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A STUDY OF LAKES WITH SLENDER NAIAD (*NAJAS FLEXILIS*)

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An Roinn Tithíochta,
Rialtais Áitiúil agus Oidhreachta
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Front cover, small photographs from top row:

Limestone pavement, Bricklieve Mountains, Co. Sligo, Andy Bleasdale; **Meadow Saffron** *Colchicum autumnale*, Lorcan Scott; **Garden Tiger** *Arctia caja*, Brian Nelson; **Fulmar** *Fulmarus glacialis,* David Tierney; **Common Newt** *Lissotriton vulgaris,* Brian Nelson; **Scots Pine** *Pinus sylvestris*, Jenni Roche; **Raised bog pool**, Derrinea Bog, Co. Roscommon, Fernando Fernandez Valverde; **Coastal heath**, Howth Head, Co. Dublin, Maurice Eakin; **A deep water fly trap anemone** *Phelliactis* sp., Yvonne Leahy; **Violet Crystalwort** *Riccia huebeneriana*, Robert Thompson

Main photograph:

Slender Naiad *Najas flexilis* growing in a carpet of *Chara virgata* and *Chara aspera* in Kiltooris Lough at 2 m
Cilian Roden

A study of lakes with Slender Naiad (*Najas flexilis*)

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Executive Summary

Between 2016 and 2018, 40 lakes in the western half of Ireland were surveyed both for vegetation and the presence of Slender Naiad *Najas flexilis.* All lakes were surveyed by snorkelling. Data collected included species present, plant euphotic depth or maximum depth of colonisation, percentage vegetation cover, substrates, relevé species composition measured using the Braun-Blanquet scale, and all obvious signs of environmental damage. All macrophytes (angiosperms, bryophytes and charophyte algae) were identified to species level. In many cases, data on lake nutrient status were available from the EPA or previous surveys.

Lake size ranged from 2.5 ha to over 2,000 ha. Lakes occurred on a variety of rock types including shales, granite, sandstone, schist and metamorphosed limestone but not on Carboniferous limestone. Lake alkalinity ranged from 5 to 70 mg/l with an average of 25 mg/l.

The data were used to describe typical vegetation of the lakes. Nearly all lakes contained both *Isoetes lacustris* and *Potamogeton perfoliatus*. Three major vegetation types were recognised: a shallow sub littoral zone (to 1.5 m depth) of Isoetid type species including *Eriocaulon aquaticum, Lobelia dortmanna* and *Littorella uniflora*; a mid-water (1.5-3 m) *Isoetes lacustris* zone; and finally a deep-water zone (3-5 m) with a suite of species including *Najas flexilis, Potamogeton berchtoldii, Nitella confervacea* and *Chara virgata*. In addition, some lakes had base-rich plants such as *Chara aspera* or *Potamogeton gramineus* while others contained plants of base-poor water such as *Subularia aquatica* or *Juncus bulbosus.*

Species-richness is related to plant euphotic depth, low water colour (<40 Hazen Units) and low (<0.015 mg/l) total phosphorus. The most species-rich lakes had more than 30 species recorded while the poorest lakes had fewer than 20. Several lakes had several rare or under-recorded species such as *Hydrilla verticillata* or *Pilularia globulifera*. Some lakes had fewer species present than in previous surveys.

Najas flexilis was recorded in 25 of the lakes surveyed and had vanished from three lakes in which it was recorded since 2000. The recent appearance of *Elodea canadensis* at two of the lakes was linked to the population extinctions.

The data were used to define a *Najas flexilis*-type lake characterised by alkalinity intermediate between oligotrophic and marl lakes, clear water, a deep euphotic depth and a flora with both low base- and high base-requiring plants. Such lakes appear to be scarce in Ireland or Scotland and even more so in continental Europe. This type is equated with EU Habitats Directive Annex I habitat 3130.

A system to evaluate the conservation condition of *Najas flexilis*-type lakes is proposed based on the following factors: area, presence and quality of deep-water vegetation, typical species, introduced species, euphotic depth, colour, total phosphorus and hydrological regime. *Najas flexilis* populations are assessed on population extent, size and density.

It is concluded that many *Najas flexilis*-type lakes are in poor or bad condition including the lake (Lough Leane) with formerly the largest *Najas flexilis* population in Ireland. Ballynakill Lough, Co. Galway is regarded as the best example of the type in Ireland.

An Appendix with site reports for all lakes surveyed is provided as a separate pdf-file and hard-copy volume.

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We thank all those who have helped us during our work on *Najas* lakes. Dr Áine O Connor has been the mainstay of the project from commissioning the work to editing final reports and helping us to clarify our ideas. Dr Deirdre Tierney and the other staff of the Environmental Protection Agency (EPA) have generously provided data about many of our study sites. Dr Neil Lockhart kindly identified bryophyte specimens. Clare Heardman helped in several surveys in Kerry.

1 Introduction

1.1 The Slender Naiad, *Najas flexilis*, in Ireland

Najas flexilis (see Figure 1) is a rare water plant within the European Union, consequently it is listed in Annex II of the EU Habitats Directive (Council Directive 92/43/EEC) as a species of community interest and in need of protection in the member states. It is Vulnerable on the European Red List and is one of only four species with predominantly northern distribution that are threatened (Bilz *et al*., 2011). Ireland and Scotland are the species' main location in Europe, although it is widespread in North America. The plant is a small annual that grows on the bottom of lakes, so it is difficult to find and is often overlooked. Year to year fluctuations in seed germination may also result in large variations in annual population size.

Figure 1 *Najas flexilis* growing at 2 m in Lough Leane in 2013; in 2019 it could not be re-found at this station.

Najas flexilis has been known as a characteristic macrophyte of western Irish lakes since the mid-nineteenth century (Praeger, 1934). Sub-littoral surveys in the 1970s showed that a characteristic *Najas flexilis* vegetation occurred in these lakes with *Potamogeton berchtoldii* a frequent companion species (Heuff, 1984).

Evidence of decline led to *Najas flexilis* being assessed as Near Threatened on the Irish Red List (Wyse Jackson *et al*., 2016) and in *Unfavourable-Inadequate* (*Poor*) *Conservation Status* in reports to the EU covering periods from 2000-2018 (NPWS, 2007, 2008, 2013c, 2019c). Nevertheless, several recent surveys (Roden, 2004, 2005, 2013; Roden & Murphy, 2014) have shown that extensive populations of *Najas flexilis* continue to occur in Ireland. Data gathered in these surveys suggest that many lakes with *Najas flexilis* have other recurrent associated species and it would be useful to recognise a *Najas flexilis*-type lake. Roden (2004, 2005, 2007) suggested that such lakes are characterised by the presence of both *Isoetes lacustris*, a species typical of base-poor water, and *Potamogeton perfoliatus*, often found in more base-rich water; an unusual combination that occurs in mesotrophic lakes, frequently with *Najas flexilis* (see Figure 2). Other macrophytes such as *Hydrilla verticillata*, *Callitriche hermaphroditica*, *Potamogeton obtusifolius* and the charophyte *Nitella confervacea*, which are scarce or uncommon in Ireland, also appear to favour this type of mesotrophic lough. *Hydrilla verticillata* is known only from two Irish lakes, both of which also contain *Najas flexilis*.

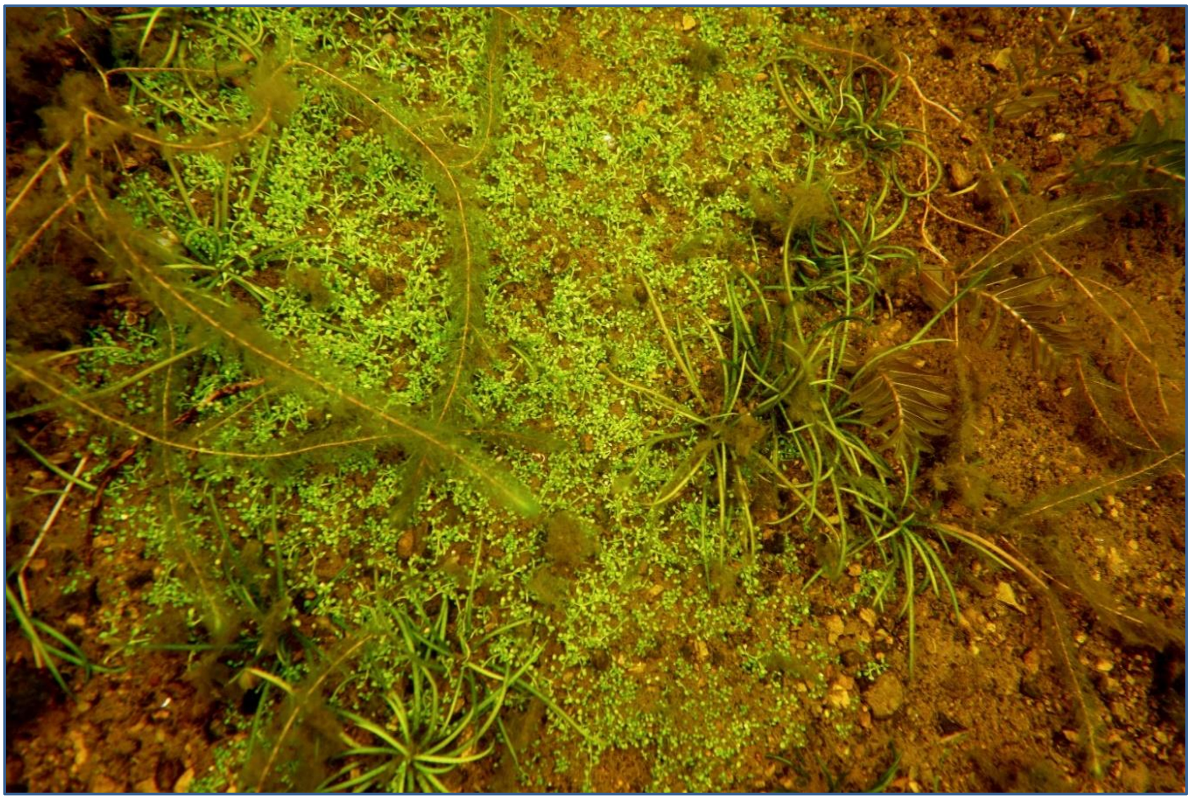


Figure 2 Mid-water vegetation (1.5 m) in Lough Leane. A sheet of *Elatine hexandra* is accompanied by a short form of *Potamogeton perfoliatus*, *Isoetes lacustris* and *Myriophyllum alterniflorum*. This combination of *Isoetes* and *P. perfoliatus* is characteristic of *Najas flexilis*-type lakes.

In a recent review, O Connor (2015) showed that the EU Habitats Interpretation Manual (CEC, 2013) has vague definitions of northern European soft-water lake habitats (codes 3110 and 3130), and in practice these cannot be easily distinguished in the field and may well occur together in a single water body. She suggested that type 3110 corresponds to Isoetid-dominated oligotrophic lakes, while the more mesotrophic type 3130 could be represented in Ireland by *Najas flexilis*-type lakes (referred to in O Connor (2015) and NPWS (2019) as 'mixed *Najas flexilis* lake habitat' and in NPWS (2013) as 'soft-water lake with base-rich influences'). While there are some data available on oligotrophic lakes in Ireland (*e.g.* Free *et al*., 2009), no formal definition of *Najas flexilis*-type lakes has been published.

Studies in Scotland (Wingfield *et al*., 2004), throughout Britain (Duigan *et al*., 2006) and mainland Europe (reviewed by Murphy, 2002) also demonstrate that oligo/mesotrophic lakes contain a species-rich flora distinguishable from oligotrophic Isoetid lakes. In general, these lake types (including Scottish Machair Lochs) seem comparable to Irish *Najas flexilis*-type lakes, supporting the hypothesis that at least two broad categories of northern European soft-water lake exist, and that these might be equated to EU types 3110 and 3130. However, they do not always easily relate to the EU habitat classification, for example Duigan *et al*. (2006) found a close correspondence between habitat 3130 and their lake groups C1, C2, D and E, as well as representatives of 3130 in their group B, while habitat 3110 was found in groups B and C2. Group E had close correspondence to habitats 3140 (marl lakes) and 3150, as well as 3130 (Duigan *et al*., 2006).

The purpose of this study was to establish objective grounds for distinguishing a lake vegetation type characterised by the presence of *Najas flexilis* and/or associated plant species. In addition, it aimed to establish the current conservation status of both *Najas flexilis* and its associated lake vegetation type in Ireland.

1.2 Are *Najas flexilis*-type lakes an ecological reality?

A trite definition of a *Najas flexilis*-type lake is obviously a lake with a population of *Najas flexilis*. A more comprehensive definition would attempt to include the characteristics, biological, chemical and physical, which are associated with such lakes. Marl lakes, for example, are defined in terms of high alkalinity, low levels of total phosphorus, a flora dominated by charophytes and benthic cyanobacterial crusts and great water transparency (Roden *et al*., 2020a). For an equivalent definition of *Najas flexilis*-type lakes, it would be necessary to demonstrate a consistent vegetation, flora and physical and chemical characteristics that would separate *Najas*-containing lakes from other soft-water lakes found in Ireland. Alternatively, an analysis of lakes with *Najas flexilis* might show a very wide variety of characteristics, which would make the concept of a *Najas flexilis*-type lake of little value.

O Connor (2015) set out the difficulties of defining Irish lakes in terms of the EU Habitats Directive categories. She proposed that, in Ireland, habitat type 3130 should include *Najas flexilis*-type lakes, while habitat code 3110 should include more oligotrophic lakes, and habitat code 3160 should include acid oligotrophic or dystrophic lakes. The present survey was undertaken, in part, to test the hypothesis that Irish lakes containing *Najas flexilis* form a group that can be defined using objective measures which separate *Najas flexilis*-type lakes from lakes included in types 3110 and 3160.

Previous work has shown that a *Najas flexilis* community occurs in Irish lakes (Heuff, 1984). It has also been shown that Irish lakes containing *Najas flexilis* have some common characteristics (Roden, 2004, 2005, 2007; Roden & Murphy, 2014). The most obvious floristic feature is that nearly all surveyed lakes with *Najas flexilis* had populations both of *Isoetes lacustris* and *Potamogeton perfoliatus*. This fact is significant, as the former species is widely regarded as typical of oligotrophic soft-water lakes, while the latter is found mainly in mesotrophic or eutrophic lakes, often on limestone. Free *et al*. (2005, 2006) suggested, based on a sample of 200 lakes, that in soft-water lakes containing *Isoetes lacustris*, alkalinity is less than 20 mg/l. Few lakes in their sample contained *Najas flexilis* populations, but other data on lakes with *Najas flexilis* showed several cases of alkalinity exceeding 40 mg/l (C. Roden survey for NPWS in 2005). In addition, these lakes were more species-rich than many typical soft-water examples. Roden & Murphy (2014) reviewed recent data on Irish *Najas flexilis* records and concluded that lakes with *Najas flexilis* contained a wide range of species often seen as typical of either oligotrophic or eutrophic habitats. Thus, before this survey, there was some evidence that lakes with *Najas flexilis* might form a group or cluster separated from other soft-water lakes on the basis of differences in species composition and higher alkalinity values.

1.3 The current study

The study described in this report was undertaken between 2016 and 2018. The primary purpose was to collect data on the botany of the submerged macrophytes of possible *Najas flexilis*-type lakes. This was done by using snorkel survey with boat cover to allow accurate estimates of plant position (established by GPS) and depth (established by diver's depth gauge) (see Chapter 2). The data were analysed to establish lake species lists, vegetation communities and maximum depth of plant colonisation (euphotic depth). In turn, these data were compared with available data on water chemistry and catchment bedrock to establish the environmental conditions of *Najas flexilis*-type lakes and to establish if the *Najas flexilis*-type lake is a useful category in the classification of Irish lake types (see Chapter 4). Chapter 5 discusses methods to assess conservation condition both of *Najas*-type lakes and *Najas flexilis* populations. Conclusions are given in Chapter 6. This *Irish Wildlife Manual* includes site reports for 40 study lakes (Appendix V, separate pdf file and hard-copy volume).

2 Materials and methods

2.1 Site selection

The central hypothesis tested in this survey was that *Najas flexilis* occurs in a specific type of lake, which differs from most base-poor Irish lakes, and can be distinguished by flora, vegetation and water chemistry. To test this hypothesis it was necessary to survey several types of soft-water lake

- Those known to contain *Najas flexilis*
- Those known to contain *Isoetes* spp. and *Potamogeton perfoliatus*
- Lakes thought to be transitional between Habitats Directive type 3130 and types 3110, 3140 and 3150
- Those with a basin of rocks with intermediate base content such as shale, Dalradian marble or sandstone/limestone.

A total of forty sites (Figure 3, Table 1) was surveyed over three summer field seasons, during the months when *Najas flexilis* is visible. It was decided that a minimum of twenty sites would have known *Najas flexilis* populations (Table 2), as it was clearly essential that a significant proportion of the surveyed lakes should contain *Najas flexilis*, and that these should span the species' known Irish distribution including the core geographical regions of Connemara Co. Galway, Co. Donegal and Co. Kerry. Lists of lakes with *Najas flexilis* were available from previous surveys undertaken by C. Roden and P. Murphy on behalf of the NPWS (Roden, 2002, 2003, 2004, 2005, 2007; Roden & Murphy, 2014). In addition, several new populations had been discovered in the course of lake surveys undertaken by the Irish Environmental Protection Agency (EPA) for the purposes of the Water Framework Directive. Records for the species are held in the NPWS rare plant and *Najas flexilis* databases and reports prepared under the Habitats Directive (Article 17 Reports) (NPWS, 2007, 2008, 2013, 2019; O Connor, 2013).

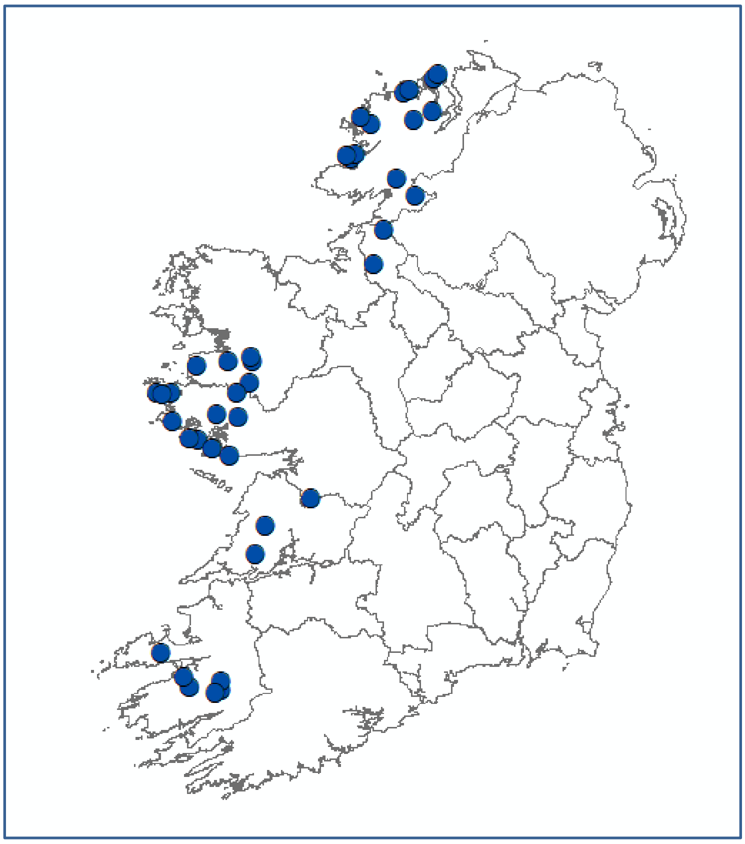


Figure 3 The distribution of the 40 study lakes.

The known *Najas flexilis* sites chosen included most of the best examples of *Najas flexilis* populations in Ireland (Tables 1 and 2). These were Shannagh, Kindrum, Sessiagh, Port, Akibbon, Kiltooris, Mullaghderg and Sheskinmore, Co. Donegal, Ballynakill Connemara (Figure 4), An Chaolaigh, Na gCaor and Foorglass, Co. Galway, and Acoose, Caragh, Leane, Long Range, and the Upper Lake Killarney, Co. Kerry.

Figure 4 Ballynakill Lough near Cleggan, Co. Galway. Despite its unexceptional appearance, this is perhaps the most species-rich *Najas* lake in Ireland.

Another group of *Najas flexilis* populations discovered by C. Roden since 2000 had not yet been surveyed in any detail and were included in the survey. These were Nahaltora and Nageltia, Co. Mayo, Chluain Toipin, na Creibhinne (Figure 5) and Maumeen, Co. Galway.

The lakes included with new records for the species from the EPA were Anure, Derg and Fern, Co. Donegal, Moher, Co. Mayo (Figure 6), and Illauntrasna and Bofin, Co. Galway.

Some sites were chosen because they contained both *Isoetes lacustris* and *Potamogeton perfoliatus*, a combination identified by C. Roden as typical of lakes with *Najas flexilis*, despite the absence of *Najas flexilis*. These sites were Mask, Counties Mayo and Galway, Aughrusbeg and Ballynakill Gort, Co. Galway and Anscaul, Co. Kerry (Figure 7).

The remaining seven sites chosen were largely outside the known geographical range of *Najas flexilis* and had not been examined by snorkel survey previously, but were thought to possibly constitute *Najas flexilis*-type lakes based either on basin bedrock or drift flora. The sites included in the survey were: Eske, Co. Donegal (basin includes Carboniferous limestone and Dalradian schist); Melvin, Counties Leitrim and Fermanagh (Carboniferous limestone and sandstone); Carrigeencor, Co. Leitrim (drift flora of *Isoetes lacustris* and *Potamogeton perfoliatus*); Derryierin, Co. Mayo (close to Nageltia and similar in bedrock); Courhoor, Co. Galway (similar bedrock to Ballynakill Connemara); Knocka, Co. Clare (drift flora); and Cloonmackan, Co. Clare (similar bedrock to Knocka).

Figure 5 Loch na Creibhinne, Baile na hAbhann, Co. Galway. This shallow coastal lake was too rocky to use an outboard engine, instead sampling was by Canadian canoe. The lake contains a large population of *Najas flexilis*.

Figure 6 Lough Moher, south-west of Westport, Co. Mayo. In places the lake is fringed with emergents such as *Schoenoplectus lacustris*, *Phragmites australis* and *Equisetum fluviatile*, as well as floating-leaved plants such as *Potamogeton natans*. This development of extensive emergent vegetation may indicate disturbance (note conifer plantation in background and compare to Figure 4 Ballynakill). Note snorkeller on left side of photo.

Figure 7 Anscaul Lough, Dingle Peninsula, Co. Kerry. This lake is a marginal *Najas flexilis*-type lake with a limited flora and no *Najas flexilis*. It does contain both *Isoetes* and *Potamogeton perfoliatus* and unexpectedly a substantial population of the normally base-demanding *P. crispus*.

Most lakes were visited once during the study. In two cases, An Chaolaigh and Nageltia, the sites were resurveyed, as the initial visits did not confirm previous records of *Najas flexilis*. Two visits were paid to Lough Anure, owing to an out-board engine failure on the first visit.

The majority of lakes were comprehensively surveyed by snorkelling transects and sampling relevés (Table 2, see also Section 2.2). After initial investigations by snorkelling, however, some lakes were considered not to warrant full survey on the basis of flora, lack of suitable habitat, shallow euphotic depth, or because *Najas flexilis* was unlikely to occur (Table 2). On the last day of survey a large population of *Najas flexilis* was discovered by grapnel in Loughauneala but, logistically, detailed snorkel survey was not possible. Loughauneala was revisited in summer 2021, however, and account of that survey is included in Appendix V.

Table 1 Lakes surveyed (2016-2018) as part of the study. Grid references are for the geometric centroid of the lake, at 1:50,000 scale. Alternative names and spellings are given in parentheses. Names are emboldened for those lakes included in most of the analyses in Chapter 3. The three letter codes are those used in graphs in Chapter 3.

Lake name(s)	Code	County	Grid reference	Year(s)	SAC
Acoose	ACO	Kerry	V7561585251	2018	000365, Killarney National Park, Macgillycuddy's Reeks and Caragh River Catchment SAC
Akibbon	AKI	Donegal	C0686318565	2018	002176, Leannan River SAC
an Chaolaigh (Caolaidh, Lough Killa)	ACH	Galway	L8035630770	2016, 2017 & 2018	002111, Kilkieran Bay And Islands SAC

Lake name(s)	Code	County	Grid reference	Year(s)	SAC
Anscaul	ASL	Kerry	Q5851205140	2017	000375, Mount Brandon SAC
Anure	ANU	Donegal	B8199616107	2017 & 2018	-
Aughrusbeg	ABG	Galway	L5579258173	2017	001228, Aughrusbeg Machair and Lake SAC
Ballynakill Connemara (Ballinakill)	BAC	Galway	L6411158108	2016	-
Ballynakill Gort (Ballinakill)	BAG	Galway	R4639195651	2016	-
Bofin	BOF	Galway	M0339744013	2018	002034, Connemara Bog Complex SAC
Caragh	CAR	Kerry	V7227890806	2017	000365, Killarney National Park, Macgillycuddy's Reeks And Caragh River Catchment SAC
Carrigeencor		Leitrim	G8312933762	2018	-
Chluain Toipin (Chluain Toipín, Shannaghcloontippen)	CHT	Galway	L9095745756	2016	002034, Connemara Bog Complex SAC
Cloonmackan		Clare	R1945880266	2018	-
Courhoor		Galway	L5954357138	2017	-
Derg	DRG	Donegal	H0813674284	2017	002301, River Finn SAC
Derryierin		Mayo	M1246377009	2018	-
Eske	ESK	Donegal	G9724383605	2017 & 2018	000163, Lough Eske and Ardnamona Wood SAC
Fern	FRN	Donegal	C1802723427	2017	002176, Leannan River SAC
Foorglass (Lettershask East)	FOO	Galway	L6335242982	2018	-
Illauntrasna	ILL	Galway	L8878425340	2018	-
Kiltooris	KTS	Donegal	G6774797080	2017	000197, West Of Ardara/Maas Road SAC
Kindrum	KIN	Donegal	C1866943076	2016	001151, Kindrum Lough SAC
Knocka	KNA	Clare	R1374063275	2017	-
Leane	LEA	Kerry	V9342488845	2018	000365, Killarney National Park, Macgillycuddy's Reeks and Caragh River Catchment SAC
Long Range	LOR	Kerry	V9328283637	2016	000365, Killarney National Park, Macgillycuddy's Reeks and Caragh River Catchment SAC
Loughauneala		Galway	L9288223333	2018	-
Mask	MSK	Mayo & Galway	M1070463710	2016	001774, Lough Carra/Mask Complex SAC
Maumeen	MAM	Galway	L6547741132	2016	002034, Connemara Bog Complex SAC
Melvin		Leitrim & Fermanagh	G8947653429	2017	000428, Lough Melvin SAC
Moher	MHR	Mayo	L9766376651	2017	-
Mullaghderg (Mullaghderg West)	MDG	Donegal	B7619819733	2017	001141, Gweedore Bay And Islands SAC

Lake name(s)	Code	County	Grid reference	Year(s)	SAC
na Creibhinne (Creibhinne, Nagravin)	CRE	Galway	L9906621559	2016	-
na gCaor (Nageeron)	NCR	Galway	L7511231586	2017	002119, Lough Nageeron SAC
Nageltia		Mayo	M1106579027	2016 & 2018	-
Nahaltora	NLA	Mayo	L7919774281	2017	001932, Mweelrea/Sheeffry/Erriff Complex SAC
Port (an Phoirt)	PRT	Donegal	C0113934714	2016	00147, Horn Head And Rinclevan SAC
Sessiagh (an tSeisigh)		Donegal	C0427836149	2018	000185, Sessiagh Lough SAC
Shannagh	SNH	Donegal	C2136645329	2017	001975, Ballyhoorisky Point To Fanad Head SAC
Sheskinmore	SEK	Donegal	G6999295803	2018	000197, West Of Ardara/Maas Road SAC
Upper Lake Killarney	UPR	Kerry	V9059882013	2018	000365, Killarney National Park, Macgillycuddy's Reeks and Caragh River Catchment SAC

2.2 Field Survey and data recording

2.2.1 General survey of macrophyte vegetation

Benthic vegetation was sampled in relevés along transects. Survey was by snorkelling or scuba-diving (Figure 8), with boat support where possible (Figure 9). The field survey methods used are described below and were similar to those used for marl lakes, which are detailed in Roden *et al*. (2020b).

Figure 8 Paul Murphy and Jim Ryan prepare to snorkel in Lough Nageltia. While weight belts, wet suits and fins are cumbersome to carry to remote sites, snorkelling requires far less equipment than SCUBA diving.

Figure 9 Recorder (Paul Murphy) in boat, filling in data sheet on Aughrusbeg Lough.

Survey Team

A minimum of two personnel was required. Person one (the recorder) was responsible for boat handling, recording all data, operating the GPS receiver and navigation. Persons two and three (the samplers or divers) were snorkellers (or scuba divers) and responsible for data collection, photography and sample gathering. For the majority of lakes, two snorkellers were used; this allowed more accurate recording of species and vegetation cover, as well as further exploration of the lake to check for other vegetation or species not noted on the chosen transects. Generally, C. Roden and J. Ryan acted as samplers while P. Murphy acted as recorder and boat handler.

Site access

Not all lakes were easily accessible. The larger lakes are mostly in public ownership and public slipways were used to launch boats. Smaller lakes were sometimes accessible by private roads or tracks. In cases where it was not possible to launch a boat, a light-weight Canadian canoe was brought to the shore by portage. Some lakes could only be accessed on foot over rough ground. In these small lakes, boat cover was dispensed with and the recorder remained on the shore.

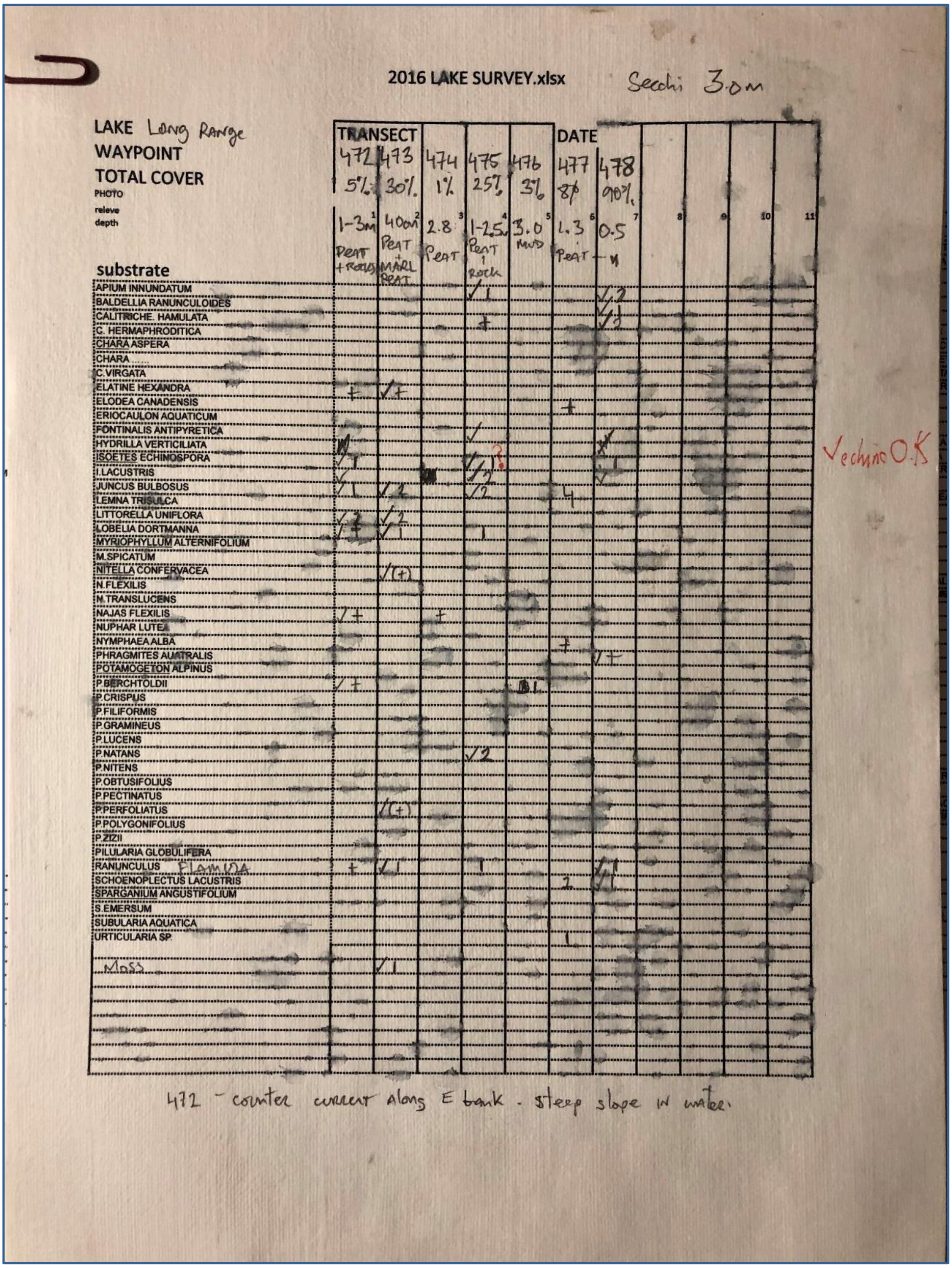
Choice of sampling transects

Sampling transects were chosen so as to cover the entire lake. Between three and nine transects were surveyed, depending on both lake size and vegetation diversity. Transect positions were on exposed and sheltered shores. Care was taken to include shores of rock, shingle and soft sediment. Transects running from the shore to beyond the euphotic depth were surveyed by snorkelling, with boat support. Relevés (2 m x 2 m) were taken along the transect, each sampling a homogenous area of vegetation with a depth variation of less than 20 cm. At least one relevé was sampled in each distinct vegetation zone, and with every increase in depth of 1 m. Field measurements included species composition and cover, euphotic depth, transect and relevé positions.

Sufficient transects were sampled to allow a full description of the species and vegetation present. In general sampling ended when the number of species encountered ceased to increase.

