community structure based on Bray–Curtis similarities of taxa abundance data for the seasons.

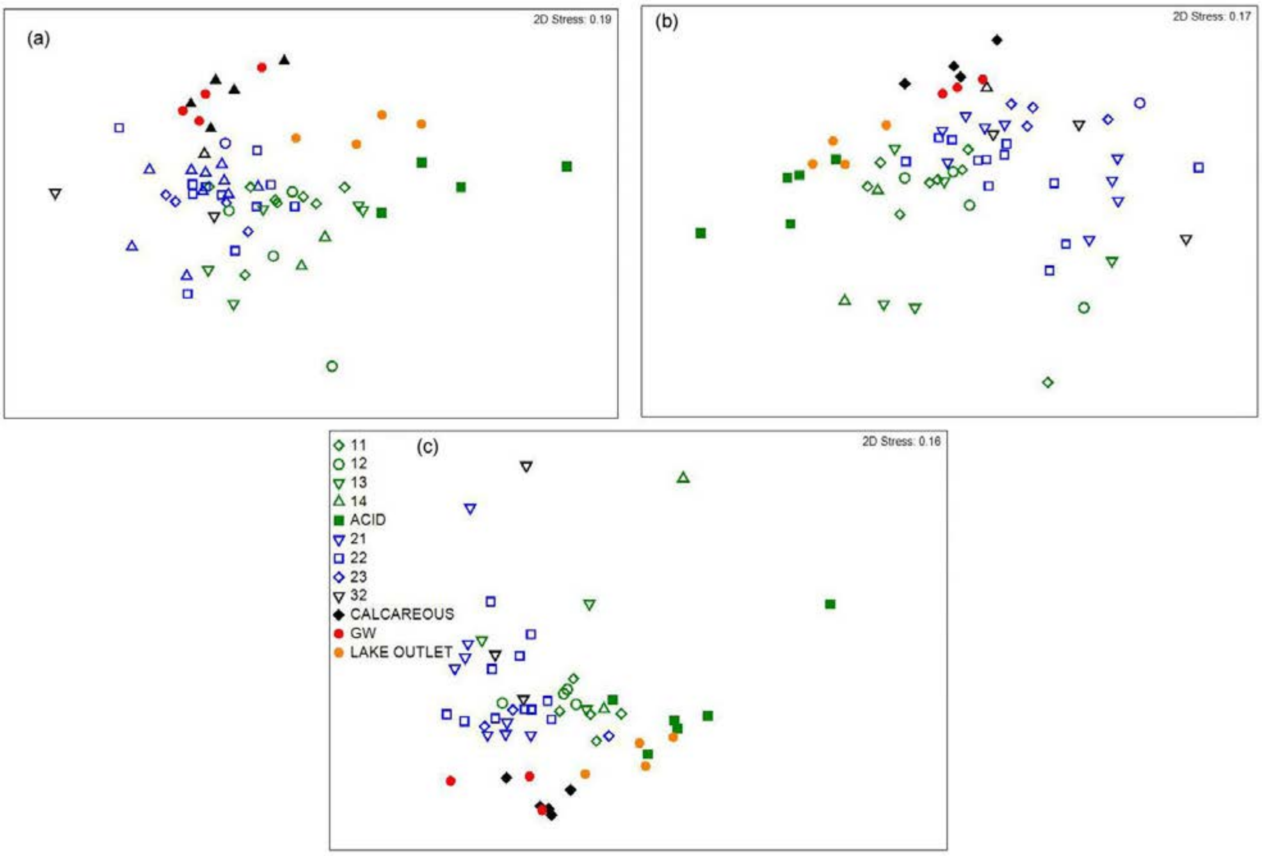

Figure 5.8. Multidimensional scaling plot of (a) spring, (b) summer and (c) autumn/winter phytobenthos community structure, based on Bray–Curtis similarities of abundance data. Solid fill symbols represent RARETYPE river types. Open symbols represent RIVTYPE sites categorised by national type, closed symbols represent RARETYPE sites. Green symbols represent 100% siliceous geology, blue symbols represent mixed geology sites and black symbols represent >25% calcareous geology. The spring acid outlier was the OWENGOWLA, while the acid outlier in summer and autumn was the CLOGHOGE.

precipitate and groundwater-dominated sites hosted assemblages similar to what would be expected in the calcareous national types (Type 32).

5.4.2 Relationship between phytobenthos assemblages and environmental variables

Total hardness/conductivity and pH accounted for between 11% and 18% of the observed variation in the biological data across sampling seasons. Generally, substrate composition was not found to be significantly correlated with the observed variation in the phytobenthos biological data. The highest percentage of variance explained by the environmental variables occurred in spring where total hardness, pH and the percentage of calcareous geology accounted for 20% of the variation observed in the biological community.

5.4.3 TWINSPAN ordination of phytobenthos data

Similar to the macrophyte data, no discernible pattern was defined using TWINSPAN classification for the phytobenthos community in any of the sampling seasons.

5.5 Comparison of Rare Versus National Types When All BQEs Are Combined

The RARETYPE and RIVTYPE datasets for all BQEs were combined for both spring and summer and the resulting communities subject to PERMANOVA. Each season was analysed separately. The community structure consisting of all BQEs varied significantly among types in spring ($F_{13,64}$ = 2.60, P < 0.05) (Figure 5.9) and summer ($F_{13,62}$ = 2.51, P < 0.05). As observed, when the BQEs were analysed separately, highly calcareous and groundwater-dominated sites hosted spring communities similar to their corresponding national river type (P > 0.05) (Types 31 to 32), i.e. those with calcareous geology and hardness values > 100 mg $CaCO_3 L^{-1}$, while the naturally acid sites had communities similar to three of their corresponding siliceous national types (Types 12 to 14) (P > 0.05). Under the national typology, soft-water lake outlets should host communities similar to the existing Type 11, but this was not the case (P = 0.006). The outlets

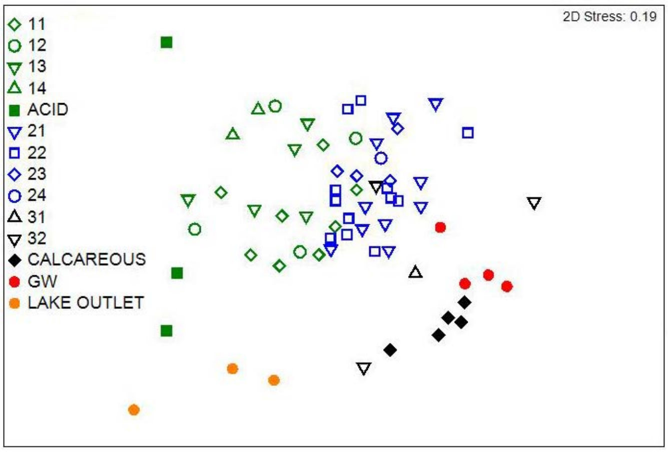

Figure 5.9. Multidimensional scaling plot of combined data for all biological quality elements in spring, based on Bray–Curtis similarities of abundance data. Open symbols represent RIVTYPE sites categorised by national type, closed symbols represent RARETYPE sites. Green symbols represent 100% siliceous geology, blue symbols represent mixed geology sites and black symbols represent > 25% calcareous geology. The upper outlier is the CLOGHOGE acid site while the lower outlier is the OWENCARROW lake outlet.

did have communities similar to two of the national siliceous types (12 and 14), but this was marginal as P-values were just above 0.05 ($P = 0.054$ and $P = 0.057$ respectively). Similar results were found for summer communities. Interestingly, naturally acid sites did not differ from the calcareous geology Type 32 sites as expected in spring, but summer communities were different.

5.6 Summary of Key Results

The national typology is based on hardness/geology and slope, with geology running along a gradient of hardness from 100% siliceous (hardness $< 35\,mg\,CaCO_3\,L^{-1}$) to > 25% calcareous (hardness $> 100\,mg\,CaCO_3\,L^{-1}$). The potential rare highly calcareous with precipitate and groundwater-dominated types investigated in this study fall into national Types 31 and 32. The analysis conducted in this study showed these rivers to hosted communities similar to those expected under the national types for all BQEs. The site on the Black River behaved as an outlier and may indicate either a higher groundwater influence than at the other sites or some anthropogenic impact.

The RARETYPE naturally acid sites had macroinvertebrate and macrophyte communities comparable to those of existing siliceous, soft-water types, although the phytobenthos assemblages varied significantly.

The soft-water lake outlets presented the strongest evidence for their designation as a separate biological sub-type. Under the national typology they would be classed as Type 11 (based on geology and slope). In terms of their macroinvertebrate community structure, they hosted communities that were significantly different from the communities observed in the RIVTYPE siliceous Type 11 to 14 sites previously described, in spring but not in summer. The lake outlets hosted macrophyte communities similar to siliceous types with different slopes but varied from Type 11, while the phytobenthos was distinct from the siliceous types across all sampling seasons despite grouping close to RARETYPE naturally acid sites. The analysis based on *Q*-value indicator groups also clearly distinguished them from Type 11.

Based on this evidence, only the lake outlets can be justified as a biological sub-type distinct from the existing national types.

6 Can Current Metrics Detect Impact in Rare River Types?

6.1 Community Structure of Potential Reference Versus Impacted Sites for Potential Rare Types

6.1.1 Macroinvertebrate communities of potential reference versus impacted sites

Variation in community structure between potential reference and impacted sites was heavily influenced by river type ($F_{4,36}$=2.93, P<0.05) with only highly calcareous sites recording a significantly different community across river status (P=0.03) (Figure 6.1). The impacted calcareous sites had higher abundances of black fly larvae *Simulium* spp., the caddisflies *Silo* spp. and *H. siltalai*, mayfly *B. rhodani*, and dipteran (fly) taxa such as *Antocha* spp. and Empididae, than potential reference sites. Plecopteran taxa such as *Leuctra* spp. and the mayflies *Ecdyonurus* spp. and *Caenis* spp., as well as the caddisflies *Lepidostoma hirtum* and *Metalype fragilis*, were more abundant in reference sites. There was a significant seasonal effect on the communities ($F_{1,36}$=8.85, P<0.05).

6.1.2 Macrophyte communities of potential reference versus impacted sites

There was a significant interaction effect in terms of macrophyte community structure between condition (i.e. reference/impacted) ($F_{4,28}$=1.99, P<0.05) and potential river type ($F_{3,28}$=2.39, P<0.05). There was overlap between the effects of the two factors tested and so a difference of status was detected in some but not all river types. In this case, for lake outlets potential reference sites hosted macrophyte communities significantly different from those of impacted outlets. *Juncus bulbosus, Marsupella emarginata*, *Pellia epiphylla*, *Batrachospermum* sp., and *Schoenoplectus lacustris/Scirpus lacustris* were present only in potential reference lake outlets, while *Oenanthe crocata, Juncus effusus, Chiloscyphus polyanthus, Lemna minor, Polygonum hydropiper, Stachys palustris, Apium nodiflorum* and *Myosotis scorpioides* were found in impacted lake outlets. With reference to the Mean Trophic Rank (MTR) scores, most of the latter species would not be considered tolerant of enriched conditions.

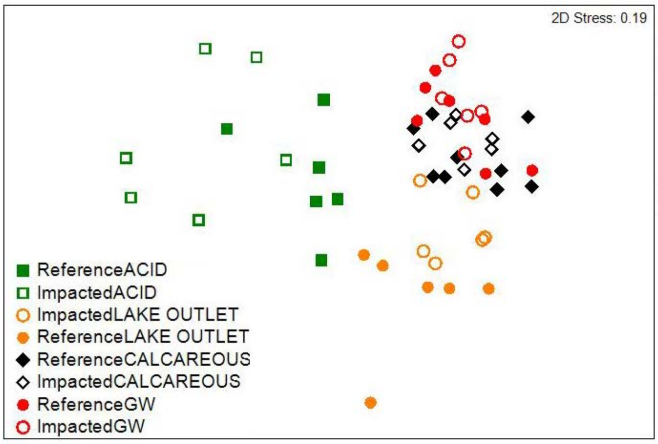

Figure 6.1. Multidimensional scaling plot of macroinvertebrate community structure based on Bray–Curtis similarities of log(x+1) transformed abundance RARETYPE data for spring and summer seasons. Closed symbols represent potential reference sites and open symbols represent impacted sites. GW denotes groundwater-dominated sites. The lower outlier is the OWENCARROW lake outlet site.

Differences were also detected between potential reference and impacted groundwater-dominated sites (Figure 6.2). Potential reference groundwater-dominated sites had higher abundances of the mosses *Fontinalis antipyretica* and *Platyhypnidium riparioides* than impacted sites, while *Chiloscyphus polyanthus* (moss), *Sparganium* spp. (bur reed), *Schoenoplectus lacustris* (club rush)/*Scirpus lacustris* (bulrush or common club rush), *Vaucheria* (algae) and *Potamogeton* spp. (pondweed) were present only in reference sites. Impacted groundwater-dominated sites had higher abundances *of Amblystegium riparium* (moss), *Apium nodiflorum* (fool's-water-cress), *Oenanthe crocata* (hemlock water-dropwort), *Berula erecta* (water parsnip), *Riccia fluitans* (a floating bladderwort), *Ranunculus peltatus/pencillatus* (water crowfoot) and *Pellia endivifollia* (liverwort) than reference sites.

