Habitats Directive Annex I Lake Habitats

A working interpretation for the purposes of site-specific conservation objectives and Article 17 reporting

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Cover photos: From top: Upper Lake, Killarney, Lough Bunny, Co. Clare, *Chara* and *Nuphar lutea* in Lough Bunny, *Sparganium ?emersum* at Sheskinmore Lough. © Áine O Connor.

Contents

Executive summary

The purpose of this report is to provide

1. working definitions of the five Habitats Directive Annex I lake habitats in Ireland
2. further information on the national conservation status assessment of these habitats for Article 17 2013 and
3. supporting information for site-specific conservation objectives.

Five annexed lake habitats occur in Ireland

1. Oligotrophic isoetid lake habitat (3110)
2. Mixed *Najas flexilis* lake habitat (3130)
3. Hard-water lake habitat (3140)
4. Rich pondweed lake habitat (3150)
5. Acid oligotrophic lake habitat (3160)

The EU interpretations of these habitats are vague and have caused confusion across Member States. The working definitions presented here recognise significant overlap among habitats and the likely co-occurrence of two or more habitats in many lakes. All five habitats are currently in unfavourable conservation status, and Ireland is considered to have particular responsibility for the conservation of the hard-water lake habitat (3140).

The information provided will form the basis for future Article 11 surveillance and Article 17 reports. Required studies are also identified and prioritised.

Acknowldgements

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1. Introduction

Habitats Directive Annex I freshwater habitats are not as readily recognisable or distinct from one another as many of the Annex I terrestrial habitats. The descriptions of these habitats provided in the EU interpretation manual (CEC, 2013) is somewhat general and requires further refinement for individual member states. The purpose of this document is to provide a more refined and detailed working interpretation of the five Annex I lake habitats found in Ireland. The document is intended to provide supporting information for site-specific conservation objectives for these habitats, as well as the conservation assessments of these habitats for the 2013 and future Habitats Directive Article 17 report (NPWS, 2013 a and b).

The document is divided into six sections, as follows

1. This short introduction
2. A detailed section providing further interpretation and description of the five Irish Annex I lake habitats
3. Notes on the approach to assessing the habitats' conservation status for the 2013 Habitats Directive Article 17 report. These summarise and contain some additional material, particularly on mapping, to that provided in the Article 17 forms and backing documents (NPWS, 2013b)
4. Explanatory text to support the site-specific conservation objectives
5. A section recommending further survey and study required to test the working interpretation presented, as well as to support the conservation of the habitats
6. A bibliography.

One appendix is also provided.

2. Habitats Directive Annex I Lake Habitats in Ireland

2.1 The Habitats Directive

Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, or the Habitats Directive, lists natural habitats on the first Annex for which Member States must establish Special Areas of Conservation (SACs). Habitats are listed on Annex I because they are in decline, have a restricted range or are outstanding examples of the typical characteristics of biogeographical regions found within the EU. The Natural Habitats are divided into nine broad habitat groups. The third group is freshwater habitats and is further divided into standing and running waters. Six of ten standing freshwater habitats are considered to occur in Ireland.

The purpose of the designation of SACs is to enable the habitats and species to be maintained or, where appropriate, restored at a favourable conservation status in their natural range. This is to be achieved through the provisions of Article 6 of the Directive, which can broadly be divided into the implementation of conservation measures and the prevention of damage. Damage or deterioration should be prevented by taking the necessary steps, where such damage can reasonably be foreseen (Article 6(2)), and through the Appropriate Assessment process (Article 6(3)).

2.2 What are the Annex I Lake Habitats found in Ireland?

Five Annex I lake habitats occur in Ireland, namely:

1. 3110 Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*)
2. 3130 Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*
3. 3140 Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.
4. 3150 Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* — type vegetation
5. 3160 Natural dystrophic lakes and ponds

In addition, the priority habitat 3180 * Turloughs is a sixth Irish standing freshwater Annex I habitat. These simple statements, however, belie the significant difficulties involved in interpreting what is meant by each of the lake habitats. They also mask the large gaps in data on Irish lakes that make the development of a full Irish lake habitat classification system impossible at this time. As the first step in producing a site-specific conservation objective and an Article 17 assessment for a habitat or species is mapping its distribution, pragmatic solutions must be found to interpreting what the habitats are and how to overcome the lack of data on where they are found.

The interpretation manual of EU habitats relies heavily on vegetation communities and associated characteristic or differential species to describe the habitats on Annex I to the Directive (CEC, 2013). This is unsurprising for an Annex that deals primarily with terrestrial habitats where the biomass is dominated by higher plants. The interpretation manual also uses vegetation communities, combined with some geomorphological descriptions, to interpret the lake habitats. Despite the significant challenges presented by this approach, as elucidated on further below, three of the five Annex I lake habitats listed for Ireland can quite readily be interpreted in the Irish context. Two of the habitats (3110 and 3130) are very similar, however, being based on the same phytosociological order (*Littorelletalia uniflorae*) and having five named plant species in common and are, consequently, very difficult to distinguish. Examination of descriptions of the ecology of the listed plant species, the CORINE biotope classes and the Order *Littorelletalia uniflorae* demonstrates that, botanically, these two habitats refer to marginal lake communities (CEC, 1991, Preston and Croft, 1997, White and Doyle, 1982) (see Appendix I for notes taken from these texts). The distinction between the two appears to be that the description of 3110 represents more permanently flooded, shallow, sheltered lake margins with fine sediment, while the description of 3130 refers to more amphibious communities that tolerate and sometimes require (22.12 x 22.32) emersion, i.e. further upslope than 3110. If this is the case, it is likely that the two represent stages or zones along one or more types of lake shoreline vegetation gradients, commonly found in Ireland, rather than distinct vegetation communities.

2.3 The classification of lake habitats – questions of scale?

The observation that at least two of the Annex II lake habitats refer to marginal/amphibious and not truly aquatic communities, introduces the need for a more general discussion on how to use rooted macrophytes to describe or classify lakes. Traditional concepts of vegetation communities and habitats do not necessarily transfer easily to aquatic systems. Terrestrial habitats and communities can typically be distinguished visually, using a combination of structural features and species composition. To most eyes, a lake is represented by a planar surface of water. Terrestrial habitats and communities are complex entities, generally containing multiple species, often reaching high species diversity and infrequently dominated, in terms of cover, by a single species. Submerged lake vegetation is typified by continuous zones, colonies or other patches of individual species. Where vegetation patches are composed of more than one species, diversity is low and the cover is often overwhelmingly dominated by a single species. In lakes, the key environmental driver of these patterns in the vegetation is light penetration. To capture the influences of other environmental drivers on lake macrophytes, a number of larger spatial scales need to be examined. To understand the influences of exposure and substratum, generally considered to be important environmental drivers, lakes will likely have to be divided into sub-units based on sheltered/exposed shorelines and steep/shallow slopes. To understand the importance of catchment geology and water chemistry, species composition will have to be examined at the whole-lake scale or, for large mixed-geology lakes, at a lake-basin scale. Conceptually, therefore, a lake sub-unit delineated based on some combination of exposure, slope and geology is probably most closely allied to a terrestrial vegetation community. This lake vegetation community concept would typically, therefore, be of a far larger spatial scale than its terrestrial equivalent.

A number of concerns can be raised in relation to the use of marginal/amphibious communities to describe lakes. Firstly, these are determined by very local environmental conditions, such as slope, exposure, sediment/soil and small-scale hydrological variation and, importantly, are influenced by the fringing terrestrial communities. Management of the lake shore and surrounding land is also an important factor. Submerged communities, by contrast, are determined by geomorphological and geochemical factors at lake-scale and catchment scale. Also, it is the submerged macrophytes that include species that are characteristic of or restricted to lakes and ponds. They also often harbour rare species (such as *Najas flexilis*, and many charophyte species). Marginal communities are not necessarily restricted to lake-margins, being also found on river edges, in temporary pools and puddles, in wet grassland, along damp tracks and almost anywhere there is surface ponding. At least some of these marginal communities also require a degree of disturbance, brought about by water level fluctuations, the activities of livestock or movement of machinery. Water level changes likely provide the necessary disturbance around lakes, however, lake level fluctuations are almost ubiquitous in Ireland owing to the highly seasonal rainfall patterns. Studies of the vegetation of standing waters have shown that the use of marginal and emergent species in combination introduces noise into multivariate analyses that tends to obscure the separation of distinct classes or types (Palmer *et al*., 1992, Duigan *et al*., 2007).

If the appropriate scale for describing Irish lake vegetation communities is a lake sub-unit based on some combination of exposure, slope and geology, it follows that any one lake could, and perhaps should, contain more than one lake community. It may be possible to sum these vegetation types into lake types, however, the usefulness of such an approach is questionable given the inherent complexity and variation in Irish lakes.

The five Irish Annex I habitats, as described in the interpretation manual of EU habitats (CEC, 2013), appear to refer to a variety of spatial scales, hence habitats 3140 and 3160 could be interpreted as more representative of a whole-lake scale (or lake types), while habitat 3150 may be most closely aligned with the above described concept of a lake vegetation community, and the apparently indistinguishable habitats (3110, 3130) seem to describe what are, conceptually at least, fringing 'terrestrial' communities.

2.4 The Working Interpretation of the Five Lake Habitats

The premise used in this document has been to re-interpret the five habitats for Ireland and to align them to the above concept of a lake vegetation community (i.e. a scale appropriate to the key environmental drivers of exposure, slope and geology (geology being taken to cover natural variations in water and sediment chemistry)). The interpretations were largely based on work by Hester Heuff and Jim Ryan (Heuff, 1984 and personal communications), Cilian Roden (Roden, 1999, 2000, 2002, 2003, 2004, 2007, Roden and Murphy, 2013, 2014, in prep. and personal communications) and the Irish EPA (Free, *et al*. 2006, 2009). The five lake habitats are here defined as:

- **3110 Oligotrophic isoetid lake habitat.** A habitat dominated by isoetids. Characteristic species include *Isoetes lacustris, Isoetes echinospora, Littorella uniflora, Lobelia dortmanna* and *Deschampsia setacea*. The habitat frequently occurs on sheltered, gently sloping shorelines. It is generally associated with peatland areas and base-poor water (pH often <6.5).
- **3130 Mixed *Najas flexilis* lake habitat.** Typified by habitats with *Najas flexilis*, this is a more species rich habitat than 3110. It also contains *Isoetes lacustris, Isoetes echinospora,* and *Littorella uniflora*, but combined with some broad-leaved pondweeds such as *Potamogeton perfoliatus*. While frequently associated with peatland, this habitat type is found in catchments with more mixed geology, including at least some base-rich influence and pH closer to neutral (pH 7).
- **3140 Hard-water lake habitat.** A habitat dominated by lower plants, notably cyanobacteria ('krustenstein') and diverse, abundant *Chara* species. Higher plants are limited in extent. The habitat is found on karstified limestone, other limestone and calcareous coastal sands and is typified by a marl substratum.
- **3150 Rich pondweed lake habitat.** A pondweed (*Potamogeton* spp.) dominated lake habitat, with circum-neutral pH or higher found in low-lying, large, naturally more productive catchments. This habitat type is typified by a high diversity of higher plant species.
- **3160 Acid oligotrophic lake habitat.** A species poor habitat, at its most typical dominated by aquatic *Sphagnum* spp., at its margins intergrading with blanket bog.

More detailed information on these interpretations is given in the following sections (2.6 to 2.10).

It is worth noting that in Ireland, similar lake communities can occur in more than one environmental scenario, so hard-water lakes that are dominated by charophytes and certainly fit the description for habitat 3140 are found on coastal calcareous sands. These lakes, while similar to the more typical hard-water lakes on karst limestone, also show some consistent biological variations (Roden, in prep). Conversely, seemingly similar lakes, in terms of substratum types, depth, exposure and surrounding habitats, can have significantly different water and/or sediment chemistries and, hence, different biological communities. An example here is lakes containing *Najas flexilis* that frequently have higher species richness than the more typical, species-poor oligotrophic lakes in predominately peatland catchments.

2.5 The overlap among the Irish standing freshwater habitat types

As noted above, it is accepted that more than one Annex I lake habitat can occur in a single lake, owing to the complex Irish geology. Loughs Mask and Corrib are the prime examples, having both oligotrophic isoetid/mixed *Najas flexilis* basins and bays (3110/3130) and classic hard-water lake habitat (3140). It is likely that a large number of lakes containing habitat 3130 also have patches of habitat 3110. A schema was devised for such co-occurrences (Figure 1). It can be seen that hard-water lake habitats have the greatest potential for overlap, co-occurring at some sites with the turlough habitat and in some lakes with habitat 3130 (e.g. Loughs Corrib and Mask) and in larger, lowland catchments with the rich pondweed lake habitat (3150) (e.g. the Shannon system). In this schema it is assumed that the hard-water lake habitat does not co-occur with the more oligotrophic, base-poor 3110 habitat, but that mixed geology leads to more mixed water chemistry supporting a more diverse 3130-type habitat. Exceptions to this rule are thought likely to occur in poorly mixed, shallow bays such as are found along the western shorelines of Loughs Mask and Corrib. In smaller, well-mixed lakes however, it would seem unlikely that the oligotrophic isoetid lake habitat (3110) will co-occur with 3140.

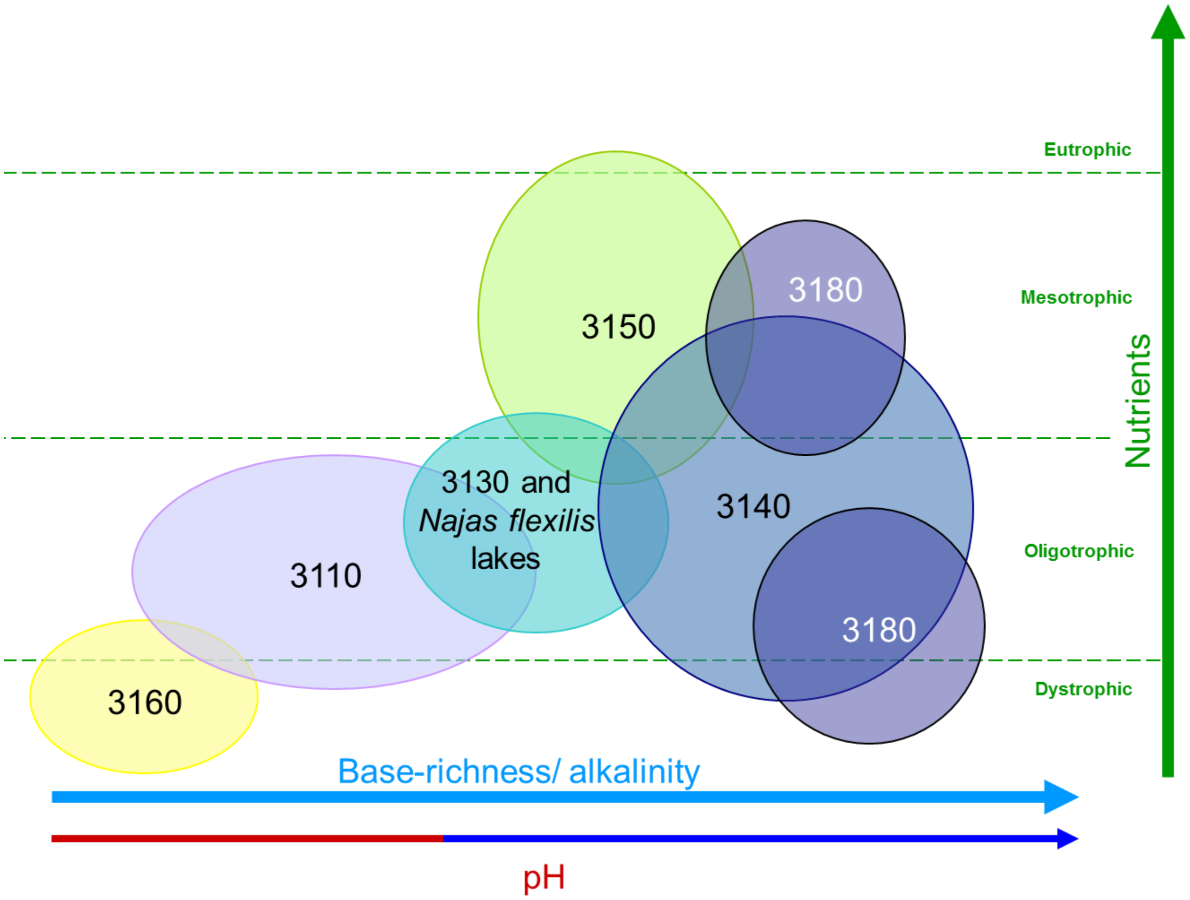


Figure 1 **Theoretical separation of Annex I lake habitats along dominant environmental gradients.** 3180 is the priority habitat turloughs. Turloughs could be considered to form a biological and morphological continuum along a number of environmental gradients, including those shown. For the purpose of this schematic, two turlough types are shown: highly calcareous oligo- to ultraoligo-trophic turloughs, which can have areas of deep permanent water containing habitat 3140, and mesotrophic, less base-rich turloughs with areas of permanent water dominated by broad-leaved pondweeds (habitat 3150).

2.6 3110 Oligotrophic isoetid lake habitat

Habitat 3110, the oligotrophic isoetid lake habitat (in the Directive entitled 'Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*)' typically occurs in soft-water, nutrient poor lakes frequently associated with acid bedrock catchments (notably granite and old red sandstone) overlain by peatland. The habitat is best developed on more gently sloping lake beds, over variable substrata, and along sheltered shorelines. It is dominated by species with an isoetid growth form, namely *Isoetes lacustris, Isoetes echinospora, Littorella uniflora, Lobelia dortmanna* and *Eriocaulon aquaticum*. *Juncus bulbosus*, *Myriophyllum alterniflorum*, *Potamogeton polygonifolius* and *Sparganium angustifolium* also frequently occur, as does *Deschampsia setacea* in Connemara. Ireland is a stronghold for the habitat, given the large number of lakes in which it occurs and its widespread distribution (Free *et al*., 2009). Even in Ireland, however, the oligotrophic isoetid lake habitat is under significant pressure from eutrophication, peatland drainage and, to a lesser extent, acidification.

The full list of typical species for the habitat was based on the interpretation manual of EU habitats (CEC, 2013), available publications on lake macrophyte communities in Ireland (Visser and Zoer, 1972, 1976, Heuff, 1984, Free *et al*., 2006, 2009) and Great Britain (Palmer 1989, 1992, Palmer *et al*., 1992, Duigan *et al*., 2006), as well as publications on aquatic macrophyte species (Preston, 1995, Preston and Croft, 2001) and EPA macrophyte raw data from routine Water Framework Directive monitoring (2001-2012). The list of typical species is: *Isoetes lacustris, Isoetes echinospora, Littorella uniflora, Lobelia dortmanna, Eriocaulon aquaticum, Juncus bulbosus, Potamogeton polygonifolius, Sparganium angustifolium, Deschampsia setacea* (in Connemara)*, Subularia aquatica, Pilularia globulifera, Nitella translucens, Nitella opaca, Nitella confervacea, Myriophyllum alterniflorum, Nymphaea alba, Nuphar lutea, Potamogeton natans, Utricularia intermedia, Utricularia minor, Eleogiton fluitans*. Notes on the ecology of some of these species can be found in Appendix I.

2.7 3130 Mixed *Najas flexilis* lake habitat

Habitat 3130, the mixed *Najas flexilis* lake habitat, is entitled 'Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*' in the Habitats Directive. As noted in Section 2.2 and explained in greater detail in Appendix I, habitat 3130 in Ireland, as defined in CEC (2013), is essentially indistinguishable from habitat 3110. An attempt has been made, therefore to re-interpret habitat 3130 in a biologically meaningful manner. Given the name includes the terms 'oligotrophic to mesotrophic', habitat 3130 was considered best placed to cover lake habitats of circum-neutral, low-nutrient waters found in catchments of mixed geology. Peatland is often widespread in the catchments of these lakes, with base-rich influences coming from basalt, limestone, marble, sedimentary deposits or calcareous coastal sand. The Annex II macrophyte *Najas flexilis* is a character species of this habitat. The co-occurrence of *Potamogeton perfoliatus* and *Isoetes lacustris* is also characteristic. The associated rare species and relatively greater species richness, means habitat 3130 is of high conservation value. Ireland is a stronghold for *Najas flexilis* and the habitat, where it is widespread particularly along the western fringe (NPWS, 2013b,c, Roden and Murphy, 2014). The habitat is under significant pressure from eutrophication, peatland drainage and, to a lesser extent, acidification. It is likely that habitat 3110 co-occurs with 3130 in many lakes.

Information on the species associated with *Najas flexilis* was used to develop the typical species list. Roden (2004) noted the frequent co-occurrence of *Potamogeton perfoliatus* and *Isoetes lacustris* in *Najas flexilis* lakes. Roden (2004) described two groups of associated species; the first group included *Callitriche hermaphroditica*, several *Chara* species and broad-leaved pondweeds (*Potamogeton* spp.). A similar list of associated species was noted by Preston and Croft (2001). The second group of associated species identified included *Elatine hexandra* and *Nitella translucens* (Roden, 2004). Roden (2004) noted that other local or rare species were encountered in the *Elatine* *hexandra* and *Nitella translucens* group, including *Pilularia globulifera*, *Isoetes echinospora* and *Potamogeton obtusifolius*. Another rare macrophyte associated with *Najas flexilis* lakes is *Hydrilla verticillata*. Roden (2007) noted that *Eriocaulon aquaticum* also frequently occurs in *Najas* lakes.

The final list of typical species for the mixed *Najas flexilis* lake habitat 3130, based on Roden (2002, 2004, 2007), cross-checked with Heuff (1984), Palmer (1989, 1992), Palmer *et al*. (1992), Preston and Croft (2001) and Duigan *et al*. 2006, 2007), was: *Apium inundatum, Callitriche hermaphroditica, Chara aspera, Chara virgata, Elatine hexandra, Eriocaulon aquaticum, Fontinalis antipyretica, Hydrilla verticillata, Isoetes echinospora, Isoetes lacustris, Juncus bulbosus, Littorella uniflora, Lobelia dortmanna, Myriophyllum alterniflorum, Najas flexilis, Nitella confervacea, Nitella flexilis, Nitella translucens, Pilularia globulifera, Potamogeton berchtoldii, Potamogeton gramineus, Potamogeton natans, Potamogeton obtusifolius, Potamogeton perfoliatus*, *Sparganium angustifolium, Utricularia* sp.

Other *Potamogeton* species can also occur, and the habitat may be linked with another rare macrophyte, *Luronium natans* (see Appendix I for a note on the status of *Luronium natans* in Ireland). For further information on *Najas flexilis* see *Najas flexilis* Article 17 Backing Document (O Connor, 2013).

2.8 3140 Hard-water lake habitat

Habitat 3140, 'Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.', is strongly associated with lowland lakes over limestone bedrock, particularly Dinantian pure bedded limestone. The habitat is also found on calcareous sand at the landward side of machair plains, along the north-western and western coast. The hard-water lake habitat is dominated by algae, particularly *Chara* species, but is also of international conservation importance for its krustenstein, a cyanobacterial crust that is found on bedrock, stones and cobbles in shallow waters to 2 m depth (Roden and Murphy, 2013). The crust is species rich, but the cyanobacterium *Schizothrix fasiculata* dominates in terms of abundance. A variant of the crust can also form on hard submerged peat and occasionally on loose pebbles forming rounded 'oncoliths'. A very rare water beetle, *Ochthebius nilssoni* is associated with the krustenstein in a number of Irish hard-water lakes. Charophyte diversity is high in Irish 3140 lakes, and includes a number of rare and threatened species (Stewart and Church, 1992). A characteristic depth-related vegetation zonation has been described from Irish hard-water lakes, with up to six distinct zones (see Table 1) (Roden and Murphy, 2013, in prep.). This type of vegetation is uncommon in the EU and some of the best European examples occur in Ireland. As a result, Ireland has a special responsibility with respect to habitat 3140.