Sampling methods

Sub-littoral vegetation was examined by snorkelling with boat cover. Depths were measured using a diver's depth gauge and position determined using a hand-held GPS recorder (Garmin GPSmap 60CSx, accurate to ±5 m). Vegetation relevés or quadrats (2 m x 2 m) were sampled by snorkelling and the data recorded by the boat-handler (Figure 10). In general, fewer than five taxa occurred per relevé, so recording was a simple exercise. Specimens for later examination were stored in plastic bags and identified within three days of collection. On one occasion, scuba gear were used to explore the Upper Lake, Killarney.



2016 LAKE SURVEY.xlsx   Secchi 3.0m

LAKE Long Range

	TRANSECT					DATE					
WAYPOINT	472	473	474	475	476	477	478				
TOTAL COVER	5%	30%	1%	25%	3%	8%	90%				
PHOTO											
releve	1	2	3	4	5	6	7	8	9	10	11
depth	1-3m	40cm	2.8	1-2.5m	3.0	1.3	0.5				
substrate	Peat + Rocks	Peat + Marl Peat	Peat	Peat 1 Rock	Mud	Peat	– "				
APIUM INNUNDATUM				✓1			✓2				
BALDELLIA RANUNCULOIDES							✓1				
CALITRICHE. HAMULATA				+			✓2				
C. HERMAPHRODITICA											
CHARA ASPERA											
CHARA											
C.VIRGATA											
ELATINE HEXANDRA	+	✓+									
ELODEA CANADENSIS						+					
ERIOCAULON AQUATICUM											
FONTINALIS ANTIPYRETICA				✓							
HYDRILLA VERTICILIATA	[illegible]						✗				
ISOETES ECHINOSPORA	✓1			✓1 ?			✓1				
I.LACUSTRIS	✓			✓2			✓				
JUNCUS BULBOSUS	✓1	✓2		✓2							
LEMNA TRISULCA						4					
LITTORELLA UNIFLORA	✓2	✓2									
LOBELIA DORTMANNA	✓+	✓1		1							
MYRIOPHYLLUM ALTERNIFOLIUM											
M.SPICATUM											
NITELLA CONFERVACEA		✓(+)									
N.FLEXILIS											
N.TRANSLUCENS											
NAJAS FLEXILIS	✓+		+								
NUPHAR LUTEA											
NYMPHAEA ALBA						+					
PHRAGMITES AUSTRALIS							✓+				
POTAMOGETON ALPINUS											
P.BERCHTOLDII	✓+				B1						
P.CRISPUS											
P.FILIFORMIS											
P.GRAMINEUS											
P.LUCENS											
P.NATANS				✓2							
P.NITENS											
P.OBTUSIFOLIUS											
P.PECTINATUS											
P.PERFOLIATUS		✓(+)									
P.POLYGONIFOLIUS											
P.ZIZII											
PILULARIA GLOBULIFERA											
RANUNCULUS FLAMMULA	+	✓1		1			✓1				
SCHOENOPLECTUS LACUSTRIS						2	✓1				
SPARGANIUM ANGUSTIFOLIUM											
S.EMERSUM											
SUBULARIA AQUATICA											
URTICULARIA SP.						1					
Moss		✓1									

V echino O.K

472 – counter current along E bank – steep slope in water.

Figure 10 Survey sample sheet filled in by recorder in boat, as dictated by snorkeller/sampler. Data on species present, cover depth *etc.* are shown. Red writing in margin added in laboratory after confirmation of *Isoetes echinospora*.

The location of each station (relevé), identified by waypoint number, is shown in the maps of each lake (see Appendix V site reports, provided as a separate pdf file and hard-copy volume). Maps were based on the OSi orthophoto series. For a small number of relevés, it was not possible to take a GPS position: these could not be assigned a separate waypoint number and were designated using decimal points, *e.g.* as 574.1, 574.2, *etc.*, where 574 was the nearest waypoint. The distance between these relevés never exceeded 20 m.

2.2.2 Survey of *Najas flexilis* populations

The *Najas flexilis* populations were fully surveyed at lakes where the species was encountered, with the exception of Loughauneala where it was not possible owing to logistical reasons. The following were recorded

- Date
- Location
- Density of *Najas flexilis*
- Photos of plants, when possible
- Depth
- Associated species
- Cover abundance of *Najas flexilis* and associated species (using Braun-Blanquet abundance scale)
- Substrate description
- Bare substrate (estimated percentage cover)
- Notes on any major pressures at each lake site

Herbarium specimens were also collected for lodging with **DBN**, the herbarium of the National Botanic Gardens, Glasnevin.

A separate database for *Najas flexilis* was prepared. Data (transect and relevé numbers, position, depth, time, date, population size, population extent, species, abundance, substrate, *etc.*) were entered into an MS Excel spreadsheet for analysis.

2.3 Water chemistry analysis

Where possible, physico-chemical data from the EPA were used (Table 2). The EPA supplied lake water quality data for 2009 to 2015, inclusive. These data were summarised, and all figures shown in nutrient tables are averages of all data collected from each lake in the time period.

In lakes where data were not available from the EPA, other sources were used, these included

1. Nutrient data from analyses of samples collected by C. Roden in September 2005 as part of survey work for NPWS
2. Data from Heuff (1984) and Free *et al*. (2006)
3. Samples collected in January and February 2019 by P. Murphy and analysed by a commercial laboratory (CLS Galway). Parameters measured included alkalinity, pH, conductivity, total phosphorus, colour, and chlorophyll *a*.

2.4 Data analyses

Comprehensive species lists were produced for each lake and these data were used to group lakes using cluster analysis, with groups distinguished at the 50% similarity level. An NMS ordination was also performed on the lake species lists. These analyses were used to distinguish *Najas flexilis*-type lakes from other lake types. Lakes that did not qualify as *Najas flexilis*-type lakes were omitted from subsequent analyses.

Relevé data from *Najas flexilis*-type lakes were then analysed using cluster analysis, with groups distinguished at the 50% similarity level. Indicator species analysis was used to define the members of each species group with the method of Dufrêne and Legendre. Two sets of analyses were run: the first on the full relevé data set; the second on the sub-set of relevés that contained *Najas flexilis*.

Biological and physico-chemical data were graphed and summarised in order to elucidate the ecological drivers and pressures impacting on the vegetation. A principal components analysis was also run using vegetation and environmental data.

Multivariate statistical analyses were performed using PC Ord version 6. Graphs were prepared using the Mac OS programme Datagraph.

2.5 Digital Mapping

The position of all relevés sampled was mapped using GIS. The following data were included in the shapefile attribute table for each relevé sampled

- Relevé code (waypoint number)
- Position (Easting and Northing from field GPS reading)
- Water depth
- Vegetation type
- Abundance of *Najas flexilis* (Braun-Blanquet scale)

Maps showing these data are provided in each site report (Appendix V, separate pdf file and hard-copy volume).

Table 2 Details of lake surveys. The date(s) of survey, number of transects and relevés sampled are given, as well as the source of the water chemistry data used. EPA data are for 2009-15. 'Roden 2005' are data based on analysis of samples collected by C. Roden in September 2005 and analysed by Glan Uisce Teo, Galway. The final three columns detail whether there are verified records for *Najas flexilis*, either during or before this study (*Records for *Najas flexilis* in Illauntrasna in 2007 and Derg in 2012 could not be confirmed by subsequent survey, or through voucher, and so have been rejected). The final column details whether the species was recorded during this survey (2016-2018).

Lake name	Survey date(s)	Number of transects & (relevés)	Water chemistry data source	*Najas flexilis* recorded	Year *Najas flexilis* first discovered	*Najas flexilis* - this survey
Acoose	04/09/2018	4 (21)	EPA	Yes	1971	Yes
Akibbon	22/08/2018	3 (23)	EPA	Yes	1977	Yes
an Chaolaigh	14/07/2016, 21/09/2017, 13/09/2018	3 (21)	This survey	Yes	1996	Yes
Anscaul	12/07/2017	4 (21)	This survey	No	n/a	No
Anure	25/07/2017, 18/07/2018	4 (21)	EPA	Yes	2009	Yes
Aughrusbeg	5/07/2017, 06/09/2017	5 (21)	EPA	No	n/a	No
Ballynakill Connemara	19/07/2016	6 (45)	EPA	Yes	2003	Yes
Ballynakill Gort	11/07/2016	5 (24)	This survey	No	n/a	No
Bofin	25/07/2018	4 (15)	EPA	Yes	2007	Yes
Caragh	03-04/08/2017	9 (39)	EPA	Yes	1877	Yes
Carrigeencor	13/07/2018	1 (5)	This survey	No	n/a	No
Chluain Toipin	13/07/2016	4 (24)	This survey	Yes	2013	Yes
Cloonmackan	08/06/2018	0	none available	No	n/a	No
Courhoor	06/07/2017	0	none available	No	n/a	No
Derg	19/07/2017	2 (0)	EPA	No*	(2012)	No
Derryierin	14/08/2018	0	none available	No	n/a	No
Eske	19/07/2017, 12/07/2018	3 (16)	EPA	No	n/a	No
Fern	29/08/2017	5 (20)	EPA	Yes	2009	Yes
Foorglass	24/07/2018	3 (18)	This survey, Roden 2005	Yes	1975	Yes
Illauntrasna	13/09/2018	2 (9)	EPA	No*	(2007)	No
Kiltooris	24/07/2017, 26/07/2017	5 (35)	EPA	Yes	1989	Yes
Kindrum	17/08/2016	7 (26)	EPA	Yes	1916	Yes
Knocka	3/08/2017, 10/08/2017	4 (25)	This survey	Yes	2017 (this study)	Yes
Leane	05/09/2018	4 (14)	EPA	Yes	1886	Yes
Long Range	08/09/2016	6 (19)	EPA	Yes	1994	Yes
Loughauneala	13/09/2018	0 (grapnel)	none available	Yes	2005	Yes
Mask	26/07/2016	1 (11)	not examined	No	n/a	No

Lake name	Survey date(s)	Number of transects & (relevés)	Water chemistry data source	*Najas flexilis* recorded	Year *Najas flexilis* first discovered	*Najas flexilis* - this survey
Maumeen	21/09/2016	4 (12)	This survey, Roden 2005	Yes	2005	Yes
Melvin	18/07/2017	0	not examined	No	n/a	No
Moher	17/08/2017	4 (20)	EPA	Yes	2008	Yes
Mullaghderg	25/07/2017	4 (16)	This survey	Yes	1919	Yes
na Creibhinne	30/08/2016	4 (10)	This survey, Roden 2005	Yes	2005	Yes
na gCaor	21/09/2017	4 (15)	This survey, Roden 2005	Yes	1974	Yes
Nageltia	27/07/2016, 25/08/2018	0	This survey	Yes	2004	No
Nahaltora	18/08/2017	4 (12)	This survey	Yes	2004	Yes
Port	18/08/2016	3 (15)	This survey	Yes	1989	Yes
Sessiagh	23/08/2018	2 (7)	EPA	Yes	1981	No
Shannagh	28/08/2017	6 (14)	EPA	Yes	1989	Yes
Sheskinmore	19/07/2018	1 (8)	This survey	Yes	1981	Yes
Upper Lake	06/09/2018	3 (0)	EPA	Yes	1906	No

3 Results

A total of 40 lakes was examined in this study, including known sites for *Najas flexilis* (see Table 2) and other species-rich lakes with *Isoetes lacustris* and *Potamogeton perfoliatus*. Seven of the 40 lakes were largely unknown prior to the study but considered to have potential to contain the species or the habitat by virtue of records for drift specimens and/or geology. In one of the seven, Knocka Lough, Co. Clare, a new population of *Najas flexilis* was discovered (Figure 11). In total, *Najas flexilis* was recorded in 25 lakes during this study (2016-2018) (see Table 2 and Appendix I). The species could not be found at three lakes where it was previously recorded: Nageltia, Sessiagh and Upper (Table 2). Records for the species at two lakes, Derg and Illauntrasna, could not be confirmed. Both lakes were also found to be highly oligotrophic and, as a result, the unconfirmed records are not currently accepted. Therefore, *Najas flexilis* is known from a total of 28 of the 40 study lakes (Table 2 and Appendix I).

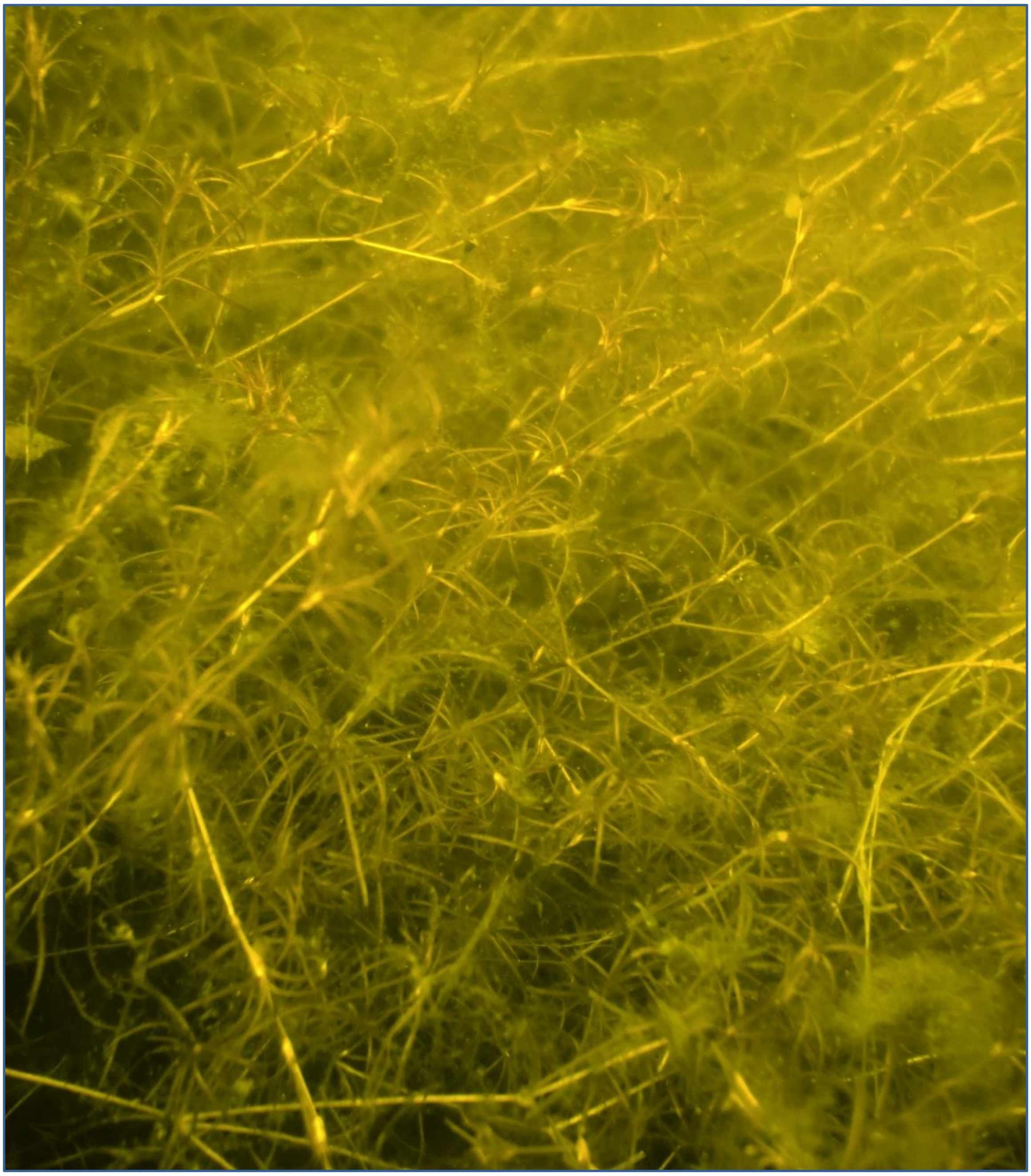


Figure 11 A sward of *Najas flexilis* at 3 m in Knocka Lough. Dense swards of *Najas flexilis* occur in the best examples of *Najas flexilis*-type lakes.

39 of the lakes were surveyed by snorkelling. One site, Loughauneala, was sampled using a grapnel and shown to contain a large population of *Najas flexilis*. Broad, brief surveys were conducted at five sites judged, in the field, not to be suitable for *Najas flexilis*: Carrigeencor, Cloonmackan, Courhoor, Derryierin and Melvin. A single transect with five relevés was sampled at Carrigeencor; relevés were not sampled at the other four (Table 2). Relevés were also not sampled at Lough Derg, which was found to be species-poor and highly-oligotrophic and where efforts concentrated on searching for *Najas flexilis*. Finally, relevés were not taken at two lakes with previous confirmed records for *Najas flexilis*, Nageltia and Upper Lake, where the survey concentrated on searches for the species (Table 2). In consequence, relevé data were gathered for 32 lakes (Table 2). Other variations in data across the study sites resulted from lake morphology: some were very shallow and a maximum depth of vegetation colonisation could not be determined; and the availability and quantity of water chemistry data (see Table 2 and Appendix II). As a result of these various factors, data for the 40 sites were not used in all analyses, however a core group of 28 lakes, emboldened in Table 1, were included in most. Further information is provided in the sections below.

Summary biological data for the lakes are given in Appendix I. Physico-chemical data are provided, where available/examined, in Appendix II. Appendices III and IV have the indicator species analyses from the vegetation analyses undertaken (see Section 3.3). Site reports for all lakes surveyed are provided in Appendix V, as separate pdf-file and hard-copy volume.

3.1 Preliminary vegetation analysis - recognition of *Najas flexilis*-type lakes

Macrophyte species lists for 33 lakes were analysed by cluster analysis and ordination using NMS (Figure 12). The seven lakes excluded from this analysis were those not comprehensively surveyed (Loughauneala, Carrigeencor, Cloonmackan, Courhoor, Derryierin, Melvin and Nageltia). Three main groups were distinguished and are illustrated by colour on Figure 12, these were

1) Group 1 - The majority of lakes surveyed
2) Group 2 - A group of six lakes with above median alkalinity, largely in Co. Donegal
3) Group 12 - Four shallower lakes (1-3 m depth) situated on the coast of Connemara, all of which have populations of *Najas flexilis*.

In addition two other lakes with *Najas flexilis* grouped together (Knocka and Fern) (Group 15), while four lakes without *Najas flexilis*, Ballynakill Gort, Illauntrasna, Anscaul and Derg, were shown to be more distant from the three main groupings.

Potamogeton species, as well as *Chara curta* were most common in the higher alkalinity Group 2 lakes (Figure 13), while *Subularia aquatica* was commonest in the coastal Connemara lakes (Group 12) (Figure 14). Few of the commoner species (*e.g. Littorella uniflora* or *Chara virgata*) were confined to a single cluster analysis group, indicating the overall floristic similarity of the lakes. These results largely accord with field experience which recognised that some lakes containing *Najas flexilis* had an unusual flora that included presumed hard-water species such as *Chara curta* or *Myriophyllum spicatum*, while most had a more soft-water flora. Nearly all lakes containing *Najas flexilis*, however had both *Isoetes lacustris* and *Potamogeton perfoliatus*. Lough Fern is thought to be nutrient enriched and lacks *Isoetes lacustris* but it is not obvious why Knocka Lough groups with it (Group 15).

The ordination confirmed the field observations that Lough Derg and Lough Illauntrasna have distinct vegetation and are not *Najas flexilis*-type lakes. Neither contains *Najas flexilis* or *Potamogeton perfoliatus*, nor does the Kilbride, or the south-western, arm of Lough Mask. In consequence, these three lakes were not included in subsequent data analyses. Although Anscaul and Ballynakill Gort did not have *Najas flexilis*, they were included in the further analyses as each contains *Isoetes lacustris* and *Potamogeton perfoliatus*. Because of the very recent invasion by *Elodea canadensis*, disappearance of *Najas flexilis* and uncertainty as to its ecological condition, data from Sessiagh, Co. Donegal were not used in other data analyses.

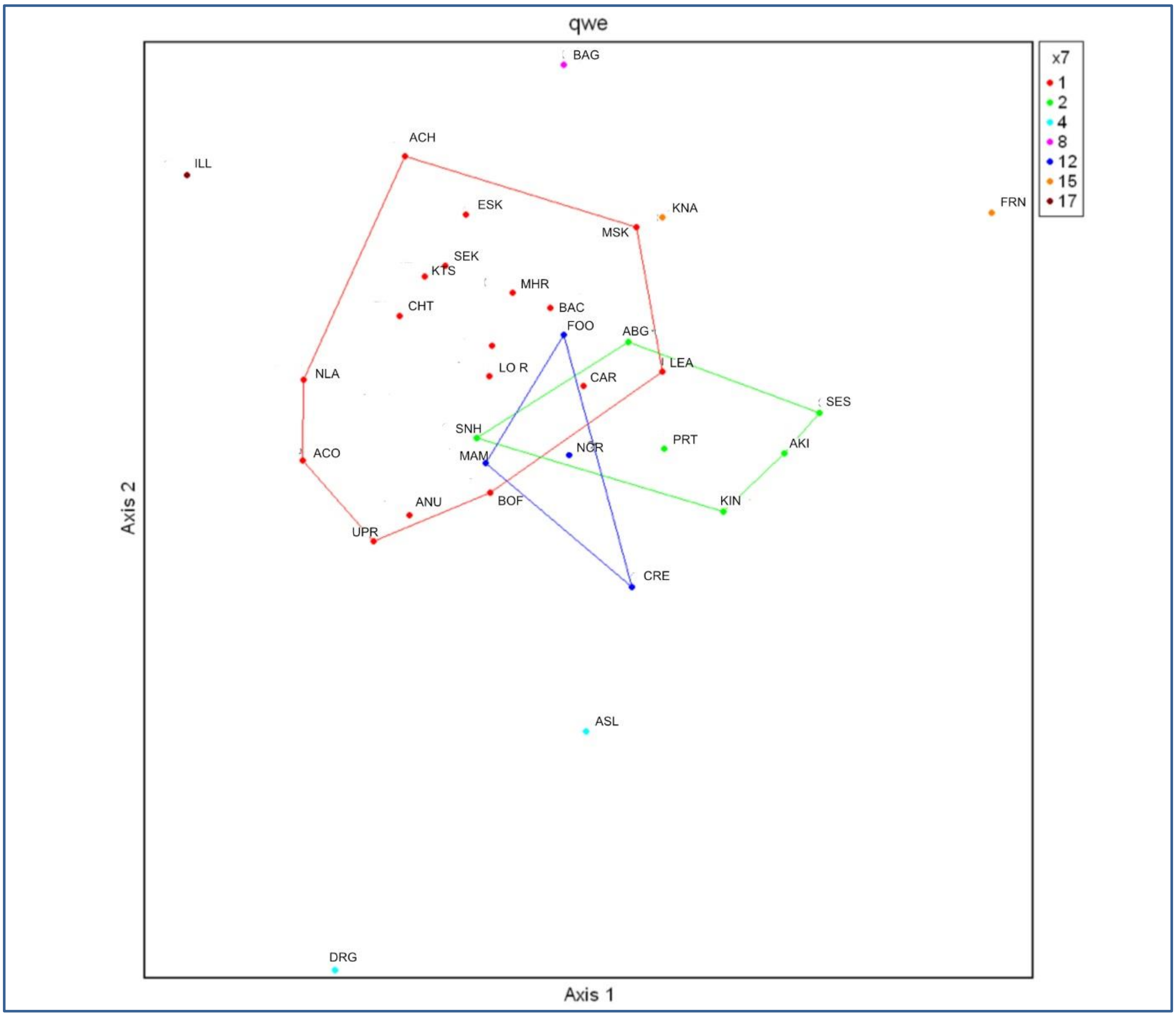


Figure 12 NMS plot based on species lists for the lakes. Colours and lines denote the groups derived from the cluster analysis. Group 1 (red) contains the majority of lakes sampled. Group 2 (green) has the more alkaline lakes largely found in Donegal. Group 12 (blue) includes Connemara coastal lakes. Knocka Lough and Lough Fern form Group 15. The remaining lakes appear marginal to the three main clusters. (NMS plot using Sorensen distance measure yielding a 3-dimensional solution with stress of 16.423).

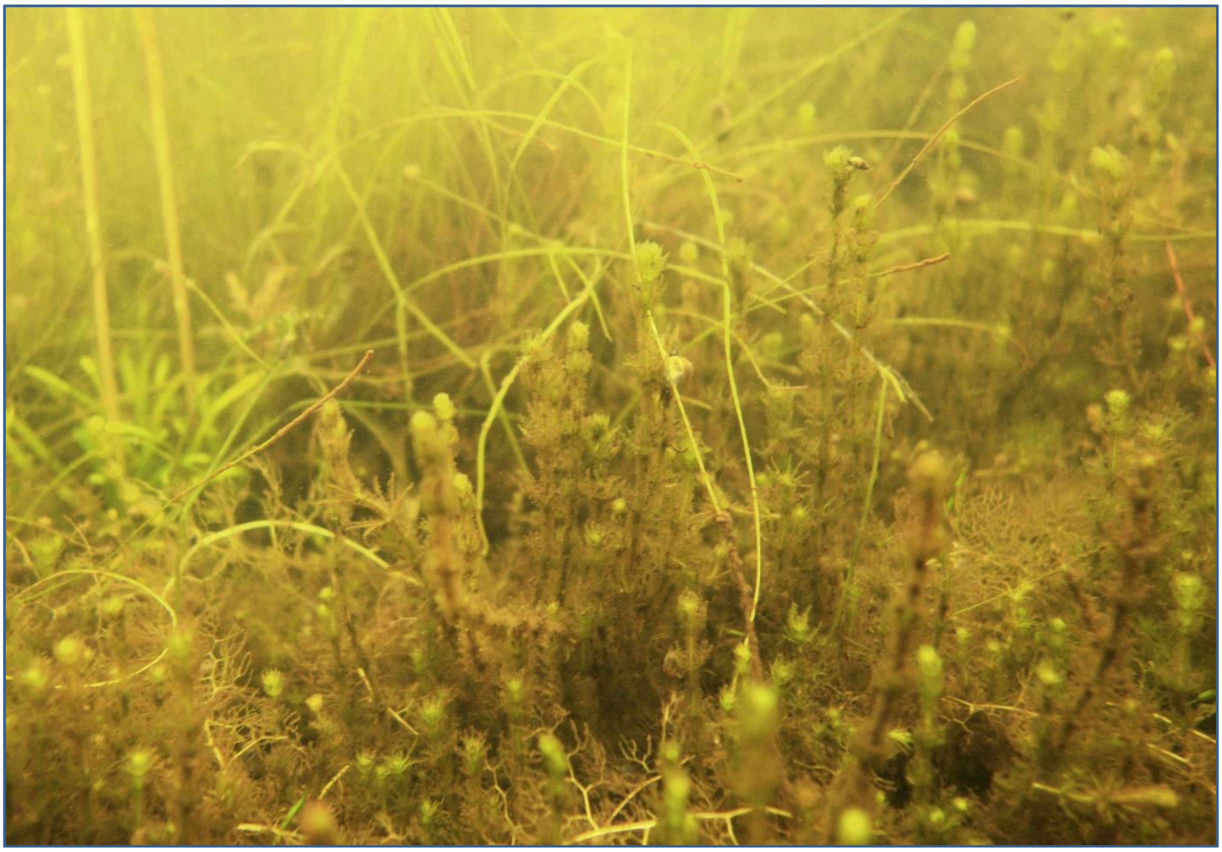


Figure 13 *Chara curta,* normally a species of marl lakes, grows in Kindrum Lough in an unencrusted form. It also grows in Port Lough. Here it is growing in shallow water (<1 m) accompanied by *Lobelia dortmanna*, *Utricularia* species and the long unbranched axes of *Nitella spanioclema*.

Figure 14 *Subularia aquatica* sward in Loch an Chaolaigh. This scarce species is abundant in shallow water of some Connemara lakes. Its persistence in Loch an Chaolaigh contrasts with decline of *Najas flexilis* in this lake.

3.2 The adequacy of sampling

Figure 15 shows the relationship between species number (*i.e.* the cumulative number of species recorded) and numbers of relevés sampled for two lakes, Maumeen with a small number of species, and Ballynakill Connemara with a large number of species. In both cases the curve approaches a limit, *i.e.* levels-off, suggesting sampling was adequate to generate accurate species lists.

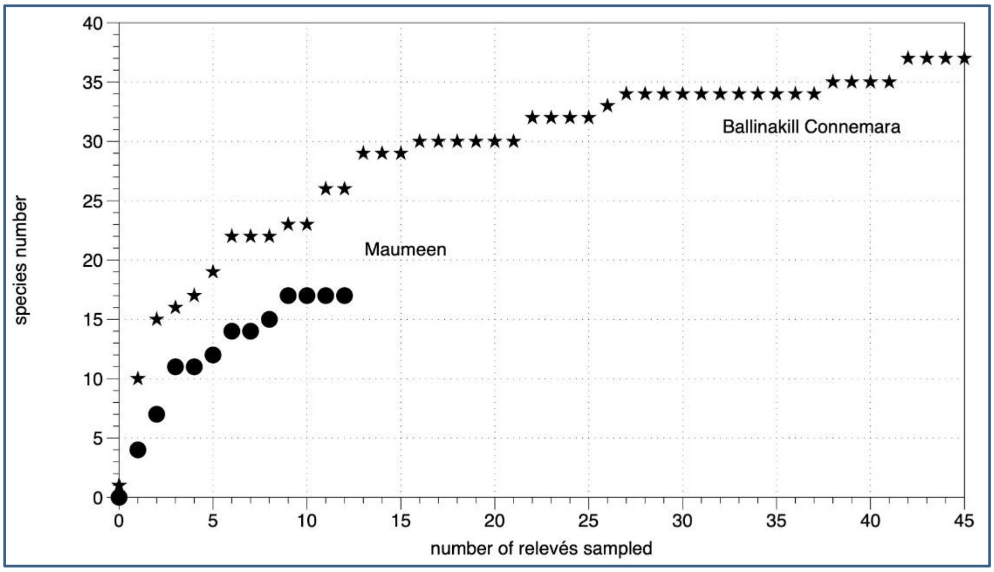


Figure 15 Cumulative species number plotted against number of relevés sampled for Ballynakill (Ballinakill) Connemara and Maumeen.

Figure 16 shows the numbers of species recorded against the numbers of relevés sampled at the core 28 sites (see Table 2). Across the lakes, there is a large variation in numbers of species recorded for a given number of relevés sampled, indicating that species number is not strongly correlated with the numbers of relevés. A comparison between Figures 15 and 16 shows that in the case of Ballynakill Connemara, if only 15 relevés were sampled, the number of species would still be 30, higher than most other lakes.

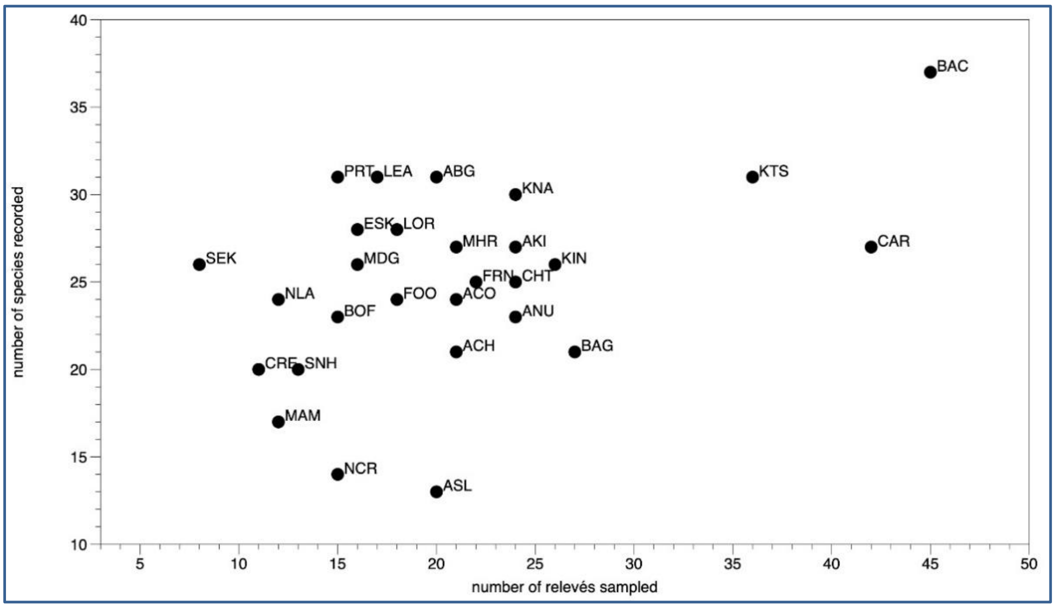


Figure 16 Plot of the number of species recorded from each lake against number of relevés sampled. The plot shows that there is no strong relationship between the two factors, which in turn indicates that the number of species recorded is not a function of numbers of relevés sampled. The three letter codes used are given in Table 1.

3.3 Detailed vegetation analyses

The vegetation of *Najas flexilis*-type lakes was further analysed using relevé data. A total of 542 relevés was collected across the 28 core lakes identified as *Najas flexilis*-type lakes (see Table 2 and Appendix III). These relevé data were analysed by cluster analysis to define vegetation units and by indicator species analysis to distinguish characteristic species. Cluster analysis distinguished a total of 22 groups, however 10 had fewer than 10 relevés each (a total of 54 relevés). Three major groups were present (Groups 1, 4 and 5), accounting for 344 of the 542 relevés used in the analysis, and were found to relate to water depth and lake euphotic depth.

3.3.1 Group 1 (*Lobelia*, *Littorella* and *Eriocaulon*)

This group comprised 114 relevés and corresponds to the often encountered soft-water Isoetid lake edge vegetation. The main indicator species were *Littorella uniflora*, *Lobelia dortmanna* and *Eriocaulon aquaticum* (see Appendix III). This vegetation unit occupies a depth range of 0-1.5 m (Figure 17) and was found in nearly all lakes surveyed. Similar vegetation is found in many soft-water lakes that do not contain *Najas flexilis*. *Littorella uniflora* swards also occur in many more hard-water lakes. While *Littorella uniflora* tends to be dominant on stony or gravel shores (Figure 18), soft sediment shores often have abundant *Lobelia dortmanna* (Figure 19) or *Eriocaulon aquaticum* (Figures 20 and 21). *Eriocaulon aquaticum* is very abundant in certain lakes within the range of *Najas flexilis* but it is not found in some Co. Donegal, Co. Mayo and Co. Kerry lakes.

The group is close to Subunit XVa of Heuff (1984) which had character species *Lobelia dortmanna* and *Eriocaulon aquaticum*, however *Littorella uniflora* was not regarded as occurring in that vegetation unit.