No significant difference in macrophyte community structure was observed between potential reference and impacted sites for either the naturally acid rivers or the highly calcareous sites

6.1.3 Phytobenthos communities of potential reference versus impacted sites

Similar to the pattern observed in the macroinvertebrate communities, the effect of potential river type was stronger on community structure than the effect of status, with only naturally acid sites showing a significant difference between communities in potential reference and impacted sites ($F_{4,78}$=4.93, P<0.05) (Figure 6.3). Potential reference acid communities had higher abundances of *Tabellaria flocculosa, Achnanthidium minutissimum, Brachysira neoexilis, Pinnularia subcapitata, Achnanthidium caledonicum* and *Fragilaria gracilis,* while abundances of *Eunotia subarcuatoides, Eunotia exigua, Peronia fibula,* and *Eunotia incisa* were higher in impacted acid sites. The species at the impacted sites are typical of highly acidic sites (M. Kelly, Bowburn Consultancy, January 2017, personal communication). The assemblages varied across seasons ($F_{2,78}$=3.82, P<0.05) and between acid and groundwater-dominated sites ($F_{3,78}$=2.39, P<0.05).

6.2 Comparison of Metrics

For each BQE, the current metric adopted and intercalibrated in Ireland has been calculated and where possible metrics from the UK have also been used.

6.2.1 Macroinvertebrate metrics

6.2.1.1 Q-value

The EPA river quality rating scheme (*Q*-value) has been successfully intercalibrated for both the Northern and Central Baltic GIGs of which Ireland is part (EU, 2008, 2013). This metric was developed in the 1970s to detect the effects of organic pollution and was developed independently of river type (Flanagan and Toner, 1972). The *Q*-value rating is based on the sensitivity of various invertebrate taxa

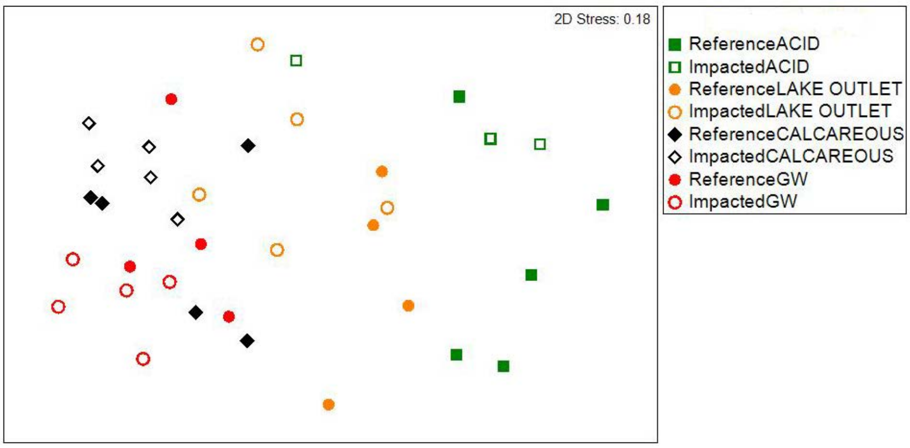

Figure 6.2. Multidimensional scaling plot of macrophyte community structure based on Bray–Curtis similarities abundance data for summer RARETYPE data. Closed symbols represent potential reference sites and open symbols represent impacted sites. GW denotes groundwater-dominated sites.

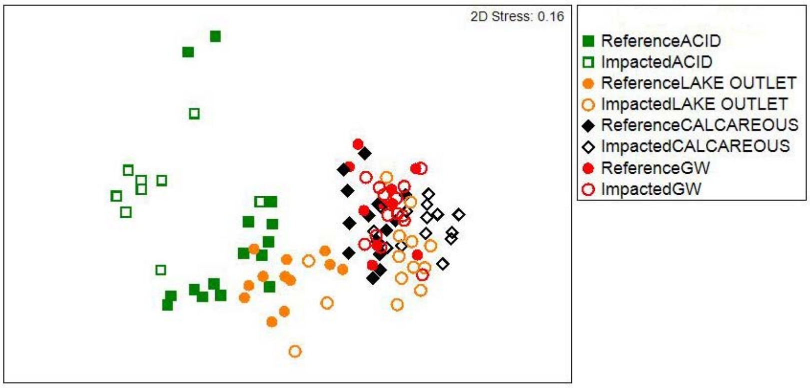

Figure 6.3. Multidimensional scaling plot of phytobenthos community structure, based on Bray–Curtis similarities of square-root transformed abundance data for spring, summer and autumn seasons. Closed symbols represent potential reference sites and open symbols represent impacted sites. GW denotes groundwater-dominated sites.

to the effects of organic pollution, with sensitive taxa being progressively replaced by more tolerant taxa in polluted environments. This metric was developed independently of river type but within each category, ranging from sensitive to tolerant, it has taxa representative of a wide range of types, e.g. from hard water to soft water, such that different typologies are "built in" to the system. The relationship between the *Q*-value and land use has been established (Donohue *et al.*, 2006). It has been found to accurately detect and measure the impact of nutrient enrichment such that national nutrient standards have been based on the relationship between *Q*-value and nutrient concentrations. Sites are assigned to one of five basic water quality classes, ranging from Q1 indicating serious pollution to Q5 representing unpolluted conditions, with four intermediate values, Q4–5, Q3–4, Q2–3 and Q1–2 (see Toner *et al.*, 2005). The *Q*-value is then converted into an ecological quality ratio (EQR) score ranging from 0.2 (bad) to 1 (high) (Irish Government, 2015) in order to assign a WFD status (Table 6.1). A fundamental principle inherent to the *Q*-value system is that of obtaining an indication of the poorest conditions likely to occur at a site over the course of the year, which typically is high summer when high temperatures and low flows compound the effect of pollutants entering the river. Essentially this means incorporating a temporal reference condition into the assessment. As many insect taxa have life cycles that evolved to avoid stressful summer conditions, e.g. emergence, aestivation, it is important to be cognisant of insect life cycles and emergence periods when predicting what species are likely to be present during times of peak stress on the aquatic ecosystem.

Ideally, the *Q*-value should be normalised to the season, i.e. it should be assessed with a moving temporal reference condition for Q5 which incorporates a detailed knowledge of emergence periods. Thus, a sample taken in March with, for example, an abundance of *Rhithrogena* and stoneflies such as *Protonemura* but lacking Heptageniidae such as *Ecdyonurus* or *Heptagenia* should score lower. However, a summer sample taken at the same site may lack many Category A taxa, depending on the time of sampling, as a result of adult emergences. In

Table 6.1. The EPA's quality rating scheme (*Q*-value) and corresponding ecological quality ratio values and WFD status classes defined by the intercalibration exercise

Q-value	EQR	Boundary EQR	WFD ecological status
5.0	1.0		High
4.5	0.9		High
High/good boundary		0.85	
4.0	0.8		Good
Good/moderate boundary		0.75	
3.5	0.7		Moderate
3.0	0.6		Poor
2.5	0.5		Poor
2.0	0.4		Bad
1.5	0.3		Bad
1.0	0.2		Bad

the present study the *Q*-value calculations took into account these seasonal life history effects but did not make any adjustments for possible effects of the unusual habitat conditions of the potential rare river types.

With the exception of the GLORE, which was rated Q4 in summer, all potential reference calcareous sites scored Q5/4–5 (EQR 0.9–1), representing high status in both summer and spring, while the impacted sites were rated Q4, i.e. good status, in spring, an increase from Q3–4 (moderate status) in summer (Table 6.2). The same applied to the groundwater-dominated sites with the exception of the BLACK where low-oxygen groundwater input or an anthropogenic impact is suspected. Two of the naturally acid sites were rated Q4; this is unsurprising as the *Q*-value is not an effective metric in acid or episodically acid waters.

Differences in the *Q*-value between potential reference and impacted acid sites were detected in summer but not in spring. All acid sites scored Q5 in spring though

Table 6.2. *Q*-value, Whalley, Hawkes, Paisley and Trigg (WHPT) score, number of scoring taxa recorded (NTAXA) and Average Score Per Taxon (ASPT) for all river categories for summer and spring sampling seasons

River type	Status	River name	Summer				Spring			
			Q-value	WHPT score	WHPT NTAXA	WHPT ASPT	*Q*-value	WHPT score	WHPT NTAXA	WHPT ASPT
Naturally acid	Potential reference	CLOGHOGE	4–5	164.3	23	7.1	5	158.5	20	7.9
		OWENVEAGH A	4	86.5	13	6.7				
		OWENVEAGH B					5	186.5	24	7.8
		DOIRE HOIRBIRT	4	122.9	20	6.1	5	200.1	28	7.1
	Impacted	BUNADOWEN	3–4	90.1	14	6.4	4–5	133.8	18	7.4
		LUGDUFF	3–4	73.6	11	6.7	4–5	113.8	16	7.1
		VARTRY	3–4	126.1	18	7.0	4–5	114.6	16	7.2
Highly calcareous with calcium precipitate	Potential Reference	ABBERT					4–5	201.1	32	6.3
		CAHER	4–5	178.8	24	7.5	5	229.4	31	7.4
		GLORE	4	173.8	27	6.4	4–5	238.9	33	7.2
		MOY	4–5	192.9	29	6.7	5	237.4	36	6.6
		SHIVEN	4–5	187.3	31	6.0	5	219.8	35	6.3
	Impacted	BALLYFINBOY	3–4	163.4	26	6.3	4	203.3	29	7.0
		DEAD	3–4	180.5	30	6.0	4	201.1	31	6.5
		SKANE	4	170.1	28	6.1	4	177.9	30	5.9
Groundwater-dominated	Potential reference	BLACK	3–4	131.9	21	6.3	3–4	120.5	18	6.7
		BEHY	4–5	200.5	30	6.7	5	203.9	29	7.0
		ISLAND	4–5	145.3	21	6.9	5	194.0	29	6.7
		MOYREE					4–5	214.4	32	6.7
	Impacted	BUNNANADDAN	3–4	84.1	13	6.5	3–4	108.4	19	5.7
		NANNY	4	165.1	25	6.6	4–5	191.7	28	6.8
		NUENNA	3–4	124.7	19	6.6	4	206.0	30	6.9
Lake outlets	Potential reference	GWEEDORE	3–4	113.5	18	6.3	4–5	156.3	23	6.8
		LEANNAN	3–4	117.7	19	6.2	4–5	197.5	30	6.6
		OWENCARROW	3–4	83.2	14	5.9	4	132.1	20	6.6
	Impacted	ANNALEE	3	122.3	23	5.3	3–4	181.1	30	6.0
		GENTLE OWEN'S STREAM	3–4	133.9	23	5.8	3–4	191.2	32	6.0
		KNAPPAGH	3	119.5	22	5.4	3–4	186.9	30	6.2

Shaded cells indicate site was not sampled in that period. *Q*-values are derived from application of the *Q*-value methodology.

it must be noted, as previously mentioned, that the *Q*-value was not designed to measure the impact of increased acidity.

Two groundwater-dominated sites, one potential reference site (BLACK) and one impacted site (BUNNANADDAN) were consistently rated Q3/3–4, while the other potential reference sites had *Q*-values reflecting high status and the impacted sites had *Q*-values indicating good/moderate status in summer and good/high status in spring. The lower *Q*-value in the BLACK River may be a result of the low DO levels recorded in summer (44.1%) and autumn (35.7%). EPA chemistry data show that this site has consistently low DO percentage saturation, averaging 80% between 2009 and 2012 but fluctuating between a minimum of 59% and maximum of 97% (Table 6.3). Again based on data collected by this study and EPA chemical data (2009–2012), the river did not receive high levels of MRP (0.046 mg P L^{-1}, 95th percentile) or ammonia (0.094 mg N L^{-1}, 95th percentile), but just breached the high-status thresholds for these determinands (0.045 mg P L^{-1} and 0.090 mg N L^{-1}). The maximum value of 0.148 mg P L^{-1} in the EPA 2009–2011 data, however, suggests that there may be occasional pollution episodes here. The BUNNANADDAN, on the other hand, failed to meet good status (Table 6.3). The BLACK also had a biochemical oxygen demand (BOD) value of 1.73 mg O_2 L^{-1} in summer and 2.41 mg O_2 L^{-1} in spring, which is higher than the threshold for good status (≤ 1.5 mg O_2 L^{-1}). However, this is based on one measurement in each season. BOD in the BLACK between 2009 and 2011 ranged from 0.5 to 1.95 mg O_2 L^{-1}, with an average value of 0.65 mg O_2 L^{-1}; it should be noted that the limit of detection for this test is 1 mg O_2 L^{-1} (Table 6.3). Thus, the BOD levels recorded in the present study may not be representative of the site. The BOD of the other potential groundwater-dominated reference sites were between 0.5 and 1.2 mg O_2 L^{-1} (compatible with high status) in summer, but between 2.81 and 3.99 mg O_2 L^{-1} in spring (Table 6.3). Again these readings are much higher than the values recorded by the EPA over the period 2009–2012 (Table 6.3).

Oxygen saturation levels at two of the potential reference groundwater-dominated sites (BEHY and ISLAND), which had *Q*-value scores of 4–5/5, were 81.7% and 99.5%, respectively, in summer, though levels did fluctuate between 66% (BEHY) in summer and 120% (ISLAND) in spring (Table 6.3). No nutrient impact was detected in these sites in this study or in the EPA data (2009–2012). This suggests that the low DO levels in the BLACK are most likely due to natural drivers such as the high input of low-oxygen groundwater.