Where the characteristic zones occur (Table 1), higher plants are generally restricted to the *Chara rudis* zone and sheltered shorelines. Roden and Murphy (in prep.) noted that 3140 lakes with euphotic depth of greater than 8 m do not show the typical zonation, having *Chara contraria* dominating at mid and deep water, where *Chara rudis* and *Chara globularis/virgata* normally occur. Degraded hard-water lake habitats have abundant angiosperms, indistinct charophyte zones, loss of the characteristic deeper zones and damaged/decaying krustenstein.

Table 1 **The characteristic vegetation of the hard-water lake habitat (3140) (*after Roden and Murphy, 2014*).** The zones are listed in order of increasing water depth.

Vegetation unit	Characteristics	Core species
Krustenstein	Krustenstein with some small charophytes growing on rock and gravel	Krustenstein, *Littorella uniflora, Chara virgata* var. *annulata, Chara aspera*, *Ophrydium versatile*
Chara curta	Communities dominated by *Chara curta*. These communities often extend into areas with sparse beds of *Phragmites* or *Schoenoplectus*, and other angiosperms may occur.	*Chara curta, Chara contraria, Chara aculeolata, Phragmites australis, Potamogeton gramineus, Utricularia vulgaris*
Chara rudis	*Chara rudis* communities occur at mid depth both as monospecific beds or with a diverse array of angiosperms including *Hippuris vulgaris, Nuphar lutea, Myriophyllum verticillatum/spicatum*, large *Potamogeton* species or *Elodea canadensis*	*Chara rudis, Potamogeton* x *nitens, Potamogeton perfoliatus, Schoenoplectus lacustris*
Chara globularis	Below the *Chara rudis* unit, *Chara globularis* or *Chara virgata* (see Roden and Murphy (2013), for discussion of *globularis* vs. *virgata*) can form extensive swards which extend to 8m below the surface	*Chara globularis, Chara virgata*
Nitella flexilis/Chara denudata	The deepest macrophyte vegetation units consist of ecorticate charophyceae, either *Nitella flexilis* or *Chara denudata*; these communities extend to 9m depth.	*Chara denudata* or *Nitella flexilis*
Oscillatoria	Mats of purple red *Oscillatoria* grow below the ecorticate charophyte zone close to the base of the euphotic zone. In places the mats are extensive, covering several square metres.	*Oscillatoria*

Coastal lakes present a particular classification challenge being strongly influenced by the sea and, frequently, wind-blown sands. Where there are calcareous sands and/or limestone bedrock, a coastal hard-water lake habitat can occur and this differs from more typical hard-water lake habitat in being very shallow (less than 5 m) with cloudier water and, generally, having greater abundance of higher plants. Species such as *Ranunculus baudotii* and *Potamogeton pectinatus* may be characteristic. Furthermore coastal hard-water lakes, such as Aillebrack or Fahy, appear to be naturally more nutrient rich than hard-water lakes over limestone bedrock (Roden and Murphy, in prep.). It is likely that coastal hard-water lake habitats inter-grade with or are related to habitats 3150 and also 3130 and more survey work is needed to characterise and classify coastal lakes properly.

The list of typical species of the hard-water lake habitat in Ireland was based on the 2011 and 2012 work of Cilian Roden and Paul Murphy on behalf of NPWS and is dominated by algae (Roden and Murphy, 2013, in prep). The core species of the characteristic zones were used as the typical species (Roden and Murphy, 2013): Krustenstein, *Ophrydium versatile, Oscillatoria, Chara aculeolata, Chara aspera, Chara contraria, Chara curta, Chara denudata, Chara globularis, Chara rudis, Chara virgata* var. *annulata, Chara virgata, Nitella flexilis, Littorella uniflora, Phragmites australis, Potamogeton gramineus, Potamogeton* x *nitens, Potamogeton perfoliatus, Schoenoplectus lacustris, Utricularia vulgaris,* and the water beetle, *Ochthebius nilssoni.*

Ochthebius nilssoni is a vulnerable water beetle recently recorded in Ireland and otherwise known only from a single lake in northern Sweden (O'Callaghan *et al*., 2009, Foster *et al*., 2009). In Ireland the species is distinctly associated with krustenstein in the hard-water lake habitat. The species is now known from at least five hard-water lakes in counties Clare, Galway and Mayo.

In addition, a characteristic water beetle fauna of vegetation rafts in hard-water lakes has been described (Nelson *et al*., in prep.). While this assemblage is not strictly associated with the krustenstein or charophyte flora, it is worthy of note and the characteristic species are: *Agabus unguicularis, Hydroporus angustatus, Hydroporus memnonius, Hydroporus planus, Hydroporus striola, Hydroporus tessellatus, Hydroporus umbrosus, Ilybius ater, Ilybius guttiger, Ilybius quadriguttatus, Cercyon convexiusculus, Coelostoma orbiculare, Anacaena limbata, Anacaena lutescens, Hydrobius fuscipes, Enochrus coarctatus,* and *Enochrus testaceus.*

The high alkalinity and calcium and magnesium concentrations of the hard-water lake habitat are the result of the significant groundwater contribution to these lakes. The catchments of many hard-water lakes are dominated by groundwater pathways, rather than surface run-off and rivers. This distinguishes the hard-water lake habitat from other lake habitats, but is a common feature with the priority habitat turloughs (3180) and, indeed, habitats 3140 and 3180 co-occur at a number of sites.

Habitat 3140 is under significant pressure from eutrophication, the primary sources of pollutants being agriculture and municipal and industrial wastewaters. Pollutant pathways through groundwater are a significant concern, in particular the high phosphate concentration recorded in karst aquifers (Craig *et al*., 2010).

2.9 3150 Rich pondweed lake habitat

The rich pondweed lake habitat 3150 (in the Directive entitled ‘Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* — type vegetation’), occurs in lowland, base-rich lakes in the midlands and north east of Ireland. Here it is characterised by high abundance and diversity of pondweeds (*Potamogeton* spp.), such as *Potamogeton lucens*, *Potamogeton praelongus*, *Potamogeton perfoliatus*, *Potamogeton obtusifolius*, *Potamogeton berchtoldii* and *Potamogeton pectinatus*. Other rooted, predominantly-submerged higher plants frequently co-occur, including, *Myriophyllum spicatum*, *Hippuris vulgaris*, *Callitriche* spp., *Sagittaria sagittifolia* and *Ceratophyllum demersum*, while free-floating species such *Lemna trisulca* are also common. The habitat is generally associated with large lakes in large catchments, such as those of the Shannon system, and with small, but naturally more productive lakes, such as those found in parts of the drumlin-belt of Cavan, Monaghan and Leitrim or the lowlands south east of the Burren. The Directive’s name for this habitat (“eutrophic”) has caused some confusion and discomfiture with freshwater ecologists specialising in water quality. Ireland does not have significant phosphorus-rich deposits, hence there are few, if any, lakes that can be characterised as naturally “eutrophic” in line with the standard OECD approach of using total phosphorus and chlorophyll *a* concentrations, and water transparency (OECD, 1982). It is possible that naturally eutrophic conditions do exist in some coastal freshwater lakes (these could perhaps be considered the ‘freshwater extreme’ of the coastal lagoon habitat), however such sites require further investigation. While further study of the habitat is required, it seems certain that the pondweed-rich variant found in Ireland requires mesotrophic waters, as defined by the OECD methods. 3150 lakes typically have well-developed reedswamp, fen and/or marsh communities around much of their shoreline. Wet woodland would have surrounded much of their shoreline in the past and has survived or re-colonised patches of many 3150 lake shores. Lakes with habitat 3150 are associated with catchments dominated by mineral soils and, hence, some of the most intensive agricultural lands in Ireland. Consequently, the habitat has been under pressure from eutrophication since the 1970s or before.

The interpretation manual of EU habitats lists plant species associated with the rich pondweed lake habitat 3150 (CEC, 2013). This list was reviewed against available publications on lake macrophyte communities in Ireland (Heuff, 1984, Free *et al*., 2006, 2009) and Great Britain (Palmer 1989, 1992, Palmer *et al*., 1992, Duigan *et al*., 2006) and, in particular, publications on aquatic macrophyte species

(Preston, 1995, Preston and Croft, 2001). EPA macrophyte raw data from routine Water Framework Directive monitoring (2001-2012) were also reviewed. Habitat 3150 is notable for the abundance and diversity of pondweeds, particularly the broad-leaved species and many of their hybrids. This review produced the following list of typical species: *Callitriche* spp., *Ceratophyllum demersum, Chara* spp., *Hippuris vulgaris, Lemna gibba, Lemna minor, Lemna trisulca, Myriophyllum spicatum, Nuphar lutea, Potamogeton berchtoldii, Potamogeton filiformis, Potamogeton friesii, Potamogeton gramineus, Potamogeton lucens, Potamogeton natans, Potamogeton obtusifolius, Potamogeton pectinatus, Potamogeton perfoliatus, Potamogeton praelongus, Potamogeton pusillus, Potamogeton* x *zizii, Sagittaria sagittifolia, Sparganium emersum, Spirodela polyrhiza.*

The non-native, *Elodea canadensis* is also frequent in habitat 3150.

Further work is required to fully describe the typical and characteristic species of the rich pondweed lake habitat 3150, particularly *Potamogeton*, *Chara* and *Callitriche* species, the natural variations in the habitat in Ireland and how the habitat changes as a result of anthropogenic impacts.

2.10 3160 Acid oligotrophic lake habitat

The acid oligotrophic lake habitat 3160 (in the Directive entitled 'Natural dystrophic lakes and ponds') is mainly associated with small lakes and ponds in Atlantic and upland blanket bog, and wet heath. As for other ombrotrophic peatland habitats, the habitat is species poor botanically, but has relatively greater invertebrate species richness. Low species richness is, however, not synonymous with low conservation value, as many of the species are strongly associated with and sometimes restricted to the acid oligotrophic habitat. The acid oligotrophic lake habitat is variable across its Irish range, with altitude, geology, and distance from the sea the most likely drivers of the variation (van Groenendael *et al*., 1979, Drinan, 2012). While individual sites are typically species poor, among-site variation means that the habitat displays higher species richness at landscape and regional scales. Furthermore, the invertebrate fauna is characterised by some rare and threatened species, such as the endangered downy emerald dragonfly (Drinan *et al*., 2011). In terms of macroinvertebrate species richness, lakes and ponds with habitat 3160 are dominated by Coleoptera (water beetles), followed by Trichoptera (caddisfly larvae) and Heteroptera (aquatic bugs, such as water boatmen) (Drinan, 2012).

The interpretation manual of EU habitats provides a short list of plant species associated with the acid oligotrophic lake habitat 3160 and also notes the presence of Odonata (CEC, 2013). This list was reviewed against available publications on relevant lake and pond communities in Ireland (Drinan, 2012, Drinan *et al*., 2011 Visser and Zoer, 1972, 1976, Heuff, 1984, Free *et al*., 2006, 2009) and Great Britain (Palmer 1989, 1992, Palmer *et al*., 1992, Duigan *et al*., 2006), as well as publications on aquatic macrophyte species (Preston and Croft, 2001), aquatic invertebrate groups (Nelson and Thompson, 2004, Foster *et al*., 2009, Nelson *et al*., in prep) and EPA macrophyte raw data from routine Water Framework Directive monitoring (2001-2012). This review produced typical species lists, including typical plant species, typical chydorid cladoceran species and typical aquatic macroinvertebrate species. The typical plant species were: *Sphagnum cuspidatum, Sphagnum auriculatum* (= *denticulatum*), *Juncus bulbosus, Potamogeton polygonifolius, Cladium mariscus, Eleogiton fluitans, Menyanthes trifoliata, Myriophyllum alterniflorum, Nitella flexilis, Nitella translucens, Nymphaea alba, Sparganium angustifolium, Utricularia intermedia, Utricularia minor.*

Drinan (2012) recorded a total of 24 macrophyte species in 13 blanket bog lakes, with species richness at individual sites varying from one to 14. Lowland lakes had significantly greater median species richness (11) to upland lakes (5). Upland lakes were characterised by *Juncus bulbosus*, *Carex rostrata* and *Menyanthes trifoliata*. Lowland lakes had these same species, plus species such as *Cladium mariscus*, *Eleogiton fluitans*, *Eriocaulon aquaticum*, *Utricularia intermedia* and *Hypericum* *elodes*. Other species that were frequently encountered and more abundant in lowland lakes included *Potamogeton polygonifolius* and *Lobelia dortmanna* (Drinan, 2012).

The typical chydorid cladoceran species were: *Alona affinis, Alona costata, Alona rustica, Alonella excise, Alonella nana, Alonopsis elongata, Camptocercus rectirostris, Chydorus sphaericus, Eurycercus lamellatus* and *Pleuroxus truncatus.*

Drinan (2012) investigated the chydorid cladoceran communities in blanket bog lakes and found *Alonopsis elongata, Chydorus sphaericus, Alonella excisa* and *Alonella nana* were common to all sites, while lowland lakes were characterised by *Alona affinis, Pleuroxus truncatus, Eurycercus lamellatus, Camptocercus rectirostris* and *Alona costata,* and upland lakes by *Alona rustica*.

The typical aquatic macroinvertebrate species were: *Acilius sulcatus, Aeshna juncea, Agabus arcticus, Cordulia aenea, Dytiscus lapponicus, Gyrinus minutus, Gyrinus substriatus, Helophorus flavipes, Hydroporus gyllenhalii, Hydroporus obscurus, Hydroporus pubescens, Hydroporus tristis, Ilybius aenescens, Leptophlebia vespertina, Pyrrhosoma nymphula, Sigara scotti.*

Nelson *et al*. (in prep.) identified the following water beetle species as characteristic of upland and moorland lakes: *Gyrinus minutus, Gyrinus substriatus, Acilius sulcatus, Agabus arcticus*, *Ilybius aenescens, Hydroporus gyllenhalii, Hydroporus obscurus, Hydroporus pubescens, Hydroporus tristis,* and *Helophorus flavipes*. Drinan (2012) found that the commonest macroinvertebrate species in the blanket bog lakes studied were *Leptophlebia vespertina* (Ephemeroptera), *Pyrrhosoma nymphula*, *Aeshna juncea* (both Odonata) and *Sigara scotti* (Heteroptera). The gastropod *Lymnaea peregra*, the ephemeropteran *Caenis luctuosa*, the trichopterans *Mystacides azurea, Polycentropus irroratus, Holocentropus dubius* and smaller dytiscid beetles such as *Hydroporus erythrocephalus* and *Nebrioporus assimilis* were more frequent and abundant in lowland blanket bog lakes (Drinan, 2012). By contrast, upland blanket bog lakes had larger dytiscids such as *Dytiscus laponicus, Colymbetes fuscus* and *Acilius sulcatus*. Rare invertebrates found in the habitat were the endangered downy emerald dragonfly, *Cordulia aenea,* and the near threatened *Agabus arcticus* and *Dytiscus lapponicus* (Foster *et al*., 2009, Drinan *et al*., 2011, Nelson *et al*., 2011, Drinan, 2012).

2.11 Implications of the working interpretation of lake habitats

This re-interpretation of the lake habitats is somewhat at odds with the original selection of SACs for lake habitats 3110 and 3130 in Ireland. At the time when SACs were first selected for lake habitats, an earlier version of the EU interpretation manual (Version 12 of 1995) was in existence. In it, habitat 3130 was named "oligotrophic waters in medio-European and perialpine area with amphibious vegetation: *Littorella* or *Isoetes* or annual vegetation on exposed banks (*Nanocyperetalia*)" and the description stated:

> *1) Oligotrophic to mesotrophic standing waters of plains to subalpine levels of the Continental and Alpine Region* ***and mountain areas of other regions****, . .*

The interpretation used by the NPWS at the time was, therefore, to designate upland, predominately corrie lakes as SACs for habitat 3130 as Ireland is within the Atlantic Region[1]. However, the references to 'mountain areas' was removed from subsequent versions of the manual. The current interpretation of habitat 3130 in Ireland is that it is associated with low-lying areas.

[1] It is worth noting that this interpretation appears to have led to the widespread use, in Ireland, of the terms 'lowland oligotrophic' and 'upland oligotrophic' to mean habitats 3110 and 3130, respectively. This definition appears to be nowhere written down and the terms are misleading and inaccurate.

32 SACs were originally selected for habitat 3110, and nine for 3130, with three SACs selected for both. These SACs were examined between 2013 and 2015 and a number of changes were made to the qualifying interests in 2015. The majority of the selections matched the current interpretation, the SACs containing good examples of the habitats. Five SACs were, however, considered to have been incorrectly selected for habitat 3130. Four of these (Site Codes 000093, 000584, 001952 and 2122) contain only upland lakes, which are dominated by habitat 3110 in Ireland (grading into 3160). As a result, 3130 was dropped from the qualifying interests for these four sites and replaced with habitat 3110. 3130 was also dropped from the fifth site, Owenduff/Nephin Complex SAC (000534), which is dominated by base-poor geology and blanket peat and, therefore, lake habitats 3110 and 3160.

Mount Brandon SAC (000375) is dominated by upland lakes and was originally selected for habitat 3130 only. Owing to the mixed geology of the site, however, 3130 was retained as a qualifying interest. Survey is required to confirm the presence and conservation value of habitat 3130 on the site. 3110 was added to the site's qualifying interests in 2015, on the basis of its corrie lakes.

Lake habitat 3130 was added as a qualifying interest to 18 SACs in 2015. All of these were previously selected for *Najas flexilis*, a characteristic species of the habitat. The sites are: Site Codes 000147, 000164, 000185, 000197, 000297, 001141, 001151, 001311, 001774, 001975, 002031, 002034, 002074, 002111, 002118, 002119, 002130, and 002176. Eight of these 18 SACs were considered to have been incorrectly selected for habitat 3110 and that habitat was removed as a qualifying interest (Site Codes 000185, 001141, 001151, 001311, 001975, 002118, 002119, 002130). The selection of these sites for 3110 was a result of the earlier interpretation of that habitat (as being lowland and associated with 'sandy plains'). The re-examination in 2015 determined that 3110 was never present or had an insignificant presence on the sites.

The result of the 2015 review was that 29 SACs are now selected for habitat 3110, and 22 for 3130, with ten SACs selected for both. Appendix II lists all SACs selected for Annex I lake habitats and the Annex II lake macrophytes, *Najas flexilis*¸ and indicates changes made to qualifying intersts in 2015.

3. Article 17 Reporting

3.1 Introduction

Article 17 of the Habitats Directive requires Member States to report every six years on the implementation of the Directive and the conservation status of the natural habitats and wild species listed on the Annexes. The most recent Irish report was submitted in 2013, covered the period 2007 to 2012, inclusive, and had assessments of 58 habitats, including the five lake habitats, and 61 species, including *Najas flexilis*. This section gives an overview of the approach taken to assessing lake habitat conservation status for Article 17 2013, as well as some additional information on the mapping process. NPWS (2013b), the volume of forms, notes and audit trails, provides the specific detail on the individual lake habitat conservation assessments.

The term ‘conservation status’ refers to the status of a habitat or species at national or biogeographical scale. The status of a habitat or species within a site is called its ‘conservation condition’. The methodology for assessing conservation status has been developed by the European Topic Centre. The most recent guidelines were produced for reporting on the 2007-2012 period (Evans and Arvela, 2011). The conservation status of a habitat is assessed using four parameters

1. Range
2. Area
3. Structure and Functions
4. Future Prospects

And these four are combined to give an Overall Conservation Status. These parameters are dealt with in turn below. There is a strong emphasis in this text on digital (GIS) mapping, given the prescribed reporting formats and the data analyses necessary, in particular for range and area.

3.2 Range

Range is reported for Article 17 as a spatial dataset based on a 10 km grid. The mapping steps involved in producing a range dataset are generally as follows

1. The national distribution of the habitat or species is mapped as points or, where possible, polygons/polylines.
2. The point/polyline/polygon distribution is used to produce a 10 km square distribution, by selecting all Irish National Grid 10 km squares that contain the habitat/species.
3. The 10 km square distribution is used to produce a national range. Where the distribution data are comprehensive, the range may be mapped as the current distribution. Alternatively, the ‘Range Tool’ provided by the European Topic Centre may be used, where appropriate. This tool ‘fills’ 10 km ‘gaps’ in the distribution. Where geographical, environmental or other factors preclude the possibility of the habitat/species occurring, however, 10 km squares can be removed from the interpolated distribution range.
4. The range, based on Irish National Grid, is transformed to a European projection (LAEA) for submission to the EU.

As there have been few comprehensive surveys of Annex I habitats in Ireland, the most challenging aspect of range mapping is usually step 1 – producing a point/polyline/polygon distribution. This step generally requires collating, interpreting and validating relevant data, often from disparate sources.

Given the difficulties in the interpretation of Annex I lake habitats (see Section 2), mapping their distribution was demanding. Fortunately, there are good data on the general distribution of lakes, at various scales, from the available basemaps (e.g. Six-inch and Discovery Series maps).

3.2.1 Ecological and environmental data sources

The principal ecological/environmental data sources used in the production of the Annex I lake habitat distribution for Article 17 2013 were

1. Vegetation community and lake habitat data
    a. Heuff (1984)
    b. Roden (1999, 2000, 2012)
    c. Bruinsma *et al*. (2009)
    d. Roden and Murphy (2013, in prep.)
2. Aquatic macrophyte species records
    a. van Groenendael *et al*. (1979)
    b. Heuff (1984)
    c. FitzGerald (1994)
    d. Charophyte records, collated and frequently also collected by Nick Stewart for the aquatic plant atlas (Preston and Croft, 2001)
    e. Free *et al*. (2006, 2009)
    f. EPA routine Water Framework Directive macrophyte monitoring (data from 2001-2012 used)
    g. *Najas flexilis* records (Najas_fleixilis_version_2.1_Feb_2013.shp and Najas_flexilis_LakeSegment.shp)
    h. Drinan (2012)
3. Personal communications
    a. Dr Cilian Roden
    b. Jim Ryan
    c. Dr Mike Wyse Jackson
4. Other ecological data
    a. Coastal lagoon distribution (Inventory_of_Irish_Coastal_Lagoons_2011_polygons.shp)
    b. Turlough distribution (Ar1712_3180_Point_Distribution.shp)
5. Environmental data
    a. Bedrock geology (GSI Bedrock 500k and GSI Bedrock 100k)
    b. Subsoils (SOIL_subsoils_ie feature class, EPA WFDGeodatabse Version Oct 2011)
    c. Soils (SOIL_Soils_ie feature class, EPA WFDGeodatabse Version Oct 2011)
    d. Peatland mapping (Derived Irish Peat Map Version 2, which depicts the spatial extent of three peatland types in Ireland: raised bog, low-level blanket bog and high-level blanket bog)
    e. GSI Karst features
    f. Contours/altitude
    g. Physico-chemical data (Tables 2.1 and 2.3 of Free *et al.* (2006) which provided spatial, physical and chemical (including alkalinity) information on candidate reference condition lakes)
6. Imagery
    a. OSi orthophotography (2005 and 2000)
    b. MS Bing satellite images

3.2.2 Map base

The national distribution of the lake habitats were mapped as lake polygons. The "WFD_LakeSegment" feature data class from the EPA's Water Framework Geodatabase (WFDGeodatabase.mdb, Version Oct 2011) was used. This feature class contained 12,217 separate polygons at 1:50,000 scale.

3.2.3 Mapping rules

A number of rules were employed in the classification of lake habitat, including

1. **Lake habitat co-occurrence**. In line with Figure 1, Section 2.5, it was assumed that Annex I lake habitats can co-occur within the same lake or pond as follows
    a. 3110 can co-occur with 3160 and 3130, and, in exceptional cases, 3140
    b. 3130 can co-occur with 3110, 3140 and 3150
    c. 3140 can co-occur with 3130 and 3150, and, in exceptional cases,3110
    d. 3150 can co-occur with 3130 and 3140
    e. Generally, only two lake habitats co-occur, with the exception of large mixed lakes such as Lough Corrib and Mask, which are assumed to contain 3110, 3130 and 3140.
2. **Co-occurrence with turloughs**. Also in line with Figure 1, Section 2.5, it was assumed that some Annex I lake habitats could co-occur with turloughs (3180), namely
    a. 3140 can co-occur with 3180
    b. 3150 can co-occur with 3180
3. **Brackish habitats**. It was assumed that the Annex I lake habitats did not occur in brackish waters including inlets, bays and coastal lagoons.
4. **Lake area**. Habitat 3160 is described as occurring in lakes and ponds, and many of the water bodies in which it occurs are small in area. The other four habitats (3110, 3130, 3140 and 3150), however, were assumed generally not to occur in lakes of less than 1 ha in area. However, where site-specific data existed, demonstrating the presence of the habitat in a lake of smaller than 1 ha, polygons were classified (as 3110, 3140 or 3150). It is worthy of note that almost 70% of all lake segments in the WFD_LakeSegment feature class had an area of less than 1 ha.