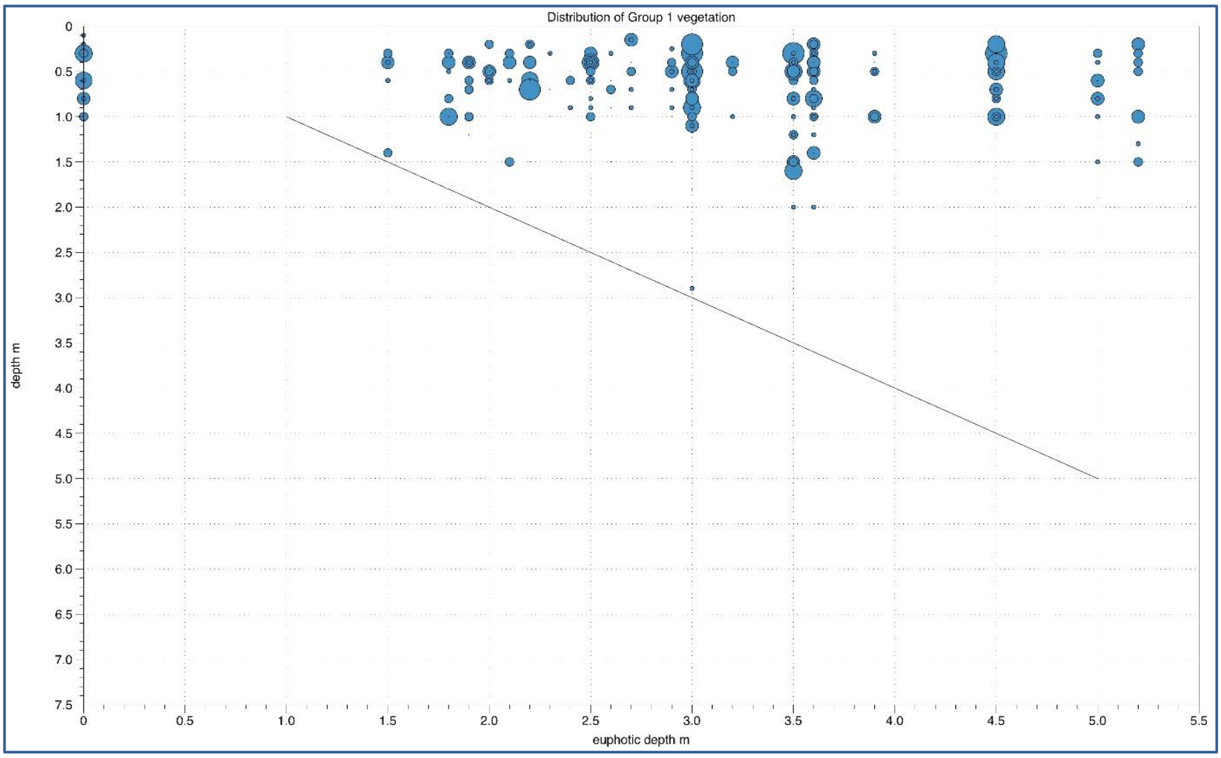


Figure 17 Depth distribution vegetation Group 1. Relevés with Group 1 vegetation are plotted against relevé depth (Y-axis) and lake euphotic depth (diagonal line). Each point corresponds to a single relevé. Relevé depth was measured by depth gauge. Euphotic depth is the euphotic depth of the lake in which the relevé was taken. Circle size is proportional to total cover value of the species in the group in each relevé. Consequently, some relevés with minor presence of the species group are shown, even though they are assigned to different species groups in the cluster analysis.

Figure 18 *Myriophyllum* and a sward of *Littorella uniflora* with one *Isoetes lacustris* plant in the lower right hand corner. Shallow-water vegetation (<1 m) on rock and gravel, Lough Leane.

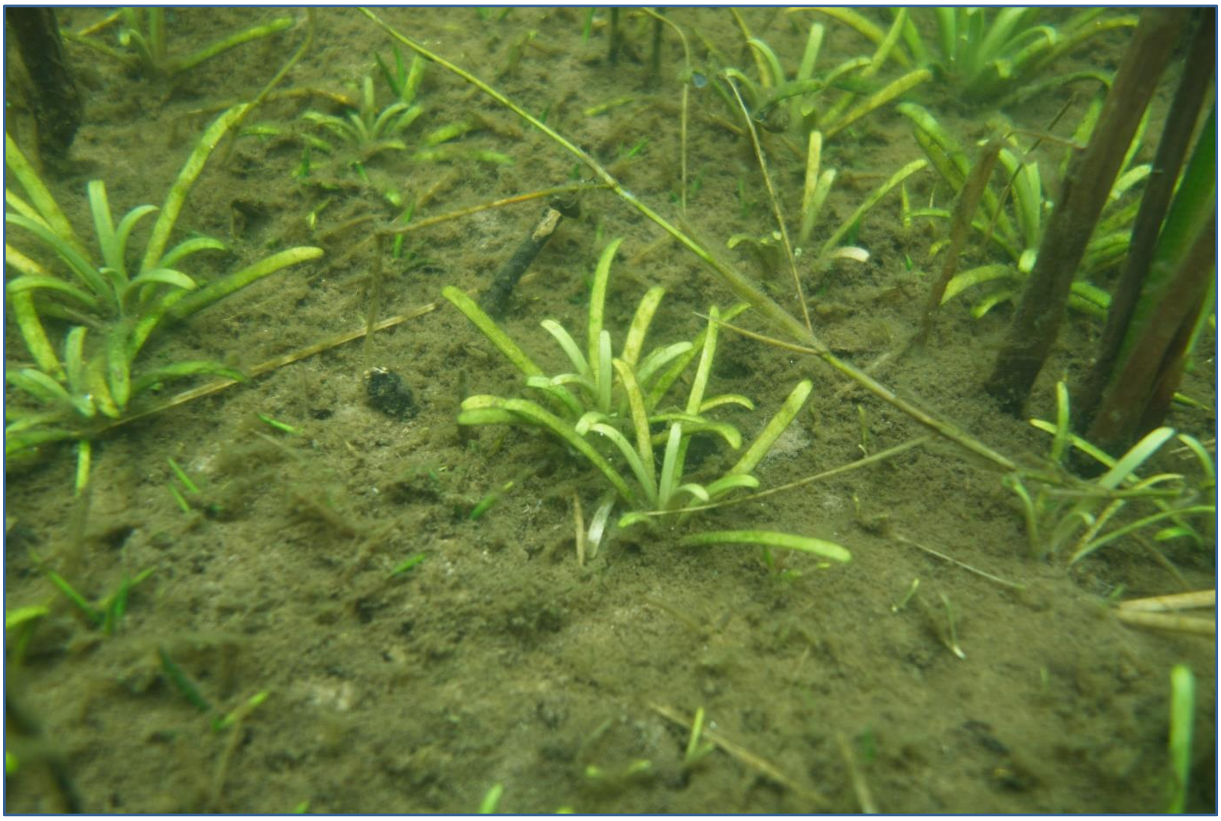


Figure 19 *Lobelia dortmanna* growing in the shallow sublittoral of Lough Eske. Note vertical stems of *Schoenoplectus lacustris*.

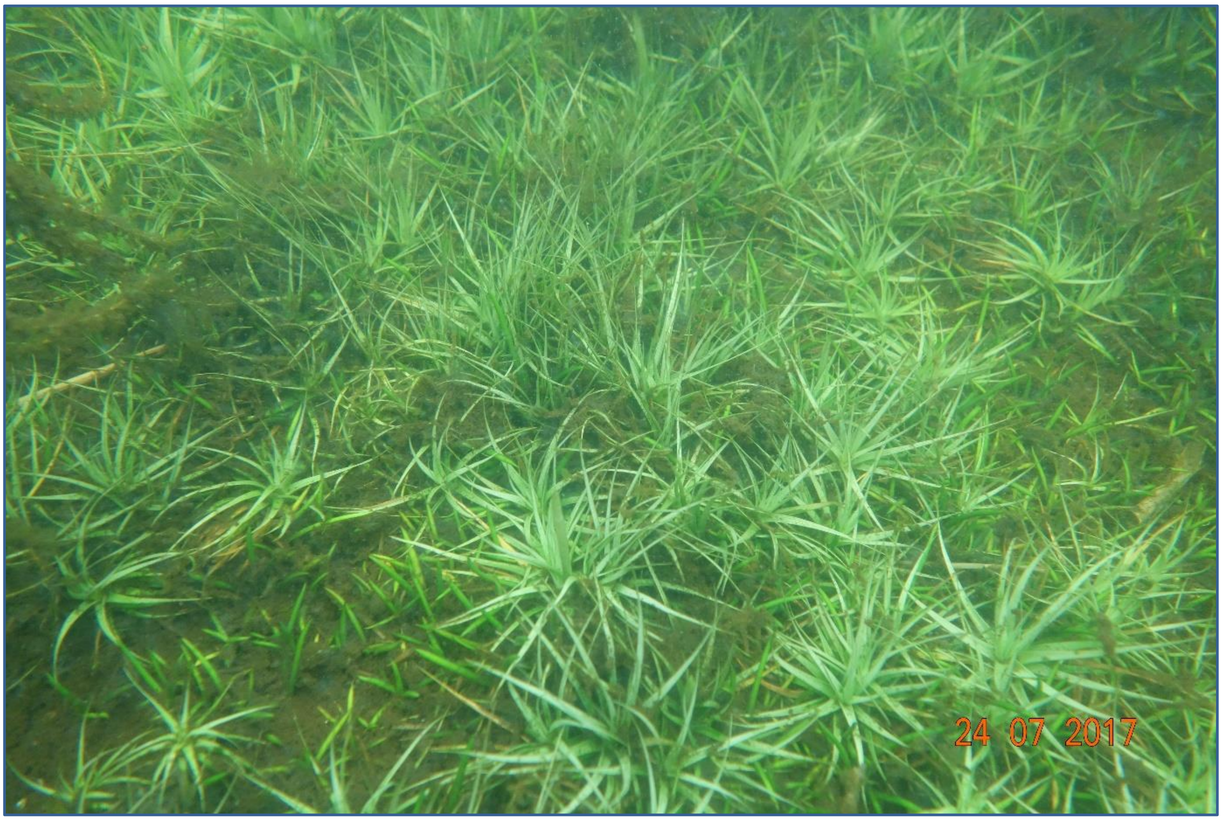


Figure 20 Mixed sward of *Littorella uniflora* (bright green tubular leaves) and grey-green *Eriocaulon aquaticum* rosettes at 1 m in Kiltooris Lough.

Figure 21 Flowering heads of *Eriocaulon aquaticum* about 50 cm below the water surface, possibly indicating a recent rise in water level due to heavy rain. Lough Caragh.

3.3.2 Group 4 (*Isoetes lacustris*)

Group 4 contained the largest number of relevés (132). These were characterised by an abundance of *Isoetes lacustris* (see Appendix III). *Isoetes lacustris* forms a sward with few other constant species (Figures 22 and 23). This zone occurred at depth ranges from 0.5 -3.0 m or even deeper (Figure 24). It occurred in all survey sites, except Lough Fern. It is not confined to *Najas flexilis*-type lakes, rather is almost ubiquitous in soft-water lakes and also occurred in survey sites Mask, Illauntrasna and Derg. While Free *et al*. (2005) suggested that *Isoetes lacustris* is rarely found in lakes with alkalinity above 20 mg/l, this survey shows the species can occur at alkalinities up to 70 mg/l (Kindrum). Group 4 is similar to subunit XVII in Heuff (1984) which had *Isoetes* as a character species. Heuff (1984) noted it occurred below the *Lobelia*-*Eriocaulon* unit at depths of 0.3-3.0 m in oligo-mesotrophic water. Our field experience confirms this pattern.

Figure 22 Mid-water vegetation in Lough Caragh. A sward of *Isoetes lacustris* with *Utricularia* sp. Note the floc of peat and organic particles. While often encountered in the survey, it is not known if this is a natural occurrence or a product of excessive losses from bogland.

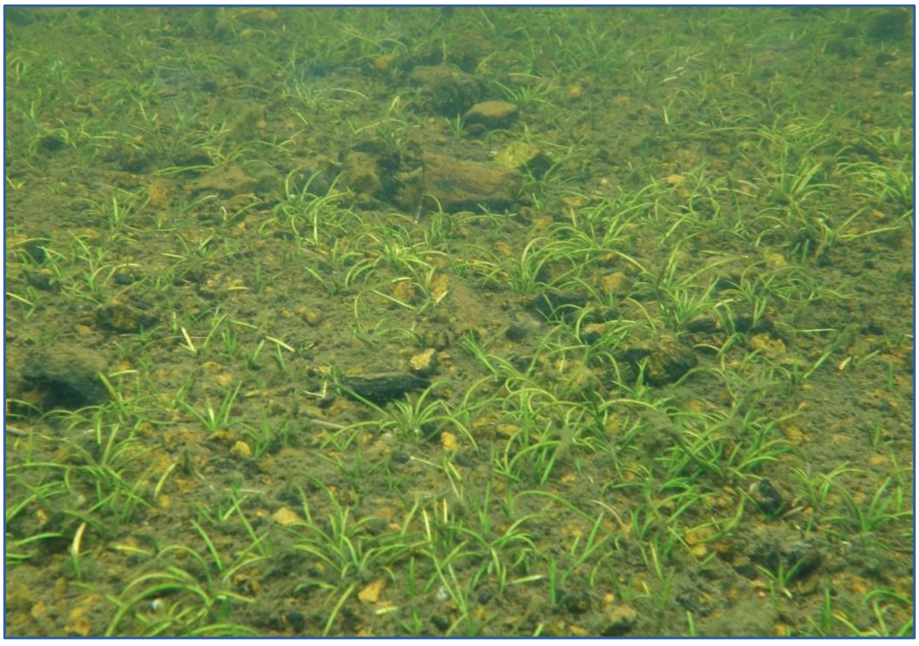


Figure 23 Scattered sward of *Isoetes lacustris* at 1.5 m in Lough Leane.

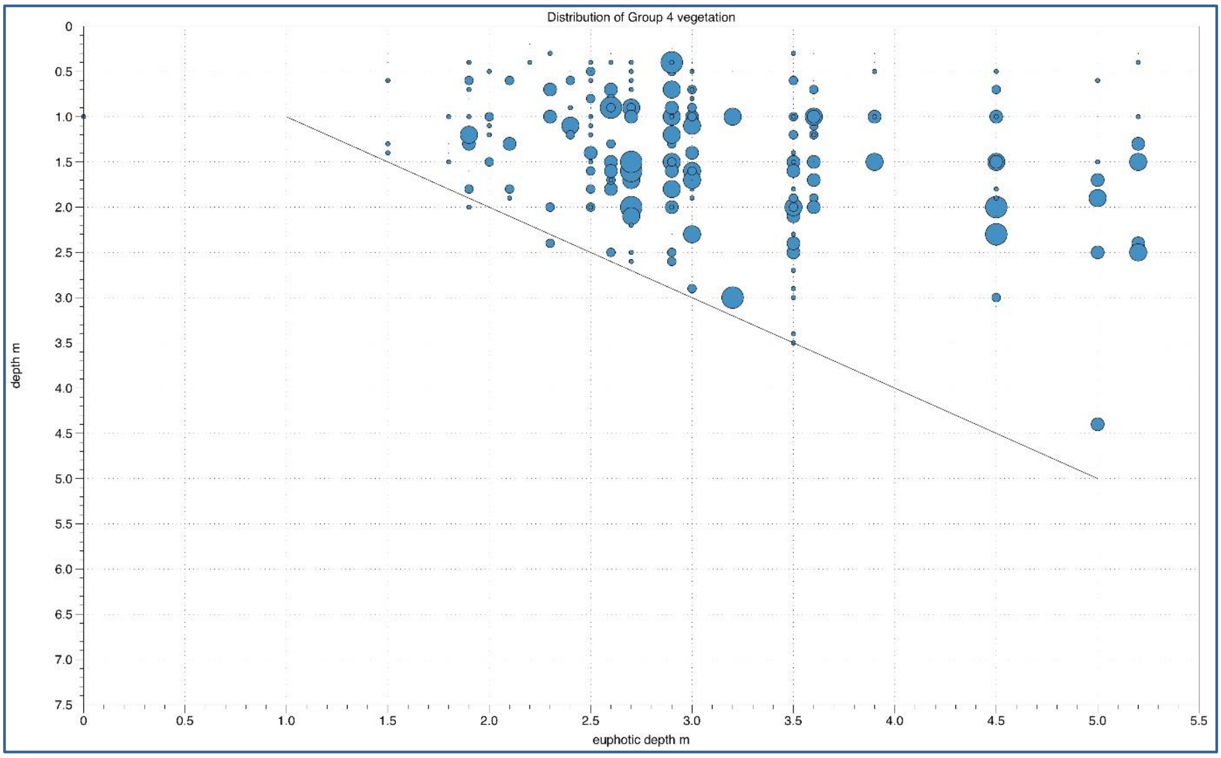


Figure 24 Depth distribution vegetation Group 4. Relevés with Group 4 vegetation are plotted against depth (Y-axis) and lake euphotic depth (diagonal line).

3.3.3 Group 5 (*Najas flexilis* or deep-water vegetation)

The third largest group with 98 relevés consists of *Najas flexilis* (Figure 25) and other species that tend to grow in water deeper than the *Isoetes lacustris* zone. The species list is quite extensive and includes *Najas flexilis*, *Potamogeton berchtoldii* (Figure 26), *Potamogeton perfoliatus, Chara virgata* (Figure 27) and *Nitella confervacea* (Figures 28), as well as species such as *Callitriche hermaphroditica* (Figure 29) and *Nitella translucens* which also occur in other groups. This group is found from the base of the euphotic zone to about 1 m depth (Figure 30). The upper limit varies from lake to lake but it is normally found below or slightly overlapping the *Isoetes lacustris* zone. It may be significant that most species in this group are small in size, compared to many species of *Potamogeton* or *Elodea canadensis*, and the characteristic form of the vegetation is an open low sward. Even *Potamogeton perfoliatus* tends to grow as a small form, often less than 1 m in height (see Figure 2).

In general, cover values are low (1 to 2, or less than 25%) in Group 5 with much exposed mud or silt, presumably reflecting lower light intensity. Several species, such as *Najas flexilis* and *Callitriche hermaphroditica*, are annuals that grow in these open conditions. *Nitella translucens* also grows at the euphotic limit and is very common in lakes with *Najas flexilis*, but is placed in a separate group (Group 3) with few associates. This may reflect the tendency of *Nitella translucens*, like many charophytes, to form high cover value stands that exclude other species. Deep-water vegetation can be a mosaic of *Nitella translucens* stands interspersed with open vegetation of Group 5, although *Nitella translucens* also co-occurs with *Najas flexilis* at lower cover values.

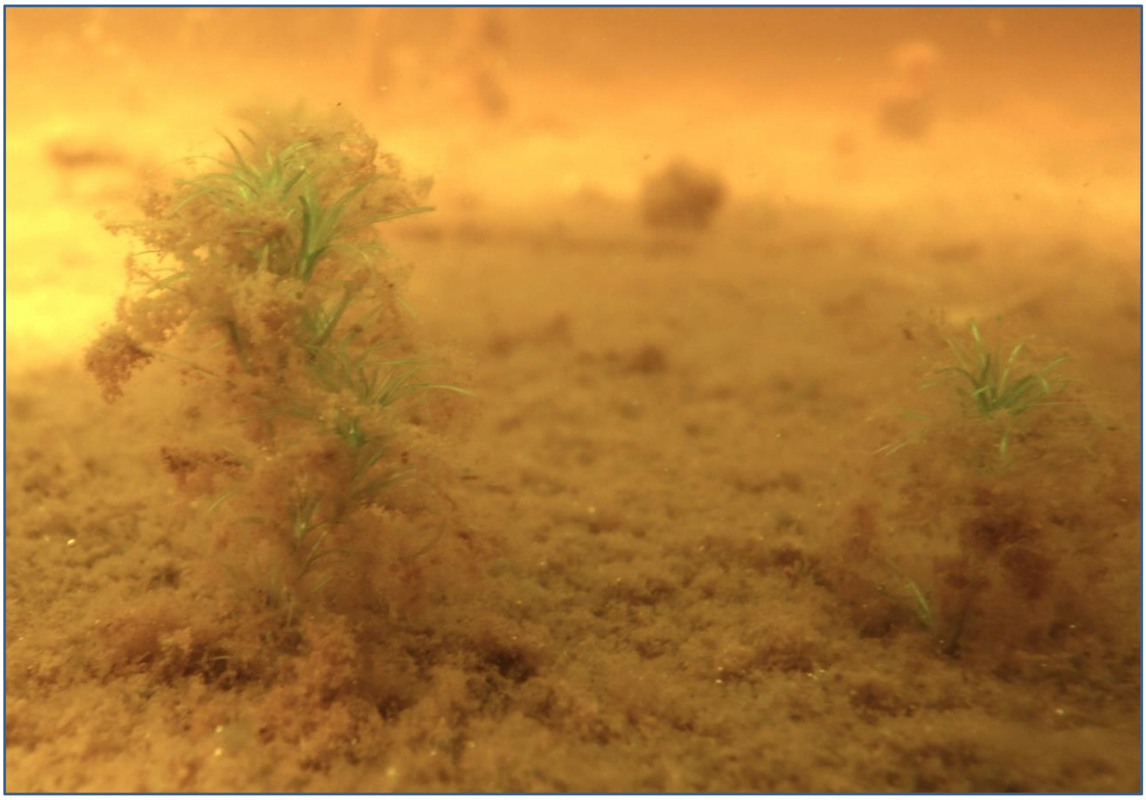


Figure 25 Isolated plants of *Najas flexilis* growing on the sandy bottom of Lough Mullaghderg. Note the floc of organic material that clings to the plant surface.

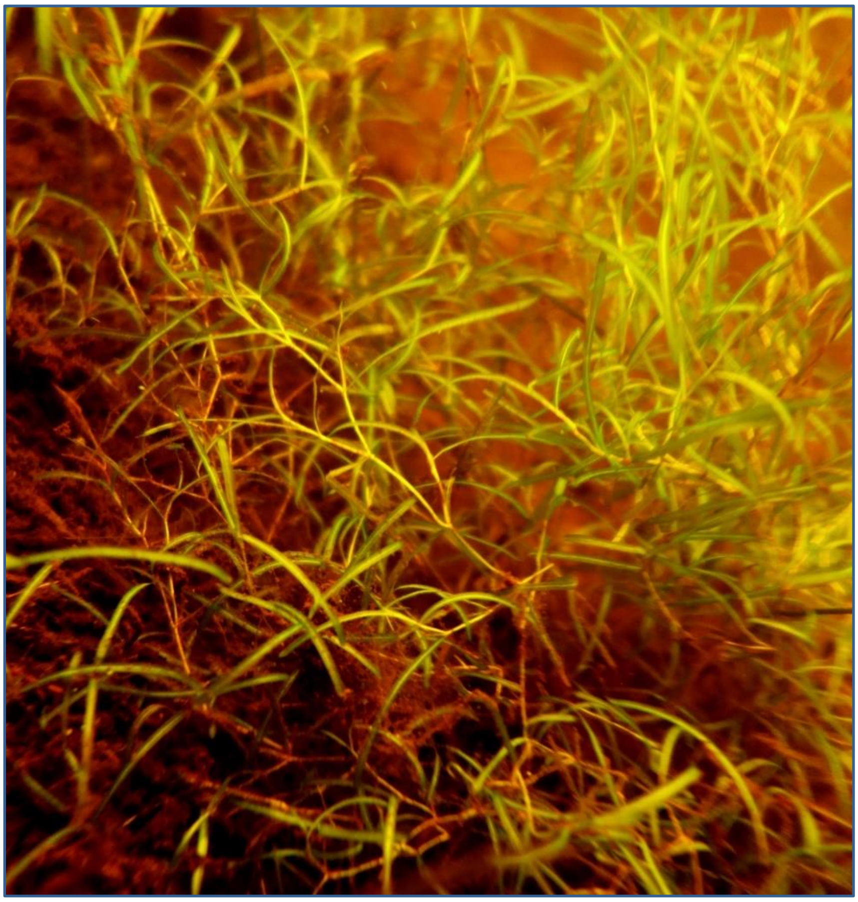


Figure 26 *Potamogeton berchtoldii* growing at depth in Knocka Lough at 3 m. This is a very characteristic species of deep-water vegetation.

Figure 27 *Najas flexilis* growing in a carpet of *Chara virgata* and *C. aspera* in Kiltooris Lough at 2 m. Carpets of *Chara virgata* and other charophytes are a feature of some *Najas* lakes that possibly separate the *Najas flexilis* lake type from many oligotrophic lakes and demonstrate a connection with marl lakes.

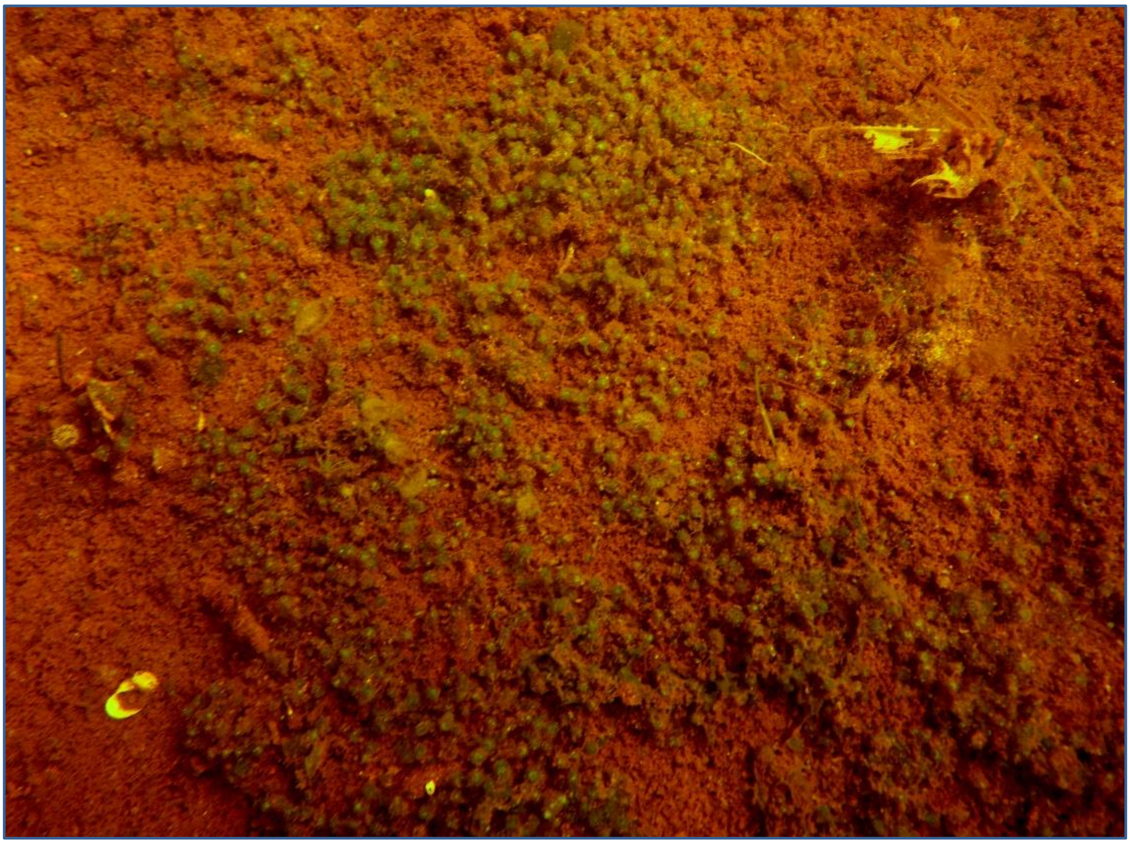


Figure 28 The very small *Nitella* species, *N. confervacea* grows at depth (>2 m) and forms extensive carpets in some clear-water lakes such as Kiltooris. It is a characteristic member of the deep-water vegetation.

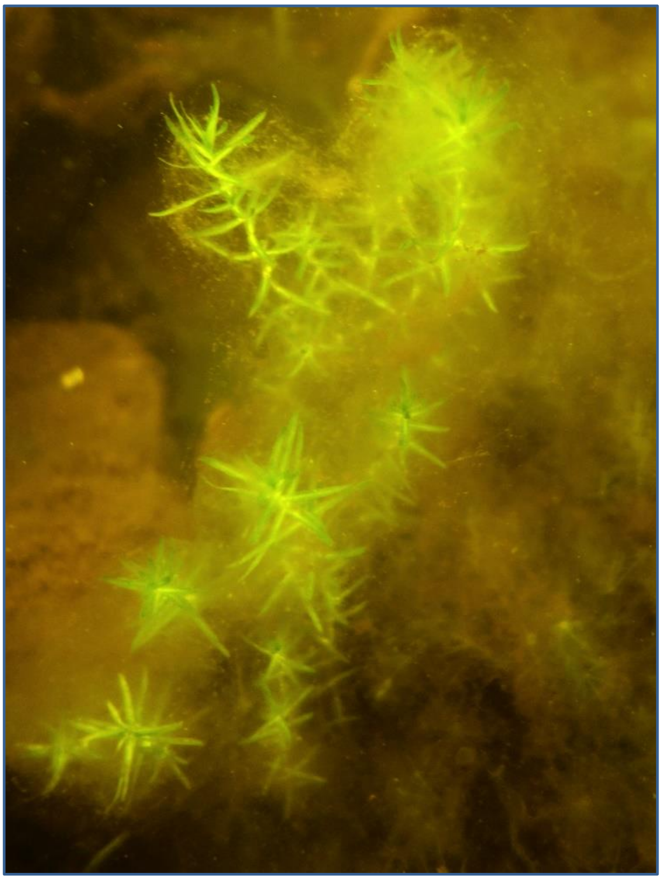


Figure 29 *Callitriche hermaphroditica* growing at a new station in Knocka Lough. The plant grows at (>2.5 m) and is entangled with filamentous algae.

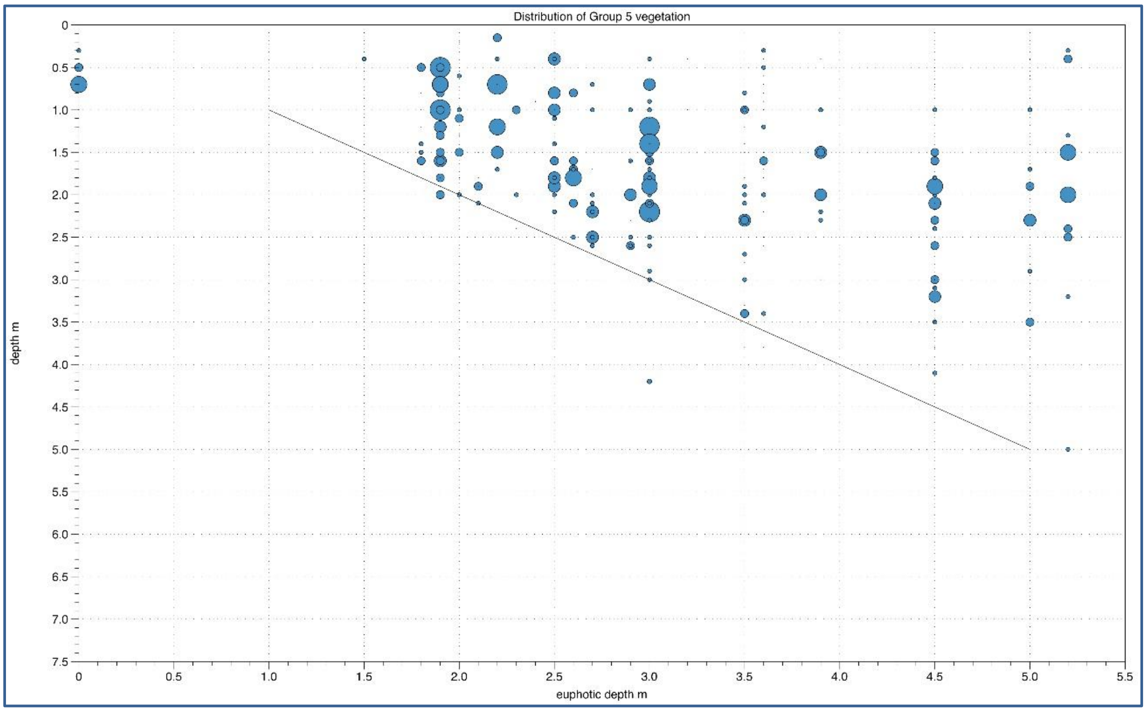


Figure 30 Depth distribution vegetation Group 5. Relevés with Group 5 vegetation are plotted against depth (Y-axis) and lake euphotic depth (diagonal line).

The extent to which the Group 5 deep-water vegetation is confined to *Najas flexilis*-type lakes is unclear. Certainly *Najas flexilis*, and probably *Nitella confervacea*, are characteristic of *Najas flexilis*-type lakes: lakes with intermediate alkalinity, *Isoetes lacustris*, *Potamogeton perfoliatus*, and a deep-water vegetation. No comparable vegetation is found in marl lakes, which occur as alkalinity increases above 100 mg/l. However, with increasing eutrophication, the Group 5 vegetation can be replaced by a broad-leaved *Potamogeton* community typical of eutrophic lakes, *e.g.* Loch na gCaisleach in west Co. Galway supported a *Najas*-*Nitella* community in 2005 that has since been replaced by dense stands of *Potamogeton perfoliatus* (C. Roden, field observation, September 2019). Similarly, in some less alkaline lakes, a *Potamogeton berchtoldii*-*Callitriche hamulata* community can be found below the *Isoetes* community (*e.g.* Glenbeg Lough, Beara Peninsula, Co. Cork, C. Roden field observation September 2019).

We tentatively suggest that Group 5 vegetation is replaced by a sparse *Isoetes lacustris*—*Potamogeton berchtoldii*—*Callitriche hamulata* community at lower alkalinity, while higher alkalinity leads to the charophyte vegetation of marl lakes. Eutrophication probably leads to dominance of broad-leaved *Potamogeton* species and *Elodea canadensis*.

Group 5 appears similar to subunit XIX in Heuff (1984), which had *Najas flexilis* and *Potamogeton berchtoldii* as character species.

3.3.4 Other vegetation groups identified

The remaining groups are much smaller with 25 or fewer relevés in each and, thus, did not occur in all 28 lakes included in the analysis.