Interestingly, when a breakdown of the *Q*-value is examined, no Group A pollution-sensitive taxa were recorded at the BLACK, which is understandable given the low DO (Table 6.4). The site also had a low abundance of Groups D and E pollution-tolerant macroinvertebrate taxa. This emphasises the point that if low DO levels are natural, as it appears they are for the BLACK River, then such sites may constitute a separate type requiring separate reference conditions. However, based on the three groundwater-dominated sites used in the present study this cannot presently be justified on the basis of the statistical analysis (see section 5.1) of full community composition or representation of Group A, Group B or Groups A–E. The BLACK River site is an outlier with perhaps a higher groundwater input than the other sites. Further analysis of similar sites would be required to test this.

In terms of the lake outlets, the potential reference sites achieved Q4–5/5 in spring, reflecting high status, while the impacted outlets only achieved moderate to good status (Table 6.2). However, in summer, all lake outlet sites were rated Q3/3–4. The potential reference lake outlet sites consistently met the high status threshold for both MRP and ammonia (see Chapter 2) in this study and during EPA surveys (2009–2012), raising the possibility that the moderate summer *Q*-value may be due to the lake influence, and further suggesting that lake outlets may warrant classification as a sub-type with a reference biological condition that is not a typical Q5 faunal community, as outlined in section 5.1. The reference condition for these sites may therefore require adjustment, perhaps with a lower *Q*-value score than for the ideal reference condition community, and especially when calculating an EQR for reporting to the European Union under the WFD. As will be noted below, further studies are required to determine the environmental conditions, in particular hydromorphology, that structure the communities in these lake outlets, and whether or not the same would apply to outlets from calcareous lakes.

Table 6.3. Nutrient (ammonia, MRP and nitrate), DO percentage saturation and BOD values for groundwater-dominated sites

Status	Site	Summer 2014					Autumn 2014					Spring 2015					EPA Results 2009–2011			
		Ammonia (mg N L^{-1})	MRP (mg P L^{-1})	Nitrate (mg N L^{-1})	DO% saturation	BOD	Ammonia (mg N L^{-1})	MRP (mg P L^{-1})	Nitrate (mg N L^{-1})	DO% saturation	BOD	Ammonia (mg N L^{-1})	MRP (mg P L^{-1})	Nitrate (mg N L^{-1})	DO% saturation	BOD	Ammonia (mg N L^{-1})	MRP (mg P L^{-1})	DO% saturation	BOD
Potential reference	BLACK	0.027	0.013	0.437	44.1	1.73	0.012	0.016	0.304	35.7	0.62	0.016	0.005	1.331	82.0	2.41	0.04 (0.018–0.069)	0.038 (0.0025–0.148)	79.0 (61–95)	0.65 (0.5–1.9)
	BEHY	0.011	0.005	1.055	81.7	1.24	0.01	0.005	0.94	66.4	2.57	0.009	0.011	1.237	92.8	2.81	0.03 (0.005–0.06)	0.017 (0.0025–0.04)	93.0 (90–97)	0.75 (0.5–1.9)
	ISLAND	0.039	0.014	0.348	99.5	0.45	0.02	0.009	0.269	76.4	2.94	0.017	0.005	0.346	120.3	3.99				
	MOYREE											0.008	0.007	0.845	77.9	0.99	0.04 (0.04–0.05)	0.01 (.01–0.012)		0.50 (0.5–0.5)
Impacted	NANNY	0.014	0.003	0.529	100.5	2.4	0.010	0	0.50	68.9	1.92	0.014	0.004	1.897	116.9	3.48				
	NUENNA	0.010	0.010	5.069	140.4	7.91	0.020	0.010	5.49	71	1.70	0.009	0.007	5.825	138.9	6.17	0.02 (0.002–0.05)	0.02 (0.005–0.087)	99.7 (87–128)	0.64 (0.25–2.2)
	BUNNANADDAN	0.138	0.020	1.407	85.7	3.67	0.03	0.02	0.55	63.5	6.78	0.012	0.018	0.635	64.7	1.54	0.03 (0.015–0.07)	0.04 (0.03–0.05)	72.0 (57–88)	0.60 (0.5–1.4)
	GAINE	0.022	0.015	2.654	91.6	1.35	0.04	0.03	3.46	81.2	3.34	0.02	0.01	3.246	118.5	5.98				
	LOUGH LENE–ADEEL STREAM	0.010	0.005	0.793	87.2	3.08	0.02	0.01	1.174	73.1	4.19	0.012	0.002	0.743	78.8	2.42				

RARETYPE sites were sampled once per season. The mean minimum and maximum values recorded by the EPA for the period 2009–2011 are also included.

Table 6.4. EPA *Q*-value ratings for each site and season broken down by the percentage abundance recorded in each *Q*-value sensitivity category (based on the averages of three kick samples in spring and two in summer)

			Summer								Spring							
River type	Status	Site	% A	% B	% C	% *Baetis rhodani*	% D	% E	No. Group A taxa	Q-value	% A	% B	% C	% *Baetis rhodani*	% D	% E	No. Group A taxa	Q-value
Naturally acid	Potential reference	CLOGHOGE	6.4	7.7	85.8	29.3	0.1	0.0	4	4–5	29.9	49	21	0	0	0.00	7	5
		OWENVEAGH A	2.1	35.2	62.8	1.5	0.0	0.0	2	4								
		OWENVEAGH B									29.2	13	57	20	0	0.00	8	5
		DOIRE HOIRBIRT	3.3	6.3	90.2	2.7	0.3	0.0	3	4	13.3	6	79	16	2	0.00	7	5
	Impacted	BUNADOWEN	0.3	17.1	82.6	0.0	0.0	0.0	1	3–4	55.0	24	21	0	0	0.00	6	4–5
		LUGDUFF	1.9	0.6	97.4	0.0	0.0	0.0	2	3–4	49.6	35	15	0	0	0.00	6	4–5
		VARTRY	1.1	9.3	89.2	0.0	0.4	0.0	3	3–4	59.7	31	10	0	0	0.00	4	4–5
Highly calcareous with calcium precipitate	Potential reference	ABBERT									3.1	13	82	11	3	0.00	7	4–5
		CAHER	2.4	32.5	65.1	11.3	0.1	0.0	2	4–5	8.7	22	69	13	0	0.00	6	5
		GLORE	0.3	23.4	70.7	0.3	5.6	0.0	1	4	1.1	15	81	7	3	0.00	7	4–5
		MOY	0.4	27.4	70.9	2.3	1.4	0.0	4	4–5	8.4	25	65	0	1	0.00	4	5
		SHIVEN	2.0	19.6	76.0	0.2	2.4	0.0	3	4–5	6.4	15	68	11	10	0.00	6	5
	Impacted	BALLYFINBOY	0.1	6.2	93.6	2.1	0.1	0.0	1	3–4	3.2	18	79	12	0	0.00	3	4
		DEAD	0.1	10.8	88.3	12.3	0.7	0.0	2	3–4	2.0	3	94	47	0	0.00	6	4
		SKANE	0.2	15.9	82.6	3.1	1.2	0.0	4	4	0.7	9	89	14	1	0.00	5	4
Groundwater-dominated	Potential reference	BLACK	0.0	12.7	87.1	2.5	0.2	0.0	0	3–4	0.0	20	80	7	0	0.00	0	3–4
		BEHY	2.0	9.1	86.4	4.9	2.6	0.0	3	4–5	11.9	6	82	5	0	0.00	8	5
		ISLAND	2.7	25.0	71.9	0.9	0.4	0.0	3	4–5	21.4	20	57	8	2	0.00	6	5
		MOYREE									5.4	17	73	10	4	0.00	4	4–5
	Impacted	BUNNANADDAN	0.0	41.1	58.9	0.7	0.0	0.0	0	3–4	0.0	51	49	14	0	0.00	0	3–4
		NANNY	2.9	12.2	84.9	0.1	0.0	0.0	2	4	5.7	23	71	4	0	0.00	5	4–5
		NUENNA	0.1	9.3	90.6	3.4	0.0	0.0	2	3–4	1.4	48	51	10	0	0.00	6	4
Lake outlets	Potential reference	GWEEDORE	0.3	41.3	53.0	0.2	5.4	0.0	1	3–4	6.3	10	73	17	11	0.00	4	4–5
		LEANNAN	0.2	19.5	62.6	0.0	17.7	0.0	2	3–4	12.5	7	52	3	29	0.00	5	4–5
		OWENCARROW	0.1	33.3	59.8	13.3	6.7	0.0	1	3–4	17.4	1	39	21	43	0.00	3	4–5
	Impacted	ANNALEE	0.0	0.5	96.7	3.6	2.8	0.0	0	3	0.1	6	90	4	4	0.00	4	3–4
		GENTLE OWEN'S STREAM	0.1	1.4	91.0	1.5	7.6	0.0	1	3–4	1.6	2	93	25	3	0.00	3	3–4
		KNAPPAGH	0.0	0.3	92.1	1.4	7.6	0.0	0	3	0.7	2	90	9	7	0.00	2	3–4

6.2.1.2 Average Score Per Taxon

The Whalley, Hawkes, Paisley and Trigg ASPT (average score per taxon) metric replaced the Biological Monitoring Working Party (BMWP) metric developed by Armitage *et al*. (1983) as a measure of general degradation in UK rivers (WFD-UKTAG, 2008). Using the BMWP metric, each taxon present at a site is assigned a tolerance value, determined using expert judgement, ranging from most tolerant to least tolerant on a scale of 1 to 10. The sum of the individual scores gives the BMWP score, which is then divided by the number of scoring taxa to give the Average Score Per Taxon (ASPT). Though calculated in a similar way to BMWP and ASPT, the WHPT ASPT is based on modified BMWP values weighted for abundance (Whalley and Hawkes, 1996, 1997; Paisley *et al.*, 2007). Generally, ASPT scores above 6 are indicative of good water quality.

Most of the WHPT ASPT values were above 6.0 (Table 6.2). In summer, all impacted lake outlet sites were below this value, scoring between 5.3 and 5.8, while one reference site (OWENCARROW) returned a value of 5.9. In spring, two impacted sites, the SKANE (highly calcareous) and BUNNANADDAN (groundwater dominated) returned values of 5.9 and 5.7, respectively. The lack of difference for acidic sites is to be expected, as they are more appropriately assessed using the Acid Water Indicator Community species index (AWICsp) metric, which, unlike ASPT, was developed to detect acid impact (section 6.3.1.2).

6.2.1.3 Acid water indicator community species index

The AWICsp index was developed to detect the impact of acid inputs on river water bodies (Davy-Bowker *et al.*, 2005; Hildrew *et al.*, 2010; Murphy *et al.*, 2013). It has not been routinely applied in Ireland but was one of the metrics used in the HYDROFOR project (Kelly-Quinn *et al.*, 2016). The EPA is currently evaluating this metric for use in monitoring acid waters. The index is based on the relationship between the occurrence of taxa and observed mean pH, and scores taxa between 1 (large abundances of extremely acid-tolerant taxa) and 14 (high abundances of extremely acid-sensitive taxa) (WFD-UKTAG, 2014a). To achieve reliable results using the AWICsp index, sites must meet specific chemical criteria, i.e. pH < 7 and Ca^{2+} concentrations < 4 mg L^{-1} (WFD-UKTAG, 2014a). During development of EQR boundaries for this metric, the influence of natural acidity on the invertebrate community was accounted for by including dissolved organic carbon (DOC) in the reference typology (McFarland, 2010; WFD-UKTAG, 2014a). The humic reference threshold should be used when sites have DOC concentrations ≥ 10 mg L^{-1}. AWICsp scores based on a 3-minute multihabitat kick sample from spring were calculated for all sites that met the criteria outlined above, i.e. all sites in the naturally acid category (Table 6.5), and assessed using the boundaries for the most appropriate reference type (UK (humic), Scotland (clear) and England and Wales

Table 6.5. Chemical criteria and AWICsp scores and classification under the typology outlined by WFD-UKTAG (2014a) for all naturally acid sites sampled in spring

Status	Site	WFD-AWICsp Score	pH	Ca	DOC	Scotland (clear) EQR	England and Wales (clear) EQR	UK humic EQR	Aluminium (µg Al/l)
Potential reference	CLOGHOGE	6.23	5.75	1.03	11.10	Moderate	Moderate	Good[a]	139
	OWENVEAGH	8.21	6.76	2.50	1.92	High	High		16
	DOIRE HOIRBIRT	9.15	6.79	3.80	2.97	High	High		15.5
Impacted	BUNADOWEN	5.36	4.80	1.10	7.19	Bad	Poor		61
	LUGDUFF	5.88	5.25	0.60	0.76	Poor	Poor		42
	VARTRY	5.33	5.68	1.50	0.48	Bad	Poor		9

Where DOC values were < 10 mg L^{-1}, classification was made using either threshold for clear rivers.

[a]Most applicable for this high DOC site.

(clear)) (WFD-UKTAG, 2014a). Generally, AWICsp scores of 7 or above are reflective of good water quality.

Two of the naturally acid sites recorded Acid Water Indicator Community index (AWIC) scores corresponding to high status (OWENVEAGH and DOIRE HOIRBIRT). Of the three reference and three impacted acid sites only one, the CLOGHOGE, recorded DOC levels exceeding 10 mg L^{-1} during the spring and so the humic reference was only applied to this site (Table 6.5). If the point made by Webb (1947) is taken into account, attributing the relatively low pH values in some surface waters in Wicklow to the acidity of the peat being greater than elsewhere in Ireland (i.e. composed of more acid humic material), then the CLOGHOGE might be considered as being of high status. Using the humic reference this site was classed as "good", while the other potential reference sites met the threshold for high status. DOC levels in two other sites increased above this threshold in summer, with one recording a DOC concentration of 29.65 mg L^{-1} (BUNADOWEN). The metric identified that all three impacted sites as "poor" using the clear reference for England and Wales, while two sites (BUNADOWEN and VARTRY) dropped a class to "bad" under the Scottish clear EQR thresholds (Table 6.5).