3.2.4 Mapping process

The "WFD_LakeSegment" feature data class was used to create a new shapefile (Lake_Habitat_Segment_Classified.shp (various versions)) and a series of fields were added, including

1. Habitat classification from Article 17 2007 (FEG, 2007)
2. Polygon area categories (0 to 1 ha, 1 ha to 3ha, 3 ha to 6 ha and 6 ha plus)
3. 2013 Habitat classification (3110_2013, 3130_2013, 3140_2013, 3150_2013, 3160_2013, 3180_2013, Source_2013, Comment_2013)

The Lake_Habitat_Segment_Classified.shp went through a number of versions, with the number of lake polygons classified into one or more Annex I lake habitats increasing at each stage. The final version used for Article 17 2013 was Lake_Habitat_Segment_Classified_v7.0.shp and had classified 6,193 polygons into one or more of the five Annex I lake habitats.

The process of classifying the individual lake/pond polygons was a lengthy one, with vegetation community, lake habitat and aquatic macrophyte species data examined first, followed by other data (see Section 3.2.1 above). The chronology was as follows

1. The overlap with turloughs was examined and lake habitats 3140 or 3150 assigned, where appropriate
    a. 245 polygons were confirmed as turloughs, and an additional 64 were identified as potential turloughs. Of this 309 total, 49 were considered to also contain lake habitats: 43 had lake habitat 3140 and six had 3150.

2. Polygons were classified into lake habitat 3140 (the key data sources were Roden and Murphy (2013, in prep.), Roden (1999, 2000, pers. comm.), Heuff (1984) (Types 4 and 6 lakes), charophyte records from Nick Stewart and others, charophyte abundance data from EPA monitoring, bedrock geology, karst features, alkalinity and imagery.
3. All lakes with records of *Najas flexilis* were classified as having habitat 3130.
4. Polygons were classified into lake habitat 3130 using other available data (EPA macrophyte records of co-occurrence of *Potamogeton perfoliatus* and *Isoetes lacustris*, SAC qualifying interests and environmental data (including geographical location and bedrock geology)). Only lakes occurring at less than 200 m altitude and of greater than 1 ha in area were classified as having habitat 3130.
5. Polygons were classified into lake habitats 3110 and 3160, initially using available vegetation and macrophyte data and then by concentrating on lakes within peatland catchments (bog-complex SACs were examined, other SACs with blanket bog as a qualifying interest, the Derived Irish Peat Map and areas of blanket peat soils). The approach was as follows
    a. The principal data sources for habitat 3110 were the EPA routine Water Framework Directive macrophyte monitoring (data from 2001-2012 used), Free *et al*. (2006, 2009) and Heuff (1984)
    b. Habitat 3110 was assigned to high altitude lakes (> 200 m) of greater than 1 ha in area
    c. Habitat 3110 was assigned to lakes surrounded by peatland (upland and Atlantic blanket bog and wet heath) of greater than 1 ha in area
    d. In Atlantic blanket bogs overlying complex geology (e.g. Roundstone Blanket Bog), habitat 3110 was assigned to all lakes, regardless of size
    e. In general, habitat 3160 was assigned to all water bodies of less than one hectare located in blanket peat and at high altitude. In areas of base-poor geology with deep peat and/or altitudes of greater than 400 metres, the habitat was also assigned to larger lake segments
    f. Aquatic macrophyte data were used to verify 3160 lakes and ponds (EPA Macrophyte raw data, Free *et al*., 2006, 2009, Heuff, 1984), although these were limited to a small number of sites
6. Polygons within SACs selected for lake habitat 3150 were classified as that habitat, based on the associated explanatory notes and EPA macrophyte records. Heuff (1984), EPA macrophyte records and bedrock data were used to classify polygons as 3150, outside of those SACs.
7. The distribution of each of the five lake habitats was reviewed and anomalies or gaps in the range further investigated and corrected as necessary.

3.2.5 Mapping outputs

The final, over-arching shapefile was Lake_Habitat_Segment_Classified_v7.0. This contained 12,132 polygons, as at an early step 85 coastal lagoon and turlough segments were deleted from the dataset. In future, it is recommended that base datasets be kept entire, with polygons classified correctly by the inclusion of additional fields and clear notes/comments. Of the 12,132 polygons in the final shapefile, 6,669 lakes were examined to a greater or lesser extent

- 476 of the 6,669 were unassigned (or 7.1% by number and 6.3% (7,646 ha) by area of the polygons examined), as they were turloughs, artificial lakes or ponds (ornamental, mill ponds, reservoirs, quarry ponds, mine tailings), fens, bogs or non-wetland features[2]

[2] The mapping errors encountered in the WFD_LakeSegment feature class were typically for small polygons of < 1 ha in area.

- 6,193 segments were classified and were used in mapping the distribution of lake habitats
    - 2,221 > 1 ha
    - 3,972 < 1ha
    - 5,322 were assigned just one lake habitat
    - 867 were assigned two lake habitats
    - four were assigned three lake habitats
    - 25 lakes were assigned one lake habitat, plus the turlough habitat
    - a large number of lakes were classified using a combination of environmental data and imagery. Confidence is generally low in the classification of segments using this method.

5,463 lake polygons were not examined and were not used in mapping the distribution of the lake habitats.

Lake_Habitat_Segment_Classified_v7.0 was then split by habitat into

1. 3110_Lake_Segment_Distribution_AOC_06Jun2013_FINAL.shp - 1,276 polygons
2. 3130_Lake_Segment_Distribution_AOC_Final_06Jun2013.shp – 417 polygons
3. 3140_Lake_Segment_Distribution_AOC_Final_06Jun2013.shp – 527 polygons
4. 3150_Lake_Segment_Distribution_AOC_Final_06Jun2013.shp - 574 polygons
5. 3160_Lake_Segment_Distribution_AOC_Final_06Jun2013.shp - 4,274 polygons

These shapefiles were used to produce the Irish National Grid 10 km distributions, by selecting all 10 km squares intersecting the lake polygons. The five 10 km distribution shapefiles were

1. 3110_10km_distribution_AOC_FINAL_172_Squares_06Jun2013.shp
2. 3130_10km_distribution_AOC_FINAL_178_Squares_06Jun2013.shp
3. 3140_10km_distribution_AOC_FINAL_167_Squares_06Jun2013.shp
4. 3150_10km_distribution_AOC_FINAL_88_Squares_06Jun2013.shp
5. 3160_10km_distribution_AOC_FINAL_130_Squares_06Jun2013.shp

Figure 2 maps each lake habitat, based on these polygon and 10 km distribution shapefiles.

Range maps were then derived from the ING 10 km square grid distribution maps using the recommended Range Tool. The Favourable Reference Range was reported as this 2013 derived range for each of the five lake habitats. Of the derived range maps, only that for habitat 3150 was modified. Eight 10 km squares were removed, where habitat 3150 was considered not to occur owing to the geology, soils and documented occurrence of other standing water habitats within the mapped lakes. The final range maps are presented in Irish National Grid in NPWS (2013 a and b). It is likely that a number of the unoccupied 10 km squares within the derived ranges do **not** contain the relevant lake habitat. The reasons for this include inappropriate geology, subsoils, soils, and/or altitude, or the absence of lakes and ponds.

3.2.6 Differences in range mapping between 2013 and 2007

There was a large number of differences in the lake habitat range maps produced in 2007 and 2013 Article 17 reports. These can broadly be considered to result from improved data or methodological differences.

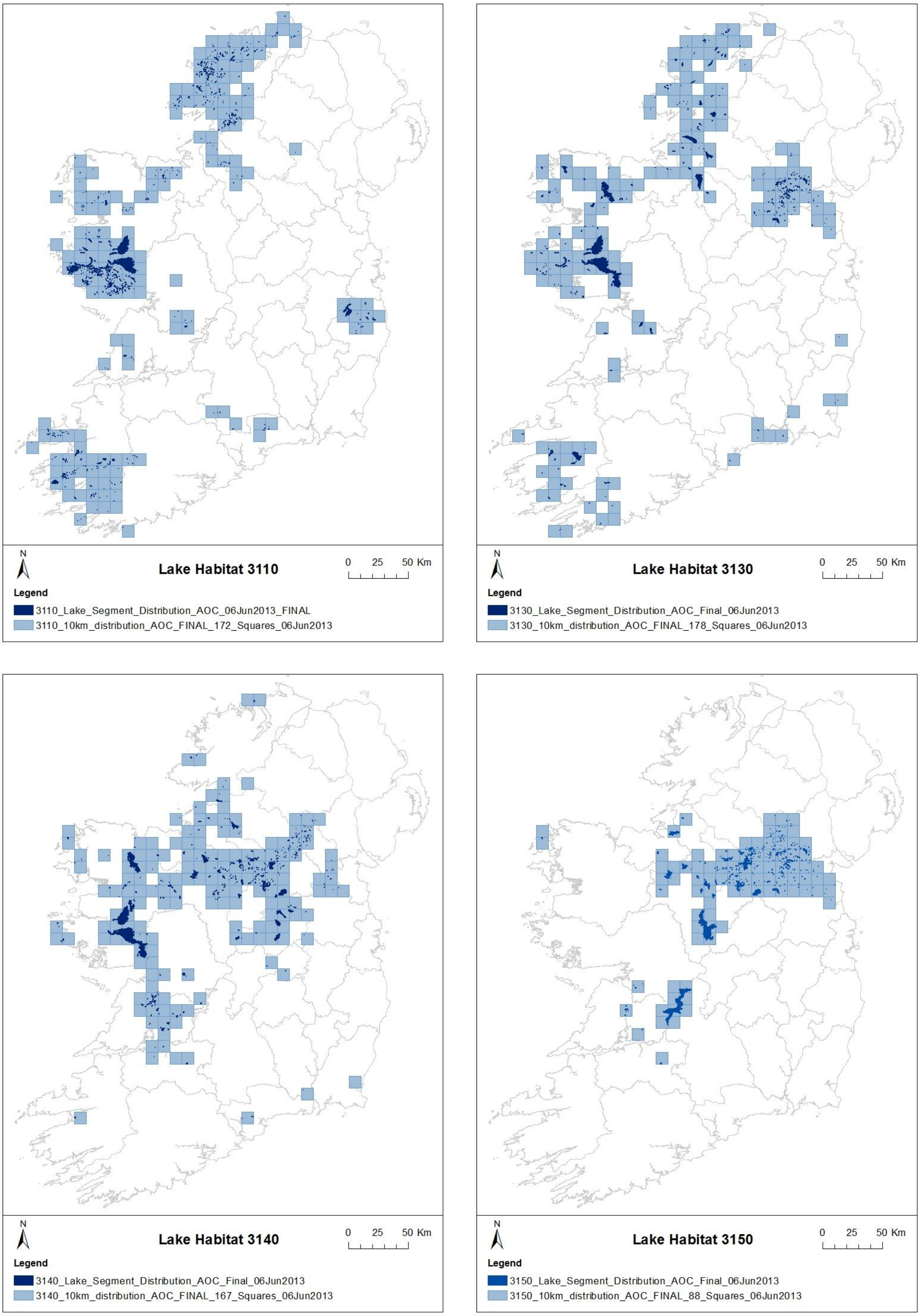


Figure 2 Distribution of the five Annex I lake habitats used for Article 17 2013. Lake polygon and ING 10 km square distributions are both presented.

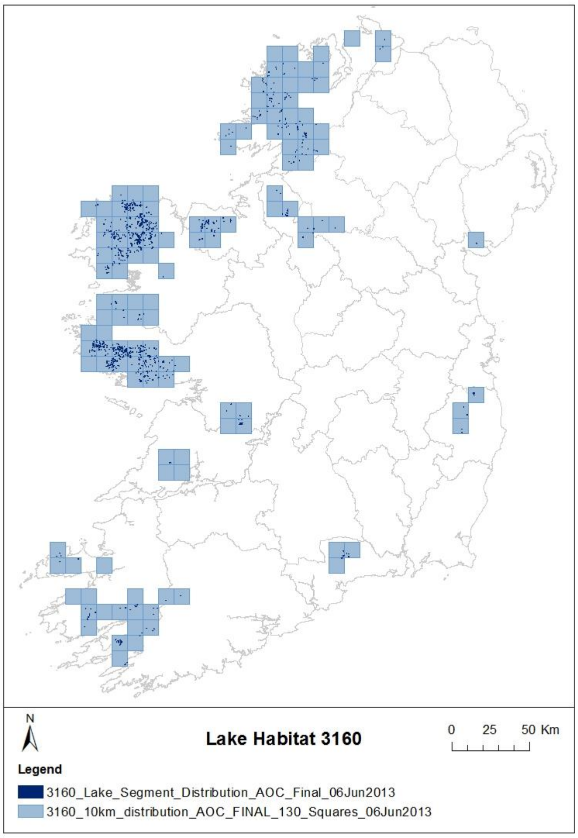


Figure 2 continued.

The reinterpretation of the Annexed lake habitats, presented in Section 2, can be considered an improvement in data. The main sources of new data between reporting periods were hard-water lake survey (Roden and Murphy, 2013, in prep), EPA WFD lake macrophyte records and the acid oligotrophic lake PhD (Drinan, 2012). In 2013, greater use was also made of historical data on lake vegetation (e.g. Visser and Zoer, 1972, 1976, van Groenendael *et al*., 1979, Heuff, 1984, FitzGerald and Preston, 1994, Roden, 1999, 2004, Free *et al*., 2006, 2009).

There was a number of methodological changes between reporting periods. The basemaps were different, although both were produced for WFD purposes and at 1:50,000 scale. In 2007, the ranges of the Annex I lake habitats were mapped using GIS modelling (FEG, 2007). The modelling allowed a lake to be classified into one habitat type only, however the models could not separate habitats 3110 and 3130. No lakes were classified as 3150 in 2007. The Habitats Directive title for the rich pondweed lake habitat (3150) uses the term ‘Natural eutrophic’. The authors used a water quality (as opposed to botanical) interpretation of the habitats and considered that ‘naturally eutrophic’ lakes do not occur in Ireland (FEG, 2007). In Ireland, the botanical interpretation of the rich pondweed lake habitat is that it occurs in waters classified as ‘mesotrophic’ using standard water quality approaches (see Section 2.9 for further information).

In 2007, a total of 11,924 individual lake segments were classified into one of three habitat categories as follows

1. 3110 or 3130 (a total of 7,728 lakes)
2. 3140 lakes (3,470)
3. 3160 lakes (726 lakes).

A further methodological difference between 2007 and 2013 was that the new Range Tool developed for 2013 produced larger ranges in comparison to the method of range mapping used in 2007 (see example in *Najas* flexilis report in NPWS, 2013c).

In summary, the reasons for the differences between reporting periods were

1. a better understanding of the habitats
2. the separation of habitats 3110 and 3130, which were not distinguished in 2007
3. the mapping of the rich pondweed lake habitat (3150), which was not mapped in 2007
4. the removal of turloughs, lagoons and other non-lake segments
5. the removal of lake segments of less than one hectare in area unless site-specific information identified the presence of the habitat in the small lake/pond and
6. a different range tool.

3.2.7 Range as a measure of the conservation status of lake habitats

Range is likely to be an insensitive measure for the conservation status of lake habitats. Lakes can be ‘created’ by the damming of rivers and while their area can be reduced through drainage or processes of natural succession, they are unlikely to be destroyed. In a temperate, oceanic climate such as that of Ireland, it is unlikely that the true range of any of the five lake habitats will change. The quality of the habitat (structures and functions) may deteriorate significantly, however, and this is the key measure of the conservation status of these habitats.

3.3 Area

The surface area of each habitat was estimated based on the total surface area of the lakes containing that habitat. As the distribution data were incomplete, a two-step process had to be adopted. Firstly, the areas of all classified lake segments were summed by habitat type. Secondly, Annexed lake habitats were assigned to the remaining lake area (i.e. the area that had not been examined during the range mapping process) in proportion with the classified areas. These steps are expanded upon below.

The five final polygon distribution files (see Section 3.2.5 above) were used to calculate the area of each habitat in the classified lake segments. Each shapefile contained a ‘HECTARE’ area field from the original WFD_LakeSegment and this was summed, with the following results

1. 3110_Lake_Segment_Distribution_AOC_06Jun2013_FINAL.shp - 37,733.78 ha or 377.3 km^2
2. 3130_Lake_Segment_Distribution_AOC_Final_06Jun2013.shp – 52,158.77ha or 521.6 km^2
3. 3140_Lake_Segment_Distribution_AOC_Final_06Jun2013.shp – 51,532.68 ha or 515.3 km^2
4. 3150_Lake_Segment_Distribution_AOC_Final_06Jun2013.shp - 38,134.09 ha or 381.3 km^2
5. 3160_Lake_Segment_Distribution_AOC_Final_06Jun2013.shp - 22.2 km^2

To estimate the area of each lake habitat in the unclassified lake segments, correction factors were first created to account for mapping errors and then the remaining unclassified area was assigned in proportion with the classified lake segments, as follows

1. **Correction factors.**
    a. For lake habitats *3110*, *3140* and *3150*, the correction factor was based on the full dataset, regardless of lake area. Of the 6,669 polygons examined during the range mapping process 476 were considered not to contain Annex I lake habitats for a number of reasons (see Section 3.2.5 above). These 476 represented 6.3% by area of the 6,669 polygons examined. 5,463 lake segments were not examined and these had a total area of 96.5 km^2. This area was, therefore, reduced by the 6.3% correction factor to 90.4 km^2.

b. For lake habitat *3130*, the correction factor was based on lake segments of greater than 1 ha in area only, as this habitat was not assigned to any lakes of smaller than 1 ha in area. 284 polygons of > 1 ha in were considered not to contain Annex I lake habitats. These represented 6.3% by area of the polygons of > 1 ha in area examined (= 7,576.97 ha out of 120,987.9 ha). 1,214 lake segments of > 1 ha were not examined, with a total area of 85.4 km^2. This area was, therefore, reduced by the 6.3% correction factor to 80 km^2.

c. For lake habitat *3160*, the correction factor was based on lake segments of less than 1 ha in area only, as the vast majority of lakes > 1 ha that contain the acid oligotrophic lake habitat were captured by the distribution mapping process. 192 polygons of < 1 ha were considered not to contain Annex I lake habitats and these represented 7% by area of the 4,164 polygons < 1 ha examined (= 69 ha out of 983 ha). 4,249 lake segments of < 1 ha were not examined, with a total area of 11.1 km^2. This was reduced by the 7% correction factor to 10.3 km^2.

2. Assigning unclassified area.

a. *3110* - 33% of the total area of the classified segments was assigned to habitat 3110, hence 33% of the unclassified area (90.4 km^2) or 29.8 km^2 was assigned to habitat 3110.

b. *3130* – 46% of the total area of the classified segments > 1 ha was assigned to habitat 3130, hence 46% of the unclassified area > 1 ha in area (80 km^2) or 36.8 km^2 was assigned to habitat 3130.

c. *3140* - 45% of the total area of the classified segments was assigned to habitat 3140, hence 45% of the unclassified area (90.4 km^2) or 40.7 km^2 was assigned to habitat 3140.

d. *3150* - 33% of the total area of the classified segments was assigned to habitat 3140, hence 33% of the unclassified area (90.4 km^2) or 29.8 km^2 was assigned to habitat 3150.

e. *3160* – 96% of the total area of the classified segments < 1 ha was assigned to habitat 3160, hence 96% of the total area of unclassified segments < 1 ha in area (10.3 km^2) or 9.9 km^2 was also assigned to habitat 3160.

The two figures were then summed to give the final estimated area

1. *3110* - 377.3 km^2 + 29.8 km^2 = **407.1** km^2
2. *3130* – 521.6 km^2+ 36.8 km^2= **558.4** km^2
3. *3140* – 515.3 km^2+ 40.7 km^2= **556** km^2
4. *3150* – 381.3 km^2+ 29.8 km^2= **411.1** km^2
5. *3160* - 22.2 km^2+ 9.9 km^2= **32.1** km^2

It must be acknowledged that the approach used overestimated the total area of Annex I lake habitats, as it assumed that **all** natural lakes or ponds contain at least one Annex I lake habitat, which is unlikely to be the case. Furthermore, 871 of the classified lakes were considered to have more than one Annex I lake habitat (see Section 3.2.5 above), with the full surface area assigned to each habitat. Even where only one lake habitat occurs, it seldom covers an area equivalent to the surface area of the lake. Accurate mapping of submerged macrophyte communities is challenging and time-consuming and is unlikely to be routinely employed in monitoring the conservation condition of individual sites, so that lake surface area will remain the only available indicator of conservation status of the habitat area into the future.

As for lake habitat range, the national areas of the lake habitats are thought unlikely to change significantly over time. This combined with mapping errors and difficulties in measuring area accurately (especially under water), make area an insensitive indicator of conservation status.

3.4 Structure and functions

Structure is the material components or framework of a habitat and is often formed by species, but also includes non-organic material such as soil or other substratum (Evans and Arvela, 2011). Functions are the ecological processes occurring at relevant temporal and spatial scale, such as regeneration and nutrient cycling (Evans and Arvela, 2011).

Structure and functions represent the quality of lake habitats. Both structure and functions can deteriorate significantly and are the key measures of the conservation status of a lake habitat and its conservation condition at site level. The specific structures and functions of the five Annex I lake habitats have not been fully elucidated, owing to the absence of baseline data on their distribution and characteristics, and of research into their environmental drivers and requirements. Significant data are available, however, on lake water quality and these were used to inform the structure and functions assessments in 2013. Specific information on the structure and functions of habitat 3140 were available through surveys undertaken in 2011 and 2012 (Roden and Murphy, 2013, in prep.) (see Section 3.4.1 below). It was assumed throughout the 2013 assessments that restoration of lake habitats is possible regardless of the severity of the deterioration in habitat quality.

3.4.1 3140 structure and functions

As part of the 2011 baseline survey of three of the most important hard-water lakes in Ireland (Lough Bunny, County Clare, Lough Carra, County Mayo and Lough Owel, County Westmeath), Roden and Murphy (2013) developed a method for assessing the conservation condition of habitat 3140 using structural and functional elements. Roden and Murphy then tested their methodology on 25 hard-water lakes in 2012 (Roden and Murphy, in prep.). The results of these surveys informed the structure and functions assessment for habitat 3140.

Roden and Murphy (2013) recommended that vegetation should be sampled by snorkelling between June and September, once every three years. Each lake basin should be sampled individually. The indicators developed were

1. Maximum depth of vegetation and species composition at base of euphotic zone. At least two separate transects should be examined, one on the sheltered (usually western) shore and one on the exposed (eastern) shore. Depth should exceed 6 m.
2. Presence of all major *Chara* zones, (*Chara curta, Chara rudis, Chara globularis and Chara denudata/ Nitella flexilis*), especially the *Chara globularis* and *Chara denudata* zones (see Section 2.7 for further information).
3. The krustenstein zone should be intact and not colonised by bryophytes. Some monitoring locations should be close to inflowing rivers. As this zone can be sampled from the shore, ten or more relevés should be examined.
4. Angiosperms should not extensively colonise either the krustenstein zone or the base of the euphotic zone. A little *Littorella uniflora* and *Potamogeton* species may occur with cover values less than 2 (Braun-Blanquet scale).
5. Secchi transparency should on average exceed 6m.
6. Total phosphorus, chlorophyll *a* and Secchi transparency should be sampled in lakes of high conservation value, at least four times per year, every third year.