Group 2 is dominated by *Juncus bulbosus* (Figure 31). *Eleogiton fluitans* and *Utricularia* spp. are also characteristic. This group appears to be confined to lakes with shallower euphotic depths, as shown in Figure 32, possibly due to higher water colour and bogland drainage. It matches subunit XVI of Heuff (1984) which grows on peaty soil at 0.75-2 m depth in soft-water lakes.

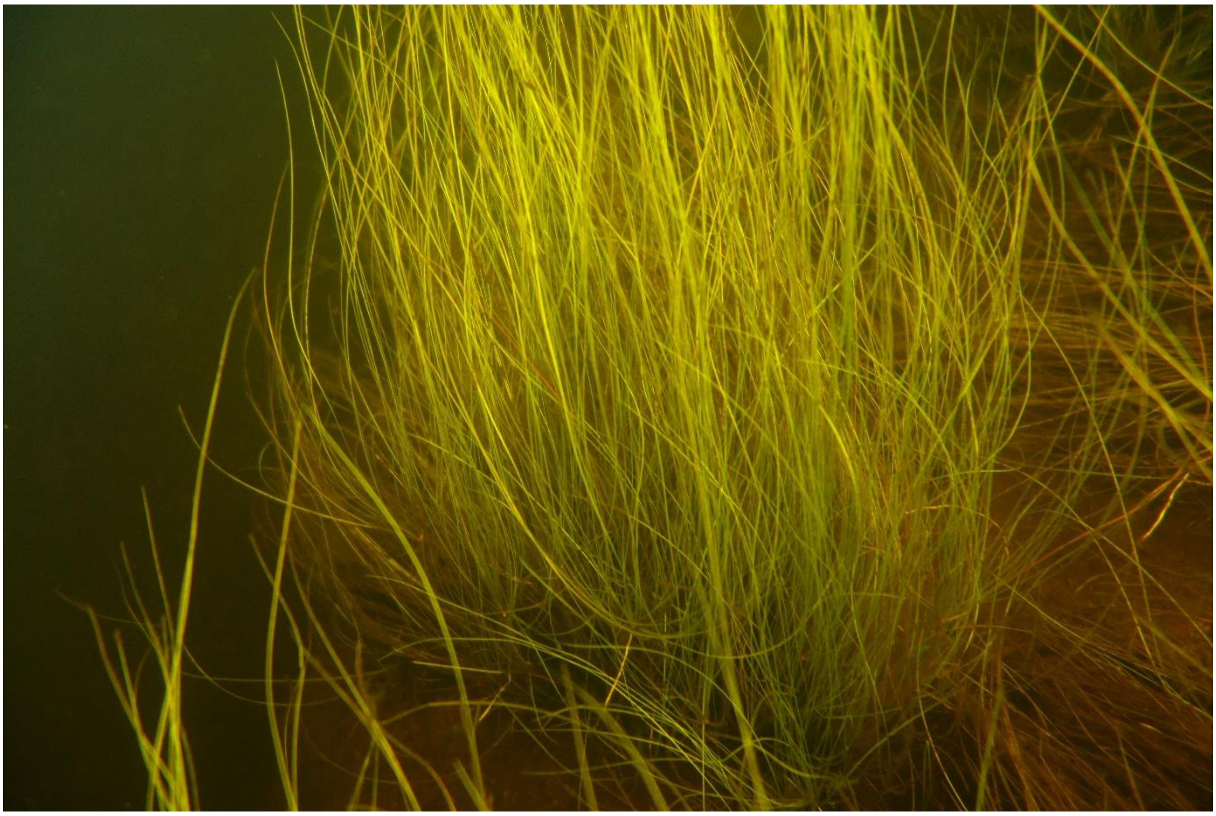


Figure 31 *Juncus bulbosus* growing in the peat-stained waters of the Long Range.

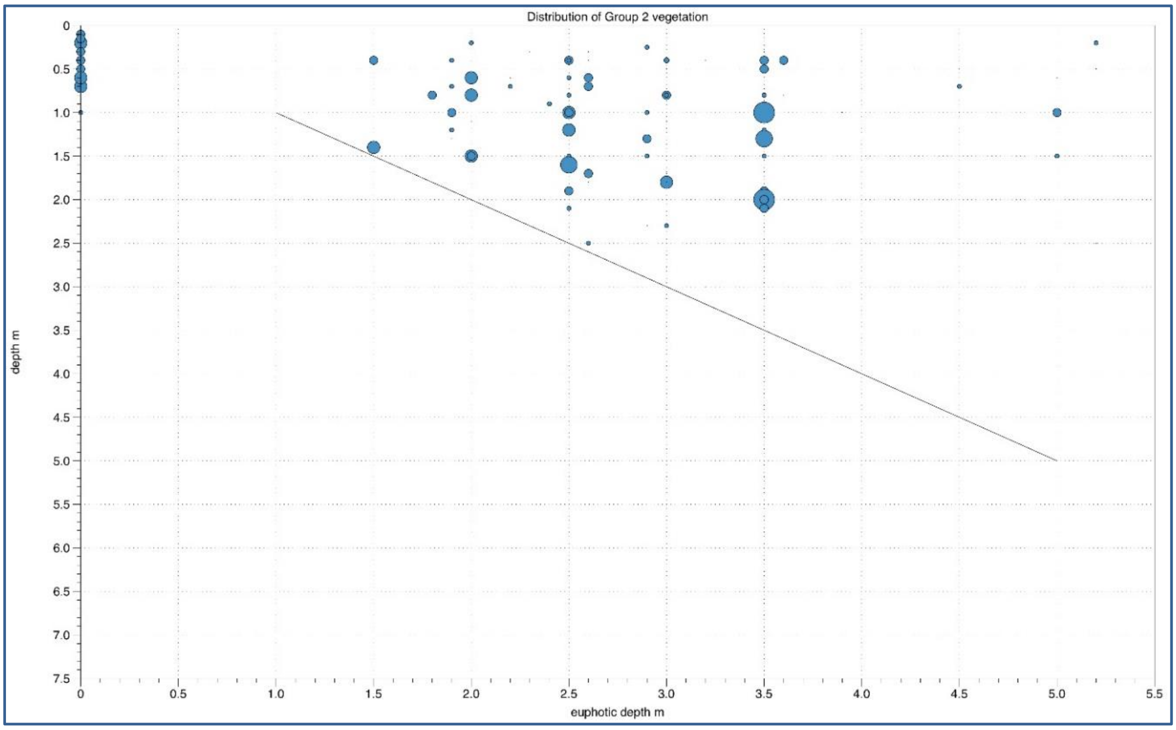


Figure 32 Depth distribution vegetation Group 2. Relevés with Group 2 vegetation are plotted against depth (Y-axis) and lake euphotic depth (diagonal line).

Group 3 consists of stands of *Nitella translucens* (Figure 33). The separation of these *Nitella translucens* stands from the other deep-water species of Group 5 reflects the dominance of this charophyte, which excludes other species (Figures 34 and 35). The community is comparable to subunit XXIB of Heuff (1984). Several other small groups appear to be satellites of the deep-water group. For example Group 19 with *Hydrilla verticillata*, *Callitriche hermaphroditica* and *Potamogeton berchtoldii* is confined to Ballynakill Lough but is clearly related to Group 5, Equally Group 21 with *Potamogeton praelongus* (mainly found in Lough Acoose) is another variant.

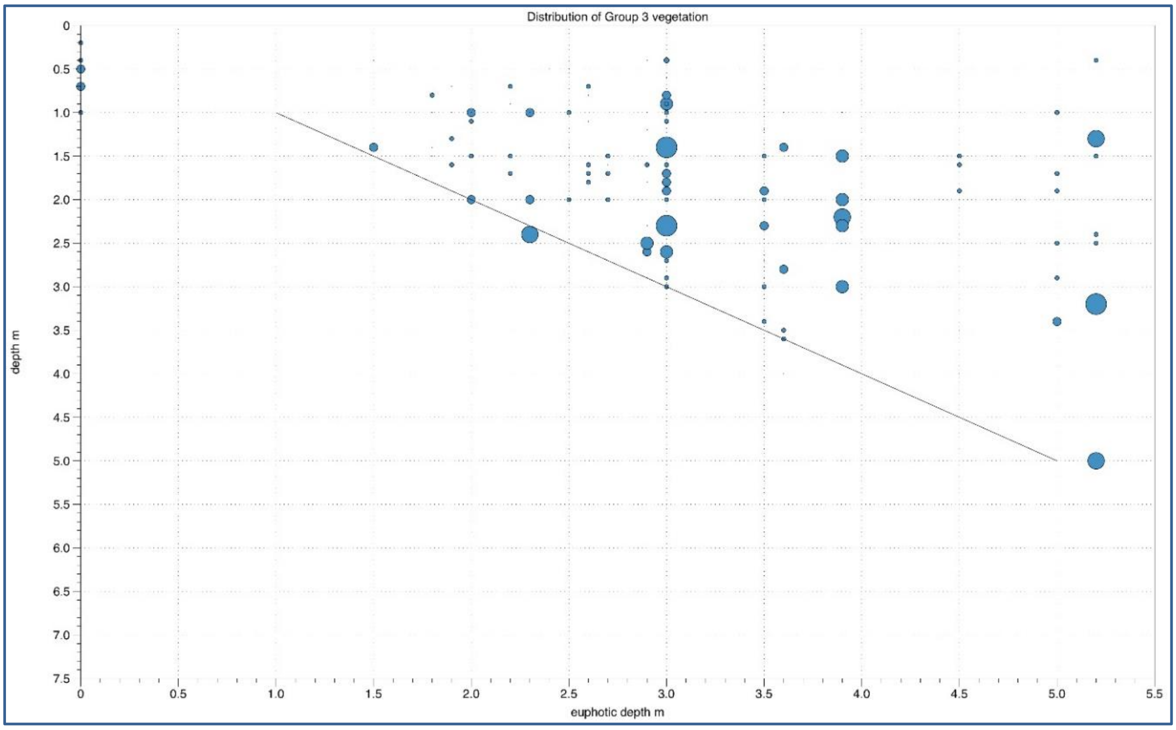


Figure 33 Depth distribution vegetation Group 3. Relevés with Group 3 vegetation are plotted against depth (Y-axis) and lake euphotic depth (diagonal line).

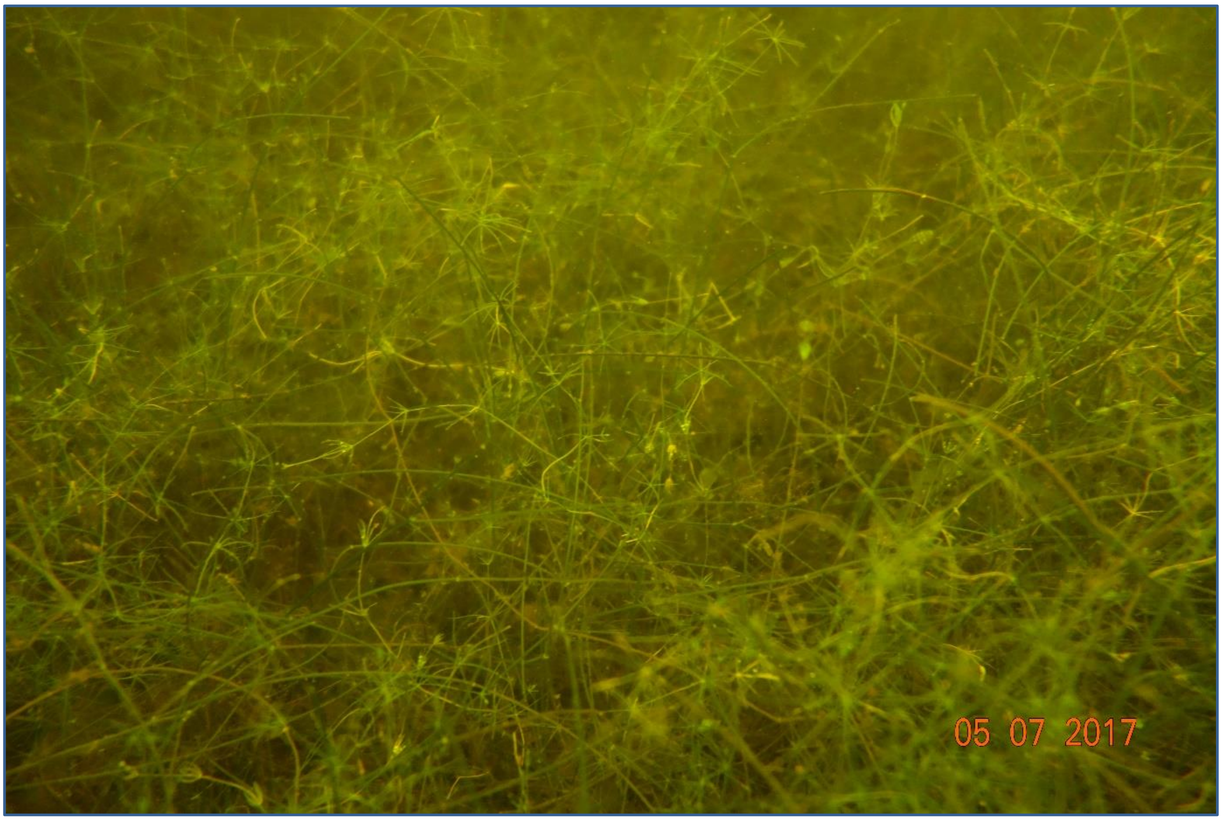


Figure 34 Deep-water vegetation of *Nitella translucens* and some *Chara virgata* growing at 4 m in Aughrusbeg Lough.

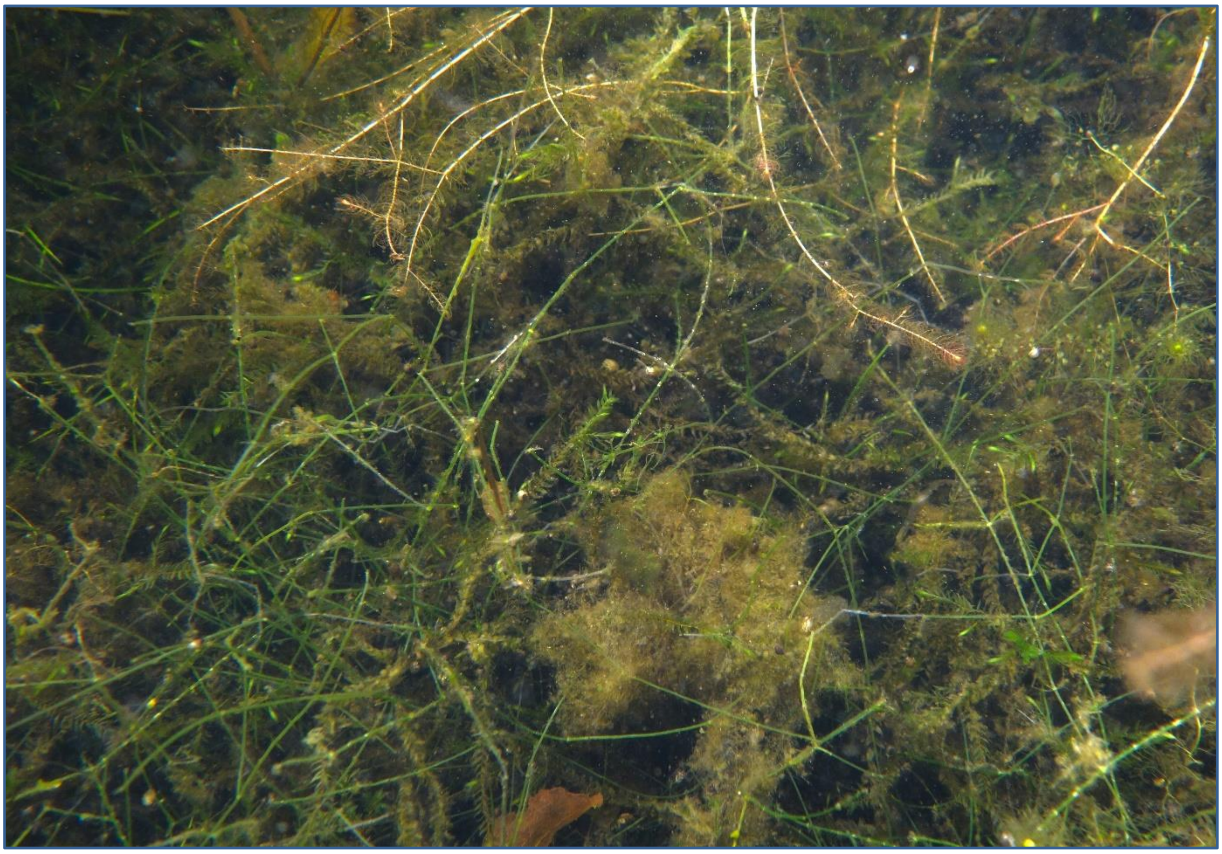


Figure 35 A carpet of *Nitella translucens* (narrow green tubes) and feather-like stems of *Fontinalis antipyretica* at 2.5 m in Lough Sessiagh.

Group 14 has as indicator species *Chara aspera, Scorpidium scorpioides* and pondweeds (*Potamogeton pectinatus*, *Potamogeton filiformis* and *Potamogeton* × *nitens*). The analysis of whole lake floras (Section 3.1) indicated a separate group of lakes with *Najas flexilis* with above average alkalinity, and this distinction is reflected in Group 14, which contains species normally not found in oligotrophic lakes. The group resembles sub unit XXV of Heuff (1984) who noted *Chara aspera*, *Myriophyllum spicatum* and *Potamogeton pectinatus* as core species. She regarded the unit as typically found in calcareous water.

Group 13 with *Chara curta* (a near relative of *Chara aspera*, found in marl lakes) is confined to Port and Kindrum loughs, and also contains species associated with higher alkalinity. In general, both groups occur in shallow water.

Group 16 includes *Isoetes echinospora*, *Subularia aquatica* and *Apium inundatum*. This rarely-encountered grouping was found largely in Connemara lakes, but is difficult to interpret as *Isoetes echinospora* is often not identified in the field. *Subularia aquatica* is generally a plant of shallow water.

Group 8 is a *Phragmites australis—Nymphaea alba* group. *Potamogeton natans* is also associated with this group. *Phragmites australis* and *Schoenoplectus lacustris* beds are occasional in these lakes, but dense extensive beds are rare and probably atypical of relatively nutrient-poor lakes. Inevitably snorkel-based surveys will also under sample such vegetation as it is inaccessible to boat-based survey. Most relevés were taken at the edge of these beds where floating-leaved species such as *Potamogeton natans* occur (see Figure 6).

Group 11 is an *Elodea canadensis—Potamogeton* group that is atypical of oligotrophic lakes and may be transitional to eutrophic *Potamogeton*-dominated lakes. *Nitella spanioclema* is, surprisingly, associated with the group, possibly because it is mostly found in Kindrum Lough which is somewhat impacted by eutrophication.

Group 12 is the *Nuphar lutea—Schoenoplectus lacustris—Lemna trisulca* group. It is similar to the vegetation found in degraded marl lakes and possibly indicates eutrophication. It was largely confined to Ballynakill Gort. Note however that *Schoenoplectus lacustris* occurs in other groups and many of the lakes surveyed.

3.3.5 Analyses of the sub-set of relevés containing *Najas flexilis*

Similar cluster and indicator species analyses were run on the sub-set of 113 relevés containing *Najas flexilis* (see Appendix IV). The three largest groups distinguished in this analysis (Groups 1, 2 and 3) accounted for 73 of the 113 relevés with *Najas flexilis*. Group 1 had *Najas flexilis* associated with *Potamogeton perfoliatus and Nitella confervacea*. In Group 3, *Najas flexilis* was found with *Isoetes lacustris* and *Utricularia* sp. Group 2 had *Najas flexilis* with *Potamogeton berchtoldii*. Groups 1 and 2 are similar to the deep-water group (Group 5, Section 3.3.3) identified from the cluster analysis of all relevés, while Group 3 resembles the *Isoetes* group (Group 4, Section 3.3.2). The table (Appendix IV) thus indicates that most *Najas flexilis* plants occur in the deep-water grouping or the *Isoetes* grouping with the remaining distributed in the other groupings listed. Several of the groups are variants of the deep-water grouping (Groups 4, 6, 10), while Group 7 includes species of the shallow water: *Littorella* and *Eriocaulon* vegetation. This range of vegetation types shows that *Najas flexilis* is not confined to the deep-water vegetation but can occur in shallow-water communities albeit rarely.

3.3.6 Characteristic *Najas flexilis*-type lake vegetation

A subjective interpretation of *Najas flexilis*-type lake vegetation can be summarised as follows

- All *Najas flexilis*-type lakes have three vegetation zones (with the exception of very shallow examples such as Sheskinmore)
    1) *Lobelia–Littorella* (Group 1)
    2) *Isoetes lacustris* (Group 4) and
    3) Deep-water vegetation (Group 5). In some places a monoculture of *Nitella translucens* (Group 3) replaces the Group 5 deep-water vegetation
- More alkaline lakes support *Chara aspera* (Group 14) and *Elodea–Potamogeton* (Group 11) communities
- Conversely, more oligotrophic, or even dystrophic, variants support *Subularia–Isoetes echinospora* (Group 16) or *Juncus bulbosus* (Group 2) communities
- Eutrophication leads to the *Nuphar–Lemna trisulca* community (Group 12).

3.4 Species-richness

The number of species occurring is a raw measure of biodiversity in a lake. Figure 36 summarises the species-richness across the 39 study lakes (Loughauneala, sampled by grapnel only, was excluded). Three figures are given: the number of species recorded during the study (blue bar); the number of species known from the lakes before this study (orange bar - available for 32 of the lakes); and the combined total number of species (grey bar, also given for 32 lakes). Eleven lakes have combined richness of 30 or more species, and one of these (Lough Leane) has records for more than 40 species (see Figure 37). During the study, 30 or more species were recorded in six lakes, between 20 and 29 species in 22 lakes, between 10 and 19 species in nine lakes, and fewer than 10 species in two lakes (Figure 36). Figure 36 illustrates that the study improved the knowledge of macrophyte species-richness in these lakes, but also documented losses of species from some.

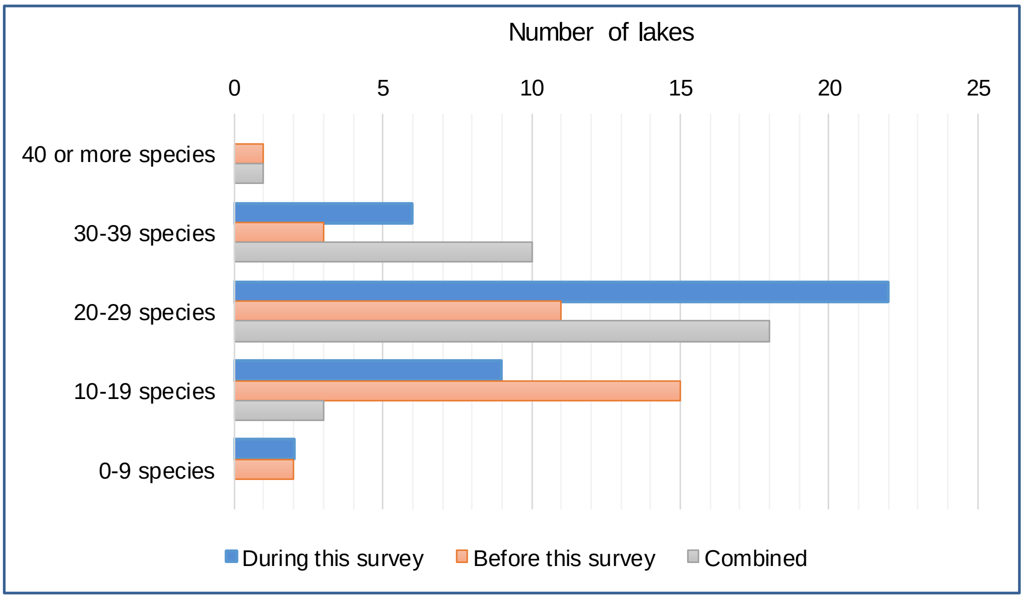


Figure 36 Aquatic macrophyte species-richness across the study lakes. Figures are given for 39 lakes in the current study (blue bar), the 32 lakes with records available from before the study (orange bar) and the total, combined species-richness for those 32 lakes.

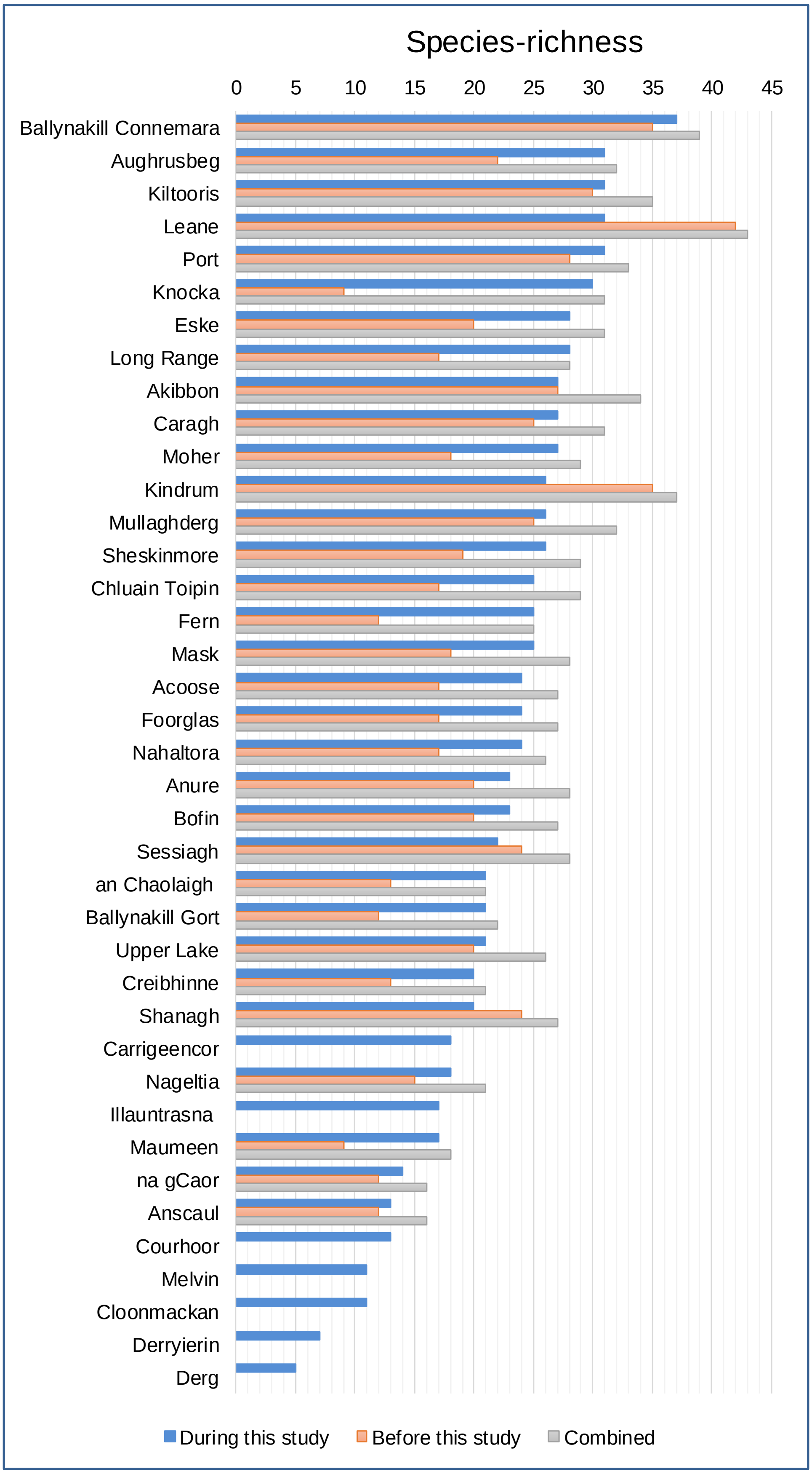


Figure 37 Lake macrophyte species-richness. The blue bars show the numbers of species recorded during this study; the orange bars are the numbers recorded in previous surveys and the grey bars show the total numbers of species recorded in a lake across all surveys.

Figure 37 shows the number of aquatic macrophyte taxa recorded in each of the study lakes (see also Appendix I). Lough Leane has the highest combined richness, with 43 species, however only 31 species were recorded during the study and the lake was found to be seriously impacted by eutrophication, having lost characteristic species and habitats. The most species-rich lake during the study was Ballynakill Connemara, with a total of 37 species including several unusual species, such as *Hydrilla verticillata*, *Nitella confervacea*, and a diverse *Potamogeton* flora. The other lakes where 30 or more species were recorded during the study were Aughrusbeg, Kiltooris, Knocka and Port.

The most species-poor lake in the study was Lough Derg, with only five species recorded. Seven species were recorded at the next most species-poor lake, Derryierin.

Najas flexilis was found in only two of the 11 lakes where fewer than 20 species were recorded during the study: Maumeen (17 species during the study) and na gCaor (14). The relatively low species-richness at Maumeen may be related to the prevalence of bare rock and scarcity of gravel and fine sediment. The low species-richness and sparse vegetation at Loch na gCaor may result from its shallow depth and wind exposure.

Eleven fewer species were recorded at Lough Leane during this survey than in previous surveys combined. This represents a decrease in species-richness of more than 26%. The other lakes with significant decreases in species-richness were Kindrum and Shannagh. While 26 species were recorded at Kindrum during the study, this was nine fewer (-26%) than in previous surveys, and 11 fewer than the combined species-richness. Species such as *Chara aspera*, *Nymphaea alba*, *Potamogeton natans*, *Potamogeton obtusifolius*, *Potamogeton pectinatus* and *Potamogeton* × *nitens* were not re-found at Kindrum Lough, which has shown signs of eutrophication for many years. At Shannagh, species-richness decreased by four species (-17%), however species may have been overlooked because the water was very dark and turbid following heavy rainfall. Species-richness was also slightly lower at Sessiagh (-8%, two species) when compared to previous surveys.

Species-richness is, of course, dependent on sampling effort (see Figures 15 and 16). It may also be related to lake size or, more exactly, the available macrophyte habitat area, which is itself dependent, at least in part, on water depth and light penetration. Relationships between species-richness and environmental parameters are explored in Section 3.7 below.

3.5 Rare Species

Najas flexilis-type lakes contain a very varied flora, possibly on account of their intermediate alkalinity between marl and oligotrophic lakes. Apart from *Najas flexilis*, other rare species include

- *Hydrilla verticillata* (Figure 38) is only known from two lakes in Ireland, Ballynakill Connemara (Roden, 2005; this survey) and Rusheenduff at Renvyle (Caffrey & Rorslett, 1989) which also has *Najas flexilis*. It is abundant in Ballynakill Connemara and not under threat. Listed in the Flora (Protection) Order, 2015 (S.I. No. 356 of 2015).
- *Pilularia globulifera* (Figure 39) was recorded from five lakes (Ballynakill Connemara, Long Range, Nageltia, Nahaltora and Upper Lough) as well as Lough Mask. It is abundant in Nageltia and Lough Mask where it grows in water up to 1 m depth. In Lough Mask it is especially abundant around underwater springs. Listed in the Flora (Protection) Order, 2015 (S.I. No. 356 of 2015).
- The moss *Fissidens fontanus* (*Octodiceras fontanum*) was recorded from two sites: Lough Leane and Ballynakill Connemara; where it grows on submerged rocks. It is known from five sites in Ireland (Lockhart *et al*., 2012).

Figure 38 *Hydrilla verticillata* growing at 3 m in Ballynakill Lough Connemara. Grazing snail in background suggests appreciable available calcium.

- *Baldellia ranunculoides* subsp. *repens* is abundant in Lough Leane, Lough Caragh and the Long Range. It also occurs in Muckross Lake. It forms dense mats not unlike *Eriocaulon aquaticum* and occupies a similar niche in the shallow sub littoral. It is very different from subsp. *ranunculoides* which consists of single scattered plants. It is not reliably recorded elsewhere in Ireland at present.
- *Isoetes echinospora* was recorded from 15 lakes. Identifications were based on microscopic examination of spores, so it is quite possible that the species was overlooked on occasion in the field. It would appear to be a common species in *Najas flexilis*-type lakes, especially those of lower alkalinity.
- *Subularia aquatica* occurred in five lakes in Connemara, although there are old records for Caragh and Leane in Co. Kerry.
- *Nitella confervacea* was found in 13 lakes and is thought to be a frequent companion of *Najas flexilis* (Stewart & Church, 1992).

- *Chara muscosa* is an obscure taxon only known from two sites in the world, both in Ireland. Both sites were surveyed in this study. *Chara muscosa* was re-found in Aughrusbeg Lough but not in the original site Mullaghderg, where it was first recorded in 1917. Mullaghderg was altered by drainage and now consists of two lakes. Only the western lake was examined in this study. At Aughrusbeg, the plant is occasional at the west end of the lake growing on sandy sediment in less than 1 m, along with *Chara aspera*.
- *Nitella spanioclema* (see Figure 12) is another obscure taxon, again only found in Ireland and described in Bullock-Webster (1919) and Groves & Bullock-Webster (1920). It was collected at its original sites at Shannagh Lough and Kindrum Lough. Similar material has been collected at other lakes by C. Roden, but the exact status of the taxon is unclear.

Figure 39 *Pilularia globulifera* in Lough Mask, growing in a characteristic manner only seen underwater. The normally buried axes instead grow unattached in mid-water, rooted to the substrate only at one end.

3.6 *Najas flexilis*

Table 2 and Appendix I show the lakes where *Najas flexilis* was recorded before and during the study. Twenty-five lakes were found to contain populations of *Najas flexilis* during the study. This included a new population of *Najas flexilis* discovered at Knocka Lough, one of the lakes largely unknown prior to the survey. In three lakes where *Najas flexilis* had been seen by C. Roden since 2000, the species could not be re-found. Two records of *Najas flexilis* made by EPA biologists were not confirmed, one site was fully surveyed (Illauntrasna), one (Derg) was not. Both Illauntransa and Derg were found to have highly-oligotrophic, species-poor floras (see also Sections 3.1 and 3.3). *Najas flexilis* had been noted on one occasion only in each lake and no herbarium specimens are available.