6.2.2 Macrophyte metrics

The MTR has been adopted as the metric to assess the status of macrophytes in Irish rivers and has been intercalibrated for only one of the common river types, RC4 medium-sized catchment (100–1000 km^2), lowland, 8–25m wide and alkalinity > 0.4 mEq/L. This includes 3 of the 12 Irish river types (Types 31, 32 and 33) and also overlaps with intercalibration type RC6 (EU, 2013). The MTR was developed by Holmes *et al*. (1999) as a method of assessing the trophic status of rivers using macrophytes in the UK. This method was developed to detect the effects of nutrient enrichment and is calculated using a combination of species tolerance scores [species trophic rank (STR), which is a value assigned to each taxon based on its sensitivity or tolerance to nutrient enrichment and species cover values (SCV) (the estimated cover abundance of each taxon)]. The STR scores were assigned using expert judgement and range from 1 to 10 (Holmes *et al.*, 1999). High-scoring plants, e.g. *Marsupella emarginata* (liverwort), are indicative of water bodies low in nutrients, while low-scoring taxa are associated with tolerance of nutrient enrichment or above background nutrient inputs, *e.g. Vaucheria* spp.(algae). As the metric is a qualitative assessment and can be influenced by the physical character of the river, it cannot be used to compare sites that are physically different because some river types such as lowland rivers would naturally score lower than other types. Generally, sites with an MTR of ≥ 65 are unlikely to be eutrophic while those with scores ≤ 25 may be physically damaged or suffering from the impacts of nutrient enrichment or toxicity (Holmes *et al.*, 1999). MTR scores that fall between 25 and 65 indicate sites that are either likely to be eutrophic or at risk of becoming eutrophic, but natural variation in the physical make up of sites may affect the MTR. Where scores fall between 45 and 65, the number of scoring taxa present at a site is extremely important when interpreting the score, because unimpacted sites with a high number of species with STRs between 4 and 6 may bias the MTR to 40–60. This highlights the difficulty in applying bioassessment metrics to rare river types where macrophyte communities may be affected by natural variation in the physical characteristics of the water body. Holmes *et al*. (1999) set out a predictive framework of the MTRs to be expected in unimpacted sites of different river types.

The MTR scores were converted into their corresponding EQR scores to allow comparison against the intercalibrated status bands, but it must be stressed that because only one intercalibration river type [RC4 medium-sized catchment (100–1000 km^2), lowland, 8–25 m wide, alkalinity > 0.4 mEq/L corresponding to Irish types 31, 32 and 33] has been intercalibrated in Ireland, the results must be viewed with caution, especially for the siliceous river types. For the intercalibrated types, the high/good status boundary is an EQR of 0.74 and the good/moderate boundary is 0.62 (EC, 2012). If the metrics can detect impacted sites from potential reference sites then impacted sites would be expected to have lower MTR and higher river macrophyte nutrient index (RMNI) scores than unimpacted sites of the same type.

Generally, the number of scoring taxa recorded was below 10 at the majority of sites, both potential reference and impacted. All naturally acidic sites, both potential reference and impacted, had EQRs indicative of high status when compared against the intercalibrated status. With the exception of two sites, one potential reference and one impacted, they all recorded MTR values ranging between 72 and 94, and RMNI scores (2.22–3.29) reflecting low nutrient conditions and indicating that the sites are not affected by nutrient enrichment (Table 6.6). Holmes *et al.* (1999) set out predicted MTRs of between 68.1 and 83 for high-quality oligo-mesotrophic, oligotrophic and ultra-oligotrophic rivers in the UK. As both metrics are

Table 6.6. MTR, EQR and River Macrophyte Nutrient Index (RMNI) scores for all rivers sampled during the summer season

Type	Status	Site	MTR	EQR[a]	NTAXA	RMNI	NTAXA
Naturally acid	Potential reference	CLOGHOGE	91.20	1.82	6	2.59	4
		OWENVEAGH	87.33	1.75	7	2.22	6
		DOIRE HOIRBIRT	83.64	1.67	3	3.29	3
		OWENGOWLA	58.24	1.16	3	2.50	3
		GLENEALO	76.67	1.53	4	5.03	3
	Impacted	BUNADOWEN	72.14	1.44	4	2.73	3
		LUGDUFF	94.21	1.88	5	3.22	4
		VARTRY	52.08	1.04	4	4.16	4
Highly calcareous with calcium precipitate	Potential reference	ABBERT	25.74	0.51	10	6.72	9
		CAHER	38.57	0.77	8	4.80	6
		GLORE	33.06	0.66	8	6.87	7
		MOY	18.38	0.37	7	6.53	8
		SHIVEN	22.12	0.44	7	6.43	7
	Impacted	BALLYFINBOY	17.78	0.36	6	6.78	6
		DEAD	19.76	0.40	7	6.94	4
		SKANE	33.53	0.67	6	6.40	4
		CLARE	21.47	0.43	5	6.62	7
		DEEL	30.36	0.61	7	6.42	10
Groundwater-dominated	Potential reference	BLACK	30.83	0.62	5	6.27	4
		BEHY	46.14	0.92	12	6.81	9
		ISLAND	31.90	0.64	12	6.29	11
		MOYREE	42.28	0.85	17	6.55	12
	Impacted	BUNNANADDAN	30.68	0.61	9	7.40	6
		NANNY	39.35	0.79	9	7.08	7
		NUENNA	34.62	0.69	6	6.86	6
		GAINE	39.00	0.78	7	7.45	6
		LOUGH LENE–ADEEL STREAM	32.63	0.65	7	7.52	6
Lake outlets	Potential reference	GWEEDORE	66.07	1.32	5	3.63	8
		LEANNAN	60.00	1.20	16	4.15	14
		OWENCARROW	78.28	1.57	8	3.72	7
		NEWPORT	32.69	0.65	7	6.62	9
	Impacted	ANNALEE	30.24	0.60	9	6.54	8
		GENTLE OWEN'S STREAM	30.79	0.62	8	5.92	8
		KNAPPAGH	20.00	0.40	7	7.24	4
		CULFIN	65.85	1.32	8	4.50	6
		FANE	20.00	0.40	7	6.93	6

Status is colour coded as follows: blue, high status; green, good status. Uncoloured cells indicate values below the good/moderate boundary (0.62).

[a]EQR has been determined and status assigned based on the only intercalibrated river type in Ireland (RC4, which encompasses Irish types 31, 32 and 33).

designed to detect impacts of nutrient enrichment, this study confirms that they are not suitable for measuring the effects of increased acidity.

The RMNI was developed by Willby *et al.* (2012) as part of the LEAFPACS prediction and classification system in the UK, and is similar to the MTR in that the association between a plant and nutrients is measured on a scale from 1 to 10. For example, *Vaucheria* (algae), which can tolerate a wide range of conditions from clean headwaters to more enriched lowland rivers, has an RMNI score of 8.41, while *Nardia compressa* (liverwort) is associated with low-nutrient, acid conditions and scores 1.05. However, the sensitivity scores for each taxon are determined statistically using data from more than 6000 surveys, as opposed to MTR species scores which were determined using expert judgement. Using empirical data to determine taxa sensitivity scores produces a more accurate reflection of the position of the plants along a trophic gradient. Under this metric, highly tolerant taxa, i.e. those that are dominant in enriched systems, receive high scores while highly sensitive taxa have a lower score, e.g. an RMNI score of 2 would indicate low-nutrient conditions. As with the MTR, the overall RMNI score is based on the cover-weighted average of the taxa recorded at each site, as the relative proportion cover of tolerant taxa increases with impact (Wilby *et al.*, 2012).

Neither the MTR nor the RMNI could distinguish potential reference sites from impacted sites for highly calcareous rivers with precipitate. For the more alkaline river types such as those in soft limestone, sandstone, mudstone or hard limestone catchments in England and Wales, an MTR score of between 40 and 47 may be expected (Holmes *et al.*, 1999). Of the highly calcareous river sites tested, only three of the potential reference sites recorded scores >25, with none reaching a score of 40 or above (Table 6.6). In terms of EQR and WFD status, only one potential reference site reached high status (CAHER) and one good status (GLORE), with the others recording EQRs well below the good/moderate boundary of 0.62. Three of the impacted sites had MTR values indicative of eutrophic conditions, but two sites (SKANE and DEEL) had values similar to some of the potential reference sites (Table 6.6); only the SKANE had an EQR reflecting good status. With the exception of the CAHER, which recorded an RMNI score of 4.8 indicating relatively good status, all other sites, both potential reference and impacted, scored between 6.42 and 6.94, making it difficult to separate the two groups.

Similarly, the MTR scores for all groundwater sites were between 30 and 46, indicating that all bar the BEHY and MOYREE are likely to be eutrophic. Again, there was no discernible difference between the potential reference and impacted sites, with sites in each category recording EQRs reflective of high and good status despite the fact that they were found to vary significantly in terms of community structure (see section 6.1.2). Using the RMNI, the majority of impacted groundwater sites obtained higher scores (7.08–7.52) than the potential reference sites (6.27–6.82), though the variation was relatively small (Table 6.6).

With the exception of one potential reference (NEWPORT) and one impacted site (CULFIN), potential reference lake outlets received MTR scores of between 60 and 78, indicating that they are not eutrophic, while impacted sites which tended to have concentrations of ammonia and phosphate above the threshold value for good status recorded scores almost half those of the unimpacted sites (20–30) and are defined as at risk of being eutrophic. The same pattern was reflected in the RMNI scores, with unimpacted sites recording lower scores then impacted sites (Table 6.6). Three of the four potential reference sites were deemed to be high status when compared against the intercalibrated status bands, with the NEWPORT classed as good status. Only two impacted sites had EQRs above the good/moderate boundary: the CULFIN had an EQR indicative of high status while GENTLE OWEN'S STREAM was classed as good. Based on these results, the MTR was not effective in detecting impacts for any of the rare river types, even those where community structure has been found to vary significantly between potential reference and impacted sites, as was the case with the groundwater-dominated sites. This metric is currently undergoing further testing and refinement by the EPA prior to being used in status assessment.

6.2.3 Phytobenthos metrics

The Trophic Diatom Index (TDI) was developed to detect organic/nutrient pollution (Kelly and Whitton, 1995; Kelly *et al.*, 2001) and is based on the preference of diatom taxa for varying nutrient concentrations. Taxa are assigned a score between 1 (nutrient sensitive) and 5 (nutrient tolerant). The version of the TDI intercalibrated in Ireland is comparable to TDI version 3 in the UK. The metric has gone through numerous revisions and the metric currently used in the UK is TDI4. TDI4 scores range from 0, indicating very low nutrients, to 100, reflecting very high nutrients (WFD-UKTAG, 2014b). Values between 0 and 50 are reflective of good quality, while scores ranging between 50 and 100 indicate impact. The TDI score expected under reference conditions is predicted using mean annual alkalinity data (WFD-UKTAG, 2014b). The TDI has been successfully intercalibrated for rivers with alkalinities < 150 mg/L $CaCO_3$ (Irish Government, 2015) in both the Northern and Central Baltic GIGs of which Ireland is part. In common with the MTR, however, the TDI has not been applied in the latest WFD status assessments.

As was the case with the macroinvertebrate metrics, the TDI was developed to detect nutrient enrichment and so is unlikely to reliably detect the impact of increased acidity in rivers. This is further complicated by the need to distinguish the effects of natural acidity from anthropogenic impact. Juggins *et al*. (2016) set about developing a metric for assessing acidification using diatoms in UK and Irish rivers. This resulted in the diatom acidification metric (DAM), where taxa are assigned to one of five pH groups depending on their preference, ranging from 1 (pH < 5.0) to 5 (pH > 8). Before the EQR can be calculated, the "expected" DAM value for a site in reference condition must be derived, against which the observed DAM value can be compared. The model for determining the expected DAM value includes the variables TOC and Ca^{2+}, which are largely unaffected by acidification (Juggins and Kelly, 2012; Juggins *et al*., 2016). The tool was validated using time-series data and in most cases the predicted class agreed with the status derived from invertebrate and chemical analyses. This metric has not yet been intercalibrated.

The Trophic Diatom Index version 3 (TDI3), which is comparable to the Irish officially intercalibrated revised TDI metric, and the DAM were calculated using DARLEQ2 software (Kelly *et al*., 2014). The status assigned by the DARLEQ II tool and presented in Table 6.7 must be viewed with caution because it is based on UK thresholds and expected reference conditions (WFD-UKTAG, 2014b). Where alkalinity values were outside the range of the algorithm, which was between 5 and 150 mg $CaCO_3$ L^{-1}, the appropriate limit was set, i.e. where alkalinity was above the upper limit then that value was set for the site, e.g. 150 mg $CaCO_3$ L^{-1}. Guidelines regarding the Irish revised TDI stress that it should only be applied to rivers with alkalinity values < 150 mg $CaCO_3$ L^{-1} (Irish Government, 2015). With the exception of two sites in spring (ABBERT and SHIVEN), all potential reference highly calcareous sites had scores below 50, indicating good quality and "high" status, while the impacted calcareous sites generally had scores > 50, highlighting nutrient impact (Table 6.7). With the exception of the BLACK River in autumn, all potential reference groundwater-dominated sites returned scores in line with good quality and good–high status (Table 6.7). The results of the impacted groundwater-dominated sites were mixed, with only the BUNNANADDAN and NUENNA reporting scores consistently > 50, indicative of moderate status across spring and summer. The GAINE and the LOUGH LENE–ADEEL STREAM appeared to show no impact in spring and summer, while the NANNY generally recorded TDI values ≤ 50 (moderate–high status) (Table 6.7). All potential reference lake outlets had good water quality with TDI values between 2 and 32 (Table 6.7). Three of the impacted lake outlets (ANNALEE, GENTLE OWEN'S STREAM and KNAPPAGH), all of which tended to have elevated ammonia and MRP concentrations (Table 3.2), had TDI scores indicating nutrient enrichment in summer and autumn; ANNALEE and GENTLE OWEN'S STREAM scored below 50 in spring, however, indicating good status (Table 6.7).