Roden and Murphy (in prep.) suggested that in very transparent lakes, an extensive *Chara rudis* zone is absent. They also noted that Secchi transparency of 4 m may be sufficient in some lakes. Regardless of the absolute target, there should be no decline in Secchi transparency. Roden and Murphy (in prep.) also found that the scheme does not work for coastal hard water lakes, which are naturally more productive. The suggested modifications to the scheme were

1. Euphotic depth, measured by snorkelling, (0-4 m = bad, 5-6 = poor, >6 = good)
2. Secchi depth (0-2 m = bad, 2-4 = poor, >4 = good)
3. Krustenstein (absent = bad , overgrown or decaying = poor, present = good)
4. Charophyte zones (absent = bad, 1-2 = poor, > 3 = good)
5. Angiosperms (throughout euphotic zone = bad, confined to surface and *Chara rudis* zone = good)

(Roden and Murphy, in prep.).

3.4.2 Other Annex I lake habitats structure and functions

Indicators and targets for structure and functions need to be established for the other four lake habitat types. It is likely that similar field survey methods to those recommended for habitat 3140 will need to be used and that the structure and functions indicators will also be similar, covering

1. Typical species (algae, bryophytes, vascular plants and invertebrates)
2. Characteristic zonation or other spatial patterns in vegetation
3. Depth distribution of vegetation, particularly maximum depth

Vegetation zonation/pattern is likely to include assessment of species composition and abundance (including positive and negative indicators), spatial distribution and condition indicators. Interim targets have been set for some of these indicators for the purposes of site-specific conservation objectives (see Section 4.5).

3.4.3 Use of water quality data for structure and functions assessment

Water quality is a key driver of lake ecology, and nutrient enrichment leading to eutrophication of freshwaters is one of the most significant environmental challenges globally. Annex I lake habitats are typically associated with high water quality and the absence of eutrophication impacts. As a result, information on water quality (gathered for the purposes of a more general assessment of 'environmental health') can be used to inform the structure and functions assessments for Annex I lake habitats. Sections 4.5.6 to 4.5.12 provide further information on the relationships between Annex I lake habitats and general water quality, while the text below describes how water quality data were used in the assessment of structure and functions in 2013.

The large body of work undertaken for the WFD has not specifically considered the five Annex I lake habitats, but did develop an Irish WFD lake typology with 13 lake types, based primarily on alkalinity, depth and area (Working Group on Characterisation and Risk Assessment, 2005, Free *et al.*, 2006). This typology was verified using phytoplankton, macrophyte and littoral and profundal macroinvertebrate data from candidate reference-condition lakes. The macrophyte element of the typology study recognised three distinct macrophyte groups, one of which bore some resemblance to Annex I habitat 3140, a second that resembled habitat 3110 and the final group representing 'all the rest' (Free *et al.*, 2006). While the environmental requirements, particularly water quality requirements, of these WFD lake types were investigated, all lake types are currently treated as one under the WFD, in terms of physico-chemcial standards, objectives and measures. Lake-type-dependent boundaries have been established, however, for phytoplankton biomass (chlorophyll *a*).

Annex V of the WFD specifies the 'quality elements' that should be monitored in lakes. This is a long list and some elements are better understood and have been in use for longer than others. Significant investment was made into developing metrics (or methods) for assessing the **biological** elements, namely

1. Phytoplankton - composition, abundance and biomass
2. Other aquatic flora - composition and abundance
3. Benthic invertebrate fauna - composition and abundance
4. Fish fauna - composition, abundance and age structure

Most of the physico-chemical parameters (defined in the WFD as 'general chemical and physico-chemical elements supporting the biological elements') are widely used

1. Transparency
2. Thermal conditions
3. Oxygenation conditions
4. Salinity
5. Acidification status
6. Nutrient conditions

The Irish EPA is responsible for co-ordinating the WFD lake monitoring programme, for monitoring the lake biological quality elements (other than fish, which are monitored by Inland Fisheries Ireland) and for reporting on ecological status. The EPA WFD lake monitoring programme follows a three-year-cycle. EPA lake ecological status for the years 2009-2011 inclusive was used to inform the conservation assessment of lake habitat condition.

For the 2013 Annex I lake habitats structure and functions assessment, a number of WFD quality elements were used to assess **eutrophication** impact, namely

1. Chlorophyll *a* status (= phytoplankton biomass)
2. Nutrient condition status
3. Macrophyte status (= composition and abundance of other aquatic flora)
4. Phytobenthos status (= composition and abundance of other aquatic flora)
5. Phytoplankton composition status

Nutrient enrichment (with phosphorus and/or nitrogen) can promote phytoplankton growth (as indicated by Chlorophyll *a* concentration) leading to shading and reduced light penetration. Nutrient enrichment can also favour epiphytic and epipelic algal communities (as indicated by phytobenthos status) or more competitive submerged macrophyte species (as indicated by macrophyte status), which can out-compete the high conservation value communities and species. Chlorophyll *a*, macrophyte, phytobenthos and phytoplankton composition all demonstrate biological responses to nutrient enrichment. For those habitats and habitat sub-types considered to require **oligotrophic** conditions, as defined by the standard OECD approach, the target for each of the five listed elements was high status (see Section 4.5.6 for more information). In such cases, WFD 'good' status was considered equivalent to poor conservation condition, while moderate, poor or bad status was considered equivalent to bad conservation condition. For a site to be considered to be in favourable condition in terms of nutrients and eutrophication, all five elements must be at high status. This use of the lowest common denominator of the five quality elements is in keeping with classification under the WFD, which is derived by taking the lowest status classes for a range of specified biological, physico-chemical and hydromorphological quality elements (Tierney, *et al*. 2010). Where **mesotrophic** conditions were considered sufficient to meet the requirements of the habitat or habitat sub-type, the same approach was used but using a target of at least good status for favourable condition. Moderate WFD status was considered equivalent to poor conservation condition, and poor or bad WFD status to bad conservation condition.

WFD Acidification/Alkalisation status was used to assess whether sites were impacted by **acidification**.

Final habitat condition was then based on the lowest status class from the eutrophication condition and acidification condition. Table 2 presents a sample of lakes to illustrate the approach, while Table 3 provides summary data on the structure and functions assessment using WFD status data.

The appropriateness of using WFD status data in structure and functions assessment was tested for the hard-water lake habitat (3140). 2009-2011 WFD ecological status data were available for 78 hard-water lakes, 20 of which had conservation condition assessments by Roden and Murphy (2013, in prep.). Comparing condition assigned using WFD status data to the tailored assessments by Roden and Murphy: nine of the 20 lakes had the same conservation condition; eight were given a better assessment (i.e. were assessed as good or poor condition using WFD data, but poor or bad by Roden and Murphy), and three were assessed as poor using WFD data, but good by Roden and Murphy. These results highlight the need for further investigation into the relationship between WFD Status and the conservation condition of Annex I lake habitats.

Table 2 **Sample of 2013 lake habitat structure and functions assessment using WFD status data.** Targets are 'H' High or 'G' Good WFD status.

Annex I lake habitat	Lake	Target	Macrophyte Status	Phytobenthos Status	Chlorophyll Status	Phytoplankton Composition Status	Phytoplankton Status	Nutrient Conditions Status	Acidification /Alkalisation Status	High count	Good count	Moderate count	Poor count	Bad count	Final conservation condition 2013
3110	Pollaphuca Reservoir	H	Moderate		High	N/A	N/A	Good	High	2	1	1	0	0	Bad
3110	Upper KY	H	High	High	High	Good	High	High	High	6	1	0	0	0	Poor
3110	Shindilla	H	High	High	High	High	High	High	High	7	0	0	0	0	Good
3130	Tully	H	Good		Moderate	N/A	N/A	Good	High	1	2	1	0	0	Bad
3130	Anure	H	High	High	Good	Good	Good	High	High	4	3	0	0	0	Poor
3130	Pollacappul	H	High		High	N/A	N/A	High	High	4	0	0	0	0	Good
3140	Inchiquin CE	H	Moderate		High	N/A	N/A	Moderate	High	1	0	2	0	0	Bad
3140	Conn	H	Good		High	N/A	N/A	High	High	3	1	0	0	0	Poor
3140	Annagh/ White Lough	H	High	High	High	High	High	High	High	7	0	0	0	0	Good
3150	Muckno or Blayney	G	Bad	Moderate	Poor	Poor	Poor	Moderate	Moderate	0	0	3	3	1	Bad
3150	Ree	G	Moderate		High	Moderate	Good	Good	High	2	2	2	0	0	Poor
3150	Key	G	Good		High	N/A	N/A	Good	High	2	2	0	0	0	Good
3160	Bray Lower	H	Good		High	N/A	N/A	Good	High	2	2	0	0	0	Poor
3160	Loughaunore	H	High		Good	N/A	N/A	High	High	3	1	0	0	0	Poor

Table 3 **Summary of 2013 lake habitat structure and functions assessment using WFD status data.** Figures provided are numbers of lakes.

Annex I lake habitat	Eutrophication Impact			Acidification /Alkalisation Impact			Final Conservation condition			WFD status data available						
	Favourable	Poor	Bad	Favourable	Poor	Bad	Favourable	Poor	Bad	Macrophyte Status	Phytobenthos Status	Chlorophyll Status	Phytoplankton Composition Status	Phytoplankton Status	Nutrient Conditions Status	Acidification/Alkalisation Status
3110	22	22	13	56		1	22	21	14	56	23	56	21	21	57	57
3130	9	40	44	88		5	9	39	45	90	32	90	30	37	93	93
3140	9	26	23	54		4	9	26	23	57	21	57	21	25	58	58
3150	5	32	25	53		9	5	32	25	61	15	61	15	15	62	62
3160	0	2	1	3		0	0	2	1	3	0	3	0	0	3	3

3.4.4 Typical species

The condition of the typical species of the five lake habitats was not assessed separately to other elements of structure and functions. For the hard-water lake habitat (3140), the condition of typical species formed an integral part of the condition assessment by Roden and Murphy (2013, in prep.). For the remaining four lake habitats, the structure and functions assessment was largely based on WFD ecological status data (see Section 3.4.3 above), but some consideration was given to the following

- for lake habitat 3130, the conservation condition of the characteristic species *Najas flexilis*, was examined where relevant and available
- for habitats 3110 and 3150, EPA macrophyte raw data from WFD monitoring (2007-2012) were interrogated
- for the acid oligotrophic lake habitat (3160), listed data sources, notably Drinan (2012), were considered

Lists of typical species for each habitat are provided in Sections 2.6 to 2.10 and in NPWS (2013b).

3.5 Future Prospects

For each of the five lake habitats, future prospects were assessed using expert judgement. The assessment was informed by

- the current status of and trends in structure and functions
- pressures impacting on the habitats and their associated drivers
- the current legal and policy framework
- current and planned conservation and water quality measures

NPWS (2013b) provides clear explanatory text on the future prospects conclusions for each of the five Annex I lake habitats. Some additional information on pressures is provided below.

3.5.1 Pressures

Evans and Arvella (2011) defined pressures as follows

> *Pressures are considered to be factors which are acting now or have been acting during the reporting period*

For reporting in 2013, the EU Topic Centre provided a 'Reference list Threats, Pressures and Activities', consisting of a four-level hierarchy of coded pressures and threats. Standardising the reporting of these parameters was very useful. The expansive list (17 level-1 pressures/threats, 75 level-2, 209 level-3 and 112 level-4) did, however, give rise to a risk of variation in interpretation and usage. Selecting the appropriate standard codes for the indirect pressures (e.g. hydrological change, nutrient pollution, sediment pollution, acidification) impacting on freshwater habitats and species was somewhat problematical. These pressures are frequently diffuse, arise as a result of developments and activities from a variety of sectors and impact cumulatively. Interactions among pressures (i.e. in-combination effects) are often complex and can be difficult to predict. For many recognised pressures on Irish freshwaters, more than one option was available on the standard list. Pollution qualifiers had the potential to further add to the confusion and were avoided, with one exception, for Annex I lake habitats in 2013.

Information on pressures on general water quality, and expert judgement were used to determine the pressures impacting on each of the lake habitats. The main information sources were

1. Water Framework Directive Reports (River Basin Management Plans, associated Water Management Unit Action Plans[3] and the 2005 Article 5 Report[4].
2. National Water Quality Reports (McGarrigle, *et al*., 2010), State of the Environment Reports and Environmental Indicators (Lehane and O'Leary, 2012, EPA, 2008).

The application of these data to acid oligotrophic lake habitat (3160) was limited, owing to the small size of lakes containing that habitat and their general absence from water quality monitoring networks. The following, habitat-specific data were also used

3. for lake habitat 3130, information on pressures on the typical species *Najas flexilis*, including dedicated survey of *Najas flexilis* between 1999 and 2005 and examination of the catchments of *Najas flexilis* lakes (O Connor, 2013)
4. for lake habitat 3140, pressures on the hard-water lake habitat documented by Roden and Murphy (2013, in prep.), Roden (1999, 2000 and 2012) and Bruinsma *et al*. (2009), as well as examination of OSi 2005 orthophotographs and more recent satellite imagery during the distribution mapping process
5. for lake habitat 3160, Drinan (2012), other recent research into the impacts of conifer forest and peatland drainage on water quality, examination of OSi 2005 orthophotographs during the distribution mapping process, the Forest Service's Forestry 2007 forest cover data and the distribution of blanket peat.

Table 4 presents the pressures listed in Article 17 2013 for each of the five lake habitats, and for *Najas flexilis*. These pressures are mainly indirect and can be broadly categorised into pollution and hydrological change. Direct impacts have seldom been documented in Ireland, and generally on habitat 3160.

The following sub-sections provide summary information on the pressures under the broad headings of the impacts that manifest in freshwater. Further information can also be found in Section 4.5.

Eutrophication

Most of the pollution pressures listed lead to eutrophication of the lake habitats (H01.01, H01.02, H01.03, H01.04, H01.05, H01.08, H01.09, H02.06 and H02.07). Eutrophication is one of the best studied impacts in freshwaters and is widely monitored. It has been dealt with in Section 3.4.3 above and is the subject of much of Section 4.5 (4.5.6 to 4.5.12). In summary, enrichment with phosphorus and/or nitrogen increases primary production of phytoplankton, epiphytic and epipelic algae and/or vascular plants (macrophytes). All of these can compete with the characteristic species and communities of a lake habitat for the available resources, notably light, carbon dioxide, nutrients and space/substratum.

Acidification

There is limited evidence for acidification impacts on the biota of Irish lakes. However, the impact of acidification on *Najas flexilis*, i.e. reduced reproductive capacity, has been well documented in Scotland (Wingfield, 2004, and see NPWS 2013b for a summary).

[3] http://www.wfdireland.ie/docs/1_River%20Basin%20Management%20Plans%202009%20-%202015/

[4] http://www.wfdireland.net/wfd-charreport.html

Table 4 **Summary of 2013 pressures reported as impacting on Annex I lake habitats.** Note, the reporting format gave three importance categories: high, medium and low; limited the number of pressures that could be assigned 'high importance' to five and recommended using the fewest individual pressures possible.

	Lake habitat/species	**3110**		**3130**		**3140**		**3150**		**3160**		***Najas flexilis***	
Code	**Description**	**Rank**	Importance	**Rank**	Importance	**Rank**	Importance	**Rank**	Importance	**Rank**	Importance	**Rank**	Importance
C01.03.02	mechanical removal of peat **X**	4	High	5	High			11	Low	2	High		
H01.01	pollution to surface waters by industrial plants	6	Medium	6	Medium	3	High[3]	2	High			5	Medium
H01.02	pollution to surface waters by storm overflows	7	Medium			6	Medium						
H01.03	other point source pollution to surface water	8	Low	7	Low			3	Medium			6	Low
H01.04	diffuse pollution to surface waters via storm overflows or urban run-off							7	Low				
H01.05	diffuse pollution to surface waters due to agricultural and forestry activities	1	High	1	High	1	High	1	High	1	High	1	High
H01.08	diffuse pollution to surface waters due to household sewage and waste waters	5	High	2	High	8	Low	4	Medium	5	Low	2	High
H01.09	diffuse pollution to surface waters due to other sources not listed	2	High[1]	3	High[1]	5	Medium[1]	5	Medium			3	High
H02.06	diffuse groundwater pollution due to agricultural and forestry activities					2	High						
H02.07	diffuse groundwater pollution due to non-sewered population					4	High						
I01	invasive non-native species	10	Low	8	Low	7	Low	12	Low			7	Low
J02	human induced changes in hydraulic conditions	11	Low	9	Low							8	Low
J02.05	Modification of hydrographic functioning, general									4	High[6]		
J02.06.01	surface water abstractions for agriculture							10	Low				
J02.06.02	surface water abstractions for public water	9	Low			9	Low	8	Low				

	Lake habitat/species	3110		3130		3140		3150		3160		*Najas flexilis*	
Code	**Description**	**Rank**	Importance	**Rank**	Importance	**Rank**	Importance	**Rank**	Importance	**Rank**	Importance	**Rank**	Importance
	supply												
J02.06.10	other major surface water abstractions							9	Low				
J02.07	Water abstractions from groundwater	3	High[2]	4	High[2]			6	Medium[4]	3	High[5]	4	High
K01.02	silting up			10	Low							9	Low
K01.03	drying out			11	Low							10	Low
K02.01	species composition change (succession),			12	Low							11	Low
K02.02	accumulation of organic material			13	Low							12	Low

[1] predominately peatland drainage and degradation

[2] peatland drainage

[3] also covers discharges to groundwater

[4] used for land drainage and related activities

[5] peatland drainage in upstream catchment

[6] drainage of the outflow/downstream

Acid episodes have been recorded in Irish streams since the 1990s, and have mostly occurred during storm events (Allott, *et al*., 1997, Kelly-Quinn, *et al*., 1997, Feely *et al*., 2011). Atmospheric pollution (SOX and NOX) was identified as a cause of acidification in the 1990s, along with deposition of sea salts and organic acids. Coniferous forestry was found to increase the deposition of atmospheric pollutants (Allott, *et al*., 1997, Kelly-Quinn, *et al*., 1997). Since 1990, emissions of sulphur dioxide have decreased steadily in Ireland and across the EU. Added to that, the long-term trends in precipitation and throughfall at forest plots in Ireland show a steady decrease in sulphate concentration and a rise in pH (Aherne, Johnson and Cummins, 2012[5]). Three Irish lakes have been monitored by the EPA for acid sensitivity since the late 1980s and the lakes in counties Galway and Donegal have shown no evidence of inputs of artificial acidity, while the Wicklow lake has shown distinct improvements in pH and acid-sensitive invertebrates (Tierney *et al*., 2010). Hence, any acidification of surface waters in Ireland does not appear to be the result of deposition or scrubbing of atmospheric pollutants and the code H04.01, acid rain was judged to be inappropriate.

While organic acids were found to contribute little to acid episodes documented in the 1990s, high background levels were recorded in peatland catchments, with the highest levels found in peatland catchments with coniferous plantations (Allott *et al*., 1997). Recent work has demonstrated that Irish streams still experience acid episodes, with an increased risk downstream of plantation forestry, but in contrast to the 1990s, the primary driver is organic acids (Feely *et al*., 2011, 2013).

Higher organic acid levels are unsurprising in catchments dominated by organic soils. Disturbance of peaty soils by activities such as drainage and over-grazing, which lead to aeration and decomposition of organic matter, result in increased losses of organic acids to water. Plantation forestry on peatland may further increase organic acid losses through decomposition of the additional biomass produced by the trees.

Land drainage may also contribute to acidification impacts by effectively by-passing the natural buffering capacity within a catchment. Drains shorten the hydrological pathway for rainfall to surface waters and, therefore, reduce the potential for infiltration to soils and subsoils. The result is that the dissolution of cations by rainwater from mineral soils, subsoils or base-rich bedrock is reduced.

Codes C01.03.02X, H01.05 and H01.09 were used to cover acidification pressures from drainage and/or forestry on organic soils.

See also Section 4.5.13 for information on acidification in Ireland and potential impacts on lake habitats.

Invasive non-native species

Invasive non-native species (I01) are often considered to be one of the most significant pressures on biodiversity generally, and freshwater systems, in particular. 'Invasives' by definition show periods of extremely high biomass or population explosions and can certainly be very obtrusive. Perhaps surprisingly, however, there has been little measurement of the biological impacts of invasive species on native species and communities in natural or semi-natural Irish habitats. Furthermore, the biological and ecological interactions between native and invasive species are often poorly understood. Most importantly, the relationships between other pressures (i.e. other disturances or perturbations to structure and functions), most notably for freshwaters that of eutrophication, and the responses of invasive species are frequently overlooked.

[5] pp 175-204 http://www.ucd.ie/hydrofor/docs/HYDROFOR_Workshop.pdf

Aquatic macrophyte species such as *Crassula helmsii*, *Elodea nuttallii*, *Myriophyllum aquaticum*, *Azolla filiculoides* and *Lagarosiphon major* are considered to be invasive and have been recorded 'in the wild' in Ireland. From a rapid examination of the National Biodiversity Data Centre's Invasive Species Database, however, it appears that these species are recorded from very few Irish lakes. In terms of impacts on native lake vegetation, *Lagarosiphon major* is abundant in the northern and middle sections of Lough Corrib (Caffrey *et al*., 2010, Roden and Murphy, in prep.), where it is most likely to have impacted the 3130 or 3110 communities. Roden (2004) considered *Elodea canadensis as* a possible factor in the decline of the characteristic 3130 species *Najas flexilis* in Tully Lough. By contrast, he recorded both species co-occurring at three lakes without evidence of impact. Similarly in Scotland, *Elodea canadensis* was considered to impact on *Najas flexilis* at one lake (Wingfield *et al*., 2004), while *Elodea canadensis* and/or *E. nuttallii* co-occurred with the Annex II species at 15 lakes (Wingfield *et al*., 2004), and five Pertshire Lochs (Benthic Solutions, 2007) without evidence of significant impacts. Wingfield *et al*. (2004) considered that the potential for impact on *Najas flexilis* was likely dependent on time since introduction and lake morphology (worst in small, shallow lakes). Wingfield *et al*. (2004) also observed that competition is not always a problem, but is more likely to be where nutrients and light promote excessive growth

The zebra mussel, *Dreissena polymorpha*, is well established and abundant in many Irish lakes. They occurred in eight of the study sites in Roden and Murphy (in prep.), however ecological impacts could only be assigned to the zebra mussel in Lough Corrib, where they appeared to have contributed to the decline in krustenstein. Zebra mussels were abundant in three lakes (Arrow, Cullaunyheeda and Derravarragh), but the decline of charophyte and krustenstein communities in those lakes appeared to result from eutrophication impacts rather than competition for space with zebra mussels (Roden and Murphy, in prep.). In two lakes (Bleach and Lene), zebra mussels had low abundance and the authors suggested 'that lake enrichment leading to plankton blooms, krustenstein decay and a shallowing of the euphotic zone are necessary conditions for the explosive growth of the mussel, probably due to the filter feeder's need for a dense plankton concentration for growth.' The potential impact of zebra mussel on lake habitats remains uncertain, but will depend on the abundance of the alien species. There is increasing evidence of zebra mussels colonising fine substratum and vegetation, where they could compete directly with native species for space. Abundant zebra mussels could cause a shift in primary production from phytoplankton to benthic communities, resulting in higher water transparency and increased nutrients in the substratum and leading to characteristic species and communities being out-competed by filamentous algae and higher plants such as *Elodea canadensis*, *Lemna trisulca* and *Potamogeton* species.

Drainage

Capturing the impacts arising from land drainage was particularly challenging. Areas of wetland and other terrestrial habitats are frequently drained in Ireland and other parts of north-western Europe for purposes such as development, agriculture, forestry and peat-cutting, resulting in direct impacts to the terrestrial habitat and indirect impacts to downstream aquatic habitats and species. Code J02.07 'Water abstractions from groundwater' was used, at the Topic Centres suggestion, to indicate hydrological pressures arising from land drainage in the (upstream) catchment. It is open to debate whether the water within actively growing peat, or immediately below the ground surface in other soils, can be considered to be 'groundwater'. Code H01.09 'diffuse pollution to surface waters due to other sources not listed' was used to indicate pollution arising from such land drainage, particularly from drainage and degradation of peatland. J02.05 'Modification of hydrographic functioning, general' was used to indicate drainage/de-watering pressures resulting from drainage within or downstream of a lake or pond, i.e. where channels are excavated for the purpose of lowering the water table within the habitat.