Of the three previously known sites for *Najas flexilis* where it was not re-found, two, Upper Lake and Sessiagh, were fully surveyed. The absence of *Najas flexilis* from Upper Lake in 2018 was unexpected, however Upper is only marginally a *Najas flexilis*-type lake due to low alkalinity. In 2002, Sessiagh held a very large population of *Najas flexilis* (Roden, 2002, 2004). The most obvious difference between the 2002 and 2018 surveys was the significant increase in large macrophytes (*Potamogeton* species, *Myriophyllum spicatum* and *Elodea canadensis*) below 1.5 m. *Elodea canadensis* was first recorded in Sessiagh in 2015. Turbid water prevented full survey of the third site, Nageltia, in July 2016 and it was visited again in August 2018. As well as the increased turbidity and water colour, the deeper-water community described at Nageltia in 2004 had declined to scattered plants and was replaced by bare mud or large *Elodea canadensis* plants. *Najas flexilis* has not been seen in the lake since 2004, despite surveys in 2010, 2016 and 2018. As well as *Najas flexilis, Potamogeton obtusifolius* could not be found in 2016 or 2018. Lough Nageltia is unusual in that it is 10 km east of the nearest known station for *Najas flexilis*. Loss of the species from the lake would, therefore, result in a significant decrease in the range of *Najas flexilis* in Ireland. Nageltia was found to still hold one of the most easterly populations of *Eriocaulon aquaticum* and a large population of *Pilularia globulifera*.

Loch an Chaolaigh, was also surveyed on more than one occasion because the initial survey did not re-find *Najas flexilis*. *Najas flexilis* has been known from this small coastal lake since 1996. It was not seen in 2016 or 2018, but was present in 2017. For undetermined reasons the lake has declined in quality and the *Najas flexilis* population is smaller than in 2004 and not present in some years.

Further information on all lakes can be found in Appendix V, site reports (separate pdf file and hard-copy volume).

3.7 Environmental drivers of *Najas flexilis*-type lake vegetation

3.7.1 Geology, size and depth

Both size and depth vary greatly among the lakes: from Lough Leane with an area of almost 2,000 ha to Loch an Chaolaigh at 2.5 ha; while depth ranged from 60 m in Lough Leane to less than 2 m in Sheskinmore. Rock type is also varied (see Appendix II) but no lake entirely situated on Carboniferous limestone is known to contain *Najas flexilis*. The majority of lakes are on Dalradian schists or marble, Silurian, Ordovician or Carboniferous shales or sandstone, granite or basic igneous rocks (Appendix II). Only two lakes situated exclusively on Devonian sandstone contain substantial populations of *Najas flexilis*: Lough Acoose and the Long Range. A very small population occurs in the Upper Lake, Killarney (Roden & Murphy, 2014). Lough Leane and Lough Caragh are partially on Devonian sandstone but also on Carboniferous limestone. Many lakes with *Najas flexilis* occur close to the Atlantic Ocean (within one to five kilometres), and it is thought water chemistry is influenced by this proximity (van Groenendael *et al*., 1979, 1982).

Species-richness was not strongly correlated with lake shoreline length or surface area, possibly indicating a relatively uniform flora throughout each lake. As the area available for colonisation is also a function of euphotic depth, it may be that species diversity increases with depth of colonisation more than with horizontal extent (see Section 3.7.6).

3.7.2 Substrate

The *Najas flexilis* populations encountered in this survey grew largely on very fine silt, which in places was almost semi liquid. Such sediments inevitably accumulate in areas of least disturbance, such as below wave depth in lakes. Consequently, *Najas flexilis* tends to occur at depth. That sediment rather than light-intensity governs location is indicated by the occurrence of shallow-water populations in some lakes such as na Creibhinne and na gCaor. At one site, Loughauneala, a large shallow-water population occurs in very soft peat sediment held in a rock basin.

3.7.3 pH and Alkalinity

Summary data on water chemistry are given in Appendix II. Average pH is slightly basic (7.2; range 6.7-7.9). Alkalinity (average 25 mg/l; range 5.5-73 mg/l) exceeds the oligotrophic limit of 20 mg/l suggested by Free *et al*. (2005, 2006). No clear pattern or direct correlation was found between average alkalinity and species-richness in the surveyed lakes (Figure 40). Species-richness appears partly determined by water chemistry, however, as no lake with alkalinity of below 15 mg/l has 30, or more, recorded species. Assuming the lakes surveyed are representative, the alkalinity range of *Najas flexilis*-type lakes is approximately between 10 mg/l and 50 mg/l, with some outliers. The exact alkalinity boundaries between *Najas flexilis*-type lakes and eutrophic, marl and oligotrophic lakes requires further data from lakes in the 50-100 mg/l range and more understanding of low alkalinity lakes with *Najas flexilis* on Old Red Sandstone (Lough Acoose, The Long Range, Upper Lake, Lough Caragh) which have alkalinities of 5-10 mg/l (Figure 40). While alkalinity is not directly related to species-richness, it does influence species composition. Kindrum Lough, with an average alkalinity of 70 mg/l, has a different flora to Ballynakill Connemara, where average alkalinity was 19 mg/l.

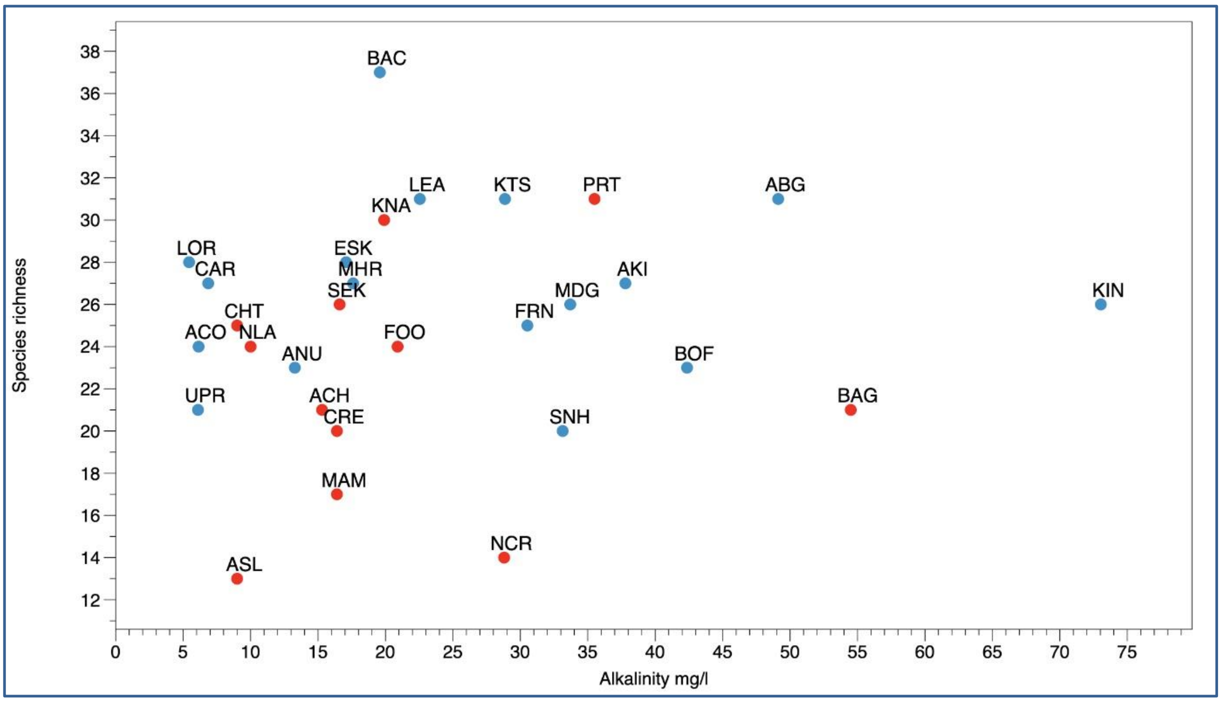


Figure 40 Lake species-richness plotted against average alkalinity. Note no correlation was found.

Figure 41 shows the distribution of selected species across alkalinity in the study lakes. While *Najas flexilis* is found in lakes with average alkalinity ranging from less than 5 mg/l to over 70 mg/l, the median value for lakes with the species is *c*. 20 mg/l and the species most frequently occurs between 15 mg/l and 35 mg/l. Figure 41 shows that more *Potamogeton* species are found in the more alkaline lakes (Figure

42), while other species such as *Pilularia globulifera* or *Isoetes echinospora* prefer less base-rich water. The graph confirms that, in addition to a characteristic alkalinity range, *Najas flexilis*-type lakes are also characterised by the presence of *Isoetes lacustris* and *Potamogeton perfoliatus*, as previously reported by Roden & Murphy (2014). Figure 41 also shows that species with very different alkalinity tolerances can co-occur in such lakes.

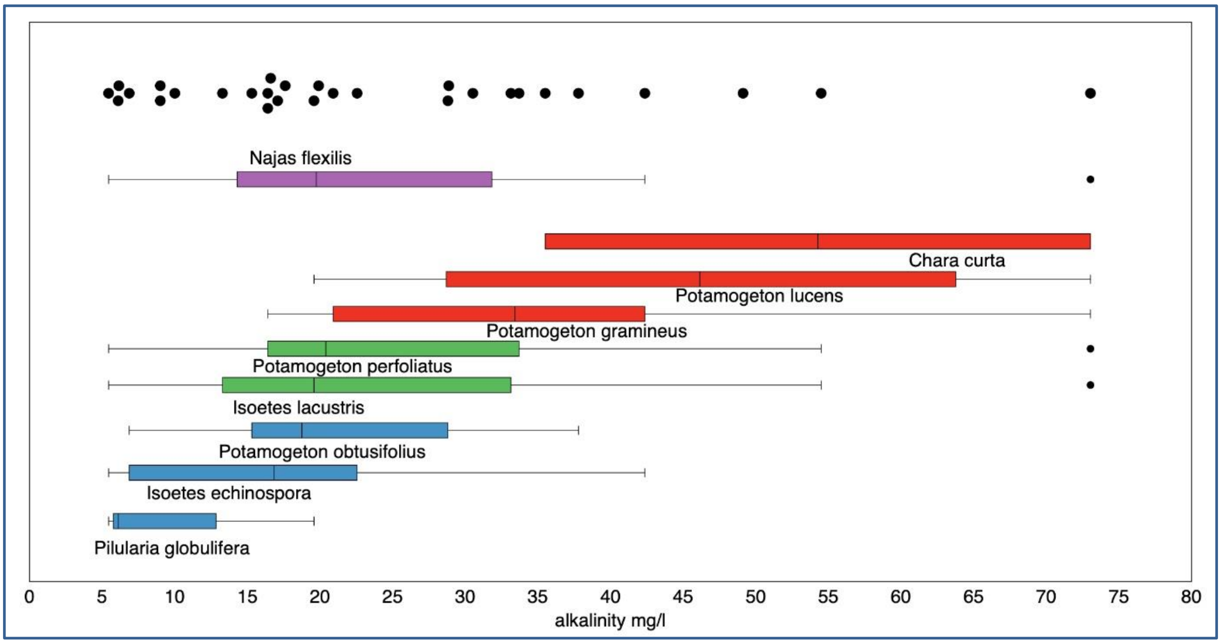


Figure 41 Alkalinity range of selected species in the study. Black discs show the average alkalinity values for the individual lakes. Whisker diagrams show distribution of selected species across alkalinity. The most alkaline lake, Kindrum, is shown on the right hand side. Note *Najas flexilis* is recorded from Kindrum but it is an outlier. Both *Potamogeton perfoliatus* and *Isoetes lacustris* occurred in almost all lakes sampled.

Figure 42 *Potamogeton gramineus* growing in shallow water on rocky ground in Aughrusbeg Lough. This species and other broad-leaved *Potamogeton* species are characteristic of the more alkaline *Najas flexilis*-type lakes.

3.7.4 Nutrients

Average total phosphorus ranged from 0.005 mg/l to 0.044 mg/l across the study sites (Table 3 and Appendix II). The overall average was 0.016 mg/l, below the current good/moderate boundary of 0.020 mg/l set by the EPA for the WFD (The European Communities Environmental Objectives (Surface Waters) (Amendment) Regulations 2019). When only the EPA data are examined, the overall average total phosphorus was 0.012 mg/l and the range 0.008-0.027 mg/l. When the data were summarised by overall conservation condition of the habitat in the lake (see Appendix I and Appendix V), there was a clear trend of increasing total phosphorus values from *Good* to *Poor* to *Bad* conservation condition (Table 3).

Table 3 Average total phosphorus data summarised by overall conservation condition of the habitat in the lake. *Good* is *Favourable*; *Poor* is *Unfavourable-Inadequate*; *Bad* is *Unfavourable–Bad*.

Total phosphorus	*Good*	*Poor*	*Bad*	All
All data (33 lakes)				
Average	0.014	0.018	0.020	0.016
Minimum	0.005	0.008	0.009	0.005
Maximum	0.028	0.044	0.034	0.044
EPA data only (16 lakes)				
Average	0.010	0.011	0.015	0.012
Minimum	0.008	0.008	0.009	0.008
Maximum	0.015	0.019	0.027	0.027

No relationship was found between species-richness and total phosphorus (Figure 43), or total oxidised nitrogen. Available data do, however, show positive correlations ($p<0.05$) between species-richness and calcium (Ca), magnesium (Mg) and potassium (K) (Figure 44).

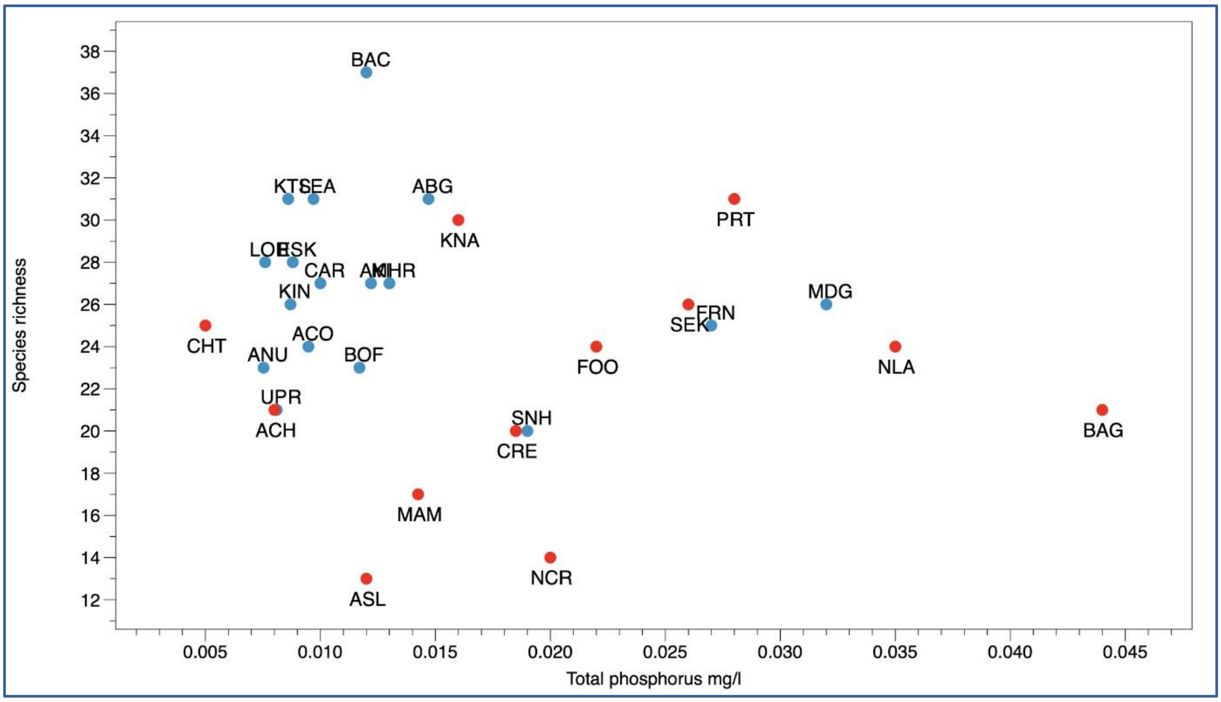


Figure 43 Lake species-richness plotted against average total phosphorus. Blue discs show averaged values from EPA data, red discs are single samples taken in winter during the study.

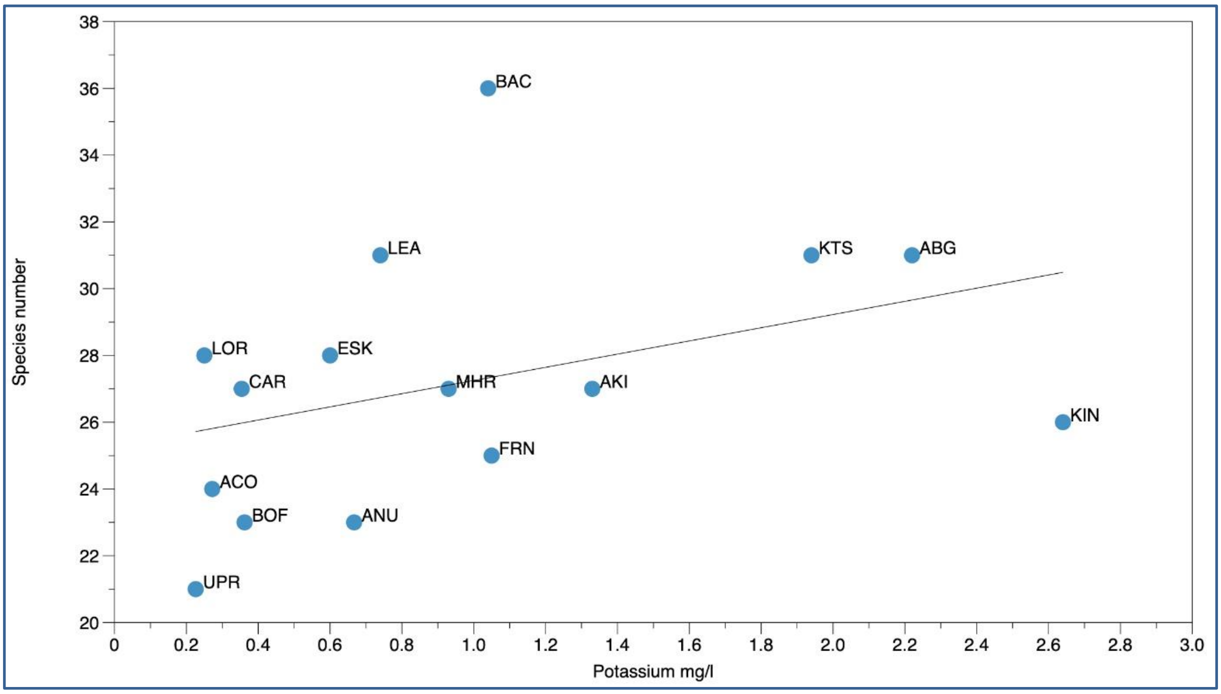


Figure 44 The relationship between species-richness and average potassium ($p<0.01$).

3.7.5 Water colour

The overall average water colour was 46 Hazen Units across the 16 lakes with EPA data, but 86 Hazen Units in winter samples collected during this survey. Water colour ranged from 27 to 149 Hazen Units across all 33 lakes, and 27 to 77 Hazen Units in the lakes with EPA averaged data, again highlighting the higher winter values (Figure 45, Table 4 and Appendix II). The difference between coloured and clear water is very obvious to divers or snorkellers as Figures 46 and 47 show. The data suggest that species-richness decreases slightly as water colour increases (Figure 45), however the relationship was not statistically significant.

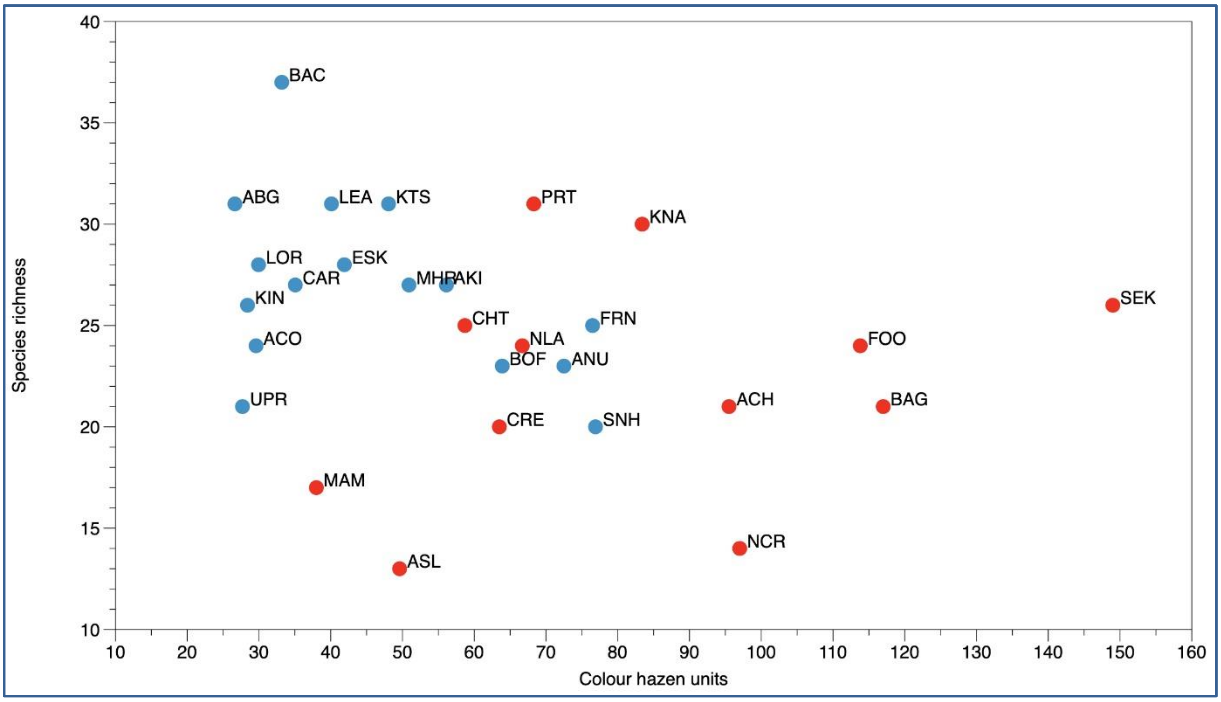


Figure 45 Lake species-richness plotted against average water colour. Averaged values from EPA data are shown as blue circles. Single samples taken in winter during the study (red circles) appear to have raised water colour.

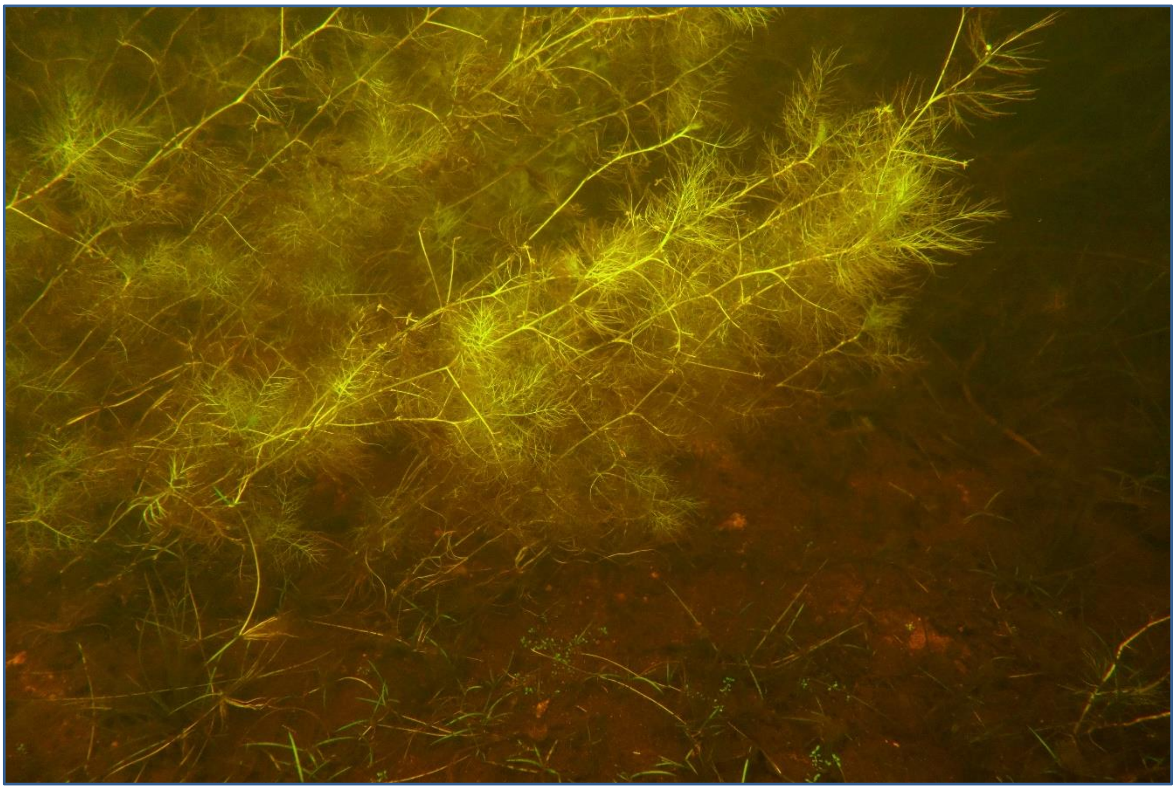


Figure 46 *Apium inundatum* growing in the Long Range at 1 m depth. Note the peaty substrate and plants of *Isoetes lacustris* and *Elatine hexandra*. The peat-stained water gives a reddish tone to the photo which contrasts strongly with photo 47 below taken in Lough Sessiagh.

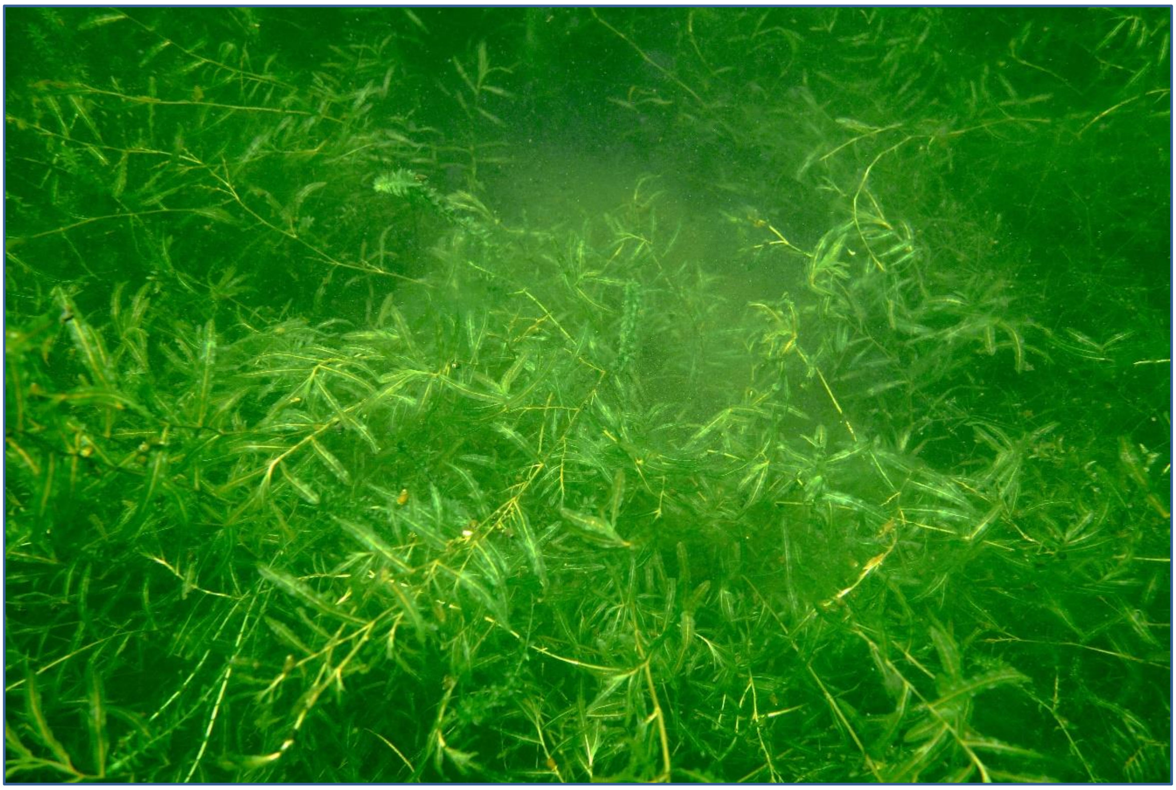


Figure 47 *Potamogeton crispus* and *Elodea canadensis* in Lough Sessiagh. Photo taken from water surface about 5 m above the lake floor visible in upper centre. Water transparency and lack of colour are striking. Unfortunately this lake has recently been invaded by *Elodea canadensis* and the formerly short *Najas flexilis*-dominated vegetation has been replaced by a dense forest of *Potamogeton* and *Elodea*, several metres high.

The relationship between water colour and total phosphorus was examined (Figure 48). Water colour was found to be positively correlated with total phosphorus ($p<0.01$).

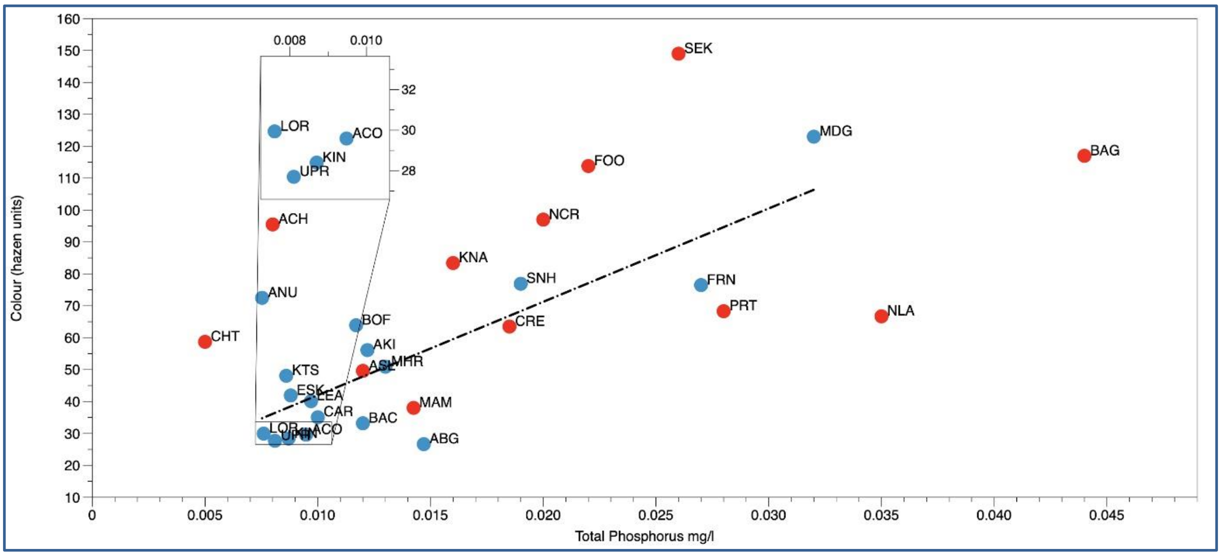


Figure 48 Water colour and total phosphorus are correlated ($p<0.01$). Averaged values from EPA data are shown as blue circles. Single samples taken in winter (red circles) clearly have raised water colour.

When lakes were grouped by their overall conservation condition (see Appendix I and Appendix V), there was an increasing trend in water colour from *Good* to *Poor* to *Bad* (Table 4).

Table 4 Average water colour data summarised by overall conservation condition of the habitat in the lake. *Good* is *Favourable*; *Poor* is *Unfavourable-Inadequate*; *Bad* is *Unfavourable–Bad*.

Water colour	*Good*	*Poor*	*Bad*	All
All data (33 lakes)				
Average	55	74	72	65
Minimum	27	28	40	27
Maximum	149	123	122	149
EPA data only (16 lakes)				
Average	29	53	55	46
Minimum	27	28	40	27
Maximum	33	77	76	77

3.7.6 Euphotic depth

Euphotic depth is the maximum depth of colonisation of macrophyte vegetation. The greater the euphotic depth, the larger the area of lake bed available for plant colonisation. In some shallow lakes in the study (na Creibhinne, Mullaghderg, Sheskinmore), it was not possible to calculate euphotic depth as plants grew at the deepest points. Across the remaining lakes, euphotic depth varied from 1.9-5.2 m, with an overall average of 3.1 m and a median of 3.0 m (2.95 m) (Appendix I). Average Secchi transparency was 2.4 m (Appendix II).

The number of species increases with euphotic depth (Figure 49). The graph indicates that the surveyed lakes form a gradient from more species-rich examples with greater euphotic depths to examples that are less transparent and less species-rich. Average euphotic depth across the lakes in the survey with 26 or more species was 3.5 m (range 2.6-5.2 m) and for the six lakes with 30 or more species was 3.8 m (range 2.8-5.2 m).

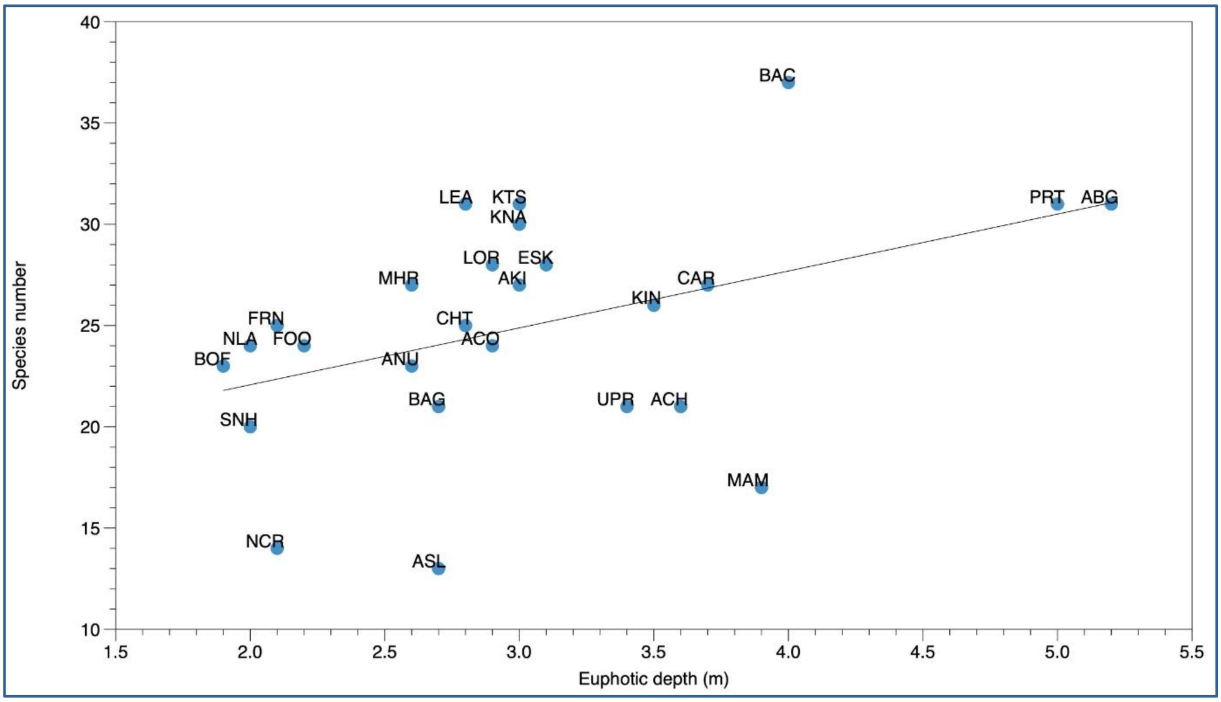


Figure 49 The relationship between euphotic depth and species-richness is significant ($p<0.05$).