As expected, the TDI metric was unable to distinguish the unimpacted from the impacted sites for naturally acid rivers, with all sites recording scores indicative of low-nutrient conditions (Table 6.7). The DAM, however, proved quite effective by consistently classifying two of the impacted sites as poor–moderate, and three of the unimpacted sites as high–good status across all seasons (Table 6.7). The CLOGHOGE, which was labelled as a potential reference site, was classed as "bad" in both spring and autumn, while the OWENGOWLA was classed as "moderate" in summer but "high" in spring and autumn (Table 6.7). Given the episodic nature of acidity in Ireland, and to ensure the DAM tool detects the impact, sampling must be conducted at the appropriate time of year to encompass episodes of low pH and acid neutralising

Table 6.7. Trophic Diatom Index (TDI3) scores, assigned status and DAM classifications for all sites across all seasons calculated using the DARLEQ II tool

			Spring		Summer		Autumn		Spring		Summer		Autumn	
River type	Status	Site	Revised TDI/TDI3	Status	Revised TDI/TDI3	Status	Revised TDI/TDI3	Status	DAM score	DAM classification	DAM score	DAM classification	DAM ccore	DAM classification
Naturally acid	Potential reference	CLOGHOGE	24.8	Good	2.6	High	24.5	Good	0.2	Bad	41.4	High	0.70	Bad
		OWENVEAGH	3.0	High	16.9	High	1.9	High	43.8	Good	44.8	High	47.6	High
		DOIRE HOIRBIRT	7.9	High	19.4	High	6.2	High	60.4	Good	77.1	High	77.9	High
		OWENGOWLA	2.2	High	16.6	High	7.0	High	34.8	High	29.0	Moderate	40.0	High
		GLENEALO	8.0	High	9.8	High	21.1	Good	90.4	High	57.8	High	68.8	High
	Impacted	BUNADOWEN	17.0	High	2.0	High	9.0	High	1.9	Bad	31.7	High	17.8	High
		LUGDUFF	0.7	High	2.9	High	1.8	High	23.5	Moderate	24.0	Moderate	23.9	Moderate
		VARTRY	0.4	High	4.7	High	2.6	High	24.9	Moderate	22.7	Poor	26.8	Moderate
Highly calcareous with calcium precipitate	Potential reference	ABBERT	61.4	Moderate			32.9	High						
		CAHER	31.6	High	28.2	High	26.9	High						
		GLORE	38.7	High	32.4	High	21.3	High						
		MOY	41.0	High	36.0	High	32.9	High						
		SHIVEN	61.4	Moderate	37.5	High	37.3	High						
	Impacted	BALLYFINBOY	62.5	Moderate	75.3	Poor	74.9	Poor						
		DEAD	77.2	Poor	70.9	Poor	78.1	Poor						
		SKANE	53.7	Moderate	81.9	Poor	66.3	Moderate						
		CLARE	50.7	Good	41.0	High	36.5	High						
		DEEL	36.7	High	60.9	Moderate								

Table 6.7. Continued

River type	Status	Site	Spring		Summer		Autumn		Spring		Summer		Autumn	
			Revised TDI/TDI3	Status	Revised TDI/TDI3	Status	Revised TDI/TDI3	Status	DAM score	DAM classification	DAM score	DAM classification	DAM ccore	DAM classification
Groundwater-dominated	Potential reference	BLACK	44.9	Good	27.8	High	77.8	Poor						
		BEHY	38.2	High	30.4	High	33.4	High						
		ISLAND	49.2	Good	37.9	High	34.3	High						
		MOYREE	26.6	High										
	Impacted	BUNNANADDAN	54.5	Moderate	53.4	Moderate	32.0	High						
		NANNY	51.4	Moderate	40.5	High	50.2	Good						
		NUENNA	57.0	Moderate	62.2	Moderate	71.9	Poor						
		GAINE	46.3	Good	51.0	Good								
		LOUGH LENE–ADEEL STREAM	27.6	High	36.0	High	69.3	Poor						
Lake outlet	Potential reference	GWEE	13.9	High	14.3	High	14.8	High						
		LEANN	4.5	High	10.4	High	2.6	High						
		OWENCARROW	4.0	High	13.0	High	4.2	High						
		NEWPORT	21.2	High	26.2	High	32.0	High						
	Impacted	ANNALEE	43.1	Good	64.4	Moderate	56.0	Moderate						
		GENTLE OWEN'S STREAM	47.6	Good	62.2	Moderate	57.2	Moderate						
		KNAPPAGH	62.1	Moderate	68.8	Poor	57.7	Moderate						
		CULFIN	29.2	Good	24.5	Good	5.9	High						
		FANE	57.8	Moderate	39.8	High								

Status is colour coded as follows: blue, high status; green, good status; yellow, moderate status; orange, poor status; red, bad status. Grey cells indicate that site was not sampled during relevant period.

capacity during periods of high flow (Juggins and Kelly, 2012; Juggins *et al.*, 2016).

Overall, the revised TDI metric was able to differentiate quite well between potential reference and impacted sites for the highly calcareous and groundwater-dominated rivers, despite potential reference and impacted sites having similar community structure. The status generated by DARLEQ II must be viewed with caution, however, because it is based on UK thresholds. In addition to this, the alkalinity for these sites was assumed to be 150 mg $CaCO_3 L^{-1}$ when alkalinity was in fact much higher. As a result, further testing is needed to ensure the metric is accurate at higher alkalinities. For the lake outlets the metric classified all potential reference sites as high, but the impacted sites that are known to receive nutrient enrichment were classified as good in spring. Further testing against more appropriate reference conditions is needed before the accuracy of this metric is fully known. Less surprising was the inability of the TDI to detect acid impact in low alkalinity sites, but the DAM was successful in classifying potential reference and impacted acid sites.

6.3 Summary of Key Findings

When all BQEs are assessed together using current metrics it is clear that some metrics for some BQEs were not able to accurately detect impact (Table 6.8), e.g. the MTR could not differentiate potential reference from impacted sites.

In the case of macroinvertebrates, the *Q*-value best distinguished potential reference and impacted highly calcareous sites in summer, and also the groundwater-dominated sites, with the exception of the BLACK site.

The *Q*-value did not separate the potential reference and impacted lake outlet sites in summer. This gives further support for their classification as a biological sub-type. The lack or low abundances of Group A and B fauna, as previously mentioned, coupled with the higher abundances of Sphaeriidae and Hydropsychidae, needs to be taken into account when calculating the *Q*-value for such sites. The reference condition may need to be adjusted for lake outlet sites. An example of such an adjustment using a sliding scale rule is given in section 7.4.

Many of the impacted sites were around the good/moderate boundary for some metrics, making it harder to detect a clear difference from reference sites, particularly in spring when some sites may have experienced some recovery. It is also possible that some of the potential references sites (e.g. BLACK) were not at reference condition.

The macroinvertebrate species-level AWICsp correctly highlighted the impacted acid sites.

Table 6.8. Summary of WFD status assigned to all sites for all BQEs surveyed in spring and summer

Type	Status	Site	Spring				Summer			
			Macroinvertebrates		Phytobenthos		Macroinvertebrates	Macrophytes	Phytobenthos	
			Q-value	AWICsp	Revised TDI (TDI3)	DAM	*Q*-value	MTR	Revised TDI (TDI3)	DAM
Naturally acid	Potential reference	CLOGHOGE	High	Good	Good	Bad	High	High	High	High
		OWENVEAGH	High	High	High	Good	Good	High	High	High
		DOIRE HOIRBIRT	High	High	High	Good	Good	High	High	High
		OWENGOWLA			High	High		High	High	Moderate
		GLENNEALO			High	High		High	High	High
	Impacted	BUNADOWEN	High	Poor–Bad	High	Bad	Moderate	High	High	High
		LUGDUFF	High	Poor–Bad	High	Moderate	Moderate	High	High	Moderate
		VARTRY	High	Poor–Bad	High	Moderate	Moderate	High	High	Poor
Highly calcareous	Potential reference	ABBERT	High		Moderate			Below Good/Moderate Boundary		
		CAHER	High		High		High	High	High	
		GLORE	High		High		Good	Good	High	
		MOY	High		High		High	Below Good/Moderate Boundary	High	
		SHIVEN	High		Moderate		High	Below Good/Moderate Boundary	High	
	Impacted	BALLYFINBOY	Good		Moderate		Moderate	Below Good/Moderate Boundary	Poor	
		DEAD	Good		Poor		Moderate	Below Good/Moderate Boundary	Poor	
		SKANE	Good		Moderate		Good	Good	Poor	
		CLARE			Good			Below Good/Moderate Boundary	High	
		DEEL			High			Moderate	Moderate	

Table 6.8. Continued

Type	Status	Site	Spring				Summer			
			Macroinvertebrates		Phytobenthos		Macroinvertebrates	Macrophytes	Phytobenthos	
			Q-value	AWICsp	Revised TDI (TDI3)	DAM	*Q*-value	MTR	Revised TDI (TDI3)	DAM
Groundwater-dominated	Potential reference	BLACK	Moderate		Good		Moderate	Good/moderate Boundary	High	
		BEHY	High		High		Good	High	High	
		ISLAND	High		Good		Good	Good	High	
		MOYREE	High		High			High		
	Impacted	BUNNANADDAN	Moderate		Moderate		Poor	Moderate	Moderate	
		NANNY	High		Moderate		Good	High	High	
		NUENNA	Good		Moderate		Moderate	Good	Moderate	
		GAINE			Good			High	Good	
		LOUGH LENE–ADEEL STREAM			High			Good	High	
Lake outlets	Potential reference	GWEEDORE	High		High		Moderate	High	High	
		LEANNAN	High		High		Moderate	High	High	
		OWENCARROW	Good		High		Moderate	High	High	
		NEWPORT			High			Good	High	
	Impacted	ANNALEE	Moderate		Good		Poor	Moderate	Moderate	
		GENTLE OWEN'S STREAM	Moderate		Good		Moderate	Good	Moderate	
		KNAPPAGH	Moderate		Moderate		Poor	Below Good/Moderate Boundary	Poor	
		CULFIN			Good			High	Good	
		FANE			Moderate			Below Good/Moderate Boundary	High	

Status is colour coded as follows: blue, high status; green, good status; yellow, moderate status; orange, poor status; red, bad status. Grey cells indicate that site was not sampled during relevant period.

7 Conclusions and Recommendations for Future Research

Some sites used in both the RIVTYPE project and the current study may be of questionable status as reference sites (e.g. BLACK). However, on account of the relatively small number of suitable sites available for the study, it was necessary to retain them in the analysis.

7.1 Objective 1: Characterising the Biological Communities of Rare River Types

The four rare river types investigated in this study could effectively be broken down into two groups based on their geology and hardness. The macroinvertebrate, macrophyte and phytobenthos communities of naturally acid sites were similar to those of soft-water lake outlets, with both hosting taxa with preferences for low-nutrient conditions such as *Tabellaria flocculosa* and *Racomitrium aciculare.* However, filter-feeding taxa such as *Hydropsyche* spp. tended to be more abundant in lake outlets, which is unsurprising given the expected higher transport of organic matter from the lake. Plecoptera, which are known to be highly tolerant of acid conditions, were also more common in naturally acid rivers. The lake outlets surveyed in this study are all fed from soft-water lakes overlying siliceous geology.

At the other end of the hardness scale, highly calcareous rivers with calcium precipitate had similar biological communities to groundwater-dominated rivers. This would indicate that the effect of cementing/calcareous precipitation on the biological communities appears to be lower than those of water chemistry and the underlying geology. This needs further investigation, however, because the degree of deposition and cementing varied across the replicate rivers.

7.2 Objective 2: The Four Potential Rare Types Versus Existing National Types

If rare river types are adequately represented by the currently described national 12-type river typology, then the rare river types would be expected to host similar biological communities to the national types. From statistical analysis, naturally acid sites would be expected to be similar to Types 11,12,13 and 14, depending on their slope; these types all have siliceous geology/low hardness and low slope. As the lake outlet sites examined all flow from soft-water lakes they would be expected to host communities similar to the acid sites, i.e. Types 11 to 14, and particularly Type 11 (based on geology and slope). Highly calcareous and groundwater-dominated sites would be expected to fit within Types 31 and 32, which have calcareous geology and high hardness concentrations. All rare types would vary from mixed geology sites. In terms of testing against the national types, data were used from the RIVTYPE project which developed the national typology and some types, e.g. Types 24 and 31, were represented by only one site. In this case any comparisons with these types had to be ignored.