Drainage within or downstream of a lake or pond can lead to significant direct damage or even the loss of the lake habitat, particularly habitat 3160. The impacts of upstream catchment land-drainage are complex: altering hydrology, particularly the pathways from land to water, and acting as a source of pollution. It is, therefore, difficult to separate drainage from the other issued detailed here. Drainage can be considered to impact on freshwaters in the following ways

1. Drains de-water and, therefore damage/destroy fringing wetlands and their associated diversity, which can impact lake structure and functions (see Section 4.5.15)
2. Decomposition of organic matter in the drained terrestrial soils (particularly peat) leads to **POLLUTION** with dissolved organic carbon, ammonia, etc.
3. Drainage changes the **HYDROLOGICAL REGIME** of receiving rivers and lakes
4. Hydrological changes, combined with increased sediment load in water lead to **EROSION** and **MORPHOLOGICAL CHANGE** in rivers and lakes
5. Drains act as a **SOURCE** of fine sediment
6. Drains provide a shorter more direct **PATHWAY** for sediment, dissolved and particulate nutrients and other pollutants (e.g. dissolved organic carbon from drained/damaged peatland, herbicides) to rivers/lakes
7. More direct **PATHWAY**s mean less contact time between water and soil, reducing the opportunities for nutrient binding and cycling, and for dissolution of minerals, altering the hydrochemistry of rivers/lakes
8. Drains are installed to facilitate land uses that typically increase the **SOURCE**s of sediment, nutrients and other pollutants

Significant impacts are likely on vegetation and invertebrate communities through physical disturbance, reduced light penetration and enrichment.

Damage to peatland

Most of the impacts associated with peatland degradation have been dealt with above. As well as leading to decreases in the pH of surface waters, disturbance to peatland typically causes increased water colour, increased dissolved and particulate organic carbon and increased ammonia losses. Drainage of peatland for peat-cutting, agriculture and forestry are the primary causes of such disturbance in Ireland. Dissolved and particulate organic carbon can increase production by heterotrophs, resulting in extensive fungal, bacterial and algal growths and potentially increasing nutrient cycling. Increased water colour and turbidity decrease light penetration. Particulate peat produces a relatively unstable substratum and macrophytes are generally sparse or absent from lakes with significant volumes of peat sediment.

A note on groundwater pathways

As many pressures impacting on lakes are indirect and often remote from the lake itself, it is very important to consider the pathways from the source to the habitat (receptor). The discussion on drainage above highlights some issues with surface and near-surface pathways. Understanding the pressures on the hard-water lake habitat (3140) is further complicated, however, by the significant groundwater contribution to these lakes. The precipitation of calcium carbonate in hard-water lakes demonstrates that a large percentage of the lake's water has at one time travelled through the ground, and specifically, base-rich bedrock or deposits. It is, however, difficult to determine the exact groundwater contribution to a hard-water lake, owing to the multiple and dispersed discharge points. Groundwater may discharge into inflowing streams or directly into the lake itself and the discharge points may vary in location and flow rates over time. This is an area worthy of significant investigation, as understanding groundwater flow paths and discharges is key to the identification of important sources of pollution and prioritisation of mitigation measures for hard-water lakes.

Craig *et al*. (2010) noted that elevated phosphate concentrations have been measured in the karstified aquifers, particularly where the groundwater is vulnerable to pollution and there are shallow soils and subsoils. Groundwater phosphate concentrations are currently measured against the phosphate standard for rivers of 35 µg P l^{-1}. This is a cause for concern because a sustained contribution of 35 µg P l^{-1} in dissolved form from groundwater could rapidly lead to exceedances of the 10 µg P l^{-1} or 20 µg P l^{-1} total phosphorus targets for oligotrophic or mesotrophic lakes. It is recommended that catchment-specific targets should be established for phosphorus in groundwater in hard-water lake catchments.

Habitat specific details on pressures and their impacts can be found in the 'Article 17 - Habitat Notes', particularly 'Field Label' 2.5 (NPWS, 2013b).

3.6 Overall status

The overall status of each lake habitat was assessed in accordance with EU Guidelines (see Table 5 below) (Evans and Arvella, 2011) and is presented in Table 6. Further information can be found in NPWS (2013b).

Table 5 Calculating the overall conservation status of a habitat. *From Evans and Arvella (2011).*

Category	**Favourable**	**Unfavourable – Inadequate**	**Unfavourable - Bad**	***Unknown***
	('green')	('amber')	('red')	*(insufficient information to make an assessment)*
Overall assessment of Conservation Status	All 'green' OR 3 'green' and 1 'unknown'	1 or more 'amber' but no 'red'	1 or more 'red'	*2 or more 'unknown' combined with green or all "unknown'*

It is worthy of note that the two lake habitats in bad status are arguably those for which Ireland has the greatest responsibility. Roden and Murphy (2013) said that the hard-water lake vegetation (3140) is uncommon in Europe, with some of the best European examples occurring in Ireland and that, as a result, their conservation value is very high and Ireland has a special responsibility in their protection. Ireland is also a stronghold for lake habitat 3110, where the habitat is widespread and abundant, particularly well developed and preserved.

Table 6 **The conservation status of Annex I lake habitats in Ireland in 2013.** Trends indicate whether the status has improved (↑), declined (↓) or remained the same (=) during the reporting period 2007-2012.

Habitat	3110		3130		3140		3150		3160	
Parameter	*Status*	*Trend*	*Status*	*Trend*	*Status*	*Trend*	*Status*	*Trend*	*Status*	*Trend*
Range	Favourable		Favourable		Favourable		Favourable		Favourable	
Area	Favourable		Favourable		Favourable		Favourable		Favourable	
Structure and Functions	Bad	↓	Inadequate	=	Bad	↓	Inadequate	=	Inadequate	↓
Future Prospects	Bad	↓	Inadequate	=	Bad	↓	Inadequate	=	Inadequate	=
Overall Conservation Status	**Bad**	↓	**Inadequate**	**=**	**Bad**	↓	**Inadequate**	**=**	**Inadequate**	↓

4. Site-specific conservation objectives

A site-specific conservation objective aims to define the favourable conservation condition of a habitat or species at site level. The maintenance of habitats and species within sites at favourable condition will contribute to the maintenance of favourable conservation status of those habitats and species at a national level.

Conservation objectives are defined using attributes and targets that are based on parameters as set out in the Habitats Directive for defining favourable status, namely area, range, and structure and functions. See Section 3 for information on how lake habitat conservation status is defined and reported on at national level.

Where a habitat is in favourable condition in a site, the conservation objective is to '**maintain'** that condition. Where a habitat is unfavourable, the objective is to '**restore'** the habitat and the notes attempt to highlight the specific attributes, particularly the relevant structures and functions, that require to be restored.

4.1 Irish SACs selected for lake habitats

As detailed in Section 2, Ireland was required to select SACs for five Annex I lake habitats:

1. 3110 Oligotrophic isoetid lake habitat
2. 3130 Mixed *Najas flexilis* lake habitat
3. 3140 Hard-water lake habitat
4. 3150 Rich pondweed lake habitat
5. 3160 Acid oligotrophic lake habitat

Figure 3 shows all SACs selected for these habitats and for *Najas flexilis*.

4.2 A note on natural variation in lake habitats, particularly coastal influences

Natural variation is expected within any habitat type and has already been documented for the hard-water lake habitat (Roden and Murphy, 2013, in prep.) (see also Section 2 above, particularly 2.4 and 2.8). Such variation means that the conservation objective targets differ among sites. In particular, coastal variants of the Annex I lake habitats may be naturally more productive, owing to the maritime influences (rain and wind-blown maritime nutrients and minerals). It is worthy of note that priority has been given to setting site-specific conservation objectives for coastal SACs, and that the targets for these lake habitats, particularly for water quality, may not be appropriate to naturally less-productive inland lakes. More stringent targets are set for the naturally oligotrophic sites. Similarly, the reports referenced in the site-specific objectives for coastal lakes may not be relevant to inland variants.

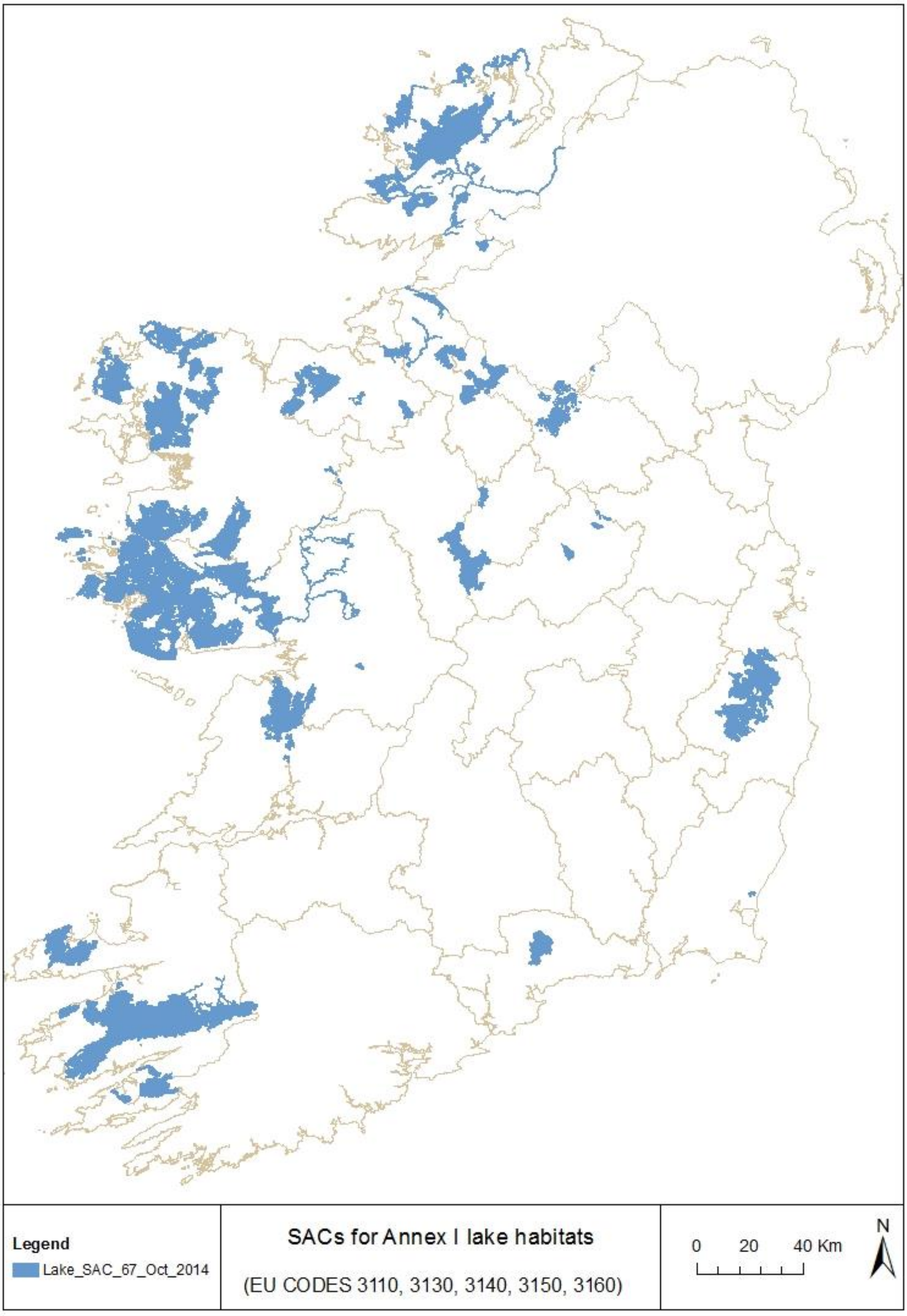


Figure 3 **Special Areas of Conservation (SACs) for Annex I lake habitats 3110, 3130, 3140, 3150 and 3160 in Ireland, and the Annex II lake macrophytes *Najas flexilis*.**

4.3 Habitat Range

Habitat range for the purposes of site-specific conservation objectives refers to the distribution of the habitat within the site.

The SACs selected for one or more lake habitats and/or *Najas flexilis* contain more c. 5,400 mapped lakes (based on the OSi 1:5,000 IG vector dataset WaterPolygons feature class 'lake' attribute), with Connemara Bog Complex SAC (site code 002034) alone having more than 1,100 mapped lakes and ponds within its boundary. While data on lake macrophytes are available from a number of sources, there has been little dedicated survey of Annex I lake habitats and/or lake vegetation in Ireland. All of these factors make mapping the distribution of the lake habitats difficult in many SACs.

An indicative lake habitat distribution map is provided with each site-specific conservation objective. A very small number of these are based on comprehensive survey of lake vegetation. In making the lake habitat distribution maps, an attempt is made to collate and use the best available information, however it is possible that relevant information may be overlooked during this desk study. Where no lake vegetation or macrophyte data are available, geological data, physico-chemical data, satellite imagery and orthophotography are sometimes used to classify a lake, in combination with expert judgement.

The notes provided with the site-specific objectives provide details, including references, for the data used to produce the distribution maps, and comment on the level of uncertainty in those maps.

Site-specific conservation objective maps are based on the OSi 1:5,000 IG vector dataset WaterPolygons feature class. This is in contrast to the Article 17 report, which used the 1:50,000 Discovery Series map base. The number of individual mapped lakes and ponds in a site, and the shoreline and areas of those individual features, will vary with the map-scale and version used.

In general, the steps involved in producing an indicative lake habitat distribution map for a site-specific conservation objective are as follows:

1. The lake habitat distribution maps developed for the 2013 Article 17 report are examined. The lake polygon data (see Section 3.2.5) are used, rather than the 10 kilometre square distributions. Many of the available reports and data on lake vegetation and macrophytes were used to produce these maps (e.g. Free *et al*., 2006, 2009, Heuff, 1984, Roden, 1999, 2000). See Section 3 on Article 17 reporting and NPWS (2013b) for further information.
2. SAC site files, particularly the Natura Forms and accompanying explanatory notes, are examined for additional information on lake vegetation and macrophytes.
3. If time allows,
    a. further literature searches are conducted, focussing on vegetation surveys and macrophyte records (e.g. county floras, the biomar study).
    b. hard-copy and electronic datasets held by NPWS are examined for macrophyte records (e.g. the scarce and rare plant database, record cards made for the aquatic plants atlas (Preston and Croft, 2001)).
    c. expert opinion is sought from within NPWS and, if possible, the wider botanical community.

These data are used to classify individual lakes/ponds into one or more of the five Annex I lake habitats. As explained in Section 2, the classification system is based on a working interpretation of these habitats for Irish lakes that may be subject to change. Artificial lakes and ponds, and coastal lagoons are not included, unless there are definitive data on the presence of the habitat(s) within the water body.

A lake habitat is generally mapped as occurring across the entire lake (i.e. the lake polygon is used) (see Figure 4 for an example). Where vegetation or macrophyte data are used to classify the lake habitat(s) present in a lake, the lake is mapped accordingly, e.g.:

- 3110 Oligotrophic isoetid lake habitat
- 3140 Hard-water lake habitat
- 3160 Acid oligotrophic lake habitat
- 3110 and 3130 Oligotrophic isoetid lake habitat and Mixed *Najas flexilis* lake habitat
- 3140 and 3150 Hard-water lake habitat and Rich pondweed lake habitat

Where other data are used, the lake is usually mapped as a potential habitat(s), e.g.:

- Potential 3130 Mixed *Najas flexilis* lake habitat
- Potential 3150 Rich pondweed lake habitat
- Potential 3160 Acid oligotrophic lake habitat
- Potential 3110 and/or 3130 Oligotrophic isoetid lake habitat and/or Mixed *Najas flexilis* lake habitat
- Potential 3140 and/or 3150 Hard-water lake habitat and/or Rich pondweed lake habitat

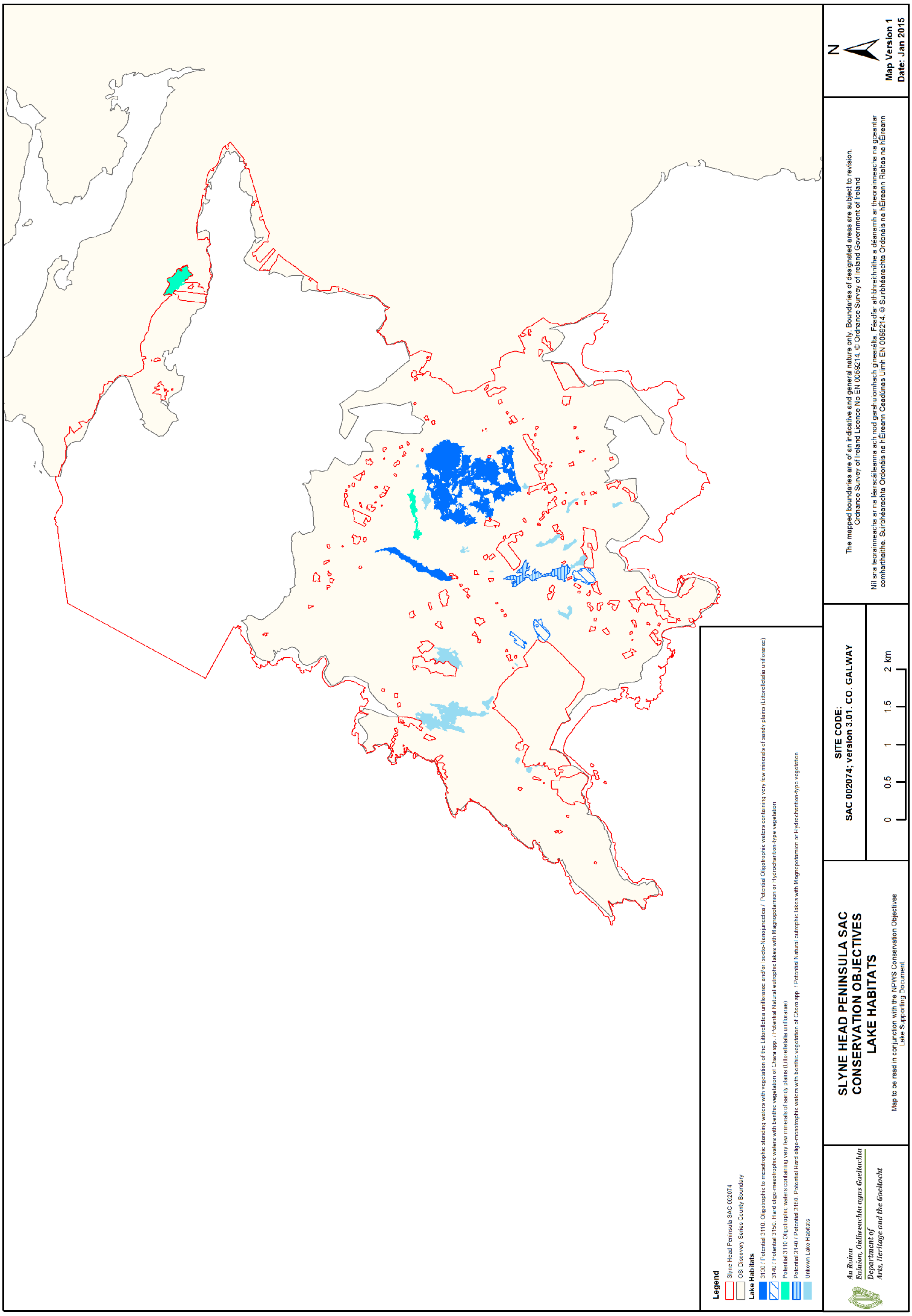
Not all lakes occurring within a site boundary will be mapped, for a number of reasons:

- The lake may not contain any Annex I lake habitats,
- The lake may contain an Annex I lake habitat that is not a qualifying interest for the site,
- There may be too little data or too much uncertainty to classify the lake.

In relation to uncertainty, coastal lakes again present the greatest difficulty in mapping, with the possibility of all five lake habitats occurring within close proximity to one another adjacent to the coast.

In most cases, the uncertainty as to the distribution of the lake habitats in the SAC will not influence the process of screening for AA or EIA as all five habitats are subject to similar pressures and threats (see Section 3 above and NPWS (2013b) for further information). Where a plan or project has the potential to have a significant effect on a lake habitat (i.e. where the habitat/lake has been 'screened-in'), classification and mapping of the habitats present in lakes will be necessary during the AA/EIA.

The **TARGET** for the habitat distribution attribute is: no decline, subject to natural processes.



surface area of a lake will vary, depending on the scale of the map used. Map version can also lead to variations in area, often as a result of modifications to lake shoreline and mapping of islands.

Where a habitat occurs in more than one lake in a site, the target is based on the sum of the areas, i.e. the total area of the lakes mapped in the habitat range (Section 4.3 above) as having or potentially having the habitat. The total lake surface area is used even where more than one habitat occurs in an individual lake.

The **TARGET** for lake area is: stable or increasing, subject to natural processes.

4.4.2 Habitat area

Detailed maps of lake vegetation are available for very few Irish lakes (see Roden and Murphy, 2013 for three hard-water examples). As a result, specific targets for habitat area can seldom be set. Where a plan or project has the potential to have a significant effect on a lake within an SAC (i.e. where the habitat/lake has been 'screened-in'), lake vegetation may have to be surveyed and its extent mapped during the AA/EIA.

Mapping lake habitats requires snorkelling survey. Regular quadrats should be sampled along transects from the shore to the maximum depth of vegetation colonisation. The location of each quadrat should be recorded from the support boat using a GPS device. Each quadrat should subsequently be classified according to its vegetation zone/community and habitat. The location and depth of each quadrat should be plotted and vegetation zones/communities and habitats interpolated and mapped, using orthophotographs, other imagery and any available bathymetric information. See Roden and Murphy (2013, in prep.) for further information on the recommended methodology.

Where the habitat is considered to be in favourable condition, the target for habitat area should be based on the sum of the vegetation zones/communities and any associated physical features that are characteristic for the habitat. Where there is evidence that the area of the habitat has decreased since the Directive came into force, or is insufficient to ensure its long-term maintenance in the lake, expert lake habitat judgement must be employed to set an appropriate target.

The **TARGET** for habitat area is: stable or increasing, subject to natural processes.

4.5 Structure and Functions

'Structure and functions' relate to the physical components of a habitat ("structure") and the ecological processes that drive it ("functions"). For lakes these include attributes such as hydrology, vegetation and various water quality attributes.

Where available, site-specific information on the condition of the structure and functions of the lake habitat is provided in the 'notes' field within the site-specific conservation objective.

4.5.1 Typical species

See Sections 2.7 to 2.10 and NPWS (2013b) for the lists of typical species for each of the five lake habitats and information on how these lists were derived. The lists were developed for the purposes of the 2013 Article 17 report, based on the working interpretation of lake habitats, and may be subject to change. Note that, in addition to plants (algae, bryophytes and vascular plants), the typical species for lake habitats include aquatic invertebrates (Sections 2.7 to 2.10, NPWS, 2013b).

It is likely that positive indicator species will be identified for each of the lake habitats over time. A number of positive indicators have already been identified for the hard-water lake habitat (see 'Core species' list in Table 1, Section 2.8) (Roden and Murphy, 2013, in prep.). Negative indicators are also useful and, for the hard-water lake habitat, the distribution of angiosperms is used (Roden and Murphy, 2013, in prep.).

Variation in typical species can be expected across the natural range of the lake habitats and particular attention should be paid to rare and threatened macrophytes and invertebrates, and to species with a restricted geographical distribution.

The **TARGET** for vegetation composition, typical species is: typical species should be present, in good condition, correctly distributed and demonstrate typical abundances.