Lakes with full development of the deep-water vegetation had euphotic depths ranging from 2.2-5.2 m, whilst those lakes that were assessed as in *Good* conservation condition overall had a euphotic depth range of 2.7-5.2 m.

Within the subset of lakes containing *Najas flexilis*, there was a significant correlation between euphotic depth and the number of relevés containing the species (Figure 50), indicating the species' preference for clear water. Equally, there was a significant correlation between species-richness and the number of relevés containing *Najas flexilis* within this sub set. This final correlation may, however, be a partial artefact, as the number of species may increase with the numbers of relevés sampled.

In summary the data show that lakes with greater euphotic depth tend to be more species-rich and to form more suitable habitat for *Najas flexilis*. This result might be expected as the vegetation analysis (Section 3.3) showed that *Najas flexilis* is characteristic of deeper water. It also showed that the species is part of a deep-water vegetation grouping. In lakes with shallow euphotic depths lacking this deep-water vegetation, several species are unlikely to occur.

The relationships between euphotic depth and water chemistry were also examined. Euphotic depth was inversely related to water colour (Figure 51). This correlation was significant for those lakes with averaged water colour values (EPA data). Single, winter samples yielded higher water colour (Figure 51).

Total phosphorus was not linearly related to euphotic depth (Figure 52). Instead, it appears that lakes with euphotic depth greater than 3.0 m have average total phosphorus concentration of less than 0.015 mg/l. An exception to this was Port Lough, however only a single winter value was available for total phosphorus.

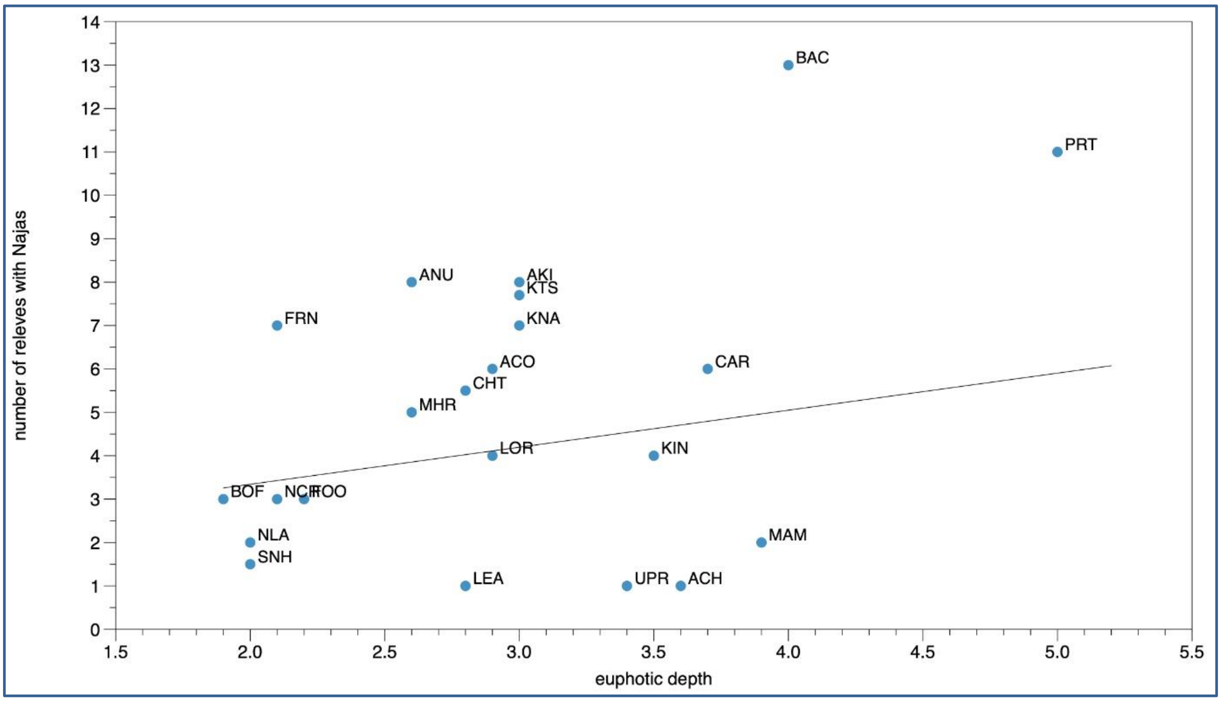


Figure 50 The relationship between euphotic depth and the number of relevés containing *Najas flexilis*. The graph displays data for 22 lakes where the species was found during the project, but excludes the three shallow lakes where it was not possible to determine the euphotic depth. The regression is significant at p<0.05).

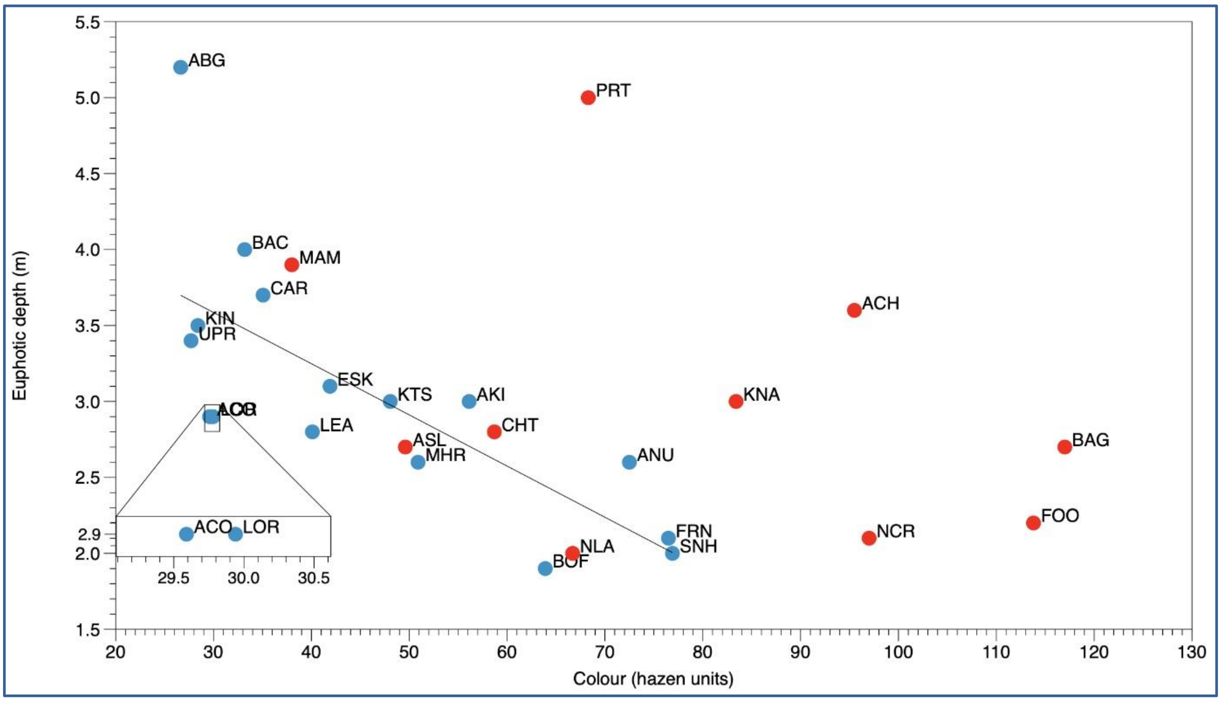


Figure 51 The relationship between euphotic depth and water colour. The graph shows 26 lakes for which colour data were available, but excludes shallow lakes where it was not possible to determine the euphotic depth. Blue discs are averaged values from EPA data and a significant relationship (line shown) was found between these averaged water colour data and euphotic depth ($p<0.01$). Single samples taken in winter (red discs) generally had raised water colour.

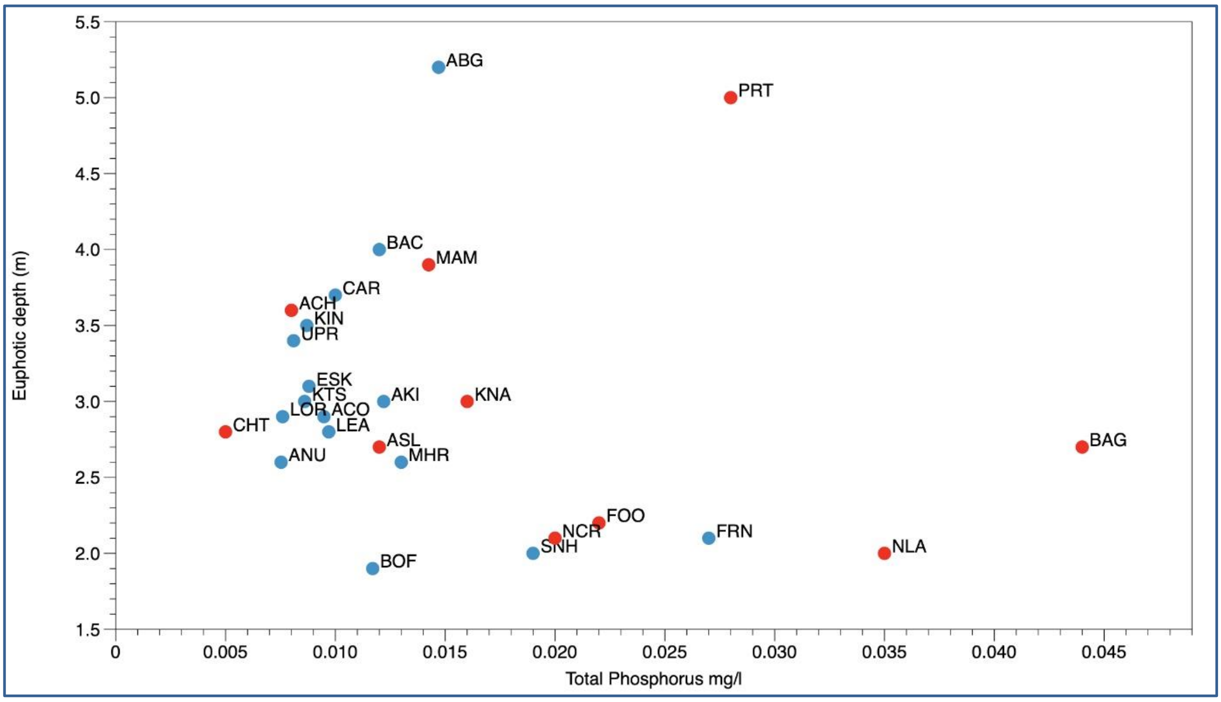


Figure 52 The relationship between euphotic depth and total phosphorus. With the exception of a single winter reading from Port Lough, all lakes with euphotic depth >2.5 m, have TP<0.015 mg/l. Red discs show lakes sampled on one occasion in early 2019, blue are averaged values based on EPA data.

3.7.7 Combined environmental drivers

The relationships between vegetation indicators (number of species, euphotic depth, number of relevés with *Najas flexilis*) and water chemistry (total phosphorus, water colour, alkalinity, pH) are summarised in a PCA (principal components analysis) of the data (Figure 53). The three measures of vegetation: euphotic depth, number of species and number of relevés with *Najas flexilis* per lake; are inversely related to water colour and total phosphorus, which co-vary. Lake alkalinity and pH are independent of all other factors. The analysis indicates that while *Najas*-type lakes occur over a range of alkalinities, measures of vegetation quality are independent of lake alkalinity but strongly determined by lake water colour and lake total phosphorus.

To summarise the environmental drivers of *Najas*-lake type vegetation

- *Najas*-type lakes are characterised by the presence of *Isoetes lacustris* and *Potamogeton perfoliatus*, as previously reported by Roden & Murphy (2014)
- Assuming the study lakes are representative, the alkalinity range of *Najas*-lakes is approximately between 10 and 50 mg/l, with some outliers
- Although species-richness is not directly correlated with alkalinity, no lake with alkalinity below 15 mg/l has more than 30 recorded species; species-richness was significantly correlated with calcium, magnesium and potassium
- Further data are required to determine the exact alkalinity boundaries between *Najas*-type lakes and eutrophic, marl and oligotrophic lakes
- Species-richness was not strongly correlated with lake shoreline length or surface area
- Lakes with greater euphotic depth tend to be more species-rich and to have more suitable habitat for *Najas flexilis*
- However some clear-water lakes with greater euphotic depths, such as Aughrusbeg, do not contain *Najas flexilis* but do have the deep-water vegetation characteristic of *Najas*-type lakes

- Lakes with shallow euphotic depths lack/have poor development of the characteristic deep-water vegetation
- Water colour is inversely correlated with euphotic depth
- Water colour is correlated with total phosphorus: it appears that lakes with euphotic depth greater than 3.0 m typically have average total phosphorus below 0.015 mg/l
- Measures of *Najas*-lake vegetation quality/condition are independent of lake alkalinity but strongly determined by lake water colour and lake total phosphorus.

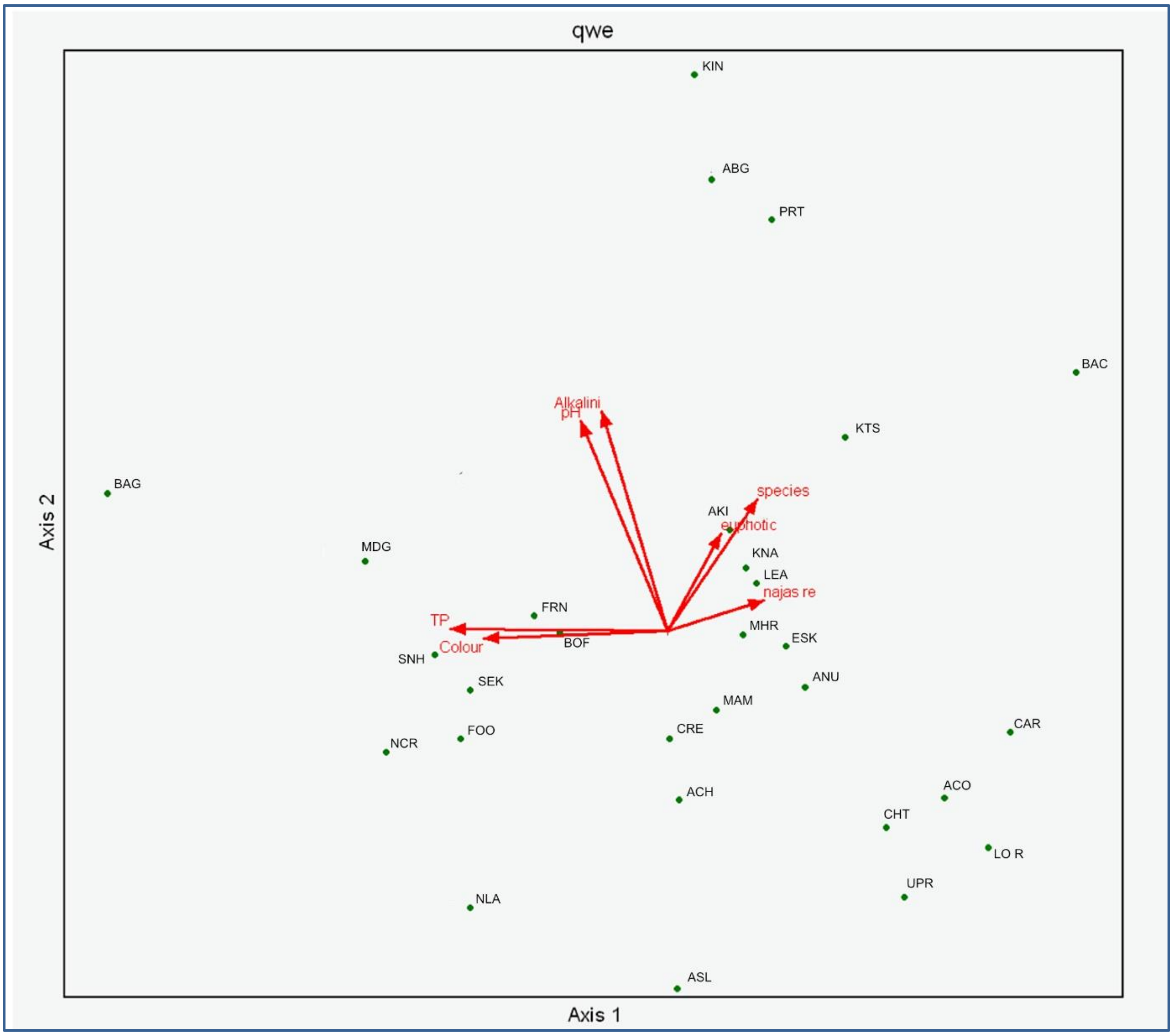


Figure 53 PCA of whole-lake vegetation indicators (number of species, euphotic depth, number of relevés with *Najas flexilis*) and water chemistry (total phosphorus, water colour, alkalinity, pH). Note the vectors for lake indicators are nearly opposite those of water colour and total phosphorus, while alkalinity and pH are orthogonal. (Principal components analysis with axes 1 and 2 accounting for 33.6% and 29.5% of variation and eigenvalues of 2.352 and 2.065).

4 Discussion

4.1 Are lakes with populations of *Najas flexilis* a distinct category?

The alkalinity of the surveyed lakes ranged from 5 to 73 mg/l and pH from 6.7 to 7.9. While the alkalinity range was wide, the values were intermediate between very oligotrophic lakes and marl lakes (Free *et al*., 2006). Many lakes in this intermediate range do not contain populations of *Najas flexilis*, so alkalinity alone cannot define a *Najas flexilis* lake. A more reliable indicator is the joint presence of *Isoetes lacustris* and *Potamogeton perfoliatus* (or *Potamogeton praelongus*). This feature, already noted before this survey, was confirmed for all the lakes where *Najas flexilis* was recorded between 2016 and 2018, with the exception of Lough Fern. Taken together these two characteristics indicate the intermediate character of lakes with *Najas flexilis* between high and low alkalinity types. Given the wide range of alkalinities found in *Najas flexilis* lakes, it seems probable that eutrophic lakes will be found to differ from *Najas flexilis* lakes more in nitrogen and phosphorus levels than alkalinity.

The wide range of alkalinity values (*e.g*. Port Lough 35 mg/l compared to Ballynakill Connemara 19 mg/l) results in a comparably wide variety of species, such as *Chara curta*, normally a species of marl lakes, in Port Lough and *Subularia aquatica*, often a species of very oligotrophic lakes, in Ballynakill Connemara. It has not been possible to define a suite of species confined to lakes with *Najas flexilis*. Instead such lakes are better characterised as having a variety of species, not otherwise found co-existing in Irish lakes. At most two other species, the extremely rare *Hydrilla verticillata* and *Nitella confervacea*, appear to be largely restricted to lakes with *Najas flexilis*. Conversely a number of species are only recorded from more coloured, shallow euphotic depth lakes, for example *Potamogeton obtusifolius* or several *Sparganium* spp., while others, *e.g*. *Callitriche hermaphroditica* or *Potamogeton lucens*, are confined to lakes with a euphotic depth greater than 3 m.

The substantial list of now rare species found in *Najas flexilis* lakes may reflect the present scarcity of clear-water intermediate alkalinity lakes in Ireland. This lake type may have been more widespread before the recent rise in eutrophication and species now considered rare, such as *Pilularia globulifera* or *Nitella confervacea*, were likely also more widespread. It is possible that some of these species are characteristic *Najas flexilis* lake taxa but in the absence of sufficient good examples the point cannot be resolved.

Lakes with *Najas flexilis* have three characteristic vegetation zones: the first is a shallow-water *Lobelia*—*Littorella*—*Eriocaulon* zone; the second an intermediate depth *Isoetes lacustris* zone (both these zones occur in many soft-water lakes), and the third and deepest zone of *Najas flexilis* and associated species (Group 5, see Section 3.3.3), which may not occur in other lakes and is perhaps diagnostic for the type.

Water colour also influences the diversity and abundance of species and vegetation in these lakes. The most species-rich examples have greater euphotic depths. An explanation for this combination of features is that *Najas flexilis* grows close to the base of the euphotic zone. In clear-water lakes, the amount of illuminated habitat is greater and a diverse community including *Najas flexilis*, *Nitella confervacea*, *Nitella flexilis*, *Nitella translucens*, *Callitriche hermaphroditica*, *Potamogeton berchtoldii* occurs. As euphotic depth decreases this community diminishes.

In summary, *Najas flexilis* lakes may be regarded as clear-water lakes of intermediate alkalinity with a well-developed deep-water vegetation and flora. Typically this flora is rich and contains species otherwise found either in more basic or more acidic lake types. Few species are restricted to *Najas flexilis* lakes. Given that almost all lakes with *Najas flexilis* contain an *Isoetes* vegetation zone, the lakes could be classified as a species-rich, more alkaline variant of the widespread soft-water *Isoetes* lake type. As several species-rich, clear-water lakes do not contain *Najas flexilis* but otherwise meet the above conditions *e.g*. Aughrusbeg Lough, it is reasonable to expand the concept of *Najas flexilis* lakes to a *Najas flexilis*-type lake including all lakes with intermediate alkalinity, good water transparency, a deep-water vegetation and an overlap of basic and acidic floras, especially *Isoetes lacustris* and *Potamogeton perfoliatus*.

4.2 The case of lakes on Old Red Sandstone

Since 2004, the authors have examined, through snorkelling, 15 lakes exclusively on the Munster Old Red Sandstone and, in the case of Anscaul, the similar Dingle Beds. Of these, only four (Acoose, Long Range, Caragh and Upper Killarney) contain populations of *Najas flexilis*, the remainder do not (Anscaul, Adoolig, Glenbeg, Glanmore, Derryvegal, Cloonee Upper and Lower, Inchiquin, Clooney, Akeen, Derriana). The four Old Red Sandstone lakes with *Najas flexilis* are unusual in that alkalinity is far lower than in all other *Najas flexilis* lakes (averages of 6.1 vs 25.7 mg/l). Despite the very low alkalinity, *Najas flexilis* is common and the characteristic combination of *Potamogeton perfoliatus/praelongus* and *Isoetes lacustris* occurs. During the study, *Najas flexilis* was not found in Upper. Upper also lacked *Potamogeton perfoliatus/praelongus* during the 2018 survey, although *Potamogeton perfoliatus* was recorded there in the past. Currently, we do not understand why *Najas* should be present at such low alkalinities, nor, being present in these lakes, why it is not found in other Old Red Sandstone sites.

4.3 Degraded *Najas flexilis*-type lakes?

While species composition in *Najas flexilis*-type lakes varies with alkalinity, lakes with very different alkalinities have comparable species-richness and euphotic depth, *e.g*. Ballynakill Connemara had alkalinity of 19.6 mg/l, euphotic depth 4 m and 36 species, while Port has alkalinity 35.5 mg/l, euphotic depth 5 m and 31 species. This is not the case with water colour: lakes with high colour have lower euphotic depth, fewer species and smaller populations of *Najas flexilis*. While there was no clear relationship between total phosphorus and species-richness, *Najas flexilis*-type lakes that were in good conservation condition were found to have average total phosphorus of 0.010 mg/l and a range of 0.008-0.015 mg/l, based on EPA nutrient data. Furthermore, both variables (colour and TP) are correlated. The question arises, is this variation in water colour and total phosphorus a natural feature, as for the variation in alkalinity, or is it a human impact? In any case, an increase in water colour results in the reduction and disappearance of the deep-water vegetation and *Najas flexilis*. A reasonable hypothesis is that damage to peatland, such as through forestry and turf cutting, has reduced water transparency in *Najas flexilis*-type lakes, through losses of dissolved and particulate organic matter, probably eliminating the *Najas flexilis*-type vegetation in the process.

The discovery of a *Najas flexilis* population during this survey in Knocka Lough, south Co. Clare, 100 km from the nearest known populations, shows that the species can be found outside its accepted range of Connemara, Co. Kerry and Co. Donegal, if suitable lakes are studied. Several other lakes may also be *Najas flexilis*-type lakes, or were so formerly, *e.g*. Lough Melvin. The present range of *Najas flexilis*-type lakes possibly reflects decline in water quality more than a biogeographical factor. Godwin (1975), for example, shows the species was more widespread formerly.

We strongly recommend a palaeoecological study of possible *Najas flexilis*-type lakes to see if evidence of their former state could be discovered, much as Bishop *et al*. (2019 have done for Esthwaite Water (England) and Loch of Craiglush (Scotland), and Wiik *et al*. (2015a, b) have done for marl lakes in England. See also Bishop *et al*. (2017).

4.4 Separating *Najas flexilis*-type lakes from other soft-water lakes

During the study, a number of lakes briefly surveyed by snorkelling were rejected as *Najas flexilis*-type lakes. Five of these, Mask, Derg, Illauntrasna, Derryierin and Courhoor, are clearly soft-water lakes with similar vegetation to Groups 1, 2, 3 and 4 as defined in Section 3.3 and Appendix III. All, however, lack broad-leaved *Potamogeton* species, except *Potamogeton alpinus* in Illauntrasna, and in no lake was a deep-water vegetation (Group 5) developed. Furthermore, the number of species recorded was low (fewer than 20 species in all bar Lough Mask) and alkalinity, where measured, was low (11.5 mg/l for Illauntrasna and 7.3 mg/l for Derg). Euphotic depth varied from 2.4-3.5 m.

These lakes were rejected as *Najas flexilis*-type lakes mainly because of the poor or absent deep-water vegetation, coupled with low alkalinity and low species-richness. It might be argued that they are merely degraded *Najas flexilis*-type lakes. It must be conceded that a diminishing euphotic depth, possibly caused by peat-runoff, will cause vegetation in all soft-water lakes to degrade towards a *Lobelia-Littorella* zone possibly followed by *Isoetes lacustris*. Further research is needed to define vegetation structure and water chemistry in Irish oligotrophic and dystrophic lakes. At present we suggest that lakes with euphotic depth greater than 3.0 m but with fewer than 15 species, alkalinity of less than 15 mg/l (with certain exceptions in Munster) and lacking Group 5 type vegetation, especially *Potamogeton perfoliatus* or other broad leaved *Potamogeton* species, are not *Najas flexilis*-type lakes. An example would be Glenbeg Lake on the Beara Peninsula, which has great water clarity a well-developed but species-poor *Isoetes lacustris* zone and scattered plants of *Potamogeton berchtoldii* close to the euphotic limit. Lakes with alkalinity above 20 mg/l, heavily peat-stained water and, consequently, no deep-water vegetation may be degraded *Najas flexilis*-type lakes.

The remaining lakes are problematic. Cloonmackan is filled with peat particles and only a single macrophyte, *Potamogeton obtusifolius*. It is impossible to state what type of lake vegetation existed before the peat sediment impacts. Lough Melvin has some of the features of a *Najas flexilis*-type lake, such as soft-water species and broad-leaved *Potamogeton* species, as well as alkalinity of 54 mg/l, but has colour of 73 Hazen Units and Secchi depth of 1.5 m (Free *et al*., 2006). It occupies a basin partly on limestone, partly on shale, but the flora where examined was depauperate and the euphotic depth poor for a large lake (>2,000 ha). In the absence of examination of any historic data, we do not attempt to classify it. It may represent many lakes now altered that could once have supported *Najas flexilis*.

Najas flexilis-type lakes naturally merge towards oligotrophic or dystrophic lakes on the one hand, and eutrophic and/or marl lakes on the other. Until the vegetation of oligotrophic-dystrophic and eutrophic lake types is clearly described it will be difficult to distinguish between natural variation in lake type and variation caused by degradation due to excess colour and/or excess total phosphorus.

4.5 The conservation value and rarity of *Najas flexilis*-type lakes in Ireland

Free *et al*. (2005, 2006) suggested that at least two Irish lake types could be distinguished based on alkalinity: *Isoetes* lakes with alkalinity less than 20 mg/l and charophyte or marl lakes with alkalinity above 85 mg/l. They noted a third type might exist in alkalinity range 20-85 mg/l. This range largely corresponds to the lakes described in this report. As noted above, these lakes are transitional in character between soft-water, eutrophic and marl lakes. While there are few species confined to this lake type, a number of species that do occur in *Najas flexilis*-type lakes are rare or protected including *Najas flexilis*, *Hydrilla verticillata* and *Pilularia globulifera*, *Nitella confervacea* and the uncertain taxa *Nitella spanioclema* and *Chara muscosa*. The most species-rich examples have euphotic depth greater than 3.5 m (in Kiltooris euphotic depth exceeded 6 m in 1999) and alkalinity above 20 mg/l. Such lakes are uncommon in Ireland. At most 60-70 Irish lakes with *Najas flexilis* are known, the majority in Connemara and Co. Donegal.

The assumption that *Najas flexilis* lakes are typical of nutrient-poor, hard, quartz-rich rocks is incorrect; they are more often found on marble, shale, or calcareous sandstone, or alternatively close to the coast where spray alters water chemistry (van Groenendael *et al*., 1979). Isolated populations of *Najas flexilis* occur, or formerly occurred, in Knocka Lough, south-west Co. Clare, Lough Nageltia, central Co. Mayo, Dahybaun, north Co. Mayo and Glenade, Co. Leitrim. While Lough Neagh, the largest lake in Ireland, is now very heavily eutrophied, early macrophyte records do suggest a *Najas flexilis*-type lake character and, indeed, that *Najas flexilis* itself occurred, as is confirmed by seeds found in post-glacial lake deposits (Jessen, 1936; Harron, 1986). Thus *Isoetes lacustris* and *Potamogeton perfoliatus* were recorded in Lough Neagh along with species such as *Subularia aquatica*, *Elatine hexandra*, *Pilularia globulifera*, *Callitriche hermaphroditica*, *Myriophyllum alterniflorum*, *Lobelia dortmanna* and *Chara aspera*, all species found in *Najas flexilis*-type lakes during the present survey. However Harron (1986) states all are now very rare. If Lough Neagh has lost its *Najas flexilis*-type lake character, it is very likely that other lowland lakes on non-calcareous bedrock have suffered a similar loss. It is possible that Lough Melvin was also a *Najas-type* lake. The historical data shows *Najas flexilis* was more widespread in the early Holocene (Godwin, 1975) and supports this view.

It is striking that members of the deep-water flora (Group 5) do persist in some very isolated lakes *e.g.* Knocka Lough, when conditions permit. This suggests that such lakes are relict examples of a type once more widespread before disturbance reduced the euphotic depth. It is also possible that similar lakes remain to be found.

Field experience, based on seeking suitable sites for *Najas flexilis,* indicates that intermediate alkalinity lakes are unusual: they do not occur on Carboniferous limestone or most areas of Devonian sandstone, and are often damaged by runoff from cutover bogs or phosphorus enrichment. Out of 201 lakes listed by Free *et al*. (2006) about 40, or 20%, had alkalinity values between 20 and 70, a much smaller fraction than made up by oligotrophic or even marl lakes. Furthermore, many of these, such as Garadice Lough Co. Leitrim are severely polluted. The best examples include Ballynakill Connemara, Port Lough, Knocka Lough and Lough Akibbon. Alarmingly, at least three other formerly excellent examples have been damaged in the last 20 years: Sessiagh (spread of *Elodea canadensis* and enrichment); Kiltooris (illegal drainage); Kindrum (excessive colour).

This report demonstrates the ecological importance, rarity and vulnerability of these lakes. Because they have not been characterised until recently, their conservation has not been prioritised. It is to be hoped that in future they will be preserved and avoid the fate of similar lakes in other countries; for example the disappearance of both *Hydrilla verticillata* and *Najas flexilis* from Esthwaite Water in the English Lake District.

5 Assessing conservation condition

5.1 A basis for evaluating and assessing *Najas flexilis*-type lakes

As discussed in Chapter 4, *Najas flexilis*-type lakes have a characteristic, well-developed deep-water vegetation and species-rich flora; with many of the species that occur being rare or protected. They are also characterised by combinations of typical soft-water species with typical hard-water species, in clear-water of intermediate alkalinity. Chapter 3 (Section 3.7) demonstrated that euphotic depth, water colour and total phosphorus, are related to the important ecological indicators of species-richness and the characteristic deep-water vegetation and, in consequence, it is recommended that these should be used in assessing the conservation condition of *Najas flexilis*-type lakes.

Species-richness was positively correlated with euphotic depth ($p<0.05$) (Figure 49). Euphotic depth is inversely related to water colour, as might be expected ($p<0.05$) (Figure 51). Thus, it may be that, as euphotic depth decreases (driven by increasing water colour), deep-water communities decline and eventually disappear. This process is independent of alkalinity and may reflect increasing run-off of peat-stained water. If one assumes that water colour is caused largely by environmental degradation in the watershed (peat cutting, drainage *etc*.), it follows that lakes with greater colour and smaller euphotic depths should be treated as being damaged. This scheme is complicated by the fact that some *Najas flexilis* lakes, *e.g*. Knocka or Chluain Toipin, are partially in peat basins and may have higher natural colour.

It may also be significant that water colour is correlated with lake total phosphorus ($p<0.001$) (Figure 48). It is notable that lakes with high numbers of species have total phosphorus less than 0.015 mg/l.

Based on available data, we suggest target values for these key parameters in '*Najas flexilis*-type lakes in Table 5. Each parameter is further explained in the following sub-sections.