The results show that for all the BQEs, highly calcareous sites with calcium precipitate and groundwater-dominated rivers all hosted communities similar to those present in national Types 31 and 32. This is not unexpected as two of the highly calcareous sites (CAHER and MOY2) used in this study were analysed in the original RIVTYPE report. However, as four replicate sites from each rare river category were included in this study, this outcome serves to further validate the national types and typology. The biological communities of the naturally acid sites and soft-water lake outlets were similar across all BQEs, but how they compared with national types depended on the particular BQE being analysed. The macroinvertebrate communities found in naturally acid sites were similar to those of the siliceous national types (Types 11 to 14), as would be expected, while lake outlet communities varied from their corresponding national type. Alternatively, the macrophyte communities of both naturally acid and lake outlets were similar to siliceous river types (Types 11 and 14, and 13 and 14, respectively). In terms of the phytobenthos communities, the lake outlets and naturally acid sites generally hosted communities distinct from all other types. The main environmental driver influencing the structure of the biological communities was consistently and unsurprisingly total hardness.

Based on the results from the present investigation, only the soft-water lake outlets present the strongest evidence for their designation as a separate biological sub-type. Under the national typology they would be classed as Type 11 (based on geology and slope). In terms of their macroinvertebrate community structure they hosted communities that were significantly different to the currently described communities for Type 11, and indeed all siliceous types, in spring but not summer. The lake outlets hosted macrophyte communities similar to siliceous types with different slopes but varied from Type 11, while the phytobenthos assemblages were distinct from the siliceous types across all sampling seasons. The analysis based on *Q*-value indicator groups also clearly distinguished them from Type 11.

Recommendation: Future sampling of lake outlet sites should be carried out in both spring and summer to better understand seasonal changes. Sampling at distances from the lake outlet would be useful to detect the limit of the lake effect on the aquatic biota. Since all the lake outlet sites were from low-alkalinity waters, further study is required to validate if this holds true for lake outlets emanating from higher-conductivity lakes overlying non-siliceous geology. Reference conditions for outflows from hard-water lakes may be more difficult to assess but there may be sufficient information in the archives to add to the dataset here.

Further investigation is required to determine the drivers (flow, hydromorphology, food availability, etc.) of the differences detected.

The three groundwater-dominated sites used in the present study cannot presently be justified as a separate type/sub-type on the basis of the statistical analysis (see section 5.1) of full community composition, or representation of Group A, Group B or Groups A–E *Q*-value taxa. The BLACK River site is an outlier, perhaps with a groundwater input different from the other sites, or with anthropogenic impacts.

Recommendation: Further biological and hydrochemical sampling of additional confined/low groundwater vulnerability sites is recommended.

7.3 Objective 3: Can Current Metrics Accurately Determine Status of Rare River Types?

The only rare river category to show a consistent nutrient impact in terms of hydrochemistry were the impacted lake outlet sites, which consistently exceeded the good status thresholds (summer and autumn) for either ammonia or MRP. This trend has also seen in EPA chemistry data from 2009 to 2012. Of the highly calcareous sites only two (DEAD and SKANE) showed elevated nutrients in summer and autumn and one in spring, but EPA chemistry data (2009–2012) again showed these sites have been impacted in the past. The acid sites did not exceed the good status threshold for nitrogen and phosphorus, which is not unusual given they are more at risk of acid impact than nutrient enrichment. In the case of the naturally acid sites this is to be expected as nutrient enrichment does not generally occur in acid-sensitive catchments, except where felling or planting of commercial forest plantations are underway (Kelly-Quinn *et al.*, 2016). The only groundwater-dominated site with elevated nutrients was the BUNNANADDAN. The fact that no physico-chemical degradation was observed in many of the impacted sites implies that those sites may be only moderately polluted, i.e. they fall between good and moderate status, which is possibly the most difficult boundary for metrics to detect. However, the hydrochemical sampling was limited to three dates and may have missed pollutant inputs.

The EPA *Q*-value rating scheme has been effective in detecting organic/nutrient pollution in Irish rivers. When applied to the rare river types it correctly identified impacted from unimpacted highly calcareous sites in both summer and spring. Similarly, potential reference lake outlet sites were correctly designated as either high or good status in spring but not in summer. For groundwater-dominated sites, two out of the three potential reference sites were classed as high status; the exception was the BLACK. As discussed previously, the low DO levels in this site appear to be driven by the input of low-oxygen groundwater and the reference condition for confined groundwater sites may need to be revised to allow good/high status to be assigned in spite of the absence of Class A oxygen-sensitive taxa. However, this cannot be supported by the results from the present study because of the limited number of references sites with potential for low-oxygen input from groundwater.

Recommendation: Further physico-chemical and biological investigation of confined/low groundwater vulnerability sites similar to the BLACK River is recommended.

Apart from highlighting the impacted lake outlets in summer, the WHPT ASPT metric was not effective in differentiating reference from impacted sites. For some groups, the need for a more appropriate metric to detect specific stressors affecting the various river types was emphasised. For example, during the spring all naturally acid sites (impacted and unimpacted) were classed as high status using *Q*-value but, when the AWICsp metric was applied, the impacted sites were correctly classified as poor quality.

The macrophyte community structure was found to vary significantly between unimpacted and impacted groundwater-dominated and lake outlet sites. While both the MTR index and the RMNI detected this difference for the lake outlets, they failed to do so for the groundwater-dominated sites. Despite the structural variation detected statistically by PERMANOVA, neither metric clearly distinguished groundwater-dominated impacted from unimpacted sites, though the RMNI did score impacted sites slightly higher, indicating higher nutrient levels. The inability of the MTR to detect impact in naturally acid sites must be expected as it is designed to detect nutrient enrichment and not the impact of acid inputs. The lake outlets were the only potential rare river type where both macrophyte metrics detected a clear difference between unimpacted and impacted sites. Although successfully intercalibrated for one river type in the Central Baltic GIG (RC4, which is equivalent to Types 31, 32 and 33 in the Irish typology, with these types also largely corresponding to Central Baltic GIG Type RC6), the MTR has not been applied in the latest status assessments. The results discussed above highlight the need for further testing and refinement of this metric before it can be applied to Irish rivers and intercalibrated for other river types. The use of macrophytes as indicators for detecting nutrient enrichment has been criticised, with some reporting that more than 90% of the variability observed using some metrics were typically attributed to factors other than human pressure (Demars *et al.*, 2012). The strong influence of environmental factors such as geology, alkalinity and flow in structuring macrophyte communities, coupled with the high plasticity of most macrophytes, can make it difficult to disentangle the effects of nutrient enrichment on plant distribution (Willby *et al.*, 2012). In the UK, the river macrophyte typology is based on alkalinity and slope, which was found to strongly influence macrophyte communities (Willby *et al.*, 2012). The issue concerning the MTR is a broader question of whether or not macrophytes should be used as indicators of specific pressures. Therefore, it may be more appropriate to use macrophytes as indicators of general degradation rather than for detecting a specific environmental pressure such as nutrient enrichment (Willby *et al.*, 2012).

Recommendation: The indicator/metric potential of macrophytes – as a component of the WFD Annex V 1.1.1 BQE "Composition and abundance of aquatic flora" – needs to be clarified by further research.

With the exception of the naturally acid sites, the revised TDI (TDI3) appeared to correctly class and separate the majority of sites. The DAM proved very effective in distinguishing impacted from unimpacted naturally acid sites, and so should be considered for use in the future to assess acid impact. It highlighted the fact that one reference site (CLOGHOGE) may not be at reference condition, or that further refinement of the status boundaries may be needed to accommodate sites similar to the CLOGHOGE, since no physico-chemical impacts were detected at this site. It is noteworthy that the EPA operational site on the Cloghoge Brook fails on pH (C. Bradley, January 2017, personal communication). Implementing and refining this metric to ensure it can reliably detect episodic acidification would solve the problem of the TDI being ineffective at low alkalinities ($< 5\,mg\,CaCO_3\,L^{-1}$). The question with the revised TDI is whether the alkalinity thresholds, i.e. ($5–150\,mg\,CaCO_3\,L^{-1}$), are sufficiently wide to reliably assess high-alkalinity rivers.

7.4 Key Recommendations for Stakeholders: Policy and Implementation

Based on the analysis presented here, only the lake outlet sites had biological communities that were sufficiently distinct from the biological communities described for the current 12 national river types to warrant consideration as a biological sub-type. The outflowing phytoplankton enhances the number of filter-feeders such as *Hydropsyche* below a lake outflow. These sites were also characterised by high abundances of Sphaeriidae and an absence of *Rhithrogena* and *Ecdyonurus.* The reference condition may need to be adjusted for lake outlet sites. An example of such an adjustment using a sliding scale rule is given in Table 7.1. Taking the macroinvertebrate *Q*-value as an example, a typology with a maximum attainable "face-value" *Q*-value of Q3–4 is assigned an EQR of 1.0 to take into account that some taxa may be naturally excluded. This applies successively down the status classes, e.g. an EQR of 0.8 for Q3 is good status, and an EQR of 0.4 if assigned Q2 is poor status in this scaled version. Similarly, in the right-hand column of Table 7.1 a reference *Q*-value of Q3 for this notional typology will result in a smaller range of potential EQRs: a site achieving a face-value Q2–3 is assigned good status in this case – because it has not departed too dramatically from the reference condition for the type – and a site with Q2 will achieve moderate status with an EQR of 0.5. This scaling or normalisation process may be applied to metrics for any BQE or pressure once the anchor values for reference conditions are known.

Below is the scaling formula, where x' is the scaled EQR and x is the metric (in this case, *Q*-value):

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)}$$

The premise is that max(x) is the metric's value at reference conditions for this typology, and min(x) is the lowest value possible. The new max–min range is scaled from 1 to 0 and status (high/good/moderate/poor/bad) is assigned to the new reduced range based on expert opinion, taking chemistry and biological factors into account and using standard guidance from the Common Implementation Strategy intercalibration documents from ECOSTAT (e.g. EC, 2011).

Adjustments to the reference condition need to be made on a case-by-case basis as the effect of natural variation may depend on the degree of that variation. Furthermore, in the case of lake outlets, the influence of the lake will most likely diminish in a downstream direction. With regard to macrophyte metrics, the taxa identified as being present only in potential reference lake outlets, such as *Marsupella* sp. and *Batrachospermum*, may prove of limited use as their absence from impacted sites is more likely due to lowland location.

In situations where calcification of the substrate occurs, it was thought that the reduction in under-stone habitat could lead to the complete elimination of ephemeropteran species, but this was not found to be the case. Given that three of the four potential reference sites all had at least small numbers of *Ecdyonurus* and *Heptagenia,* the presence of two category A *Q*-value taxa in summer, even if at low density, may be the new Q5 criterion for such sites. The extent of the calcification may also be a factor, since some of the replicate sites had extensive substrate cementing while others had more moderate calcification of the substrate. It was also interesting that in the GLORE, whose putative reference condition is perhaps a little less warranted than those of the other three, *E. danica* was found; this is often a "substitute" for *Ecdyonurus* in the slower-flowing,

Table 7.1. Suggested scaling method for EQRs, where reference communities have lower maximum reference *Q*-values, when compared with a "normal" river type's reference community

Status	Q-value	EQR	Status	Q-value	EQR	Status	Q-value	EQR
H	5	1.00	H	3–4	1.00	H	3	1.00
H	4–5	0.88	G	3	0.80	G	2–3	0.75
G	4	0.75	M	2–3	0.60	M	2	0.50
M	3–4	0.63	P	2	0.40	P	1–2	0.25
P	3	0.50	B	**1–2**	**0.20**	B	**1**	**0.00**
P	2–3	0.38	B	**1**	**0.00**			
B	**2**	**0.25**						
B	**1–2**	**0.13**						
B	**1**	**0.00**						

B, Bad status; G, good status; H, high status; M, moderate status; P, poor status.

non-riffle, midland calcareous rivers. The revised TDI was moderately effective in assessing these high-alkalinity sites, but as the alkalinity of 150 mg $CaCO_3 L^{-1}$ was applied in the calculation to sites with much higher alkalinity, the accuracy of the result is unknown, thus highlighting the need to further develop the metric. The EPA is currently refining this metric across a range of alkalinities.

In the case of the naturally acidic rivers, the presence of acid-sensitive *Baetis* sp. and *A. muticus* is useful. Category A macroinvertebrate taxa can be expected at these sites, and where anthropogenic acidity issues are suspected, the AWIC metric is more sensitive and more appropriate for accurate assessment. Although the UK AWIC status boundaries appeared to accurately classify the sites above and detect impact in the HYDROFOR project (Kelly-Quinn *et al.*, 2016), the reference typology and status boundaries need to be defined for Irish rivers. Similarly, the DAM proved very useful in detecting anthropogenic acidity and should be readily usable in Ireland, as it was developed using data from the FORWATER project conducted in Ireland (Kelly-Quinn *et al.*, 2008).

In all cases, the MTR proved unreliable in differentiating potential reference from impacted sites. Although some taxa were found only in potential reference sites for groundwater-dominated rivers and lake outlets, their absence from impacted examples of these types may be a reflection of flow conditions and available substrate rather than the natural variability caused by groundwater input and lake influences. When deriving "expected" values for river types for a specific BQE and pressure, the typology should incorporate the abiotic factors that structure the community of that element, but only those that are unaffected by the pressure if they are not currently part of the overall national typology. Examples of this are the inclusion of alkalinity in the typology for macrophytes in the UK when developing a metric for nutrient enrichment. DOC was included in the typology for acid-sensitive rivers when developing metrics to detect acidification (AWIC). Juggins *et al*. (2016) used TOC and Ca^{2+} to develop the typology upon which reference conditions could be determined for the DAM in the UK and Ireland. It is at this juncture that refining the typology may prove most beneficial in ensuring that rare river types are appropriately assessed.