4.5.2 Vegetation composition: characteristic zonation

The characteristic zonation of lake habitat 3140 has been described (see Table 1, Section 2.8) (Roden and Murphy, 2013, in prep.), however significant further work is necessary to describe the characteristic spatial patterns in the other lake habitats.

As discussed in Section 2.3, submerged lake vegetation is typified by continuous zones/bands, colonies or other patches dominated by individual species. The key environmental driver of these vegetation patterns is light penetration, leading to distinct changes with depth. Substratum particle size and chemistry are also important drivers of lake vegetation patterns, and are determined by catchment geology. Basin morphology and water currents also influence sediment sorting. Water chemistry is similarly determined by catchment geology, and currents in large or complex lakes, and is one of the drivers of lake vegetation that is most readily altered by catchment land-use. At the shoreline, wind/wave action is an important driver, influencing sediment deposition and erosion, with both rooting medium and disturbance by waves determining which species can colonise shallow water.

Spatial patterns in lake vegetation are usually readily distinguished by eye while snorkelling or diving, during the growing season. As for terrestrial vegetation, variation in vegetation colour, height, structure, growth-form and texture is discernible. Vegetation units also frequently intergrade with one another, leading to 'fuzzy' boundaries.

As noted above, the characteristic vegetation units of lake habitats 3110, 3130, 3150, 3160 in Ireland have yet to be described. A number of features of the vegetation units/zones are likely to make useful targets for this attribute, including spatial patterns (e.g. sequence with depth), character species, depth range, average depth and area, all of which have yet to be characterised.

Other indicators of the condition of vegetation units may include negative indicator species (e.g. macrophytes colonising charophyte zones, or growth of epiphyton) or vegetation 'health' (e.g. the krustenstein zone shows evidence of decay and is eventually absent from poor and bad condition hard-water lake habitat).

The **TARGET** for vegetation composition, characteristic zonation is: all characteristic zones should be present, correctly distributed and in good condition.

4.5.3 Vegetation distribution: maximum depth

The maximum depth of vegetation is often characteristic of the lake habitat, but can show some natural variation among lakes. An indicative target of > 6 m has been developed for the hard-water lake habitat (3140) (see Roden and Murphy, 2013, in prep.). Indicative targets need to be developed for the other lake habitats.

Within a lake, the maximum depth of vegetation is likely to vary along the shoreline, with exposure and morphology. A change over time in the maximum depth of vegetation at a location in a lake, however, usually indicates negative impacts, linked to decreased light penetration. Shading by phytoplankton (eutrophication) is the commonest cause of decreased light penetration, but increases in water colour or suspended sediment/turbidity can have the same result.

In undisturbed catchments, light penetration and, hence, maximum depth of vegetation is expected to be deep for all lake habitats. Lake habitats 3110 and 3130 are typically found in catchments dominated by peatland and it could be hypothesised that these habitats are associated with coloured or peat-stained water. This is unlikely to be a natural condition, however, as high colour is associated with damaged peatland, the mineralisation of peat and release of dissolved and particulate organic matter. Intact peatland catchments, by contrast, are associated with very clear water, as is illustrated by the depth range of *Najas flexilis*, typical species of habitat 3130, which can be found down to 10m depth (NPWS, 2013c, O Connor, 2013).

Information on the depth of vegetation in a lake may be available from a number of sources, such as EPA Water Framework Directive (WFD) monitoring, EPA WFD research (e.g. Free *et al.*, 2006, 2009), NPWS lake surveys (Heuff, 1984, Roden and Murphy, 2013, in prep) and other macrophyte surveys. Autecological accounts, such as those of Preston and Croft (2001) provide useful information on the depth ranges of the typical species.

The deepest vegetation colonisation is likely to be associated with corrie lakes (habitats 3110 and/or 3160) and deep hard-water/marl lakes (habitat 3140). Roden and Murphy (in prep) found abundant charophyte vegetation at the deepest point (9m) in Coolorta and at 10-11 m in Lough Rea.

The **TARGET** for vegetation distribution, maximum depth is: maintain maximum depth of vegetation, subject to natural processes.

4.5.4 Hydrological regime: water level fluctuations

Fluctuations in lake water level are almost ubiquitous in Ireland owing to the highly seasonal rainfall patterns. Water level fluctuations can, however, be amplified by a variety of anthropogenic activities including water abstractions, drainage of the lake outflow and land drainage in the upstream catchment. Upstream land drainage leads to more rapid run-off and is associated with other significant pressures, notably the degradation of peatlands leading to the release of organic acids, ammonia and other organic matter, and the intensification of agriculture, which is associated with increased soil erosion and nutrient loss. Drains also provide direct transport pathways for nutrients and other pollutants to lakes. See also Section 3.5.1.

Increased water level fluctuations can impact on lake vegetation, particularly at the upper depths of growth. The area of lake bed influenced by wave action typically increases and, hence, the substratum can be significantly altered. The results include loss of macrophyte habitat, up-rooting of plants through wave action and contraction of submerged vegetation zones. Turbidity can also increase, as a result of disturbance of fines by wave action, leading to decreased light penetration and loss of vegetation from the lower depths. Increased fluctuations can lead to nutrient releases from the littoral sediments, as a result of exposure and re-wetting, and consequent changes in species composition.

The hydrological regime of the lakes must be maintained so that the area, distribution and depth of the lake habitat and its constituent/characteristic vegetation zones and communities are not reduced.

The **TARGET** for the attribute hydrological regime, water level fluctuations is: Maintain appropriate natural hydrological regime necessary to support the lake habitat.

4.5.5 Lake substratum quality

Submerged macrophytes can grow on a range of substratum types (from peat to mineral to marl) and a range of particle sizes (cobble/grave to mud and silt), although smaller particle sizes are often favoured. Sediment chemistry is also likely to be important, notably the availability and forms of minerals such as iron and calcium. Further study is required to characterise substratum type (texture and origin) and substratum quality (notably pH, calcium, iron and nutrient concentrations) favoured by the Annex I lake habitats in Ireland.

Sections 2.6 to 2.10 and Appendix I include some information on lake habitats and substratum, and some notes are provided below. Information may also be available from sources such as EPA WFD monitoring, EPA WFD research (e.g. Free *et al.*, 2006, 2009), NPWS lake surveys (Heuff, 1984, Roden and Murphy, 2013, in prep) and other macrophyte surveys. Autecological accounts, such as those of Preston and Croft (2001), provide useful information on the substratum favoured by the typical species.

It is likely that the oligotrophic isoetid habitat (3110) is associated with a range of nutrient-poor substrates, from stones, cobble and gravel, through sands, silt, clay and peat. An association with highly organic fines is probably quite common. Substratum particle size is likely to vary with depth and exposure along the shoreline within a single lake.

The mixed *Najas flexilis* lake habitat (3130) is likely to be associated with a range of substrate types that are more productive/base-rich relative to those on which habitat 3110 is found. Substratum particle size is likely to vary with depth and along the shoreline within a single lake, however it should be noted that *Najas flexilis* is typically found on soft substrata of mud, silt or fine sand (Preston and Croft, 2001, Roden, 2002, 2004).

Habitat 3140 has a strong association with marl precipitation and soft muds, but larger particle sizes (up to and including bedrock) are also found in most hard-water lakes. Calcareous sands are common in coastal examples.

Relatively productive, soft muddy substrata are likely to dominate habitat 3150, while nutrient poor peat and silt are expected to be most common in habitat 3160.

When assessing the potential impacts of projects or plans on lake habitats, particular consideration should be given to enrichment of sediments with phosphorus, as well as changes to nitrogen cycling, both of which can cause significant changes to lake vegetation.

The **TARGET** for the attribute lake substratum quality is: Maintain appropriate substratum type, extent and chemistry to support the habitat.

4.5.6 Water quality: introduction

Water quality is a key driver of lake ecology. It has also been significantly impacted by anthropogenic activities, and eutrophication of freshwaters is one of the most significant environmental challenges globally.

Annex I lake habitats are typically associated with high water quality and the absence of eutrophication impacts. This is demonstrated by naturally low dissolved nutrients, clear water and low algal growth.

Nutrients are released to water from lands throughout a lake's catchment. Natural ecosystems are highly parsimonious in their use of nutrients however; maximising nutrient re-cycling and minimising losses, meaning that, under natural conditions, very small nutrient loads reach rivers and lakes from their catchments (Moss, 2008). Varied and widespread land-uses have, however, significantly disrupted natural processes and increased nutrient losses to water. Agriculture is the greatest exporter of phosphorus to surface waters in Ireland, followed by sewage discharges (see WFD Water Management Unit Action Plans[6]). Other important exporters of nutrients are industry, septic tanks (domestic wastewater treatment systems) and forestry.

A critical aspect of assessing whether an activity is likely to increase the nutrient load to a lake is understanding the pathway from the source to the receptor and the processes by which nutrients are mobilised. In this regard, it is important to note that the most sensitive Annex I lake habitats and sites are generally associated with high-risk pathways, namely

1. Wet to saturated, often highly organic soils overlying saturated and, frequently, thin subsoils and poorly productive aquifers. In this scenario, dissolved and particulate nutrients can rapidly be transferred to lakes through surface run-off, inter-flow, drains, ditches and other water courses. Such conditions are frequently found in the catchments of lakes with habitats 3110, 3130 and 3160.
2. Thin, highly-permeable soils and subsoils, overlying karstified limestone bedrock, with direct connections to the groundwater frequent (e.g. swallow holes, caves and turloughs). In this scenario, dissolved and particulate nutrients can be rapidly transferred to lakes via shallow to deep groundwater pathways. Groundwater pathways are associated with the hard-water lake habitat (3140), where groundwater springs and seepages emerge in lakes and/or in-flowing streams.

Nutrient enrichment increases primary production in phytoplankton, epiphytic and epipelic algae and in vascular plants (macrophytes). All of these can compete with the characteristic communities and species of the Annex I lake habitats for the available resources; notably light, carbon dioxide, nutrients and space/substratum. Charophytes, other algal species and communities and annual species, such as *Najas flexilis*, are particularly vulnerable; as well as most species/communities adapted to low

[6] at http://www.wfdireland.ie/docs/1_River%20Basin%20Management%20Plans%202009%20-%202015/

productivity environments. Species and communities of the lower levels of the euphotic zone are often the most vulnerable to eutrophication. Enrichment of the sediment, as well as of the water column, is a significant concern and an area that could benefit from further study.

The OECD fixed boundary system for lakes has been a model for assessing lake water quality since its development (OECD, 1982). It uses total phosphorus (TP), chlorophyll *a* and transparency (Secchi disk depth) to assess eutrophication impacts. Phosphorus is generally considered to be the limiting nutrient in freshwaters, hence TP concentration is the chosen indicator for nutrient enrichment. Chlorophyll *a* is a measure of phytoplankton biomass, while Secchi disk depth is an indicator of the reduction in transparency and shading caused by phytoplankton. Lakes are categorised, from lowest to highest productivity, as ultra-oligotrophic, oligotrophic, mesotrophic, eutrophic and hyper-eutrophic (see Table 7).

Table 7 OECD Fixed Boundary System for Lakes (OECD, 1982).

Trophic Category	**Annual mean TP**	**Annual mean chlorophyll *a***	**Annual peak chlorophyll *a***	**Annual Mean Secchi Disk Depth**	**Annual Minimum Secchi Disk Depth**
Units	µg l^{-1}	µg l^{-1}	µg l^{-1}	m	m
Ultra-oligotrophic	≤ 4.0	≤ 1.0	≤ 2.5	≥ 12.0	≥ 6.0
Oligotrophic	≤ 10.0	≤ 2.5	≤ 8.0	≥ 6.0	≥ 3.0
Mesotrophic	10 – 35	2.5 – 8	8 – 25	6 - 3	3 – 1.5
Eutrophic	35 – 100	8 – 25	25 – 75	3 – 1.5	1.5 – 0.7
Hyper-eutrophic	≥ 100	≥ 25	≥ 75	≤ 1.5	≤ 0.7

Lake water quality has been studied in Ireland since the mid-1970s, with work focussing on tracking changes in nutrient concentrations (particularly TP) and phytoplankton biomass (chlorophyll *a*), following the OECD approach. The lake monitoring methods were significantly augmented by the Irish EPA and associated researchers and consultants to meet the requirements of the WFD. This included the incorporation of a suite of new ecological indicators such as phytoplankton composition, phytobenthos status and macrophyte status. The EPA is responsible for co-ordinating the Irish WFD monitoring programme (which follows a three-year-cycle), for monitoring the lake biological quality elements (other than fish, which are monitored by Inland Fisheries Ireland) and for reporting on ecological status. WFD ecological status is categorised as high, good, moderate, poor or bad, with moderate, poor and bad all failing the WFD objectives. The approximate correspondence between the OECD system and the Irish WFD classification system is given in Table 8.

Table 8 Approximate correspondence between the OECD Fixed Boundary System for Lakes (OECD, 1982) and the EPA WFD ecological status classification system.

WFD Status	**WFD Colour Code**	**WFD pass/fail**	**OECD Trophic Category**
High		Pass	**Ultra-oligotrophic and Oligotrophic**
Good		Pass	**Mesotrophic**
Moderate		Fail	**Eutrophic**
Poor		Fail	**Hyper-eutrophic**
Bad		Fail	**Hyper-eutrophic**

As a result of the WFD monitoring programme, and earlier lake monitoring-programmes, significant quantities of data are available on lake water quality from the EPA and Local Authorities. The data have been used to define and support the achievement of general environmental (i.e. water quality) objectives. While achieving a general level of water quality is of inestimable importance for human health, society and economy, it does promote a 'lowest common denominator' approach to the management of freshwater resources that is inappropriate to the more sensitive freshwater habitats and species. Consequently, general water quality standards and thresholds are unlikely to support the achievement of nature conservation objectives for the more sensitive Annex I lake habitats. In the absence of habitat-specific information, however, general water quality standards and thresholds are used here, adopting a precautionary approach. Table 9 below summarises the approach used for site-specific conservation objectives and in the 2013 Article 17 report, namely that

1. The oligotrophic isoetid lake habitat 3110 by definition requires oligotrophic conditions ('**Oligotrophic** waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*)') and is, therefore, defined as requiring high status.

2. A precautionary approach was used in setting water quality targets for the mixed *Najas flexilis* lake habitat 3130, as it is assumed to be associated with naturally oligotrophic waters. Habitat 3130 is, therefore, defined as requiring high status. Adopting high status targets for lake habitat 3130 is in line with the targets used for *Najas flexilis*, a characteristic species of the habitat (NPWS, 2013 b and c). This may be overly stringent for both the species and the habitat, however, the alternative WFD target of 'good status' is considered to be insufficient to ensure favourable structure and functions. It is clear that *Najas flexilis* can be impacted by eutrophication well below the good-moderate boundary. It is likely that the most appropriate target lies somewhere between the high/good and the good/moderate boundaries established for WFD purposes. When one considers, however, that summer chlorophyll *a* typically had a concentration of c. 4 $\mu g\ l^{-1}$ in Irish lakes considered to be in reference condition (Free *et al*., 2006) and given that *Najas flexilis* was formerly more widespread in Ireland and Europe (Godwin, 1975), it is reasonable to assume that favourable and viable populations of the species and, by extension, its habitat, existed in oligotrophic lakes before large-scale anthropogenic land-use change.

3. The best examples of the hard-water lake habitat 3140, including the majority of SACs selected for the habitat, are associated with karstified limestone, marl deposition and extremely low nutrients. For lakes in catchments dominated by shallow soils and subsoils and exposed limestone pavement (i.e. catchments with extreme groundwater vulnerability), the target is, therefore, high status. Coastal sub-types are thought likely to be naturally more productive (see Section 4.2) and, therefore, a target of 'good status' is used. 'Good status' may also be set as the target in larger, more-mixed catchments with deeper soils and lower groundwater vulnerability, as these too may naturally be more productive. The approach to setting targets for hard-water (3140) habitats (i.e. high or good status, depending on assumed natural productivity) could be considered insufficiently stringent, as the natural, un-impacted trophic status of all Irish hard-water lakes is very likely to have been oligotrophic or even ultra-oligotrophic. On the other hand, hard-water lakes by definition have a high groundwater contribution and groundwater pathways are expected to provide pollutant attenuation, while high calcium carbonate concentrations may provide some in-lake buffering against phosphorus enrichment.

4. A target of 'good status' or better is used for the rich pondweed lake habitat 3150, however, habitat sub-types with a range of variation in requirements may be identified over time. It is possible that some sub-types are tolerant of a degree of eutrophication, whilst others may require conditions that are close to the 'high-good' boundary. See Section 2.9 for further information.

5. 3160 by definition requires very low nutrient waters and, therefore, the target is high status. The appropriateness of using standard WFD metrics for the acid oligotrophic lake habitat must be severely questioned, however. Enrichment of this habitat is likely to be driven by losses of ammonia and organic matter (including DOC) from degraded peatland and associated land-uses, rather than by dissolved and particulate phosphorus. The manifestation of such enrichment will be markedly different too, particularly given that the highly coloured waters associated with peatland degradation are likely to limit phytoplankton growth. Heterotrophic communities are more likely to flourish in such circumstances. Consequently, for habitat 3160, appropriate targets will need to be developed for attributes such as DOC, abundance of bacterial, fungal and associated communities, etc.

Table 9 **Water quality requirements of the five Annex I lake habitats in Ireland.** Water quality requirements are given as WFD status and OECD trophic status. See also Figure 5.

Annex I lake habitat	**Requirements WFD Status**	**Corresponding OECD Trophic Category**
3110	High	**Ultra-oligotrophic and Oligotrophic**
3130	High	**Oligotrophic**
3140	**High** (most) or Good	**Ultra-oligotrophic and Oligotrophic** or Mesotrophic
3150	Good	**Mesotrophic**
3160	High	**Ultra-oligotrophic and Oligotrophic**

Figure 5 illustrates that the true targets for the Annex I lake habitats are unlikely to lie on the WFD 'high-good' boundary, but within 'high status' (for 3110, most sub-types of 3140 and 3160), close to the 'high-good' boundary (for 3130), and within 'good status' (for 3150).

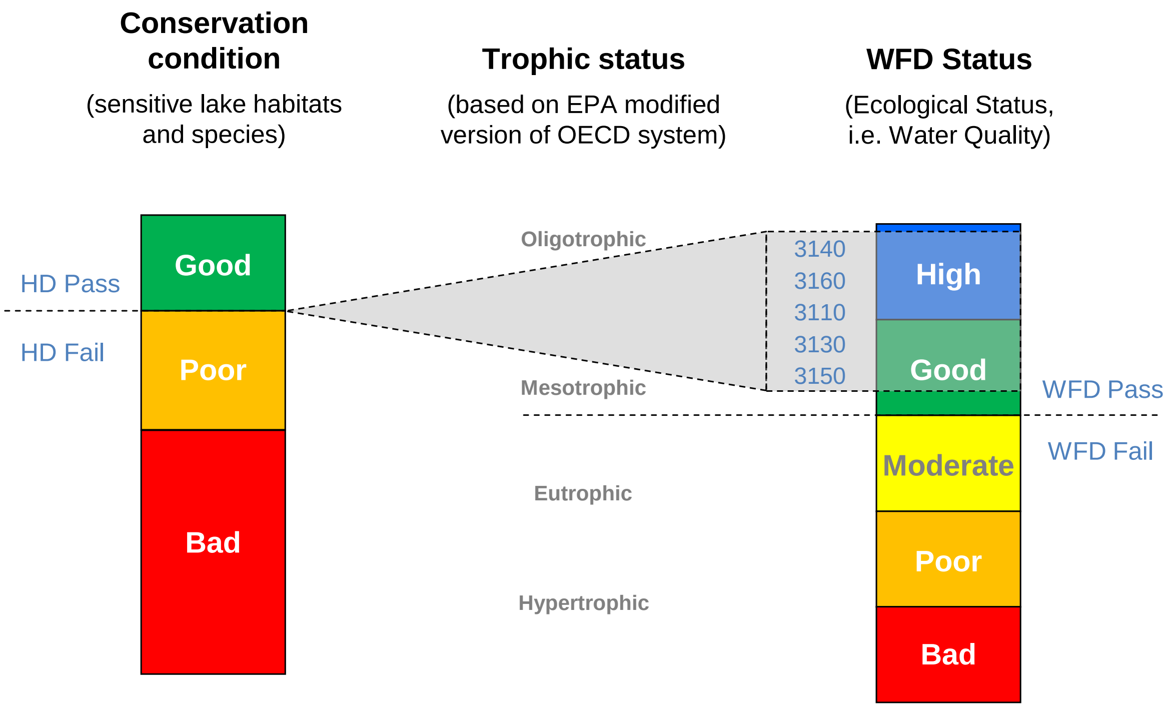


Figure 5 **The approximate correspondence between status under the Habitats Directive (HD) and the Water Framework Directive (WFD) for Annex I lake habitats.** The status of individual sites is recorded as 'conservation condition' under the HD and as 'ecological status' under the WFD. For each Annex I lake habitat, a specific target needs to be set. It is unlikely that these targets will correspond to the established WFD 'high-good' boundary. It is also likely that some of the lake habitats, e.g. 3140 will require more than one target, as a result of variation in requirements among habitat sub-types.

The following water quality attributes are used for Annex I lake habitats and expanded upon below

1. Transparency
2. Nutrients
3. Phytoplankton biomass
4. Phytoplankton composition
5. Attached algal biomass
6. Macrophyte status

4.5.7 Water quality: transparency

Transparency, traditionally measured using a Secchi disk, is related to light penetration through water and, hence, to the depth of colonisation of vegetation (see Section 4.5.3). Transparency can be affected by phytoplankton blooms (Section 4.5.9), water colour (Section 4.5.14) and turbidity (Section 4.5.15).

A target of at least 4 m has been established for hard-water lake habitat (3140) (Roden and Murphy, in prep.), however in the clearest, highest conservation value hard-water lakes it should be at least 6 m (Roden and Murphy, 2013). Habitat-specific targets will be established for the remaining lake habitats with time, but are likely to require some site-specific modifications. There should be no decline in Secchi depth/transparency at a site.

Indicative transparency targets are given in Table 10. The oligotrophic isoetid lake habitat (3110) is found in very clear water. The OECD fixed boundary system set transparency targets for oligotrophic lakes of ≥ 6 m annual mean Secchi disk depth and ≥ 3 m annual minimum Secchi disk depth. Free *et al*. (2009) highlighted the association between isoetid lakes and high transparency. The lakes they surveyed with the highest isoetid abundance had average Secchi depths of greater than 3 m. Heuff (1984) found Secchi depth of 12.25 m at Coumshingaun, Co. Waterford, a very clear, nutrient poor corrie lake considered likely to contain both the oligotrophic isoetid (3110) and acid oligotrophic (3160) lake habitats.

Table 10 **Indicative transparency targets for Irish lake habitats.** The relevant OECD (1982) boundaries are also provided. Where the annual minimum at a site is greater than the target, there should be no decline.

Annex I habitat	Annual min. Secchi disk depth	Trophic Category	OECD Annual Mean Secchi Disk Depth	OECD Annual Minimum Secchi Disk Depth
Units	m	At least	m	m
3110	≥ 3	Oligotrophic	≥ 6	≥ 3
3130		Oligotrophic	≥ 6	≥ 3
3140 (oligotrophic) [1]	≥ 6	Oligotrophic	≥ 6	≥ 3
3140 (mesotrophic) [1]	≥ 4	Mesotrophic	6 - 3	3 – 1.5
3150		Mesotrophic	6 - 3	3 – 1.5
3160		Ultra-oligotrophic	≥ 12	≥ 6

[1] The majority of Irish lakes containing habitat 3140 require oligotrophic conditions. Current trophic status cannot be taken as indicative of the productivity required to maintain the habitat at favourable condition. For many hard-water lakes, the target is restoration to oligotrophic conditions. The mesotrophic examples of the hard-water lake habitat are restricted to very large, low-lying catchments with deep soils and subsoils (e.g. the Shannon) and some coastal lakes. The hard-water habitat found in catchments dominated by karst and high groundwater vulnerability requires oligotrophic conditions.