Table 5 Conservation condition assessment parameters and corresponding targets for *Favourable* or *Good* condition

Parameter	Favourable or Good	Unfavourable-Inadequate or Poor	Unfavourable-Bad or Bad
Area of habitat	Stable or increasing	Decrease <10%	Decrease >10%
Deep-water community	Full development	Marginal	Absent
Number of species	Constant or increase in number	10% decline in species	>10% decline in species
Typical species	9 or more indicator species	<9	undefined
Introduced Species	Not present or having no impact on *Najas flexilis* population or deep-water community	Abundant introduced species ⇒ decline in *Najas flexilis* population or deep-water community	*Najas flexilis* or deep-water community entirely replaced by introduced species
Euphotic depth	≥3 m	2-3 m	<2 m
Colour	<40	40-80	>80
Total phosphorus	<0.015	≥0.015	undefined
Hydrological regime	Summer levels: <50% *Lobelia* — *Littorella* zone exposed	Summer levels: >50% *Lobelia* — *Littorella* zone exposed	Summer levels: at/below top of the *Isoetes* zone

5.1.1 Area

Lake habitat area could be set as the surface area of the lake; in this case significant changes in habitat area would only occur as a consequence of significant drainage work resulting in lowering of the water level. However, the area of habitat will also decrease if euphotic depth decreases, irrespective of changes in lake surface area. Careful monitoring of euphotic depth is, therefore, key.

In most lakes, macrophytes do not cover the entire lake bottom and the area covered by aquatic macrophytes could be estimated as lake shoreline length × average width of euphotic zone. The width of the euphotic zone can be calculated as the distance from the shore to the base of the euphotic zone, using transect waypoints as markers. If only two transects are sampled, the averaged width is obviously an approximation, but re-sampling transects will highlight changes in the area of macrophyte habitat. Where bathymetric charts are available, the area could be calculated directly as the entire lake bottom shallower than the euphotic depth.

We propose that *Good* is no change or increase in the estimated area of the habitat, Inadequate/*Poor* is less than 10% decrease and *Bad* is greater than 10% decrease between sampling rounds.

5.1.2 Deep-water vegetation community

Clear-water *Najas flexilis*-type lakes have a characteristic deep-water vegetation consisting of some or all of the following species *Najas flexilis*, *Nitella confervacea*, *Nitella flexilis*, *Nitella translucens*, *Callitriche hermaphroditica*, *Hydrilla verticillata*, *Potamogeton berchtoldii*, *Potamogeton perfoliatus* and *Potamogeton pusillus*. The extent of this vegetation is controlled both by water transparency and lake morphology. Full development occurs when some of the above species reach cover values greater than 2 on the Braun-Blanquet scale and a distinct vegetation zone is present below the *Isoetes* zone. Partial development occurs when some of the species are present but with low cover values (+ to 1) and a distinct vegetation zone cannot be discerned. Absence of the species indicates no development.

5.1.3 Number of species

The number of species in a lake is a simple measure of its quality and conservation importance and all *Najas flexilis*-type lakes where more than 30 aquatic macrophyte species are recorded during a survey are considered to be of high conservation value. There is a correlation between euphotic depth and the number of aquatic species recorded (Figure 49), and while non-significant, the data suggest higher species-richness is found in lakes with lower total phosphorus (Figure 43) and lower colour (Figure 45). The number of species/species-richness, however, can only be measured by thorough survey, as the number of species increases asymptotically with the number of relevés taken (see, for example, Figure 15). Therefore it is a difficult metric to use in monitoring surveys. Furthermore, one would expect some increase in number of species with increasing area but this relationship is not strong in the present data set. As a result, it is recommended that the number of species recorded during the survey is compared with previous site-specific data. No decline in number of species is rated *Good*, a decline of 10% from the previous total is *Inadequate/Poor*, and a decline greater than 10% is *Bad*. All previous records should be included even if they are very old. For example plants such as *Nitella confervacea*, *Chara aspera*, *Pilularia globulifera*, *Subularia aquatica* and *Potamogeton praelongus* were previously recorded from Lough Leane but have now gone — an indication of ecological decline.

5.1.4 Typical species

Empirically, the presence of *Isoetes lacustris* and *Potamogeton perfoliatus/praelongus* indicates a lake of the *Najas flexilis*-type. If either species is absent, the lake may be too eutrophic and qualify as habitat code 3150, or too oligotrophic 3110), to qualify as a *Najas flexilis*-type lake. In broad terms, a typical *Najas flexilis*-type lake should contain the commoner species of Groups 1, 4 and 5 (see Section 3.3 and Appendix III). The absence of Group 5 species would indicate an undeveloped deep-water zone and consequently a damaged lake. While many lakes do contain *Najas flexilis*, some very species-rich examples such as Aughrusbeg do not.

A list of nine rarer taxa found in *Najas flexilis*-type lakes is given in Section 3.5. No less than six of these occur in Ballynakill Connemara (*Nitella confervacea*, *Fissidens fontanus* (*Octodiceras fontanum*), *Hydrilla verticillata*, *Isoetes echinospora*, *Pilularia globulifera*, *Subularia aquatica*), suggesting this suite of species may be positive indicators of ecological condition, that is they are associated almost exclusively with lakes in *Good* condition.

A list of typical species is proposed in Table 6, based on the indicator species for Group 1 (see Section 3.3.1), Group 4 (Section 3.3.2) and Group 5 (Section 3.3.3). These are further divided into nine 'positive indicator species' and the nine rarer taxa (Section 3.5), or 'high quality indicator species'. Targets were set based on examination of the numbers of indicator species recorded in the study lakes in *Good* conservation condition: lakes should have a total of at least nine indicator species overall, with one or more of these being high quality indicator species. For example, Ballynakill Connemara has a total of 17 indicator species, 10 positive indicator species and six high quality indicator species.

Table 6 Indicator or typical species for *Najas flexilis*-type lakes. Lakes in *Good* conservation condition are expected to have nine or more indicator species, with one or more of these being high quality indicator species. Positive indicator species are associated with the three typical vegetation zones: Group 1 (*Lobelia*, *Littorella* and *Eriocaulon* zone); Group 4 (*Isoetes lacustris* zone) and Group 5 (*Najas flexilis* or deep-water vegetation). There should be no loss of indicator species between surveys.

Positive indicator species	High quality (rare) indicator species
Eriocaulon aquaticum (Group 1)	*Baldellia ranunculoides* subsp. *repens*
Littorella uniflora (Group 1)	*Chara muscosa*
Lobelia dortmanna (Group 1)	*Fissidens fontanus*
Myriophyllum alterniflorum (Group 1)	*Hydrilla verticillata*
Isoetes lacustris (Group 4)	*Isoetes echinospora*
Callitriche hermaphroditica (Group 5)	*Najas flexilis* (Group 5)
Chara virgata (Group 5)	*Nitella confervacea* (Group 5)
Nitella translucens (Group 5)	*Nitella spanioclema*
Potamogeton berchtoldii (Group 5)	*Pilularia globulifera*
Potamogeton perfoliatus (Group 5)	*Subularia aquatica*

5.1.5 Introduced species

Of the lakes surveyed, *Najas flexilis* had disappeared from two in the last 15 years: Lough Nageltia and Sessiagh Lough. In both of these lakes, the common invasive species *Elodea canadensis* was abundant in 2016-18, but absent in earlier surveys in 2004-05. At Nageltia, the deeper-water community described in 2004 had declined to scattered plants on the lake bottom, and *Elodea canadensis* was one of the commonest species in 2018. In the case of Sessiagh, repeat sampling by the EPA demonstrated that *Najas flexilis* was last recorded in 2012, with abundant *Elodea* recorded in 2015. In 2017, *Elodea canadensis* was also very abundant in Port Lough, which is within 15 km of Sessiagh. *Elodea canadensis* was not recorded in Port Lough in 2004 but in 2017, as in Sessiagh, the plants were exceptionally large and vigorous. While swards of *Chara virgata* seen in 2004 were now replaced by *Elodea canadensis*, *Najas flexilis* remained common in Port Lough. A fourth case of *Elodea* invasion may have happened in Tully Lough Co. Galway (Roden & Murphy, 2014). *Najas flexilis* was recorded there in some quantity in 1978. In 2003, Roden could not locate the species and was struck by the very dense stands of *Elodea canadensis* (Roden, 2003). In 2004, two plants were noted by the same author (Roden, 2004, 2007). In 2014, however, a small population was located near an island in the lake (Roden & Murphy, 2014).

Elodea canadensis was introduced to Ireland in the 19th century, and it appears to still be spreading to smaller and remote lakes in the north-west of Ireland. Abundant *Elodea canadensis* appears to be a negative indicator. Although two *Najas flexilis* populations could not be relocated during this study, it is possible that the plant may reappear if the *Elodea canadensis* population 'settles down' as has happened in other locations.

If *Najas flexilis* or the deep-water vegetation has declined with the appearance of *Elodea canadensis* or other invasives, the lake is rated *Poor*. Extinction of *Najas flexilis* with arrival of invasives results in a *Bad* rating.

Elodea canadensis is a threat to lakes it has not yet colonised, for example, Ballynakill Connemara.

5.1.6 Euphotic depth

Maximum vegetation depth ranged from 5.2 m to less than 2 m in the surveyed lakes. Variation in depth is influenced by peat deposits in the lake catchment. The very clearest lakes, Sessiagh and Aughrusbeg, have small rocky catchments, while lakes with shallow euphotic zones, such as Lough Nahaltora, are surrounded by (cut-over) blanket bog. While high (>30 mg/l) alkalinity *Najas flexilis* lakes are clearer in contrast to medium alkalinity *Najas flexilis* lakes, alkalinity does not correlate with euphotic depth in the lakes surveyed in this report.

The most species-rich lakes with the most extensive *Najas flexilis* populations and best-developed deep-water vegetation had maximum vegetation growth typically greater than 3 m and generally greater than 3.5 m. The six lakes where 30 or more species were recorded during the survey had an overall average euphotic depth of 3.8 m (range 2.8-5.2). The average euphotic depth across lakes in *Good* conservation condition was 3.6 m (range of 2.7-5.2 m).

The euphotic depth target for *Good* condition is set as greater than or equal to 3 m, but there should be no significant decline in maximum vegetation depth in lakes where euphotic depths is greater. As noted above, it is considered that increasing water colour leads to decreases in euphotic depth and the decline and eventual disappearance of deep-water communities. *Najas flexilis* occurred in several lakes with lower euphotic depths. This may be a natural feature of these lakes and site-specific adjustments of the targets may be necessary.

5.1.7 Colour

Measures of *Najas*-lake vegetation quality/condition are strongly determined by lake water colour and lake total phosphorus. Colour is closely linked to euphotic depth and is lower (<40 Hazen Units) for the best lakes surveyed. Lakes with high colour had lower euphotic depth, fewer species and smaller populations of *Najas flexilis*. The average water colour ranged from 27 to 77 Hazen Units across the 16 lakes with EPA data and, for the sub-set of five lakes in *Good* conservation condition, from 27 to 33 Hazen Units. The study indicated seasonal patterns with elevated water colour in winter, indicating that single samples are likely to be unreliable measures of a lake's colour. It is undetermined if lakes in peat basins have naturally higher colour than those in rock basins. Alternatively high colour is always a sign of environmental degradation. In either case an increase in colour between sampling rounds is probably a sign of declining conservation condition.

5.1.8 Total phosphorus

Data on lake total phosphorus are available from the EPA or, if not, should be collected during the survey. Single samples may be unreliable indicators and a sampling programme is necessary to determine meaningful values. Thus, results reported by the EPA are more reliable than the few values recorded during this or previous surveys. The Port Lough value of 0.028 mg/l is a single winter value and is probably atypical. More data are necessary from the smaller lakes not included in the EPA monitoring programme to set accurate reference values. The existing data indicate total phosphorus of less than 0.015 mg/l for the best quality lakes surveyed (average total phosphorus (EPA data) for lakes in *Good* conservation condition ranged from 0.008-0.015 mg/l). It may be necessary to achieve concentrations of 0.010 mg/l or below to support good vegetation condition in *Najas flexilis*-type lakes, which would match the Water Framework Directive total phosphorus standard for high status (S.I. 77 of 2019). We lack data to set a boundary for Poor-Bad.

5.1.9 Hydrological regime

While it is vital that fluctuations in lake level follow predictable seasonal trends, the necessary data can only be obtained by permanent water level gauges and are not collected during field survey. There is a good network of gauges, operated mainly by the EPA and OPW, and data are available on-line. However, certain relationships exist between vegetation zones and seasonal water level, and if these break down, the lake must be deemed to be in bad conservation condition.

In summer, water level should never be lower than the top of the *Isoetes* zone. If more than half the *Lobelia*—*Littorella* zone is exposed this is a matter for concern. The norm is that most of this zone is covered. In this survey, the formerly exceptional Kiltooris Lough (Roden, 1999) was found to be badly damaged by unauthorised drainage which reduced water level down to the *Isoetes* zone (Figure 54), this drainage may be responsible for the catastrophic decline in water quality noted. In 1999, Roden had difficulty reaching the base of the euphotic zone, suggesting depths more than 8 m, in 2017 euphotic depth was 3 m and large areas of deep-water vegetation had been eliminated.

Figure 54 Kiltooris Lough: damage to the littoral zone of this formerly pristine lake caused by recent attempts at land drainage.

In winter all zones should be submerged, including the *Littorella* and *Isoetes* zones, and it is usual for the surrounding lake side vegetation to be inundated to a depth of perhaps 50 cm.

Excessively high winter levels are not known to damage lake conditions but very high summer levels are unusual and if persistent, indicate a change in lake structure and function.

5.1.10 Shallow lakes

This scheme must be modified for a small number of *Najas* lakes which are very shallow, *e.g.* Sheskinmore, na Creibhinne or na gCaor. Another known example is Clooney Lough, Co. Donegal. In these lakes, deep-water vegetation cannot occur but *Najas flexilis* exists in shallow water and lake quality may be judged on the persistence of the species between sampling rounds, low water colour and low total phosphorus.

5.2 Other indicators of lake condition

Certain indicators may be useful, but cannot currently be used in assessing lake conservation condition; they should be measured if possible but should not over-ride the assessment based on the parameters discussed above.

5.2.1 Substrate

In general, *Najas* lakes are dominated by bedrock, sand and loose stones, silt mud or hard peat. The appearance of large expanses of raw peat would indicate excessive sediment input, as in the case of Cloonmackan Lough (Co. Clare).

5.2.2 Attached algae

Occasional blooms of filamentous algae occur in *Najas* lakes. These do not always imply excess nutrients; especially if species of the orders Zygnematales or Oedogoniales are responsible. Drifting masses of *Cladophora* species, however, may indicate a decline in water quality. Epiphytic algae occur frequently but heavy fouling which coats macrophyte leaves probably indicates eutrophication. Equally floating clumps of *Cladophora* species is an indicator of bad water condition. Such conditions were not seen in this survey but were noted in Lough Lettershask in 2014 (Roden & Murphy, 2014).

5.2.3 EPA data

The EPA have very extensive data collected from some lakes which contain *Najas flexilis*. These data are used by the EPA to determine water quality and WFD Ecological Status. Targets for total phosphorus and colour are given above. Other useful metrics include the following.

- **Alkalinity** - Largely between 20-80 mg/l but lower values may occur especially on Old Red Sandstone
- **pH** - Should be close to neutral 7.0
- **Secchi disk transparency** - Where a series of measurements is available this metric indicates water clarity. However a single measurement is less useful and often shows little connection to the euphotic depth. Measurement of euphotic depth directly by observation is preferable, but a decreasing trend in Secchi depth would indicate declining water quality
- **Macrophytes** - EPA data on macrophytes are also available and should be used to complement species lists derived from snorkel survey (note in certain cases *e.g.* Derg and Illauntrasna it was not possible to confirm EPA records of *Najas flexilis*, so important records should be confirmed by checking herbarium material before being added to species lists). Quantitative EPA macrophyte data are gathered using very different methods to snorkel survey and, therefore are not easily compared.

5.3 Assessment of *Najas flexilis* populations

As a species protected under Annex II of the Habitats Directive, it is necessary to assess and report on the conservation condition of the *Najas flexilis* population separate to that of its habitat.

Possible non-destructive metrics for assessing *Najas flexilis* populations include population extent, density, and plant size. Wingfield *et al*. (2004) also used metrics that require the harvesting of living plants, which might not be advisable for marginal populations, even though much useful data may be obtained.

The parameters proposed below cannot yield absolute values but are proportional, so allowing populations to be ranked against each other and change within an individual population to be monitored over time. Only very detailed survey work could yield absolute values for population size or extent.

5.3.1 Population extent

The areal extent of the population may be indicated by the number of transects on which the species is recorded, provided the transects are selected in order to cover the entire lake shoreline or circumference. Obviously the more transects sampled, the more accurate the data. As larger lakes require more transects, the data can be standardised by expressing the results as a proportion of the total number of transects sampled, *i.e*. the number of transects with *Najas flexilis*/the total number of transects sampled. To convert these data into estimates of extent in metres or kilometres, one multiplies by lake shoreline length. Shoreline length is chosen as in many lakes, *Najas flexilis* occurs as a band parallel to the shore rather than covering the whole lake bed. Shoreline length can be measured using Google Earth or similar applications. Given the fractal nature of shorelines it is an approximate value.

5.3.2 Population density

Population density is calculated for each lake as the average cover value of all relevés in which *Najas flexilis* is present. Cover values as Braun-Blanquet Scale values (*e.g*. 2, 1, 0.1 for =) are summed and divided by the total number of relevés with *Najas flexilis*.

5.3.3 Population size

Population size is proportional to both extent and density. A measure of population size would be the product of these variables. It is unlikely, however, that the intensity of sampling in 2016-18 was sufficient to yield meaningful estimates of population size and it would be unwise to rely on such estimates, unless statistically significant sampling is undertaken.

5.3.4 Population health

Wingfield *et al*. (2004) proposed several useful measures of plant health such as size and seed number; these can only be measured accurately by collecting a statistically reliable number of plants. While this is not advised for routine population monitoring, photos of the largest plants encountered might provide a subjective impression of population health. Field experience does suggest a relationship between species abundance and plant size.

5.3.5 Assessing change over time

These parameters (population extent, density, size and health) will indicate changes in the *Najas flexilis* population over time in a single lake. Changes in population size or health can only be detected if previous base line data are available. It is important that the transects sampled in 2016-18 are re-sampled in future surveys, if population change is to be accurately monitored.

The individual site accounts in Appendix V (separate pdf file and hard-copy volume) give previous survey results but no standardised quantitative data are available. Field notes from previous NPWS surveys in 2002-05 (Roden 2004, 2007) or Roden (1999) give some impression of population size and extent that may indicate change. As C. Roden and P. Murphy were also responsible for many previous surveys, observer memory is also of some value. The EPA surveys using grapnels or rakes so direct comparisons to data gathered using the snorkelling methodology are not reliable. EPA records for the species are usually fewer than those made by snorkelling. Nevertheless, large changes in distribution between EPA surveys probably indicates changes in the population; a case in point is the disappearance of *Najas flexilis* from Sessiagh between 2012 and 2015.

Stable or expanding populations should be assessed as *Good*, populations known to have declined are rated *Poor* while populations which have declined to a single transect or become extinct are assessed as *Bad*. In certain cases, we know populations have declined or become extinct; examples include Loch an Chaolaigh, Sessiagh Lough, Lough Leane and Lough Nageltia: in these cases the *Najas flexilis* populations are rated unfavourable *Bad*. Table 7 gives the conservation condition for the *Najas flexilis* populations surveyed during this study.

While assessment of the conservation condition of the *Najas flexilis* population and its lake habitat are separate, a final judgement for a lake must take both assessments into account (see examples in site accounts, Appendix V).

5.3.6 Ranking Surveyed populations

A more difficult task is to compare estimates of population extent or population size between lakes. As *Najas flexilis* is an annual, large variations in population size and possibly extent may be expected in different years. The case of Loch an Chaolaigh illustrates the variability of population size between years. Aerial extent is possibly the best comparative indicator between lakes, as larger lakes inevitably hold larger populations.

Table 7 ranks the importance of the *Najas flexilis* populations surveyed based on aerial extent. It is not possible however, to state whether the existing populations were once larger or if the existing population occupies all available habitat. Future reductions in population size however would indicate unfavourable condition.

The conservation condition of each *Najas flexilis* population is not necessarily linked to its ranking, as a small stable population should be rated *Good* while a large but diminishing population might be of national importance yet assessed as *Poor*.

Table 7 Conservation condition and ranking of *Najas flexilis* populations studied. Population density was calculated as the average cover value across all relevés with *Najas flexilis*. Population extent was calculated as (the number of transects with *Najas flexilis*/the total number of transects sampled) × lake shoreline length. Lakes are ranked by population extent.

Lake name	Population density	Population extent	*Najas flexilis* conservation condition	Comparison with previous survey(s)
Caragh	1	6.6	Poor	Increase in locations compared to EPA surveys but less abundant than previously at one station
Leane	0.1	6.5	Bad	Near extinction compared to survey in 2013
Anure	2.41	6.3	Good	Increase in locations compared to 2009 EPA survey
Fern	0.22	4.6	Poor	No change compared to EPA and other surveys
Acoose	0.83	3.8	Good	No change compared to EPA and other surveys
Kiltooris	0.78	3.8	Poor	Increase in locations compared to EPA surveys but less widespread than in 1999
Ballynakill Connemara	2.1	3.7	Good	No change
Long Range	0.46	3.5	Good	No change compared to previous surveys
Kindrum	0.55	3.4	Poor	Not as abundant as in 2002
na Creibhinne	0.46	3.3	Good	No change compared to previous surveys
Maumeen	0.55	3.2	Good	No change
Mullaghderg	0.1	2.9	Good	No change
Bofin	0.1	2.7	Good	Increase in locations compared to 2007 EPA survey
Port	0.95	2.6	Good	No change other than possible impact of *Elodea canadensis*
Moher	0.84	2.4	Good	Increase in locations compared to 2009 EPA survey
Akibbon	1.025	2.1	Good	Increase in locations compared to EPA and other surveys
Chluain Toipin	1.62	1.7	Good	Increase in locations compared to EPA and other surveys
Knocka	2.3	1.5	Good	No previous data
na gCaor	0.4	1.2	Good	No change
Sheskinmore	1.03	0.9	Good	No change compared to previous surveys
Foorglass	0.4	0.87	Good	No change
Nahaltora	0.1	0.6	Poor	Reduced depth distribution
Shannagh	1	0.3	Poor	Less abundant than 1999
an Chaolaigh	0.1	0.2	Bad	Far less abundant than 2004
Nageltia	0	0	Bad	Could not be found in 2016 or 2018. Last recorded in 2004
Sessiagh	0	0	Bad	Could not be found in 2018. Last recorded in 2012
Upper Lake	0	0	Bad	Could not be found in 2018. Last seen in 2014

5.4 Pressures and threats

In general, human impacts on *Najas flexilis*-type lakes are indirect in the sense that the pressures occur in the lake catchment rather than in the lake itself. Consequently, it is seldom possible to detect these pressures by direct observation, but rather analyses of aerial imagery or data on inflowing streams are necessary. Such analyses are outside the scope of this manual and here we only offer a short summary of likely pressures and threats.

5.4.1 Increases in nutrient loading

A general rise in nutrient loading (nitrogen and phosphorus) is known to have occurred in many Irish lakes. This increase reflects increased use of fertilisers on farms and forestry, and an increase in septic tanks around many lakes, as well as in urban waste water discharges. The impact of increased nutrient loads is often summarised as an increase in total phosphorus, an element which frequently limits plant and algal growth and is known to correlate with a decline in lake conservation condition. Data on total phosphorus inputs may be obtained from WFD studies by the EPA or LAWPRO. Increases in farming, forestry or housing activities detected from aerial imagery might be related to changes in lake total phosphorus. In general, it is not possible for field observation to directly detect changes in nutrient loading, even though it is probably the greatest threat to Irish *Najas flexilis* lakes.

5.4.2 Increases in water colour and sediment load

Again it is not easy to detect increases in water colour an sediment by direct observation. Aerial imagery will show whether cutover bog-land drains into the lake. In addition, drains and other artificial channels may indicate anthropogenic sources of sediment. Such features should be noted and inspected when observed during field survey. Sediment accumulation, darker water or increases in vascular plants at the point the channel enters the lake all indicate water colour/dissolved organic carbon, nutrient and sediment pressures on the lake. It should be noted that increased nutrient loading may vary independently from increases in lake colour and sediment load.

5.4.3 Excessive water abstraction

Najas lakes are often the source of clear, low-nutrient water, and consequently are used by public and private water schemes. An example is Ballynakill Connemara. Excessive abstraction, especially in dry summers, could damage these lakes. See Section 5.1.9 on hydrological regime.

5.4.4 Infilling and drainage

Lake infilling inevitably damages littoral communities, drainage which lowers lake levels is also very damaging, *e.g.* Kiltooris.

5.4.5 Other

Herbicide and pesticide usage close to the lake may have damaging impacts.

5.5 Overall assessment of Irish *Najas flexilis*-type lakes

In assessing the conservation condition of *Najas flexilis*-type lakes the following order of priority is recommended for the proposed indicators

1. **Deep-water vegetation** —all deeper lakes which lack the deep-water community should be assessed as *Bad* irrespective of other measurements; a much reduced community should be rated *Poor*. Exceptions are shallow lakes.

2. **Euphotic depth** — all lakes with euphotic depth less than 1.8-2 m should be rated *Bad* irrespective of other measurements.

3. Extinction or severe decline in *Najas flexilis* populations means the lake should be rated *Bad*.

4. Indicators such as total phosphorus, water colour and hydrological regime are assumed to be driving variables in the lake ecosystem and it is not totally established how closely they determine ecosystem structure and function; therefore conservation condition based on these indicators should not override the parameters listed above. Unfavourable values may, however, indicate impacting pressures and likely future declines in the ecosystem.

5. **Introduced species** — the impact of *Elodea canadensis* may range from catastrophic to being of little importance.

6 Conclusion

This study has confirmed the existence of a lake type intermediate between marl and natural eutrophic lakes, on the one hand, and oligotrophic lakes on the other. Besides the frequent presence of *Najas flexilis*, these lakes may be recognised by the co-occurrence of *Isoetes lacustris* and other species typical of oligotrophic lakes, with *Potamogeton perfoliatus* and other species typical of mesotrophic or eutrophic lakes. In a sense, such lakes may be regarded as a continuum between other lake types but certain species such as *Najas flexilis*, *Nitella confervacea* and *Hydrilla verticillata* appear largely confined to this intermediate type. Such lakes tend to have alkalinity values between 15 mg/l and 50 mg/l and total phosphorus levels lower than 0.015 mg/l, as well as relatively deep euphotic zones of 3-5 m.

Najas flexilis-type lakes are scarce in Ireland and western Scotland and even rarer in other parts of western Europe and consequently of great conservation value. The former more widespread distribution of *Najas flexilis* and past species lists from lakes such as Lough Neagh or Lough Melvin suggest that this lake type is diminishing in range, partly because of human disturbance through drainage and eutrophication. The remaining large *Najas flexilis* type lake in Ireland, Lough Leane in Killarney, appears to be in the process of degradation with the recent loss of many species found in *Najas flexilis*-type lakes, along with the almost complete disappearance of *Najas flexilis* itself.

Arguably many lakes containing *Najas flexilis* have already been seriously disturbed and pristine examples of *Najas* lakes are very rare. The lakes in the survey were ranked in terms of conservation importance by combining the scores for lake area, euphotic depth, number of species and number of relevés with *Najas flexilis* (Table 8). For each lake, each parameter was expressed as a percentage of the maximum value recorded for that parameter in the survey, with the exception of area which was converted to Log Area. The values obtained for the four parameters were summed and expressed as a score. The maximum possible score was 300. The scores were ranked in six groups, each with a range of fifty as follows: Rank 1 lakes scoring from 251-300; Rank 2, lakes scoring from 201-250; Rank 3, lakes scoring from 151-200; Rank 4, lakes scoring from 101-150; Rank 5, lakes scoring from 51-100; Rank 6, lakes scoring 50 or lower.

Only two lakes reach Rank 1: Ballynakill Connemara and Port in Co. Donegal. As recently as 2005, two others, Sessiagh and Kiltooris, would also have reached this rank. This result demonstrates how rare *Najas flexilis*-type lakes in excellent condition are and how fragile they are. Some other *Najas flexilis*-type lakes not surveyed in this project might also rank highly, for example Rusheenduff Lough in Renvyle, Connemara, Pollacappul Lough at Kylemore and Lough Nalawney near Errisbeg, all in Co. Galway. It is still possible that further *Najas flexilis*-type lakes remain to be discovered, especially in Co. Donegal and Co. Mayo. Nevertheless it is clear that existing *Najas flexilis*-type lakes in excellent condition are very rare, even in Ireland, the European stronghold of the lake type and the species itself. We know that *Najas flexilis* probably occurred formerly in large Irish lakes, even perhaps in Lough Neagh. Lough Leane was until recently the last surviving example of a large Irish lake with an abundant population of the species, but within the recent memory of the senior author, this population has collapsed. The diverse flora present even in 2005 is now contracting and *Najas flexilis* itself is reduced at best to a few isolated individuals. A fascinating habitat once widespread on the island is now confined to small remote loughs, largely replaced elsewhere by a monotonous and species-poor vegetation adapted to dark and phosphorus-rich water. Unless immediate efforts are made to restore these populations of *Najas flexilis* they will follow their English counterpart (in Esthwaite Water) into extinction. Such a loss would permanently damage not only Irish but European biodiversity.

Table 8 Ranking of the *Najas flexilis*-type lakes in the study. The score is the sum of area (log area), euphotic depth, species-richness and number of relevés that contained *Najas flexilis* (each expressed as a percentage of the maximum value recorded). Ranks were assigned in bands of 50.