Overall, this work provides a solid foundation for making a series of decisions to improve assessment of the true ecological status of sites in rare river types.

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Abbreviations

ANOSIM	Analysis of similarity
ANOVA	Analysis of variance
ASPT	Average Score Per Taxon
AWIC	Acid Water Indicator Community index
AWICsp	Acid Water Indicator Community species (index)
BMWP	Biological Monitoring Working Party
BOD	Biochemical oxygen demand
BQE	Biological quality element
CEN	European Committee for Standardization
DAM	Diatom Acidification Metric
dbRDA	Distance-based redundancy analysis
DISTLM	Distance-based linear modelling
DO	Dissolved oxygen
DOC	Dissolved organic carbon
d/s	Downstream
EPA	Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera and Trichoptera
EQR	Ecological quality ratio
EQS	Environmental quality standard
GIG	Geographical intercalibration group
MRP	Molybdate reactive phosphorus
MRPP	Multi-response permutation procedures
MTR	Mean Trophic Rank
NTAXA	Number of scoring taxa recorded
PERMANOVA	Permutational multivariate analysis of variance
RHAT	River Hydromorphology Assessment Technique
RMNI	River Macrophyte Nutrient Index
SE	Standard error
SIMPER	Similarity of percentages
STR	Species Trophic Rank
TDI	Trophic Diatom Index
TWINSPAN	Two-way indicator species analysis
u/s	Upstream
WFD	Water Framework Directive
WHPT	Whalley, Hawkes, Paisley and Trigg (metric)

Appendix 1 National Irish River Types (EPA, 2005)

Code	Catchment geology (% bedrock in upstream catchment by type)	Description	Hardness (mg $CaCO_3$ L^{-1})
1	100% siliceous	Soft water	< 35
2	1–25% calcareous (mixed geology)	Medium hardness	35–100
3	> 25% calcareous	Hard water	> 100
Code	**Slope (m m^{-1})**	**Description**	
1	≤ 0.005	Low slope	
2	0.005–0.02	Medium slope	
3	0.02–0.04	High slope	
4	> 0.04	Very high slope	

Example of type codes: the two codes from above are combined in order of geology (first digit) and slope (second digit), e.g. a code of 31 indicates a calcareous low-slope site. From *The Characterisation and Analysis of Ireland's River Basin Districts. National Summary Report* (EPA, 2005).

Appendix 2 EPA Code, River Name, Location, Site Code and Summary of the Hydrochemical Results for the 50 RIVTYPE Sites (Kelly-Quinn *et al*., 2005)

EPA code	River name	Location	GPS reading	Site code		pH	DO (mg L^{-1} O_2)	% Saturation	Cond (µS cm^{-1})	Alkalinity (mg L^{-1} $CaCO_3$)	Total hardness (mg L^{-1} $CaCO_3$)	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	K^+ (mg L^{-1})	Na^+ (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})
30A020110	AILLE (Mayo)	Bridge NW of Claureen – E of Killavally	M12252 80132	AILLE1	Mean	7.72	12.09	109	209	65.53	59.61	17.84	3.66	1.12	8.73	16.98	3.60
					Min.	6.70	10.56	107	58	11.60	21.61	6.17	1.51	0.95	5.90	7.78	2.41
					Max.	8.42	13.80	111	299	100.00	82.98	24.32	5.41	1.30	10.83	25.99	4.65
40B010200	BALLYHALLAN	Bridge u/s Clonmany River	C36887 46019	BHALL1	Mean	7.56	11.73	106	136	18.00	41.86	11.31	3.31	1.30	12.49	28.61	4.12
					Min.	7.35	11.06	90	112	8.13	23.31	5.01	2.63	0.62	11.35	17.99	3.97
					Max.	7.86	12.95	118	178	27.87	60.41	17.61	3.99	1.98	13.63	39.23	4.27
34B080300	BEHY (North Mayo)	Bridge SW of Oatlands House	G32513 17108	BEHYM1	Mean	7.93	12.30	106	418	212.50	258.76	75.35	17.15	2.06	20.03	29.84	9.09
					Min.	7.60	11.29	95	294	192.50	166.53	43.89	13.82	1.78	12.75	17.43	5.49
					Max.	8.20	14.20	115	547	232.50	350.99	106.8	20.47	2.35	27.31	42.25	12.69
25B030080	BILBOA	Bridge u/s Blackboy Br – Bilboa Bridge	R81537 51863	BILBO1	Mean	7.93	12.05	110	180	68.7	62.43	17.39	4.61	0.51	6.74	13.31	3.76
					Min.	7.78	11.40	108	148	52.39	48.62	14.21	3.19	0.50	4.69	12.97	3.48
					Max.	8.04	12.70	113	214	85.00	76.23	20.57	6.04	0.51	8.78	13.64	4.03
21B030100	BLACKWATER (Kerry)	Gearha Bridge	V78267 72138	BLKWA1	Mean	6.86	11.34	101	76	10.29	29.39	7.17	2.79	0.41	7.82	16.84	2.54
					Min.	6.73	10.26	101	64	6.57	19.22	4.56	1.90	0.21	7.77	12.21	2.49
					Max.	7.00	12.30	102	83	14.01	39.57	9.77	3.68	0.62	7.87	21.46	2.6
29B040300	BOLEYNEENDORRISH	Bridge N of Doonally West – Kenny's Bridge	M51419 05626	BOLND1	Mean	7.58	12.35	107	163	58.21	55.36	16.89	3.20	0.60	9.01	15.59	2.98
					Min.	7.04	10.00	93	112	29.62	38.1	10.77	2.72	0.19	7.85	12.56	2.84
					Max.	8.13	16.90	131	247	87.50	72.62	23.01	3.68	1.01	10.17	18.61	3.11
35B060010	BONET	Bridge u/s Glenade Lough	G82228 47138	BONET1	Mean	8.27	12.43	112	288	77.33	61.88	21.54	1.96	1.07	6.28	15.73	3.71
					Min.	8.17	11.70	106	256	75.00	48.53	16.88	1.55	0.33	5.75	11.93	3.70
					Max.	8.43	13.10	121	351	79.66	84.55	29.54	2.62	1.81	7.20	19.53	3.72
25B100100	BOW	Bow River Bridge	R66568 87096	BOW1	Mean	7.97	12.13	104	158	45.60	62.62	18.83	3.79		8.46	14.11	
					Min.	7.56	10.02	95	143	34.48	62.35	17.57	3.09		7.46	11.29	
					Max.	8.56	13.20	110	168	56.71	62.89	20.10	4.49		9.46	16.92	

EPA code	River name	Location	GPS reading	Site code		pH	DO (mg L^{-1} O_2)	% Saturation	Cond (µS cm^{-1})	Alkalinity (mg L^{-1} $CaCO_3$)	Total hardness (mg L^{-1} $CaCO_3$)	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	K^{+} (mg L^{-1})	Na^{+} (mg L^{-1})	Cl^{-} (mg L^{-1})	SO_4^{2-} (mg L^{-1})
27B020300	BROADFORD	Just u/s South Branch confluence – Scotts Bridge	R61044 72104	BROAD1	Mean	7.93	12.23	105	145	30.48	39.8	10.15	3.51		7.85	13.62	
					Min.	7.68	11.70	103	139	26.94	38.77	10.12	3.24		6.88	12.4	
					Max.	8.43	12.50	107	152	34.02	40.84	10.18	3.78		8.82	14.84	
28C010200	CAHER (Clare)	Bridge 2 km d/s Formoyle	M16322 08228	CAHER1	Mean	8.13	12.35	110	419	175.00	125.2	40.63	5.77		12.82	32.15	
					Min.	7.46	10.03	93	355	135.00	86.67	30.71	2.43		11.92	30.57	
					Max.	8.78	14.60	128	452	215.00	163.74	50.55	9.11		13.72	33.74	
25G210010	CAMCOR	Bridge 3 km E of Longford	N20100 01428	CAMCO1	Mean	7.05	12.36	55	118	43.67	52.63	15.40	3.44		6.65	10.41	
					Min.	6.81	11.22	12	71	23.59	38.54	11.27	2.53		6.02	9.67	
					Max.	7.20	13.5	99	165	63.75	66.71	19.54	4.35		7.27	11.15	
22C020600	CARAGH	Blackstones Bridge	V70947 86350	CARAG1	Mean	6.97	11.11	101	72	9.24	11.62	6.13	1.90		6.94	14.74	
					Min.	6.52	9.71	100	64	5.81	2.37	5.23	1.90		6.29	10.22	
					Max.	7.35	12.3	103	80	11.76	20.88	7.03	1.90		7.59	19.25	
34C050030	CLYDAGH (Castlebar)	Bridge u/s confluence of East Branch	M14276 96564	CLYDA1	Mean	7.88	12.49	108	138	10.80	41.14	11.8	2.84		8.83	17.87	
					Min.	7.41	10.72	106	62	10.80	19.05	4.68	1.79		5.4	7.91	
					Max.	8.54	13.80	109	223	10.80	54.58	16.93	3.52		10.9	28.77	
38C060100	CRONANIV BURN	Bridge u/s Dunlewy Lough	B92899 18963	CBURN1	Mean	6.85	12.12	108	73	2.32	19.39	6.26	2.33		10.3	22.59	
					Min.	6.18	10.13	94	58	0.17	19.27	2.99	1.85		8.38	15.78	
					Max.	7.27	13.90	123	95	4.47	19.52	11.71	2.87		11.54	29.41	
09D010010	DODDER	1.3 km u/s reservoir u/s of tributary	O11015 20233	DODDE1	Mean	5.60	12.05	106	38	3.69	25.13	9.93	1.59		5.25	5.39	
					Min.	4.97	11.35	99	32	3.69	3.24	1.47	0.76		4.59	4.44	
					Max.	6.12	13.30	110	41	3.69	48.04	14.36	2.96		6.32	6.6	
25D070400	DUNIRY	Just u/s Cappagh River confluence, SW of Duniry	M72142 09014	DUNIR1	Mean	7.32	12.20	104	244	88.00	76.32	25.88	2.84		8.47	17.62	
					Min.	6.68	12.20	104	232	73.5	69.58	23.76	2.49		7.21	12.03	
					Max.	7.70	12.20	104	266	102.5	83.07	28.01	3.19		9.72	23.21	

EPA code	River name	Location	GPS reading	Site code		pH	DO (mg L⁻¹ O_2)	% Saturation	Cond (µS cm⁻¹)	Alkalinity (mg L⁻¹ $CaCO_3$)	Total hardness (mg L⁻¹ $CaCO_3$)	Ca^{2+} (mg L⁻¹)	Mg^{2+} (mg L⁻¹)	K^+ (mg L⁻¹)	Na^+ (mg L⁻¹)	Cl^- (mg L⁻¹)	SO_4^{2-} (mg L⁻¹)
35D060200	DUNNEILL	Donaghintraine Bridge	G43852 34411	DUNNE1	Mean	8.21	12.31	105	373	147.08	87.65	28.07	4.26		7.78	12.01	
					Min.	7.66	11.24	98	144	46.66	38.11	11.97	1.99		6.17	8.37	
					Max.	8.69	13.90	115	523	247.5	137.2	44.17	6.54		9.39	15.66	
35D060100	DUNNEILL	Bridge 2 km u/s Dromore West	G43769 32718	DUNNE2	Mean	8.05	12.13	102	241	17.47	64.78	19.91	3.66		7.43	11.71	
					Min.	7.58	10.74	100	74	17.47	30.7	9.43	1.73		5.91	0.64	
					Max.	8.40	14.40	104	355	17.47	98.86	30.38	5.58		8.94	22.79	
37E030300	EANY WATER	Just d/s Eany Beg/More confluence	G84054 81396	EANYW1	Mean	6.97	11.45	107	149	15.57	37.84	12.03	1.89		7.93	16.34	
					Min.	6.31	10.11	101	114	10.53	31.18	9.4	1.87		6.68	9.05	
					Max.	7.55	13.60	118	214	20.61	44.51	14.67	1.91		9.18	23.63	
37E020250	EANYMORE WATER	Eanymore Bridge	G84570 81582	EANYM1	Mean	7.01	12.53	114	117	17.44	23.6	6.25	1.94		8.17	21.06	
					Min.	6.80	10.65	108	111	14.06	22.48	5.44	1.73		6.32	8.24	
					Max.	7.22	13.65	119	122	20.82	24.72	7.06	2.16		10.02	33.89	
37E020150	EANYMORE WATER	Bridge SW of Letterbarra	G88298 82357	EANYM2	Mean	7.35	13.25	116	106	17.08	35.67	10.68	2.19		8.45	16.43	
					Min.	7.22	11.60	110	86	15.88	23.61	6.42	1.84		6.83	9.45	
					Max.	7.55	15.65	128	120	18.27	47.72	14.93	2.54		10.06	23.42	
22F040100	FINOW	Bridge 0.3 km d/s Lough Guitane – Finow Bridge	W01152 85692	FINOW1	Mean	6.66	11.89	107	52	3.69	13.90	3.23	1.42		6.26	11.52	
					Min.	6.27	9.98	99	49	2.65	12.30	2.64	1.39		6.25	10.14	
					Max.	6.96	14.40	119	58	4.72	15.50	3.82	1.45		6.28	12.91	
22F020100	FLESK (Kerry)	Bridge near Glenflesk – Curreal Bridge	W06619 85385	FLESK1	Mean	6.31	11.28	94	84	18.5	22.44	5.63	2.04		7.39	14.17	
					Min.	5.60	10.75	94	63	13.4	19.18	4.44	1.97		6.89	10.07	
					Max.	6.69	11.80	94	97	23.6	25.69	6.82	2.11		7.88	18.26	
18F050030	FUNSHION	Brackbaun Bridge – NE of Kilbeheny	R88965 16817	FUNSH1	Mean	7.60	11.37	101	88	27.5	37.09	10.63	2.56		6.09	9.92	
					Min.	7.43	10.54	100	64	27.39	25.91	6.56	2.31		5.62	9.13	
					Max.	7.92	12.2	101	101	27.61	48.28	14.70	2.81		6.56	10.71	