The **TARGET** for the attribute water quality, transparency is: Maintain appropriate Secchi transparency to support the habitat.

4.5.8 Water quality: nutrients

The specific targets for nutrient concentration vary among habitats and habitat sub-types. The targets for habitat 3110 and for many examples of 3140 are at least oligotrophic and WFD 'high' status. These are also the working targets for habitat 3130 (see Section 4.5.6 above, O Connor, 2013, NPWS, 2013c and supporting documents for site-specific conservation objectives for *Najas flexilis* for more information). The target for habitat 3150 and some examples of habitat 3140 is at least mesotrophic or good status. The target for habitat 3160 is ultra-oligotrophic.

These should be taken as indicative targets only and considerable among-site variability is likely. A precautionary approach must be adopted in setting lake-specific targets. There should be no decline within class, i.e. no upward trend in nutrient concentrations.

No WFD standards have yet been set for total phosphorus in Irish lakes, however the Irish EPA used an interim high status value of annual mean total phosphorus (TP) of less than 10 µg l^{-1} for 2007-2009 status classification (Tierney *et al*., 2010). This same threshold was used as the oligotrophic lake standard in the since repealed Phosphorus Regulations (S.I. 258 of 1998) (McGarrigle *et al*., 2002, EPA, 2001). As a result, an annual mean TP of ≤ 10 µg l^{-1} is considered necessary for habitat 3110, 3130 and many examples of 3140. Where the mean TP concentrations are lower than this standard, there should be no increase in annual mean, i.e. no upward trends.

Total ammonia in oligotrophic lakes should also be in high status as defined by Schedule Five of the European Communities Environmental Objectives (Surface Waters) Regulations (S.I. 272 of 2009), that is mean annual total ammonia of ≤ 0.040 mg N l^{-1} or annual 95th percentile of ≤ 0.090 mg N l^{-1}.

For more productive examples of the hard-water lake habitat (3140) and the rich pondweed lake habitat (3150) the target is mesotrophic or good status, as a minimum.

The targets for total phosphorus and total ammonia concentrations for all five Annex I lake habitats are provided in Table 11 below.

Table 11 Nutrient concentration targets for the five Annex I lake habitats. These are based on Schedule Five of the European Communities Environmental Objectives (Surface Waters) Regulations (S.I. 272 of 2009) and Tierney *et al*. (2010). Where the annual average or the 95th percentile at a site is lower than the target, there should be no decline.

Annex I habitat	**Mean Total Phosphorus**	**Mean Total Ammonia**	**Total Ammonia – annual 95th percentile**
Units	µg P l^{-1}	mg N l^{-1}	mg N l^{-1}
3110	≤ 10	≤ 0.040	≤ 0.090
3130	≤ 10	≤ 0.040	≤ 0.090
3140 (oligotrophic) [1]	≤ 10	≤ 0.040	≤ 0.090
3140 (mesotrophic) [1]	≤ 20	≤ 0.065	≤ 0.140
3150	≤ 20	≤ 0.065	≤ 0.140
3160	≤ 5 [2]	≤ 0.040	≤ 0.090

[1] The majority of Irish lakes containing habitat 3140 require oligotrophic conditions. Current trophic status cannot be taken as indicative of the productivity required to maintain the habitat at favourable condition. For many hard-water lakes, the target is restoration to oligotrophic conditions. The mesotrophic examples of the hard-water lake habitat are restricted to very large, low-lying catchments with deep soils and subsoils (e.g. the Shannon) and some coastal lakes. The hard-water habitat found in catchments dominated by karst and high groundwater vulnerability requires oligotrophic conditions.

[2] Target based on the Phosphorus Regulations[7] Quality standards for ultra-oligotrophic Irish Lakes. It should be noted that the OECD (1982) boundary for ultra-oligotrophic lakes is ≤ 4 µg P l^{-1}

[7] The Local Government (Water Pollution) Act 1977 (Water Quality Standards for Phosphorus) Regulations 1998 (S.I. No. 258 of 1998), which were repealed by the European Communities Environmental Objectives (Surface Waters) Regulations (S.I. 272 of 2009)
7

The **TARGET** for the attribute water quality, nutrients is: Maintain average annual TP concentration of ≤ 5µg l^{-1} TP, ≤ 10µg l^{-1} TP or ≤ 20µg l^{-1} TP, or lower, as appropriate, maintain average annual total ammonia concentration of ≤ 0.040 mg N l^{-1} or ≤ 0.090 mg N l^{-1}, or lower, as appropriate, and maintain annual 95th percentile for total ammonia concentration of ≤ 0.090 mg N l^{-1} or ≤ 0.090 mg N l^{-1}, or lower, as appropriate.

4.5.9 Water quality: phytoplankton biomass

Nutrient enrichment (with phosphorus and/or nitrogen) commonly promotes phytoplankton growth leading to reduced light penetration and shading of submerged vegetation. This in turn can lead to contraction of the submerged vegetation and/or changes in vegetation zonation and species composition. Phytoplankton biomass is commonly measured as chlorophyll *a*. As for other water quality indicators, habitats 3110, 3130, 3160 and most examples of 3140 require WFD high status, whilst habitat 3150 and the naturally more productive examples for the hard-water habitat (3140) require at least WFD good status.

Schedule Five of the European Communities Environmental Objectives (Surface Waters) Regulations (S.I. 272 of 2009) establishes the criteria for calculating lake status using chlorophyll *a*. Two sets of thresholds are given, linked to lake types. The thresholds established for the moderate and higher alkalinity types (7, 8, 11 and 12) are considered appropriate for all lake habitats, as no standards have yet been set for low alkalinity, deep/shallow and small lakes (types 1 and 3), which might be more relevant for habitats 3110 and 3160.

Table 12 presents the appropriate boundaries, based on the Irish WFD standards, for the Annex I lake habitats. It also gives the relevant OECD fixed boundaries for the purpose of comparison. The OECD boundaries should also be given consideration when undertaking any assessments or designing conservation measures, particularly for the acid oligotrophic lake habitat (3160).

The **TARGET** for the attribute water quality, phytoplankton biomass is: Maintain average growing season (March-October) chlorophyll *a* concentration of < 5.8 µg l^{-1} or < 10 µg l^{-1}, or lower, as appropriate.

Table 12 **Targets for chlorophyll *a* concentration for the five Annex I lake habitats.** These are based on Schedule Five of the European Communities Environmental Objectives (Surface Waters) Regulations (S.I. 272 of 2009) and the OECD fixed boundary system (OECD, 1982). Where the average concentration at a site is lower than the target, there should be no decline.

Annex I habitat	**WFD Status**	**Growing Season Mean [2] Chlorophyll *a***	**Trophic Category**	**OECD Annual Mean Chlorophyll *a***	**OECD Annual peak Chlorophyll *a***
Units		$\mu g\ l^{-1}$	At least	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$
3110	High	< 5.8	Oligotrophic	≤ 2.5	≤ 8.0
3130	High	< 5.8	Oligotrophic	≤ 2.5	≤ 8.0
3140 (oligotrophic) [1]	High	< 5.8	Oligotrophic	≤ 2.5	≤ 8.0
3140 (mesotrophic) [1]	Good	< 10	Mesotrophic	2.5 – 8.0	8.0 – 25.0
3150	Good	< 10	Mesotrophic	2.5 – 8.0	
3160	High	< 5.8 [3]	Ultra-oligotrophic	≤ 1.0	≤ 2.5

[1] The majority of Irish lakes containing habitat 3140 require oligotrophic conditions. Current chlorophyll concentrations cannot be taken as indicative of the phytoplankton biomass required to maintain the habitat at favourable condition. For many hard-water lakes, the target is restoration to oligotrophic conditions. The mesotrophic examples of the hard-water lake habitat are restricted to very large, low-lying catchments with deep soils and subsoils (e.g. the Shannon) and some coastal lakes. The hard-water habitat found in catchments dominated by karst and high groundwater vulnerability requires oligotrophic conditions.

[2] Growing season is taken as March to October and the mean must be based on a minimum of four samples distributed across that growing season.

[3] Growing season mean chlorophyll *a* concentration would be expected to be significantly lower than this target in acid oligotrophic lake habitats.

4.5.10 Water quality: phytoplankton composition

The EPA has developed a phytoplankton composition metric for nutrient enrichment of Irish lakes. As for other water quality indicators, habitats 3110, 3130, 3160 and most examples of 3140 require WFD high status, whilst habitat 3150 and the naturally more productive examples for the hard-water habitat (3140) require at least WFD good status.

The **TARGET** for the attribute water quality, phytoplankton composition is: Maintain high or good phytoplankton composition status, as appropriate

4.5.11 Water quality: attached algal biomass

Nutrient enrichment can favour epiphytic (attached to plants) and epipelic (attached to substratum) algal communities that can out-compete the characteristic vegetation. The cover abundance of attached algae should, therefore, be low.

The EPA monitors the phytobenthos status of Irish lakes for WFD purposes. Phytobenthos status may be useful as an indicator of increases in attached algal biomass. As for other water quality indicators, habitats 3110, 3130, 3160 and most examples of 3140 require WFD high status, whilst habitat 3150 and the naturally more productive examples for the hard-water habitat (3140) require at least WFD good status.

The **TARGET** for the attribute water quality, attached algal biomass is: Maintain trace/ absent attached algal biomass (< 5% cover) and high phytobenthos status.

4.5.12 Water quality: macrophyte status

Nutrient enrichment can also favour more competitive submerged macrophyte species that can out-compete the typical and characteristic species for the lake habitat. The EPA monitors macrophyte status for Water Framework Directive purposes using the 'Free Index'. Schedule Five of the European Communities Environmental Objectives (Surface Waters) Regulations (S.I. 272 of 2009) sets the Ecological Quality Ratio (EQR) for lake macrophytes as ≥ 0.90 for high status and ≥ 0.68 for good status.

As for other water quality indicators, habitats 3110, 3130, 3160 and most examples of 3140 require WFD high status, whilst habitat 3150 and the naturally more productive examples for the hard-water habitat (3140) require at least WFD good status.

The **TARGET** for the attribute water quality, macrophyte status is: Maintain high or good macrophyte status, as appropriate.

4.5.13 Acidification status

Acidification can impact on species abundance and composition in soft-water lake habitats, which have low availability of bicarbonate and poor acid neutralising capacity (Moss, 1998, Duigan, *et al*., 2006). As a result, acidification is a concern for lake habitats 3110, 3130 and 3160, but not usually for 3140 or 3150.

In the Netherlands, Germany, Belgium, Denmark and Poland, acidification of isoetid lakes leads to a succession to vegetation dominated by submerged *Sphagnum* mosses and *Juncus bulbosus* and the loss of isoetids (Arts, 2002). *Lobellia dortmanna* is the most sensitive of the isoetids to acidification, followed by the *Isoetes* spp., with *Littorella uniflora* the most tolerant (Arts, 2002). This loss of isoetids has not, however been demonstrated in Great Britain, Ireland or other parts of Scandinavia. The differences in the response of isoetid lakes to acidification could reflect different stages along the successional process or differences in the lake and catchment characteristics (Arts, 2002).

The processes that drive the submerged vegetation's response to acidification are complex, with the calcium bicarbonate content of the substratum and the availability and form of inorganic nitrogen apparently important factors (Arts, 2002). Isoetids have slow growth rates and are adapted to oligotrophic waters with low dissolved CO_2 and nitrogen (Arts, 2002). Acidification leads to the release of CO_2 where calcium bicarbonate is present in the sediment and an increase in dissolved CO_2 favours *Juncus bulbosus* and submerged *Sphagnum* species[8] over isoetids (Arts, 2002). The effects of acidification on nitrogen chemistry and isoetids are complex. Isoetids require nitrogen in the form of nitrate and may not be capable of growth or out-competed in lakes with high ammonium concentrations. Acidification appears to change nitrogen cycling within lakes, most likely by inhibition of nitrification (the oxidation of ammonium (NH_4^+) to nitrite (NO_2^-) and then to nitrate (NO_3^-) by bacteria), which requires oxygen and a neutral to alkaline pH (Arts, 2002, Otte, 2003, Jeschke *et al*., 2013). As well as the likely increase in ammonium due to the inhibition of nitrification, the form and concentration of nitrogen in lakes may be driven by its sources, notably peatland drainage and increased livestock density in the catchment. It is likely that degradation of peatland can lead to both

[8] *Juncus bulbosus* and *Sphagnum* species can absorb carbon through their leaves and have higher growth rates than isoetids. *Juncus bulbosus* can also grow in lower light levels and at lower temperatures than isoetids.

an increased ammonium load and acidification of lakes (Allott *et al*., 1997). It should be noted that acidification of the water as a result of acid deposition is not generally a problem in Ireland. See Section 3.5.1, '*Acidification*' and O Connor (2013) for further information.

Of the typical species of habitat 3110, a number have been described as intolerant of conditions in acid water below pH 5.5, including *Pilularia globulifera, Potamogeton polygonifolius* and *Isoetes echinospora* (Arts, 2002). In addition, the following typical species of habitat 3130 were considered intolerant of pH < 5.5: *Apium inundatum, Elatine hexandra, Nitella flexilis, Potamogeton gramineus* and *Potamogeton obtusifolius* (Arts, 2002). High H^+ concentration may be toxic to some of these species (Arts, 2002). *Myriophyllum alterniflorum* appears to be intolerant of pH < 5.5 in Scandinavia and parts of continental Europe, however it can be associated with acid conditions in Great Britain and Ireland (Preston and Croft, 2001, Arts, 2002, Duigan *et al*., 2006).

The specific requirements of the three soft-water to neutral lake habitats (3110, 3130 and 3160) in terms of water and sediment pH, alkalinity and cation concentration have not been determined. The EPA monitors lake acidification status under the WFD and has established a pH standard range for soft-waters (where water hardness is ≤ 100 mg l^{-1} $CaCO_3$[9]) of > 4.5 and < 9.0 pH units (Schedule Five of the European Communities Environmental Objectives (Surface Waters) Regulations (S.I. 272 of 2009)). Arts (2002) documents changes to soft-water communities (particularly Isoetids) below pH 5.5. Free *et al*. (2009) noted acidification pressure in a cluster of isoetid lakes with negative alkalinities and pH below 5.2; *Isoetes lacustris* was present in this cluster, but *Lobelia dortmanna* and *Eriocaulon aquaticum* were absent. The authors suggested that other environmental factors, such as high colour and deep depth, could also have contributed to the absence of these species (Free *et al*., 2009).

For the oligotrophic isoetid lake habitat (3110), and adopting a precautionary approach based on Arts (2002), **minimum** pH should not be < 5.5 pH units.

For the mixed *Najas flexilis* lake habitat (3130), the targets used for the Annex II lake macrophyte *Najas flexilis* can be adopted, on an interim basis. **Median** pH values should be greater than 7 pH units. See O Connor (2013) NPWS (2013c) and supporting documents for sites-specific conservation objectives for *Najas flexilis* for more information.

Although CEC (2013) describes acid oligotrophic lakes and ponds (3160) as follows: "pH is often low, 3 to 6", Drinan (2012) measured pH in 13 blanket bog lakes bimonthly over 12 months and found that the six upland lakes had a mean pH of 5.16 and a range of 4.69-5.61, seven lowland lakes had a mean pH of 5.62 and a range of 4.81-6.18. As a result, the target for pH for lake habitat 3160 in Ireland is > 4.5 and < 9.0 pH units, in line with the surface water standards.

In alkaline water bodies, there is a risk that pH can become toxically high, owing to an increase in photosynthesis leading to the release of hydroxyl ions (OH^-) (Otsuki and Wetzel 1973, 1974). The lethal effects of most alkalis appear when pH is near 9.5, although many organisms are more sensitive (Wetzel and Likens, 1991). High pH also affects nitrogen chemistry, increasing the availability of toxic NH_3 ions. It should be remembered that nutrient enrichment, by driving increases in photosynthesis, is likely to contribute to elevations to toxic pH levels. The target for pH for lake habitat 3140 in Ireland is < 9.0 pH units, in line with the surface water standards.

In addition, water and sediment alkalinity and concentrations of cations should be appropriate to the habitat and its typical species.

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[9] Note, where water hardness is > 100 mg l^{-1} $CaCO_3$, the range is 6.0< pH < 9.0

The **TARGET** for the attribute acidification status is: Maintain appropriate water and sediment pH, alkalinity and cation concentrations to support the lake habitat subject to natural processes.

4.5.14 Water colour

Increased water colour and turbidity decrease light penetration and can reduce the area of available habitat for lake macrophytes, particularly at the lower euphotic depths. The primary source of increased water colour in Ireland is disturbance to peatland. Drainage of peatland for peat-cutting, agriculture and forestry, as well as over-grazing by sheep, are significant causes of such disturbance in Ireland. It should be noted that water colour can be very low in catchments dominated by peatland where that peatland is intact and actively growing.

No habitat-specific or national standards for water colour currently exist. A study of 199 Irish lakes produced a range for colour of 5 – 258 mg l^{-1} PtCo and a median of 38 mg l^{-1} PtCo (Free, *et al*., 2000). It is likely that the water colour in all Irish lake habitats would naturally be < 50 mg l^{-1} PtCo. Of the 197 lakes nationally for which data on colour were available in Free *et al*. (2006), the average and median concentrations were 41 mg l^{-1} PtCo and 33 mg l^{-1} PtCo, respectively.

Water colour can be extremely low in the oligotrophic hard-water lake habitat, but also in lakes with the oligotrophic isoetid lake habitat (3110) and the acid oligotrophic habitat (3160). Lakes with these habitats frequently have colour of < 20 mg l^{-1} PtCo or even < 10 mg l^{-1} PtCo (based on data presented in Free *et al*. (2006)), with hard-water lakes such as Lough Owel having very low to negligible colour.

Data were available from 16 lakes with *Najas flexilis* from Table 3.3 of Free *et al*. (2006). The range was 10 – 74 mg l^{-1} PtCo, the median 22.5 mg l^{-1} PtCo, 11 of the values were below 30 mg l^{-1} PtCo and five were below 20 mg l^{-1} PtCo. At least half of these lakes are known to have peat-cutting or other peatland degradation in their catchments, however, so the natural colour of the lakes may be lower. It is reasonable to assume, therefore, that water colour is generally < 30 mg l^{-1} PtCo or, more naturally, < 20 mg l^{-1} PtCo in lakes with habitat 3130, where the peatland in the lake's catchment is intact.

Data were available from 19 hard-water lakes (3140) from Table 3.3 of Free *et al*. (2006). The range was 1 – 75 mg l^{-1} PtCo, the median 19 mg l^{-1} PtCo, 14 of the values were below 30 mg l^{-1} PtCo, nine were below 20 mg l^{-1} PtCo and five were below 10 mg l^{-1} PtCo. It should be noted that Loughs Owel, Rea and Bunny, all of which are considered to be at favourable condition had concentrations of 1, 3 and 9 mg l^{-1} PtCo, respectively. It is reasonable to assume, therefore, that water colour should be < 10 or even < 5 mg l^{-1} PtCo in lakes with habitat 3140. Some inland hard-water lakes have significant areas of peatland in their catchment and can have peat-stained waters. The proportion of this colour that is natural versus the proportion resulting from peatland degradation is worthy of further study.

Water colour can change the quantity and quality (wavelengths) of light in water, as well as reducing its overall depth of penetration. It is associated with transparency (see Section 4.5.7) and phytoplankton biomass (chlorophyll *a*) (see Section 4.5.9). It is also associated with concentrations of dissolved organic carbon (DOC) and humic acids) (see Section 4.5.15).

Water colour can show seasonal variations, with minimum concentrations occurring in summer and maximum in autumn/early winter (Sep-Dec) (Free, *et al*., 2000). It is likely that flushing of degraded peat and other soils by autumn and early winter rain contributes to this pattern, owing to availability of humic acids in soil water following the higher decomposition of organic material over summer.

The **TARGET** for the attribute water colour is: Maintain appropriate water colour to support the habitat.

4.5.15 Dissolved organic carbon

Dissolved (and fine particulate) organic matter in the water column can have a range of complex impacts on lake ecology. Increased organic loads can stimulate microbial growth and respiration, both in the benthos and in the plankton (Forsström *et al*., 2013). Dissolved organic matter increases light attenuation, thus impacting water temperature and reducing phytoplankton productivity (Williamson *et al*., 1999, Read and Rose, 2013). From a lake habitat perspective, the greatest impact of dissolved organic matter/absorption of solar radiation is likely to be the reduction of the euphotic zone and corresponding changes in extent, zonation and composition of the benthic vegetation. Other potential impacts include changes to the zooplankton communities (organic matter can be utilised as a food by some species), changes to other invertebrate communities, reduced oxygen availability (particularly at the sediment-water interface), changes to mixing depths, increased acidity (organic acids), changes to metal toxicity, changes to other toxins, and alterations to nutrient availability (Williamson *et al.*, 1999, Wetzel, 2001, Drinan, 2012, Forsström *et al.*, 2013, Read and Rose, 2013). Overall, increased DOM in a lake can cause a shift from autotrophic (primary production) to mixotrophy or even heterotrophy (Forsström *et al*., 2013).

Dissolved organic carbon (DOC) is one of the commonest measures of dissolved organic matter, while concentrations of humic and fulvic acids are sometimes considered. BOD and COD may also be appropriate indicators of potential heterotrophic productivity. DOC is generally closely related to water colour (see Section 4.5.14) and accompanied by increases in nitrogen load (as ammonia).

Increasing DOC in surface waters has been documented across the Northern Hemisphere, including afforested peatland catchments in Ireland (Evans *et al*., 2005, Drinan 2012). Reduced air pollution (SOX) and associated acidification have been put forward as the drivers of recorded DOC increases across North America and northern Europe (Monteith *et al*., 2007). Mechanisms such as climate change, soil erosion, wetland damage, enhanced plant growth, and forest fire and harvesting have also been indicated (Williamson, *et al*., 1999, Forsström *et al*., 2013). Anthropogenically driven acidification was limited in Ireland, and it is very unlikely that acid-deposition caused decreases in DOC losses to surface waters here (see also Section 3.5.1). In Ireland, the most likely sources of elevated terrestrial DOC loads include damaged peatland and conifer plantations, with climate and hydrology as key drivers. Damage to wetlands, particularly through drainage, increases aeration and aerobic mineralisation (decay/decomposition) of organic matter. Peatlands are extensive in Ireland and have been degraded by activities such as turf-cutting, afforestation, reclamation for agriculture and over-grazing. Mineralisation of the soil (peat) and associated vegetation is the likely source of DOC from many degraded peatlands. Decay of 'waste' tree material following clear-fell harvesting of coniferous plantation is the likely source of DOC from forests, as well as needle-fall and through-put. Climate factors, particularly high rainfall events, drive DOC losses from land to surface waters and also influence wetting/drying of soils and vegetation and, thereby, mineralisation. Land drainage is likely to be a key factor in the sources, pathways and processes of DOC loss.

The **TARGET** for the attribute dissolved organic carbon is: Maintain appropriate organic carbon levels to support the habitat.

4.5.16 Turbidity

Turbidity in water is caused by suspended inorganic and organic matter and causes light to be scattered and absorbed rather than transmitted (Wetzel and Likens, 1991). As a result, it can significantly affect the quantity and quality of light reaching rooted and attached vegetation and can, therefore, impact on lake habitats. Turbidity can increase as a result of re-suspension of material within the lake, through increased water level fluctuations and wave action. It can also increase as a result of higher loads of fine inorganic matter and particulate organic matter entering the lake, owing to soil erosion, peatland degradation, etc. Finally, eutrophication increases turbidity through the larger phytoplankton crop. The settlement of higher loads of inorganic or organic material on lake vegetation communities may also have impacts on sensitive, delicate species.

The measurement of turbidity, or more particularly, the reliability of instruments and the interpretation of turbidity measurements, continues to be challenging. As a result, it is likely to be difficult to set targets for turbidity in lakes. Regardless of these difficulties, consideration must be given to potential impacts on lake macrophytes as a result of increased turbidity.

The **TARGET** for the attribute turbidity is: Maintain appropriate turbidity to support the habitat.