Lake	Score	Rank
Ballynakill Connemara	287	1
Port	270	1
Kiltooris	203	2
Knocka	198	3
Kindrum	194	3
Caragh	194	3
Maumeen	188	3
Akibbon	186	3
Anure	184	3
Aughrusbeg	183	3
Acoose	174	3
Long Range	166	3
Sessiagh	165	3
Fern	164	3
Chluain Toipin	162	3
na Creibhinne	154	3
Leane	145	4
Sheskinmore	142	4
Eske	141	4
Moher	140	4
An Chaolaigh	135	4
Foorglass	132	4
Upper lake	128	4
Bofin	124	4
Ballynakill Gort	113	4
Nahaltora	109	4
Shannagh	107	4
na gCaor	96	5
Anscaul	94	5
Mullaghderg	91	5
Nageltia	87	5

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Appendix I Summary vegetation data for the surveyed lakes

Column headings: '**Secchi**' - Secchi depth in metres; '**Survey year**' - year(s) of survey during the study; '**# of Ts**' - number of transects sampled; '**# of Rs**' - number of relevés sampled; '***Nf*+**' - *Najas flexilis* present during survey; '**# *Nf* Rs**' - number of relevés with *Najas flexilis*; '***Nf* R (m)**' - depth range of relevés with *Najas flexilis*; '**Previous *Nf***' - years in which *Najas flexilis* was recorded before the study; '**E_z (m)**' - euphotic depth in metres (*na Creibhinne, Mullaghderg, Nageltia and Sheskinmore are shallow, and euphotic depth is greater than maximum depth; ** below 1.5 m, the deep-water vegetation in Sessiagh, which has unusually clear water, had been replaced by dense *Elodea canadensis*, *Myriophyllum spicatum* and several large pondweeds to 5.4 m); '**Spp. during**' - aquatic macrophyte species-richness from this survey; '**Spp. before**' - aquatic macrophyte species-richness from previous surveys; '**Spp. comb**' - aquatic macrophyte species-richness from all surveys combined; '**Cons. Cond.**' - overall conservation condition for the lake (this study), oligotrophic lakes that did not qualify as *Najas flexilis*-type lakes were not assessed ('n/a'); '**Vegetation notes**' - observations on flora and vegetation from this survey; '**Noteworthy spp.**' - includes species recorded during the survey and/or in previous surveys; '***Ec*+**' - *Elodea canadensis* present (the only non-native species recorded during the study)

Lake name	Secchi (m)	Survey year	# of Ts	# of Rs	*Nf*+	# *Nf* Rs	*Nf* R (m)	Previous *Nf*	E_z (m)	Spp. during	Spp. before	Spp. comb.	Cons. Cond.	Vegetation notes	Noteworthy spp.	*Ec*+
Acoose	3.5	2018	4	21	Yes	6	1.8-3	1971, 1994, 2004, 2011	2.9	24	17	27	Good	Fully-developed deep-water community, *Najas* cover up to 25%	*Isoetes echinospora*, *Potamogeton praelongus*	-
Akibbon	2.0	2018	3	23	Yes	8	1.4-2.6	1977, 1991, 2002, 2009, 2010	3.0	27	27	34	Good/ Poor	Shallow lake with vegetation covering most of the lake bed, *Najas* extensive with cover up to 20%	*Nitella confervacea*, *Pilularia globulifera*	-
An Chaolaigh	-	2016, 2017 & 2018	3	21	Yes 2017	-	-	1996, 2004	3.6	21	13	21	Poor	*Najas* and species diversity at depth have declined. *Najas* is not present in some years	*Isoetes echinospora*, *Subularia aquatica*	-
Anscaul	-	2017	4	21	No	-	-	-	2.7	13	12	16	Good	A marginal *Najas*-type lake	*Potamogeton crispus*	-
Anure	1.9	2017 & 2018	4	21	Yes 2017, 2018	8	0.8-2.5	2009	2.6	23	20	28	Poor	A large *Najas flexilis* population in SE, lacking deep-water flora elsewhere	*Nitella confervacea*, *Potamogeton* hybrid (? × *griffithii*)	-
Aughrusbeg	2.5	2017	5	21	No	-	-	-	5.2	31	22	32	Good	Diverse vegetation reflecting a complex morphology and exceptional water clarity	*Chara muscosa*, *Nitella confervacea*, *Tolypella glomerata*, *Potamogeton filiformis*	Yes

Lake name	Secchi (m)	Survey year	# of Ts	# of Rs	*Nf+*	# *Nf* Rs	*Nf* R (m)	Previous *Nf*	E_z (m)	Spp. during	Spp. before	Spp. comb.	Cons. Cond.	Vegetation notes	Noteworthy spp.	*Ec+*
Ballynakill Connemara	-	2016	6	45	Yes	13	1.6-4.1	2003, 2004, 2005, 2007, 2010	4.0	37	35	39	Good	Very species-rich with several rare species and a diverse *Potamogeton* flora. Abundant *Najas* and *Hydrilla*. Probably the best example of a *Najas*-type lake in Ireland	*Nitella confervacea*, *Hydrilla verticillata*, *Isoetes echinospora*, *Pilularia globulifera*, *Subularia aquatica*, *Typha angustifolia*	-
Ballynakill Gort	-	2016	5	24	No	-	-		2.7	21	12	22	Poor	Further east than most *Isoetes* lakes in Galway. No deep-water vegetation, abundant *Lemna trisulca*	*Callitriche hermaphroditica*, *Eleocharis acicularis*, *Lobelia dortmanna*, *Isoetes lacustris*, *Oenanthe fluviatilis*	Yes
Bofin	2.1	2018	4	15	Yes	3	1-2	2007, 2010	1.9	23	20	27	Poor	Shallow euphotic depth, high colour, widespread soft-water species dominate, retains small *Najas* population but deep-water community poorly developed	*Nitella confervacea*, *Isoetes echinospora*	-
Caragh	2.5	2017	9	39	Yes	6	1.8-3.4	1877, 1896-1906, 1906, 1977, 1994, 2000, 2002, 2004, 2011	3.7	27	25	31	Poor	Relatively species-poor for its size, some scarce species (*e.g. Subularia aquatica*, *Nitella confervacea*) not been seen recently, deep-water community local in extent, evidence of decline in euphotic depth. Large *Najas* colonies in south	*Nitella confervacea*, *Baldellia ranunculoides* subsp. *repens*, *Eleocharis acicularis*, *Isoetes echinospora*, *Subularia aquatica*	Yes
Carrigeencorr	2.3	2018	1	5	No	-	-	-	3.0	18	-	-	n/a	Diverse flora, clear water, slight development of a deep-water zone with *Potamogeton perfoliatus* and *Nitella translucens*, worthy of further investigation	*Nitella translucens*, *Potamogeton gramineus*, *P. obtusifolius*, *P. perfoliatus*	-
Chluain Toipin	-	2016	4	24	Yes	5	1.6-2	2013	2.8	25	17	29	Good	A shallow, clear-water lake with diverse flora, large, and extensive population of *Najas flexilis* (cover of >50% is places)	*Nitella confervacea*, *Isoetes echinospora*, *Potamogeton alpinus*, *Subularia aquatica*	-

Lake name	Secchi (m)	Survey year	# of Ts	# of Rs	*Nf*+	# *Nf* Rs	*Nf* R (m)	Previous *Nf*	E_z (m)	Spp. during	Spp. before	Spp. comb.	Cons. Cond.	Vegetation notes	Noteworthy spp.	*Ec*+
Cloonmackan	-	2018	0	0	No	-	-	-	<1.0	11	-	-	n/a	Surprisingly barren: few species, all at low abundance	*Carex pseudocyperus, Potamogeton obtusifolius*	Yes
Courhoor	-	2017	0	0	No	-	-	-	2.0	13	-	-	n/a	Species-poor lake with peat-stained/coloured water. No deep-water community noted	-	-
Derg	-	2017	2	0	No	-	-	-	2.4	5	-	-	n/a	Extremely oligotrophic and species-poor lake, only 5 species recorded in 2 hour search by 3 snorkellers	-	-
Derryierin	-	2018	0	0	No	-	-	-	1.0	7	-	-	n/a	Species-poor, large colonies of *Chara virgata* and *Eriocaulon aquaticum*, drowned Scots Pine stumps	*Eriocaulon aquaticum*	-
Eske	-	2017 & 2018	3	16	No	-	-	-	3.1	28	20	31	Poor	Soft-water species dominate, but *Potamogeton* spp. include *P. praelongus* and *P. perfoliatus*. Deep-water vegetation absent, which may be a natural feature or a result of high colour or eutrophication	*Typha angustifolia, Isoetes echinospora*	Yes
Fern	1.3	2017	5	20	Yes	7	1.3-2	2009, 2010	2.1	25	12	25	Bad	Water colour very dark. Most species are common in soft-waters, however *Isoetes lacustris* did not occur. *Nitella* dominant below 1 m but blackened/partly decayed. *Najas* widespread but at low cover	*Nitella* sp. requires further investigation	Yes
Foorglass	-	2018	3	18	Yes	3	1-1.6	1975, 2005, 2010	2.2	24	17	27	Poor	Small, species-rich lake. *Najas* grows throughout the lake but cover did not exceed 5%. Low euphotic depth. Possible threat of eutrophication	*Callitriche hermaphroditica, Potamogeton obtusifolius, Subularia aquatica*	-
Illauntrasna	-	2018	2	9	No	-	-		3.5	17	-	-	n/a	Probably too oligotrophic to support *Najas*. Not a *Najas*-type lake. Dominated by *Isoetes* from *c*. 1 m to base of euphotic zone	*Isoetes echinospora*	-

Lake name	Secchi (m)	Survey year	# of Ts	# of Rs	*Nf*+	# *Nf* Rs	*Nf* R (m)	Previous *Nf*	E_z (m)	Spp. during	Spp. before	Spp. comb.	Cons. Cond.	Vegetation notes	Noteworthy spp.	*Ec*+
Kiltooris	2.5	2017	5	35	Yes	7	0.9-2.1	1989, 1999, 2009, 2010	3.0	31	30	35	Bad	Previously one of the best *Najas* lakes in Ireland, it has been grossly disturbed by drainage: severe reduction in euphotic depth, reduced *Najas* habitat. Still of very high conservation value	*Nitella confervacea*, *Eriocaulon aquaticum*, *Isoetes echinospora*	-
Kindrum	2.4	2016	7	26	Yes	4	1.8-3.4	1916, 1937, 1939, 1989, 1998, 2000, 2002, 2009	3.5	26	35	37	Poor	Important lake with flora transitional from *Najas*-type to marl lake. Diverse *Potamogeton* and charophyte flora. *Najas* is sparse, deep-water community poorly developed, other signs of eutrophication evident	*Chara curta*, *Chara rudis*, *Nitella confervacea*, *Nitella spanioclema*	Yes
Knocka	-	2017	4	25	Yes	7	2-3	-	3.0	30	9	31	Good	Remote from other *Najas* lakes, with large population in east and cover up to 80%. Some evidence of enrichment, including filamentous algae and *Lemna trisulca*	*Nitella confervacea*, *Callitriche hermaphroditica*, *Elatine hexandra*, *Isoetes echinospora*, *Potamogeton alpinus*	Yes
Leane	3.1	2018	4	14	Yes	-	-	1888, 1892, 1898, 1902, 1906, 1907, 1935, 1976, 1994, 2000, 2004, 2005, 2010, 2013	2.8	31	42	43	Bad	One of the most important lakes in Ireland and largest with *Najas*. But *Najas* only recorded at 1 location and deep-water community absent in 2018. Blanket of decaying algae at depth. In 2019, only 1 *Najas* plant could be found, no benthic vegetation in Ross Bay. Species diversity and euphotic depth has declined	*Baldellia ranunculoides* subsp. *repens*, *Callitriche hermaphroditica*, (*Nitella confervacea*, *Subularia aquatica* seem to have disappeared)	Yes
Long Range	-	2016	6	19	Yes	4	1-2.8	1994, 2014	2.9	28	17	28	Good	Vegetation is typical of many soft-water lakes with some *Potamogeton berchtoldii*, *Najas* and rare *Nitella confervacea* on silt in deeper water. Deep-water community limited by morphology	*Baldellia ranunculoides* subsp. *repens*, *Isoetes echinospora*, *Pilularia globulifera*	Yes
Loughauneala	-	2018	0	0	Yes	-	-	2005, 2010	-	-	-	-	n/a	Shore grapnel survey only, but abundant, fresh *Najas* retrieved	-	-

Lake name	Secchi (m)	Survey year	# of Ts	# of Rs	*Nf*+	# *Nf* Rs	*Nf* R (m)	Previous *Nf*	Ez (m)	Spp. during	Spp. before	Spp. comb.	Cons. Cond.	Vegetation notes	Noteworthy spp.	*Ec*+
Mask		2016	1	11	No	-	-	-	3.5	25	18	28	n/a	Typical soft-water isoetid vegetation and too oligtrophic for *Najas*, however several groundwater springs with abundant *Persicaria amphibia* were noted	*Callitriche hermaphroditica*, *Pilularia globulifera*	Yes
Maumeen	2.5	2016	4	12	Yes	2	2-3	2005	3.9	17	9	18	Good	*Najas* common in the southern third of the lake, more oligotrophic vegetation in northern section	*Callitriche hermaphroditica*, *Subularia aquatica*	-
Melvin		2017	0	0	No	-	-	-	2.5	11	-	-	n/a	Vegetation poorly-developed, water colour dark, drift *Cladophora* in bay sampled. *Najas*-lake communities may have occurred in past. A thorough survey may find a more diverse flora	*Chara aspera*, *C. virgata*, *Nitella opaca*, *Potamogeton* spp.	-
Moher	2.3	2017	4	20	Yes	5	0.7-2.6	2008	2.6	27	18	29	Poor	Geographically isolated *Najas* lake with several rare species at eastern extent of their range. *Najas* occurs in a band around the lake with maximum cover of 20%. Only partial deep-water community, high colour, low euphotic depth	*Nitella confervacea*, *Eriocaulon aquaticum*, *Isoetes echinospora*, *Potamogeton obtusifolius*	Yes
Mullaghderg	1.3	2017	4	16	Yes	2	1-1.2	1919, 1938, 1939, 1977, 1989, 1990, 1999	*	26	25	32	Poor	Shallow lake, high water colour, at >1 m, deep-water community partially developed: scattered *Nitella* spp. and rare, low-density *Najas* occur, or large pondweeds and *Myriophyllum spicatum*, or bare, liquefied silt	*Chara muscosa* (original site, but not seen since 1939), *Nitella confervacea*, *Isoetes echinospora*, *Potamogeton* hybrid (? × *griffithii*)	-
na Creibhinne	1.5	2016	4	10	Yes	5	1-2.2	2005	*	20	13	21	Good	Deep-water community absent, likely owing to shallow depth. Large *Najas* population growing in shallow water throughout	*Potamogeton obtusifolius*	Yes

Lake name	Secchi (m)	Survey year	# of Ts	# of Rs	*Nf+*	# *Nf* Rs	*Nf* R (m)	Previous *Nf*	Ez (m)	Spp. during	Spp. before	Spp. comb.	Cons. Cond.	Vegetation notes	Noteworthy spp.	*Ec+*
na gCaor	-	2017	4	15	Yes	3	0.5-1.5	1974, 1991, 1997, 2004	2.1	14	12	16	Poor	Shallow lake with species-poor, sparse, patchy vegetation, only partial development of deep-water community. Scattered *Najas* (≤10% cover) on south and east sides	*Potamogeton obtusifolius*	-
Nageltia	1.8	2016 & 2018	0	0	No	-	-	2004	*	18	17	21	Bad	*Najas* not seen since 2004. Water extremely turbid in 2016, deep-water community described in 2004 had declined to scattered plants, *Potamogeton obtusifolius* not re-found, abundant *Elodea canadensis*	*Nitella confervacea*, *Eriocaulon aquaticum*, *Isoetes echinospora*, *Pilularia globulifera*	Yes
Nahaltora	4.5	2017	4	12	Yes	2	0.4-1.5	2004	2.0	24	16	26	Poor	*Najas* found on one transect in the north basin with cover <5%. Deep-water vegetation partially developed. Water dark, shallow euphotic depth.	*Pilularia globulifera*	Yes
Port	3.0	2016	3	15	Yes	11	0.4-3.5	1989, 2002	5.0	31	28	33	Good	Exceptionally valuable, diverse site with unusual charophytes and very abundant, widespread *Najas*. May be threatened by the recent introduction of *Elodea canadensis*	*Chara curta*, *Nitella confervacea*, *Callitriche hermaphroditica*	Yes
Sessiagh	-	2018	2	7	No	-	-	1981, 1989, 1998, 2002, 2003, 2009, 2010	**	22	24	28	Bad	The *Najas* population was formerly very large, with up to 60% cover to 5 m, however the species could not be re-found. *Najas* and deep-water community replaced by abundant *Elodea canadensis* and associates. Eutrophication may be a factor	*Tolypella glomerata*, *Zannichella palustris*	Yes

Lake name	Secchi (m)	Survey year	# of Ts	# of Rs	*Nf*+	# *Nf* Rs	*Nf* R (m)	Previous *Nf*	E_z (m)	Spp. during	Spp. before	Spp. comb.	Cons. Cond.	Vegetation notes	Noteworthy spp.	*Ec*+
Shannagh	-	2017	6	14	Yes	1	2	1989, 1990, 1991, 1999, 2000	2.0	20	24	27	Poor	Type locality for *Nitella spanioclema*. Small population of *Najas* in the north west corner at 2 m with *Nitella translucens* and *Potamogeton perfoliatus*, below sandy area with *Chara aspera* and pondweeds. Decline in transparency and euphotic depth	*Nitella spanioclema*	-
Sheskinmore	-	2018	1	8	Yes	3	0.4-0.7	1981, 2002	*	26	19	29	Good	Atypical, extremely shallow (<1 m) site with good *Najas* population sparsely distributed amongst *Chara* swards and abundant emergent beds	*Isoetes echinospora*	-
Upper	3.8	2018	3	0	No	1	-	1906, 1976, 1994, 2014	3.4	21	20	26	Good	A low alkalinity and marginal *Najas*-type lake with oligotrophic isoetid vegetation. *Najas* known from a single location since 1906, at 4 m with rich charophyte flora, but not seen in 2018	*Nitella gracilis, Isoetes echinospora, Pilularia globulifera*	-

Appendix II Summary physico-chemical data for the surveyed lakes

Summary water chemistry data for lakes. Overall average values are given. 'Source' gives data source: 'EPA' - averaged water chemistry data provided by EPA for the period 2009-2015 were used where available; '2005' - data collected by Roden in September 2005; '2019' - samples collected by the authors (PM) in January and February 2019 and analysed at a commercial laboratory. 'n/a' - no data were available, 'n/e' - data were not examined. For further information on all fields, see Chapters 2 and 3. '**Bedrock type**' - bedrock underlying lake: B -metamorphic basic rock, D- Dalradian rock types, G - granite, OR - Old Red Sandstone , S - shale.

Lake name	Source	Bedrock type	Alkalinity (mg/l)	Calcium (mg/l)	Chloride (mg/l)	Chlorophyll *a* (μg/l)	Colour (Hazen Units)	Conduct-ivity (μS/cm)	Magnesium (mg/l)	pH (pH units)	Potassium (mg/l)	Silica (mg/l)	Sulphate (mg/l)	TON (mg/l)	TP (mg/l)
Acoose	EPA	OR	6.1	1.5	11.6	7.53	29.6	50.6	1.2	6.71	0.27	-	2.99	0.151	0.009
Akibbon	EPA	D	37.8	13.0	25.4	3.60	56.1	134.9	2.7	7.25	1.33	1.28	4.26	0.086	0.012
An Chaolaigh	2019	G	15.3	5.0	43.9	2.14	95.5	196.0	-	6.90	-	-	-	-	0.008
Anscaul	2019	OR	9.0	3.5	13.7	2.14	49.6	52.2	-	6.70	-	-	-	-	0.012
Anure	EPA	G	13.3	4.4	23.0	4.62	72.5	101.8	1.8	7.18	0.67	-	4.14	0.115	0.008
Aughrusbeg	EPA	G	49.1	20.8	-	6.58	26.6	383.0	-	7.83	2.22	-	-	0.157	0.015
Ballynakill Connemara	EPA, 2005	D	19.6	7.7	32.8	6.93	33.2	150.9	2.6	7.16	1.04	-	5.26	0.180	0.012
Ballynakill Gort	2019	S	54.5	22.0	18.9	1.00	117.0	181.0		7.60	-	-	-	-	0.044
Bofin	EPA	D	42.4	2.6	17.8	4.19	63.9	137.4	1.1	7.31	0.36	0.97	2.51	0.184	0.012
Caragh	EPA	OR	6.9	2.2	13.8	2.97	35.1	59.7	1.3	6.58	0.35	-	3.96	0.176	0.010
Carrigeencorr	2019	S	44.5	8.5	7.1	3.34	39.3	136.0	-	7.83	-	-	-	0.290	0.019
Chluain Toipin	2019	D	9.0	2.9	12.0	1.07	58.7	55.2	-	6.70	-	-	-	-	0.005
Cloonmackan	n/a		-	-	-	-	-	-	-	-	-	-	-	-	-
Courhoor	n/a		-	-	-	-	-	-	-	-	-	-	-	-	-
Derg	EPA	S	7.3	2.0	17.2	4.69	65.6	53.0	1.0	6.59	0.55		3.73	0.064	0.012
Derryierin	n/a		-	-	-	-	-	-	-	-	-	-	-	-	-
Eske	EPA	D	17.1	4.7	29.5	3.12	41.9	77.5	1.4	7.19	0.60	-	2.00	0.082	0.009

Lake name	Source	Bedrock type	Alkalinity (mg/l)	Calcium (mg/l)	Chloride (mg/l)	Chlorophyll *a* (µg/l)	Colour (Hazen Units)	Conduct -ivity (µS/cm)	Magnesium (mg/l)	pH (pH units)	Potassium (mg/l)	Silica (mg/l)	Sulphate (mg/l)	TON (mg/l)	TP (mg/l)
Fern	EPA	D	30.5	10.8	20.1	6.96	76.5	125.6	2.1	7.30	1.05	-	5.31	0.189	0.027
Foorglass	2019, 2005	B	20.9	5.4	47.0	1.99	113.8	189.5	-	7.25	-	-	-	-	0.022
Illauntrasna	EPA	G	11.5	5.4	41.0	4.76	44.5	166.1	2.7	7.20	0.87	-	7.22	0.183	0.010
Kiltooris	EPA	D	28.9	11.8	-	3.65	48.1	233.4	4.2	7.43	1.94	-	7.44	0.141	0.009
Kindrum	EPA	D	73.0	24.7	14.0	6.53	28.4	281.3	6.6	7.93	2.64	-	10.28	0.121	0.009
Knocka	2019	S	19.9	10.0	22.0	2.67	83.4	143.0	-	7.20	-	-	-	-	0.016
Leane	EPA	S	22.6	8.6	16.0	4.24	40.1	90.4	1.9	7.35	0.74	-	3.57	0.311	0.010
Long Range	EPA	OR	5.4	1.7	11.7	2.09	29.9	49.0	1.0	6.44	0.25	-	3.68	0.131	0.008
Loughauneala	n/a		-	-	-	-	-	-	-	-	-	-	-	-	-
Mask	n/e														
Maumeen	2019, 2005	B	16.4	4.7	43.2	7.75	38.0	186.5	3.2	7.18	-	-	-	0.000	0.014
Melvin	n/e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Moher	EPA	S	17.6	6.8	20.8	3.95	50.9	121.2	2.1	7.32	0.93		3.99	0.180	0.013
Mullaghderg	2019	G	33.7	6.5	18.2	1.79	123.0	189.5		7.37	-	-	-	0.000	0.032
na Creibhinne	2019, 2005	G	16.4	6.4	35.7	4.54	63.5	145.0	2.4	7.08	-	-	-	0.000	0.019
na gCaor	2019, 2005	G	28.8	9.3	60.4	1.57	97.0	249.5	1.7	7.45	-	-	-	-	0.020
Nageltia	2019	S	18.1	7.0	17.9	1.60	122.0	101.0		7.30	-	-	-	-	0.034
Nahaltora	2019	S	10.0	3.0	20.7	1.00	66.7	88.6		6.90	-	-	-	-	0.035
Port	2019	D	35.5	11.0	23.2	0.90	68.3	152.0		7.50	-	-	-	-	0.028
Sessiagh	EPA		52.5	17.2	-	3.8	18	245	6.1	7.84	1.95	-	10.86	0.101	0.008
Shannagh	EPA	G	33.1	-	-	9.20	76.9	203.2	-	7.54	-	-	-	0.240	0.019
Sheskinmore	2019	D	16.6	6.0	23.5	0.90	149.0	111.0	-	7.10	-	-	-	-	0.026
Upper	EPA	OR	6.1	1.7	10.2	1.87	27.7	46.3	0.9	6.49	0.23	-	2.86	0.141	0.008

Appendix III Indicator Species Analysis

Indicator Species Analysis of all relevés sampled in *Najas*-type lakes (see Section 3.3). Higher values indicate higher constancy and abundance of the species in the group. Significant indicator values are emboldened and corresponding p-values are given in the first column.

	Group Identifier number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	Number of relevés in group	114	25	22	132	98	13	7	17	10	5	21	20	6	16	3	12	3	3	4	3	5	3
***	***Littorella uniflora***	**42**	.	.	1	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	4	.	.
**	***Lobelia dortmanna***	**34**	1	.	2	.	.	.	1	.	.	.	.	.	.	.	2	.	.	.	1	.	.
**	***Eriocaulon aquaticum***	**29**	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.
	Myriophyllum alterniflorum	**13**	2	.	3	1	.	.	.	.	.	1	.	.	2	1	1	.	.	.	.	.	6
***	***Juncus bulbosus***	3	**65**	.	.	.	.	.	1	.	.	.	.	.	4	.	.	.	.	.	.	.	.
	Eleogiton fluitans	.	**14**	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.
*	***Utricularia* sp.**	.	**13**	.	1	.	.	.	.	.	25	.	.	1	.	.	.	.	.	.	.	.	.
***	***Nitella translucens***	.	1	**61**	2	2	.	.	.	.	.	1	.	.	1	.	2	1	.	.	.	.	.
***	***Isoetes lacustris***	3	2	.	**44**	3	2	.	.	.	.	1	2	.	.	2	.	.	.	.	.	.	.
*	***Najas flexilis***	.	4	1	1	**27**	.	6	.	.	.	2	.	.	2	.	.	.	.	1	.	.	.
*	***Potamogeton berchtoldii***	.	1	1	1	**24**	.	.	.	2	.	.	.	.	.	.	.	.	.	**12**	.	.	.
	Chara virgata	2	.	1	3	**17**	.	.	1	.	1	1	2	1	.	.	.	.	2	.	2	.	1
	Potamogeton perfoliatus	.	1	1	.	**11**	.	.	.	.	1	6	.	9	7	.	1	.	.	1	2	3	.
	Nitella confervacea	.	.	4	.	8	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	4	.
	Callitriche brutia subsp. *hamulata*	.	.	.	.	4	.	.	.	.	.	1	.	.	.	.	3	.	.	.	.	1	.
	Potamogeton pusillus	.	.	.	.	4	.	.	.	.	.	3	.	.	1	.	.	.	.	.	.	.	.
***	***Phragmites australis***	2	.	.	.	.	.	.	**58**	.	.	.	.	7	.	.	.	.	.	.	.	.	.
	Nymphaea alba	.	.	.	.	.	.	.	**16**	.	.	.	.	.	.	6	.	1	.	.	.	.	6
	Potamogeton natans	1	.	.	6	.	.	.	**13**	.	.	.	2	.	.	.	.	.	.	.	.	.	.
	Cladophora aegagropila	.	.	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.
*	***Nitella flexilis***	.	.	.	.	.	.	.	.	.	**69**	.	.	.	.	.	.	.	.	.	.	.	.
	Nitella opaca	.	.	.	.	.	.	.	.	.	**15**	.	.	.	1	.	.	.	.	.	.	.	.
	Eleocharis acicularis	.	.	.	.	.	.	.	.	.	**14**	2	.	.	.	.	.	.	.	.	.	.	.
***	***Elodea canadensis***	.	.	.	.	.	.	.	2	1	.	**47**	5	1	1	.	.	.	.	.	.	7	.
*	***Nitella spanioclema***	.	.	.	.	.	.	.	.	.	.	**33**	.	.	.	.	.	.	.	.	7	2	.
	Potamogeton crispus	.	.	.	.	1	.	.	.	.	.	9	.	.	5	.	.	.	.	.	.	.	.
***	***Lemna trisulca***	.	.	.	.	.	.	.	.	.	.	1	**59**	.	.	.	.	.	.	.	.	.	.
**	***Nuphar lutea***	.	1	.	.	.	.	.	.	.	2	1	**37**	.	.	.	.	.	.	.	.	.	.
	Schoenoplectus lacustris	.	9	.	5	.	.	.	1	.	.	1	**13**	1	.	.	2	.	.	.	.	.	.
***	***Chara curta***	.	.	.	.	.	.	.	.	.	.	.	.	**63**	.	.	.	.	.	.	.	.	.
**	***Potamogeton lucens***	.	.	.	.	.	.	.	.	.	.	.	.	**47**	.	.	.	.	.	.	.	.	.
	Chara globularis	.	.	.	.	1	.	.	.	.	.	.	.	9	.	.	2	.	.	.	.	.	.
***	***Chara aspera***	.	.	.	.	.	.	.	.	.	.	.	.	.	**90**	.	.	.	.	.	.	.	.
**	***Scorpidium scorpioides***	.	.	.	.	.	.	.	.	.	.	.	.	.	**35**	.	.	.	.	.	.	.	.
	Potamogeton x nitens	.	1	.	.	.	.	.	.	.	.	.	.	.	**13**	.	.	.	.	.	14	.	.
	Potamogeton pectinatus	.	.	.	.	.	.	.	.	.	.	.	.	.	**13**	.	.	.	.	.	.	.	.
	Potamogeton filiformis	.	.	.	.	.	.	.	.	.	.	.	.	.	**10**	.	.	.	.	.	.	.	.
	Myriophyllum spicatum	.	1	.	.	.	.	.	.	.	.	2	.	.	7	.	1	.	.	.	.	.	.
***	***Eleocharis palustris***	1	.	.	.	.	.	.	.	.	.	.	.	.	.	**72**	2	.	.	.	.	.	.
**	***Equisetum fluviatile***	1	.	.	2	.	.	.	.	.	.	1	.	.	.	**37**	.	4	.	.	.	.	.
	Potamogeton x angustifolius	.	.	.	.	.	.	.	.	.	.	.	1	.	.	**28**	.	.	.	.	.	.	.
	Cladium mariscus	.	.	.	.	.	.	.	1	.	.	.	.	.	.	**26**	.	.	.	.	.	.	.
	Potamogeton alpinus	.	.	.	.	.	.	.	.	.	.	9	.	.	.	**18**	.	.	.	.	.	.	.
	Sparganium angustifolium	.	1	.	.	1	.	.	.	.	.	3	.	3	.	**13**	.	.	.	.	.	.	.
***	***Isoetes echinospora***	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**75**	.	.	.	.	.	.
**	***Subularia aquatica***	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**31**	.	.	.	.	.	.
	Baldellia ranunculoides subsp. *repens*	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	.	.

	Group Identifier number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	Number of relevés in group	114	25	22	132	98	13	7	17	10	5	21	20	6	16	3	12	3	3	4	3	5	3
	Hydrilla verticillata	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	**69**	.	.	.
***	***Callitriche hermaphroditica***	.	.	.	.	1	.	.	.	.	2	.	.	.	.	.	.	.	.	**46**	.	5	.
**	***Potamogeton gramineus***	.	1	.	.	.	.	.	3	.	.	.	.	1	5	.	.	.	.	.	**59**	.	.
***	***Alisma plantago-aquatica***	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	1	.	.	.	**41**	.	.
	Persicaria amphibia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**33**	.	.
*	***Carex rostrata***	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	**16**	.	.
	Potamogeton praelongus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**94**	.
***	***Sparganium emersum***	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**87**
***	***Elatine hexandra***	3	.	.	2	.	.	.	.	.	2	.	.	.	.	.	.	.	2	.	.	.	**41**
***	***Potamogeton obtusifolius***	.	.	.	.	3	.	.	.	.	.	7	.	.	.	1	.	.	.	.	.	.	**29**
*	***Apium inundatum***	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**17**	.	.	.	.	.	**23**
	Fontinalis antipyretica	.	.	6	3	1	.	.	1	.	.	5	.	.	2	.	.	.	.	.	1	.	.
	Baldellia ranunculoides subsp. *ranunculoides*	1	1	.	.	.	.	.	1	.	.	.	.	.	5	.	3	.	.	.	.	.	.
	Oenanthe fluviatilis	.	.	.	.	.	.	.	.	.	.	.	9	.	.	.	.	.	.	.	.	.	.
	Lemna minor	.	.	.	.	.	.	.	1	.	.	4	.	.	.	.	.	.	.	.	.	.	.
	Sparganium natans	.	1	.	.	1	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Utricularia intermedia	.	2	.	2	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Sparganium sp.	2	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Utricularia minor	2	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Eleocharis multicaulis	.	2	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Chara rudis	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Pilularia globulifera	1	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Typha angustifolia	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Fissidens sp.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Octodiceras fontanum	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Ranunculus sp.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Ophrydium versatile	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Ranunculus baudotii	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Appendix IV Indicator Species Analysis for relevés containing *Najas flexilis*

Indicator Species Analysis of relevés in which *Najas flexilis* occurred (see Section 3.3.5). Higher values indicate higher constancy and abundance of the species in the group. Significant indicator values are emboldened and corresponding p-values are given in the first column.

	Group identifier number	1	3	2	9	5	7	10	6	4	12	8
	Number of relevés in group	40	21	12	9	8	6	5	4	3	3	2
**	*Najas flexilis*	**29**	**13**	**12**	2	7	4	2	9	**17**	2	2
	Potamogeton perfoliatus	**20**	4	**13**	.	.	.	**12**	3	.	3	.
	Nitella confervacea	**13**	.	1	.	1	2	.	.	**12**	1	.
***	*Isoetes lacustris*	2	**58**	7	.	.	6	.	2	.	.	1
	Utricularia sp.	1	**30**	2	.	2	.	.	.	.	.	3
	Utricularia intermedia	.	**14**	.	.	.	1	.	.	.	.	8
	Schoenoplectus lacustris	.	**10**	.	.	**12**	1	.	3	.	.	.
	Eleogiton fluitans	.	**10**	.	.	.	.	.	.	.	.	.
***	*Potamogeton berchtoldii*	3	6	**59**	.	2	1	2	6	.	1	2
	Sparganium angustifolium	1	.	**15**	.	.	.	.	.	2	.	4
	Eleocharis multicaulis	.	.	.	**11**	.	.	.	.	.	.	.
**	*Nitella translucens*	2	**12**	8	.	**38**	5	2	2	.	.	3
	Fontinalis antipyretica	.	5	6	.	**25**	.	.	1	.	.	.
	Equisetum fluviatile	.	.	.	.	**23**	6	.	.	.	.	.
	Alisma plantago-aquatica	.	.	.	.	**23**	.	.	.	.	.	.
	Potamogeton obtusifolius	.	4	6	.	**13**	.	.	.	.	.	.
	Carex rostrata	.	.	.	.	**13**	.	.	.	.	.	.
	Eleocharis palustris	.	.	.	.	**13**	.	.	.	.	.	.
**	*Eriocaulon aquaticum*	.	.	1	.	.	**47**	.	.	.	.	.
*	*Juncus bulbosus*	2	2	.	.	.	**46**	6	.	.	.	**19**
*	*Lobelia dortmanna*	.	.	.	.	.	**46**	5	.	.	1	.
	Apium inundatum	.	1	1	.	.	**38**	.	.	.	.	.
*	*Pilularia globulifera*	.	.	.	.	.	**33**	.	.	.	.	.
	Littorella uniflora	.	.	.	.	.	**31**	.	.	.	**23**	.
	Elatine hexandra	.	3	**14**	.	.	**25**	1	.	.	2	.
	Isoetes echinospora	.	1	.	.	4	**27**	.	.	.	.	.
	Potamogeton natans	.	.	.	.	4	**22**	.	.	.	.	.
	Ophrydium versatile	.	.	.	.	.	**17**	.	.	.	.	.
	Baldellia ranunculoides subsp. *repens*	.	.	.	.	.	**17**	.	.	.	.	.
	Cladium mariscus	.	.	.	.	.	**16**	.	.	.	.	.
	Potamogeton praelongus	.	.	.	1	1	**14**	.	.	.	.	.
	Utricularia minor	.	.	.	.	.	**14**	.	.	.	.	.
***	*Chara aspera*	1	.	.	.	.	.	**92**	.	.	.	.
	Scorpidium scorpioides	.	.	.	.	.	.	**37**	.	.	.	.
	Potamogeton gramineus	.	.	7	.	.	.	**21**	.	.	3	.
	Potamogeton x nitens	.	.	.	.	.	.	**17**	.	.	.	.
***	*Hydrilla verticillata*	1	.	.	.	.	.	.	**91**	.	.	.
	Potamogeton lucens	.	.	.	.	.	.	.	**24**	.	.	.
***	*Potamogeton pusillus*	1	.	.	.	.	.	.	.	**94**	.	.
***	*Nymphaea alba*	.	.	.	.	.	.	.	.	**67**	.	.
**	*Callitriche hermaphroditica*	7	.	1	.	.	.	.	2	**65**	.	.
	Chara virgata	1	.	9	.	4	5	.	.	**61**	.	.
**	*Nitella flexilis*	.	.	.	.	.	.	.	**17**	**61**	1	.
	Potamogeton alpinus	1	.	.	.	9	.	.	.	**16**	.	.
	Chara curta	.	.	.	.	.	.	.	.	.	**33**	.
	Baldellia ranunculoides subsp. *ranunculoides*	.	.	.	.	.	1	**14**	.	.	**16**	.
*	*Myriophyllum alterniflorum*	.	4	2	.	.	.	**11**	.	.	**46**	1
***	*Nitella spanioclema*	.	.	.	.	.	.	.	.	.	.	.

	Group identifier number	1	3	2	9	5	7	10	6	4	12	8
	Number of relevés in group	40	21	12	9	8	6	5	4	3	3	2
**	*Elodea canadensis*	1	1	.	.	4	2	3	.	.	2	.
	Sparganium emersum	2	.	.	.	.	.	.	.	.	.	.
	Callitriche brutia subsp. *hamulata*	.	5	.	.	.	7	.	.	.	.	.
	Nuphar lutea	.	5	.	5	.	.	.	6	.	.	.
	Potamogeton crispus	6	.	.	5	.	.	.	.	.	.	.
	Myriophyllum spicatum	.	1	.	.	5	8	.	.	.	.	.
	Potamogeton x angustifolius	1	2	.	.	3	.	.	.	.	.	.
	Phragmites australis	.	4	.	.	1	.	.	.	.	.	.
	Sparganium sp.	.	.	8	.	.	.	.	.	.	.	.
	Chara globularis	8	.	.	.	.	.	.	.	.	.	.
	Nitella opaca	3	.	.	.	.	.	.	.	.	.	.
	Potamogeton filiformis	3	.	.	.	.	.	.	.	.	.	.
	Chara rudis	3	.	.	.	.	.	.	.	.	.	.