EPA code	River name	Location	GPS reading	Site code		pH	DO (mg L^{-1} O_2)	% Saturation	Cond (µS cm^{-1})	Alkalinity (mg L^{-1} $CaCO_3$)	Total hardness (mg L^{-1} $CaCO_3$)	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	K^{+} (mg L^{-1})	Na^{+} (mg L^{-1})	Cl^{-} (mg L^{-1})	SO_4^{2-} (mg L^{-1})
10G010200	GLENCREE	Bridge u/s Dargle River confluence	O20272 14884	GCREE1	Mean	7.04	11.48	103	79	18.61	25.51	7.60	1.58		6.41	7.57	
					Min.	6.50	10.18	99	63	18.61	10.23	2.78	0.80		3.52	6.78	
					Max.	7.49	12.95	109	89	18.61	42.18	13.48	2.07		9.92	8.35	
28G020200	GLENDINE (Clare)	Knockloskeraun Bridge, S of Milltown Malbay	R05316 77429	GDINE1	Mean	7.23	11.42	104	202	22.55	46.09	12.77	3.45		15.4	39.99	
					Min.	6.51	10.50	100	190	14.49	36.48	8.98	3.41		13.59	24.67	
					Max.	8.00	12.10	108	216	28.17	55.71	16.56	3.49		17.2	55.31	
10G050100	GLENEALO	Ford u/s Upper Lake	T08822 96227	GNEAL1	Mean	6.32	11.29	100	28	3.39	9.01	1.85	1.07		4.57	5.09	
					Min.	5.11	10.70	93	24	2.18	7.92	1.20	0.89		4.28	4.25	
					Max.	7.12	11.70	106	33	4.61	9.88	2.23	1.20		4.85	5.94	
21G030100	GLENGARRIFF	Bridge W of Skehil	V89708 58327	GGARF1	Mean	7.07	11.66	102	77	8.31	22.20	5.22	2.23		9.54	18.01	
					Min.	6.45	10.43	97	67	6.75	21.21	5.10	1.92		8.63	17.2	
					Max.	7.40	13.40	110	89	9.87	23.20	5.33	2.54		10.44	18.81	
27G020600	GOURNA	Bridge u/s Owenogarney River confluence	R48104 64137	GOURN1	Mean	7.72	11.73	103	228	65.63	70.48	22.16	3.98		6.99	17.55	
					Min.	7.35	11.26	97	218	65	70.48	21.66	3.98		4.84	8.28	
					Max.	8.33	12.2	109	241	66.25	70.48	22.67	3.98		9.13	26.82	
35G030100	GOWLAN (Sligo)	Ford u/s Easky River confluence	G38816 26532	GOWLA1	Mean	7.54	11.06	103	191	57.52	46.66	14.52	2.52		6.63	6.88	
					Min.	6.64	10.22	97	46	2.87	8.96	2.40	0.72		4.41	3.38	
					Max.	8.07	12.2	114	294	122.19	83.03	26.17	4.30		8.32	11.98	
25G040025	GRANEY (Shannon)	Caher Bridge, S of Lough Graney	R55410 90143	GRANE1	Mean	7.80	12.62	106	204	80.56	77.9	23.28	4.80		7.58	12.99	
					Min.	7.38	10.23	95	158	58.62	58.09	17.65	3.40		5.54	8.55	
					Max.	8.12	15.6	122	281	102.5	97.7	28.91	6.20		9.62	17.42	
38G020100	GWEEBARRA	Pollglass Bridge	B94839 13968	GWBAR1	Mean	6.80	12.53	110	68	2.29	26.72	6.37	2.63		8.93	14.20	
					Min.	6.27	11.32	103	60	–0.19	11.08	1.82	1.59		6.94	4.15	
					Max.	7.38	13.26	115	80	4.76	39.47	11.92	4.52		12.04	27.19	
33K010200	KEERGLEN	Bridge NE of Doondragon	G09386 33317	KEERG1	Mean	7.62	12.26	106	183	44.95	50.77	15.62	2.85		11.49	23.45	
					Min.	7.15	11.26	101	132	27.4	31.09	9.59	1.74		9.08	11.27	
					Max.	8.16	13.8	111	243	62.5	65.18	19.63	3.93		14.85	35.63	

EPA code	River name	Location	GPS reading	Site code		pH	DO (mg L⁻¹ O_2)	% Saturation	Cond (µS cm⁻¹)	Alkalinity (mg L⁻¹ $CaCO_3$)	Total hardness (mg L⁻¹ $CaCO_3$)	Ca^{2+} (mg L⁻¹)	Mg^{2+} (mg L⁻¹)	K^+ (mg L⁻¹)	Na^+ (mg L⁻¹)	Cl^- (mg L⁻¹)	SO_4^{2-} (mg L⁻¹)
09L010250	LIFFEY	0.5 km d/s Ballyward Bridge	O02276 16126	LIFFY1	Mean	7.45	11.43	103	99	–	34.38	10.66	1.89		5.82	9.22	
					Min.	6.76	11.1	95	83	39.39	21.65	6.79	1.14		3.95	5.42	
					Max.	8.08	11.79	117	123	–	45.27	14.75	2.47		7.11	13.55	
12L020400	LITTLE SLANEY	Ford S of Coan	S98485 91766	LSLAN1	Mean	6.55	11.41	102	34	3.79	12.55	3.44	0.96		5.02	3.59	
					Min.	6.4	11.03	98	31	3.42	9.58	2.46	0.80		4.17	0.75	
					Max.	6.64	11.6	108	39	4.17	16.36	5.23	1.24		5.61	6.43	
12L020100	LITTLE SLANEY	Ford d/s Rostyduff Bridge	S94946 92339	LSLAN2	Mean	6.87	11.47	103	78	20.3	22.04	6.23	1.58		5.31	6.03	
					Min.	6.70	11.2	100	71	15.85	17.24	4.71	1.17		3.48	3.95	
					Max.	7.09	11.7	110	88	24.75	23.73	7.58	2.27		7.24	8.08	
34M020100	MOY	Bridge SE of Cloonacool		MOY1	Mean	7.78	11.95	99	356	118.13	81.46	28.27	2.64		7.74	12.35	
					Min.	7.61	11.3	95	319	98.75	75.77	26.63	2.25		6.79	1.31	
					Max.	8.00	13.2	104	392	137.5	87.15	29.9	3.03		8.7	23.38	
34M020750	MOY	At Bleanmore		MOY2	Mean	8.23	11.13	99	425	194.69	253.68	87.2	8.73		16.06	25.76	
					Min.	8.06	9.7	91	306	132.5	117.78	41.6	3.38		8.61	15.69	
					Max.	8.46	13	113	517	252.5	427.03	150.6	12.38		24.95	40.65	
25N020060	NEWPORT (Tipperary)	Bridge near Glanculloo Old School		NPORT1	Mean	7.27	12.16	111	133	27.49	57.6	17.29	3.5		7.78	10.04	
					Min.	7.04	11.01	109	103	27.49	40.8	10.32	3.35		4.49	6.72	
					Max.	7.60	13.3	113	177	27.49	74.39	24.27	3.65		11.07	13.36	
29O010700	OWENDALULLEEGH	Ford at Inchamore, N of Lough Graney		OWDAL1	Mean	8.00	13.7	117	150	49.01	46.52	14.67	2.4		7.15	17.44	
					Min.	7.68	9.8	96	118	30.52	34.25	10.63	1.87		7.11	12.12	
					Max.	8.51	17.6	139	214	67.5	58.79	18.72	2.92		7.18	22.75	
34O030050	OWENGARVE (Sligo)	Ford NW of Srah Upper		OWGAR1	Mean	7.53	12.3	106	244	105.41	73.7	25.02	2.72		7.91	14.65	
					Min.	7.12	10.3	93	124	37.47	49.34	16.03	1.9		6.24	10.52	
					Max.	8.24	15.55	116	350	160	107.92	37.43	3.51		11.3	22.23	
32O030200	OWENGLIN	Bridge SW of Clifden Lodge		OGLIN1	Mean	7.29	12.27	105	97	30.80	33.43	9.52	2.34		7.22	12.69	
					Min.	6.81	10.71	93	75	3.57	33.43	9.52	2.34		7.22	12.69	
					Max.	8.47	15.1	118	154	68.75	33.43	9.52	2.34		7.22	12.69	

EPA code	River name	Location	GPS reading	Site code		pH	DO (mg L^{-1} O_2)	% Saturation	Cond (µS cm^{-1})	Alkalinity (mg L^{-1} $CaCO_3$)	Total hardness (mg L^{-1} $CaCO_3$)	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	K^+ (mg L^{-1})	Na^+ (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})
23O030300	OWENMORE (Kerry)	Bridge at Boherboy		OMORE1	Mean	7.54	10.76	97	90	11.28	19.38	4.69	1.86		9.29	18.85	
					Min.	7.27	10.26	94	84	8.11	17.6	3.94	1.84		8.81	16.04	
					Max.	7.91	11.12	98	95	14.44	21.16	5.45	1.88		9.78	21.66	
22O030400	OWENREAGH	Bridge u/s Upper Lake (Lord Brandons cottage)		OREAG1	Mean	6.86	11.23	101	60	5.29	13.54	3.07	1.43		6.98	15.13	
					Min.	6.05	9.26	97	53	3.59	11.46	2.17	1.38		6.79	12.13	
					Max.	7.51	13	108	73	6.99	15.62	3.97	1.47		7.16	18.13	
12S020400	SLANEY	Waterloo Bridge		SLANY1	Mean	7.43	10.97	99	123	42.33	46.17	15.03	2.09		5.01	8.64	
					Min.	7.32	10.2	96	89	23.59	41.43	12.9	1.95		4.24	7.61	
					Max.	7.58	11.7	101	158	61.07	50.9	17.16	2.24		5.79	9.68	
27S030200	SPANCELHILL	Bridge NW, near Spancelhill		SHILL1	Mean	7.94	10.82	110	483	212.5	231.83	77.58	9.26		19.45	38.1	
					Min.	7.66	10.7	99	479	210	183.98	61.43	7.43		13.54	26.9	
					Max.	8.36	10.94	121	489	215	279.69	93.73	11.08		25.37	49.31	
19S020400	SULLANE	Linnamilla Bridge		SULLA1	Mean	7.43	11.38	102	139	38.97	42.28	12.94	2.42		7.44	13.39	
					Min.	7.32	10.78	97	117	35.44	35.34	10.12	2.4		6.83	11.72	
					Max.	7.59	12.2	110	152	42.5	49.22	15.76	2.45		8.06	15.06	
36S010100	SWANLINBAR	Commas Bridge (Bridge near Altbrean/ Tullydermot)		SWANL1	Mean	7.34	13.19	112	71	15.02	33.83	10.24	2.01		5.97	8.39	
					Min.	6.82	11.54	110	47	9.77	13.43	3.55	1.11		4.04	8.1	
					Max.	7.66	14.8	114	106	20.26	46.72	14.66	2.77		9.15	8.67	
12U010050	URRIN	Ballycrystal Bridge		URRN1	Mean	5.98	11.92	115	58	5.44	17.22	4.55	1.42		6.41	9.82	
					Min.	4.8	11	107	42	4.11	16.66	4.3	1.14		5.07	8.64	
					Max.	6.6	13.62	120	76	6.76	17.79	4.8	1.71		7.75	11.01	

DO, dissolved oxygen; GPS, global positioning system; max, maximum physico-chemical values; min, minimum physico-chemical values.

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

EPA Research Report 219

Characterising the Biological Communities of Rare River Types

Authors: Edel Hannigan and Mary Kelly-Quinn

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Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Identifying Pressures

Under the WFD, all EU Member States are obliged to develop a river typology upon which type-specific reference conditions can be defined to enable the accurate evaluation of ecological status. Ecological status is determined on the basis of deviation from these type-specific reference conditions. Rare or unusual river types were not adequately represented in the development of the 12-type national river typology for Irish rivers. Rare river types in this context are defined as systems that present the biota with a combination of naturally challenging or distinct environmental conditions. The RareType research project aimed to characterise the macroinvertebrate, macrophyte and phytobenthos communities of four potential rare river types: (i) groundwater-dominated rivers, (ii) highly calcareous rivers with calcium precipitate, (iii) naturally acidic rivers, and (iv) rivers strongly influenced by lakes. The RareType project aimed, to determine whether these rivers fit within the national typology and if current water quality assessment methods can adequately assess their condition, and thereby identify those under pressure from anthropogenic activities.

Informing Policy

The RareType research findings provide a solid foundation for making a series of decisions to improve assessment of the true ecological status of sites in rare river types. It will inform policy relating to development of national monitoring programmes by the EPA as well as that related to protection of aquatic biodiversity.

Developing Solutions

The RareType research findings will ensure that monitoring programmes and status assessment target the widest range of river types in Ireland by providing evidence of where designation of separate biological types/sub-types is required. For some stressors such as acid input, it identifies the need for stressor-specific metrics.

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