4.5.17 Fringing habitat

Most lake shorelines have fringing habitats of reedswamp, other swamp, fen, marsh or wet-woodland that intergrade with and support the structure and functions of the lake habitat. These fringing habitats can contribute to the aquatic food web (e.g. allochthonous matter such as leaf fall), provide habitat (refuge and resources) for certain life-stages of fish, birds and aquatic invertebrates, provide shelter for aquatic animals during inclement weather, assist in the settlement of fine suspended material, protect shorelines from erosion and contribute to nutrient cycling. Aquatic invertebrates, in particular, frequently require two distinct habitats (an aquatic, lake habitat and a terrestrial dry-or wetland habitat) for completion of their life cycles. Many use the fringing habitats for shelter, feeding and mating of the winged adults. Fringing wetland and terrestrial habitats are important pupation sites for water beetles. The following are some further examples of the contribution of fringing habitats to the structure and functions of lake habitats

a. Scrub and woodland can increase humidity and, therefore, may be important to fringing bryophyte communities
b. Scrub and woodland also provide material to feed aquatic food-webs (e.g. coarse particulate organic matter from leaf fall, which supports different invertebrate communities to those where algae dominate the food web)
c. Shade may also be important in suppressing algal growth in enriched lakes and ponds, and in moderating temperatures. An increase in temperatures may be linked to climate change, but can also result from changes to lake morphology
d. The roots of fringing trees can be important habitat for species such as the white-clawed crayfish
e. Emergent vegetation can provide cover for fish and protect shorelines from the erosive powers of wave action.

Equally, fringing habitats are dependent on the lake, particularly its water levels, and support wetland communities and species of conservation concern. The presence of fringing alkaline fen along the shorelines of lakes with the hard-water habitat is of particular biodiversity value. Many of the fringing wetland habitats support higher invertebrate and plant species richness than the lake habitats themselves.

The **TARGET** for the attribute fringing habitats is: Maintain the area and condition of marginal fringing habitats that support and are dependent on the lake habitat.

5. Required survey and studies

This document presented a re-interpretation of the five Annex I lake habitats for Ireland that should be tested through field survey and data analyses. Development of a full national lake habitat/vegetation classification system is considered overly-ambitious at this time, as it would require many years of survey to acquire a representative sample from the estimated 12,000 plus lakes and ponds. Consequently, it is recommended that efforts be concentrated on the five Annex I lake habitats and sites of recognised conservation importance. Throughout the text above, areas requiring further survey and study are highlighted. Essentially, these involve, firstly, describing or characterising the lake habitats and, secondly, understanding their ecological requirements, i.e. how to maintain/restore them at favourable conservation condition. The list below summarises some of these study areas, in an approximate order of priority

Characterisation

1. Characterisation of the mixed *Najas flexilis* lake habitat 3130 is a priority and requires some study of oligotrophic isoetid 3110, hard-water 3140 and rich pondweed 3150 lake habitats to distinguish between these four habitats. Study should focus on fully aquatic biota, particularly submerged macrophytes, and should consider invertebrates. The following is required
    a. Classification and description of communities
    b. Description of characteristic zonation or other spatial patterns, including species composition and abundance
    c. Investigation of characteristic rare and threatened macrophytes and invertebrates
    d. Confirmation and adaptation, as required, of typical species lists
    e. Description of the characteristic abundance and distribution of key typical species
    f. Definition of favourable condition for each habitat
    g. Identification of among-site variation, including any geographical, altitudinal and coastal variants
    h. Consideration of temporal variations in species and communities
2. Acid oligotrophic lakes and ponds, 3160, are worthy of a separate, dedicated study. Aquatic invertebrates are expected to be of relatively greater importance in this habitat. As above, study of 1a-1h is required. Particular attention should be given to describing distinctions between habitat 3160 in lakes versus ponds, the relationships between the habitat and surrounding habitats (typically heath and bog) and the diversity of 3160 at this larger, habitat-complex scale.
3. The distribution, quality (conservation value) and condition of Annex I lake habitats in SACs selected for their protection.
4. Determination of whether habitat 3110 is present in SACs with *Najas flexilis* lakes only (Site Codes 000185, 001151, 001975, 002118, 002130 and 002176).
5. The co-occurrence of, and relationships between the Annex I lake habitats, particularly 3110 with 3160, and 3130 with 3140 and 3150.
6. Understanding the international contexts and conservation importance for all Annex I lake habitats.
7. Further investigation and classification of coastal lakes.

Ecology

8. Collating and utilising existing data to identify the main ecological drivers of each Annex I lake habitat and how each responds to pressures.
9. For the purposes of monitoring under Article 11 of the Habitats Directive, development of relevant specific structure and function attributes and targets, and associated field survey methodologies for each Annex I lake habitat (e.g. explore the need for metrics for acid oligotrophic lakes and ponds for dissolved organic carbon, ammonia, humic and fulvic acids, pH, alkalinity, colour). Biological attributes have been developed for the hard-water lake habitat, however further work is required to develop water quality and other attributes. For habitats 3110, 3130, 3150 and 3160, the full suite of structure and functions metrics needs to be developed. As for 3140, biological metrics are likely to include
    a. Typical species (algae, bryophytes, vascular plants and invertebrates)
    b. Characteristic zonation or other spatial patterns in vegetation
    c. Depth distribution of vegetation, particularly maximum depth
    d. The use of positive and negative indicator taxa, assemblages or communities
10. Further investigation into the relationship between WFD Status and the conservation condition of Annex I lake habitats, testing the appropriateness of standard water quality (WFD) metrics for assessing conservation condition and setting conservation objectives, and modification of attributes and targets as necessary.
11. Further exploration of the concept of 'typical species' for lake habitats, including potential study of the biology and ecology of important typical species, their responses to pressures and potential usefulness in Article 17 reporting.
12. Further investigation of water colour and dissolved organic carbon, particularly in peatland catchments, and elucidation of natural background levels, the contribution of peatland degradation and land-use, and the impacts on lake habitats.
13. Study of the hydrology of Irish lakes and habitats, their natural fluctuations, and the impacts of drainage and abstraction on hydrology and lake ecology.
14. Further investigation of groundwater contributions and interactions in the hard-water lake habitat, including groundwater pollution and its impacts, and identification and management of sources and pathways of pollution (including establishment of catchment-specific targets for phosphorus in groundwater in hard-water lake catchments).
15. Development of measures to prevent direct losses of nutrients to water, including losses to groundwater.
16. Further study of acidification of peatland lakes and its impacts on habitats 3160 and 3110, and of the contribution of peatland degradation and organic acids to such impacts.
17. Study of the importance of fringing habitats to the structure and functions of lake habitats and achieving favourable conservation condition.
18. Study of the physical characteristics and chemistry of lake substratum, and the variations within and among habitats, including phosphorus and nitrogen cycles, sediment enrichment and its impacts.
19. Further study of the impacts of invasive species on lake habitats and the role of other perturbations, particularly eutrophication.
20. Investigations into the measurement, interpretation and impacts of turbidity in lakes.

21. Further development of methods for mapping the area of lake vegetation communities/zones and habitats, and for measuring changes in area over time.

6. Bibliography

Allott N., Brennan M., Cooke D., Reynolds J.D. and Simon, N. (1997) *AQUAFOR report, volume 4, a study of the effects of stream hydrology and water quality in forested catchments on fish and invertebrates*. Trinity College Dublin, Dublin.

Arts, G.H.P. (2002) Deterioration of Atlantic soft water macrophyte communities by acidification, eutrophication and alkalinisation. *Aquatic Botany* 73: 373-393.

Benthic Solutions Ltd. (2007) *Monitoring of condition, density, location and total extent/population of Slender Naiad (Najas flexilis), in the Perthshire Lunan Lochs*. Unpublished report, Scottish Natural Heritage, Perth.

Bruinsma, J., Landsdown, R., Roden, C. and Van der Wyer, C. (2009). *The Botany and Vegetation of the Lakes of South East Co. Clare*. Unpublished report to the Heritage Council, Kilkenny.

Caffrey, J.M., Millane, M., Evers, S., Moran, H. and Butler, M. (2010) A novel approach to aquatic weed control and habitat restoration using biodegradable jute matting. *Aquatic Invasions* 5 (2): 123-129.

Clabby, K.J., Bradley, C., Craig, M., Daly, D., Lucey, J., McGarrigle, M., O'Boyle, S., Tierney, D. and Bowman, J. (2008) *Water Quality in Ireland 2004-2006*. EPA, Wexford.

Commission of the European Communities (1991) *CORINE biotopes manual. Habitats of the European Community. A method to identify and describe consistently sites of major importance for nature conservation. Data specifications – Part 2*. EUR 12587/3. European Commission DG Environment.

Commission of the European Communities (2007) *Interpretation manual of European Union habitats*. Eur 27. European Commission DG Environment.

Commission of the European Communities (CEC) (2013*) Interpretation manual of European Union habitats*. Eur 28. European Commission DG Environment, Brussels.

Craig, M., Mannix, A. and Daly, D. (2010) Groundwater Quality. In: M. McGarrigle, J. Lucey, and M. Ó Cinnéide (eds.) *Water Quality in Ireland 2007-2009*. EPA, Wexford.

Donohue, I. and García-Molinos, J. (2009) Impacts of increased sediment loads on the ecology of lakes. *Biological Reviews* 84: 517-531.

Donohue, I., Leira, M., Hobbs, W., León-Vintró, L., O'Reilly, J. and Irvine, K. (2010) Rapid ecosystem recovery from diffuse pollution after the Great Irish Famine. *Ecological Applications* 20: 1733-1743.

Drinan, T.J. (2012) *The impact of conifer plantation forestry on the ecology of peatland lakes*. Unpublished Ph.D. Thesis, UCC, Cork.

Drinan, T.J., Nelson, B., Tickner, M., O'Donnell, G., O'Halloran, J. and Harrison, S. (2011) First discovery of larvae of the Downy Emerald Cordulia aenea (L.) in Ireland and the species' use of lakes in treeless blanket bog in Connemara, Co. Galway. *Journal of the British Dragonfly Society* 27: 1–12.

Drinan, T.J., Graham, C.T., O'Halloran, J. and Harrison, S.S.C. (2013a) The impact of catchment conifer plantation forestry on the hydrochemistry of peatland lakes. *Science of the Total Environment* 443: 608–620.

Drinan, T.J., Graham, C.T., O'Halloran, J. and Harrison, S.S.C. (2013b) The impact of conifer plantation forestry on the Chydoridae (Cladocera) communities of peatland lakes. *Hydrobiologia* 700: 203–219.

Duigan, C.A., Kovach, W.L. and Palmer, M (2006) *Vegetation communities of British Lakes: a revised classification*. Joint Nature Conservation Committee, Peterborough.

Duigan, C., Kovach, W. and Palmer, M. (2007) Vegetation communities of British lakes: a revised classification scheme for conservation. *Aquatic Conserv. Mar. Freshw. Ecosyst*. 17: 147–173.

Dwyer, N. (2013) The *Status of Ireland's Climate, 2012*. EPA, Wexford.

EPA (2001) *Parameters of Water Quality: Interpretations and Standards*. EPA, Wexford.

EPA (2008) Ireland's Environment 2008. EPA, Wexford.

EPA Raw Macrophyte Data. 2001-2003, 2005-2012. Lake macrophyte species cover abundance data gathered by the EPA using standard methods. Spreadsheets. EPA, Wexford.

Evans, D. and Arvela, M. (2011) *Assessment and reporting under Article 17 of the Habitats Directive Explanatory Notes & Guidelines for the period 2007-2012. Final version*. *July 2011*. European Topic Centre on Biological Diversity.

Evans, C.D., Monteith, D.T. and Cooper, D.M. (2005) Long-term increases in surface water dissolved organic carbon: Observations, possible causes and environmental impacts. *Environ. Pollut*. 137: 55–71.

Feeley H.B., Kerrigan C., Fanning P., Hannigan E. and Kelly-Quinn, M. (2011) Longitudinal extent of acidification effects of plantation forest on benthic macroinvertebrate communities in soft water streams: evidence for localised impact and temporal ecological recovery. *Hydrobiologia* 671: 217–226.

Feeley H.B., Bruen, M., Blacklocke, S. and Kelly-Quinn M. (2013) A regional examination of episodic acidification response to reduced acidic deposition and the influence of plantation forests in Irish headwater streams. *Science of the Total Environment* 443: 173–183.

FitzGerald, R. (1994) *Kerry - Vc H1 & H2. Report on preliminary survey of threatened & protected species*. Unpublished Report to the National Parks and Wildlife Service, Dublin.

FitzGerald, R. and Preston, C.D.P. (1994) Preliminary survey of *Najas flexilis*. In: FitzGerald, R. *Kerry - Vc H1 & H2. Report on preliminary survey of threatened & protected species*. Unpublished Report to the National Parks and Wildlife Service, Dublin.

Foster, G. N., Nelson, B. H. and O Connor, Á. (2009) *Ireland Red List No. 1 – Water beetles.* National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland.

Free, G., Allott, N., Mills, P., Kennelly, C., and Day, S. (2000). Colour in Irish lakes. *Verhandlungen Internationale Vereinigung für theoretische und angewandte Limnologie* 27: 2620-2623.

Free, G., Little, R., Tierney, D., Donnelly, K. and Coroni, R. (2006) *A reference-based typology and ecological assessment system for Irish lakes. Preliminary Investigations. Final Report*. Project 2000-FS-1-M1 Ecological Assessment of Lakes Pilot Study to Establish Monitoring Methodologies EU (WFD). EPA, Wexford.

Free G., Bowman, J., McGarrigle, M., Little, R., Caroni, R., Donnelly, K., Tierney, D. and Trodd, W. (2009) The identification, characterization and conservation value of isoetid lakes in Ireland. *Aquatic Conserv: Mar. Freshw. Ecosyst.* 19 (3): 264–273.

Freshwater Ecology Group (FEG) TCD and Compass Informatics (2007) Conservation assessments of freshwater lake habitats in the Republic of Ireland. April 2007. In: National Parks and Wildlife Service (Ed.*) The Status of EU Protected Habitats and Species in Ireland, Backing Documents, Article 17 Forms, Maps*. Volume 2, 1110-1256.

Forsström, L., Roiha, T. and Rautio, M. (2013) Responses of microbial food web to increased allochthonous DOM in an oligotrophic subarctic lake. *Aquatic microbial ecology* 68: 171-184.

Godwin, H. (1975) *The history of the British flora. A factual basis for phytogeography.* Cambridge University Press, Cambridge.

Heuff, H. (1984) *The Vegetation of Irish Lakes. Parts 1 and 2*. Unpublished Report to the Wildlife Service, Office of Public Works, Dublin.

Hobbs, W., Irvine, K. and Donohue, I. (2005) Using sediments to assess the resistance of a calcareous lake to diffuse nutrient loading. *Archiv für Hydrobiologie* 164: 109-125.

Irvine, K., Donohue, I., McCarthy, V., Leira, M. and Hobbs, W. (2008) History, Nutrients and Water Quality: a Study of the Lakes and Catchments of Loughs Carra and Mask. In: *The Great Western Lakes: Ecology, Heritage & Management*. The Proceedings of a Conference held at the Castlebar Campus of the Galway-Mayo Institute of Technology, 25-27 June 2004. C.R. Huxley and K. Irvine (Eds). Trinity College, Dublin.

Jeschke, C., Falagán, C., Knöller, K., Schultze, M. and Koschorreck, M. (2013) No Nitrification in Lakes Below pH3. *Environ. Sci. Technol.* 47 (24): 14018–14023.

Kelly-Quinn, M., Cruikshanks, R., Johnson, J., Matson, R., Baars, J.-R. and Bruen, M. (2008) Forestry and Surface Water Acidification—FORWATER. Report to the Western River Basin District Working Group. http://www.wfdireland.ie/docs/22_ForestAndWater/ .

Krause, W. and King, J.J. (1994) The ecological status of Lough Corrib, Ireland, as indicated by physiographic factors, water chemistry and macrophytic flora. *Vegetatio* 110: 149–161.

Lehane, M. and O'Leary, B. (2012) *Ireland's Environment 2012 – An Assessment*. EPA, Wexford.

Moss, B. (1998) *Ecology of Fresh Waters. Man and Medium, Past to Future*. Blackwell Science. Oxford.

Moss, B. (2008) The kingdom of the shore: achievement of good ecological potential in reservoirs. *Freshwater Reviews* 1 (1): 29-42.

McGarrigle, M.L., Bowman, J.J., Clabby, K.J., Lucey, J., Cunningham, P., MacCarthaigh, M., Keegan, M., Cantrell, B., Lehane, M., Clenaghan, C. and Toner, P.F. (2002) *Water Quality in Ireland 1998-2000.* EPA, Wexford.

McGarrigle, M., Lucey, J. and Ó Cinnéide M. (2010) Water Quality in Ireland 2007-2009. EPA, Wexford.

Monteith, D.T., Stoddard, J.L., Evans, C.D., de Wit, H.A., Forsius, M., Høgåsen, T, Wilander, A., Skjelkvåle, B.L., Jeffries, D.S., Vuorenmaa, J., Keller, B., Kopácek, J. and Vesely, J. (2007) Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. *Nature* 450: 537−540.

Nelson, B, Foster, G. and O Connor, Á. (in prep.) Manual of Irish Water Beetles. National Parks and Wildlife Service, Dublin.

Ní Chatháin, B., Moorkens, E. and Irvine, K. (2013) *Management Strategies for the Protection of High Status Water Bodies*. 010-W-DS-3. Strive Report Series No. 99. EPA, Wexford.

NPWS (2013a) *The Status of Protected EU Habitats and Species in Ireland. Overview Volume 1.* Unpublished Report, National Parks and Wildlife Services. Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

NPWS (2013b) *The Status of EU Protected Habitats and Species in Ireland. Habitat Assessments Volume 2. Version 1.0*. Unpublished Report, National Parks and Wildlife Services. Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

NPWS (2013c) *The Status of EU Protected Habitats and Species in Ireland. Species Assessments Volume 3, Version 1.0*. Unpublished Report, National Parks & Wildlife Services. Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

O'Callaghan, E., Foster, G.N., Bilton, D.T. and Reynolds, J.D. (2009) *Ochthebius nilssoni* Hebauer new for Ireland (Coleoptera: Hydraenidae), including a key to Irish *Ochthebius* and *Enicocerus*. *Irish Naturalists' Journal* 30: 19-23.

O Connor, Á. (2013) *Article 17 assessment form and audit trail for* Najas flexilis*, the Slender Naiad (species code 1833) – Backing Document*. Unpublished Report, National Parks and Wildlife Service, Dublin.

OECD (Organisation for Economic Co-operation and Development) (1982) *Eutrophication of Waters. Monitoring Assessment and Control*. OECD, Paris.

Oliver, D. (1851) Notes of a botanical ramble in Ireland last autumn. *Phytologist* 4: 125-128.

O'Sullivan, A. (1997) *A summary report of the rare plants survey of plant species listed on Annex II of the EU Habitats Directive*. Unpublished Report to the National Parks and Wildlife Service, Dublin.

Otte, M.L. (2003) Life in wetland environments. In *Wetlands of Ireland, distribution, ecology, uses and economic* value (M.L. Otte, Ed.). University College Dublin Press, Dublin.

Otzuki, A. and Wetzel, R.G. (1973) Interaction of yellow organic acids with calcium carbonate in freshwater. *Limnology and Oceanography* 18: 490-493.

Otzuki, A. and Wetzel, R.G. (1974) Calcium and total alkalinity budgets and calcium carbonate precipitation of a small hard-water lake. *Archiv für Hydrobiolgie* 73 (1): 14-30.

Palmer, M. (1989) *A botanical classification of standing waters in Great Britain; and a method for the use of macrophyte flora in assessing changes in water quality incorporating a reworking of data 1992*. Joint Nature Conservation Committee, Peterborough. Research and Survey in Nature Conservation, No. 19.

Palmer, M. (1992) *A botanical classification of standing waters in Great Britain; and a method for the use of macrophyte flora in assessing changes in water quality*. Nature Conservancy Council, Peterborough.

Palmer, M.A., Bell, S.L. and Butterfield, I. (1992) A botanical classification of standing waters in Britain: applications for conservation and monitoring. *Aquatic Conserv: Mar. Freshw. Ecosyst.* 2: 125-143.

Preston, C.D. (1995) *Pondweeds of Great Britain and Ireland*. B.S.B.I. Handbook No. 8. Botanical Society of the British Isles, London.

Preston, C.D. and Hill, M.O. (1997) The geographical relationships of British and Irish vascular plants. *Botanical Journal of the Linnaean Society* 124: 1–120.

Preston, C.D. and Croft, J.M. (2001) *Aquatic Plants in Britain and Ireland*. Harley Books, Colchester.

Read, J.S. and Rose, K.C. (2013) Physical responses of small temperate lakes to variation in dissolved organic carbon concentrations. *Limnol. Oceanogr*. 58 (3): 921-931.

Rich, T.C.G., Kay, G.M. and Kirschner, J. (1995). Floating water plantain *Luronium natans* (L.) Raf. (Alismataceae) present in Ireland. *Irish Naturalists Journal* 25 (4): 140 – 145.

Roden, C.M. (1999) *A survey of the sublittoral vegetation of 15 machair loughs in north west Ireland*. Report to the National Heritage Council, Kilkenny.

Roden, C.M. (2000) *A study of Charophyte algae growing in karstic habitats in the west of Ireland*. Report to the National Heritage Council, Kilkenny.

Roden, C.M. (2002) Najas flexilis *in Donegal.* Unpublished Report to the National Parks and Wildlife Service, Dublin.

Roden , C.M. (2003) Najas flexilis *in Connemara.* Unpublished Report to the National Parks and Wildlife Service, Dublin.

Roden, C.M (2004) *The distribution of* Najas flexilis *in Ireland 2002-2004*. Unpublished Report to the National Parks and Wildlife Service, Dublin.

Roden, C.M. (2005) A new station for *Hydrilla verticillata* in Connemara. *Irish Naturalists' Journal* 28 (3): 138-139.

Roden, C. (2007) Conservation Assessment of Slender Naiad (*Najas flexilis* (Willd.) Rostk. & W.L.E.Schmidt) in Ireland. March 2007. Slender Naiad (*Najas flexilis*) (1833) Conservation Status Assessment Report. Backing Document. In: National Parks and Wildlife Service (Ed.) *The Status of EU Protected Habitats and Species in Ireland, Backing Documents, Article 17 Forms, Maps*. Volume 2, 824-840.

Roden, C. (2010) *The effect of excessive water abstraction on the vegetation and conservation status of Lough Bane Count Meath/Westmeath*. 3rd Report, December 2010. Unpublished Report to Meath County Council.

Roden, C. (2012) *A report on the sub-littoral environment around selected navigation markers in the north west sector of Lough Corrib*. Unpublished report to RPS Group.

Roden, C. (2014) *A report on the aquatic macrophytes in 12 lakes along the Maam Cross to Ballynahinch Road.* Unpublished Report to RPS Group, Galway.

Roden, C. and Murphy, P. (2012) *Luronium natans*. NPWS Rare Plant Survey, 2012 Recording Card. In: *Field Survey of Rare, Threatened and Scarce Vascular Plants in Ireland, 2012*. Final Report. T. Curtis, F. Wilson, J.

Conaghan, J. Fuller, C. Roden and P. Murphy (Eds). Unpublished Report to the National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Ireland.

Roden, C. and Murphy, P. (2013) *A survey of the benthic macrophytes of three hard-water lakes: Lough Bunny, Lough Carra and Lough Owel*. Irish Wildlife Manuals, No. 70. National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

Roden, C. and Murphy, P. (2014) *Targeted survey of* Najas flexilis. Unpublished Report to the National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Ireland.

Roden, C. and Murphy, P. (in prep.) *Monitoring of hard-water lakes in Ireland using charophytes and other macrophytes*. Unpublished Report to National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

Stewart, N.F. and Church, J.M. (1992) *Red Data Books of Britain and Ireland, Charophytes*. Joint Nature Conservation Committee and Office of Public Works.

Tierney, D., Free, G, Kennedy, B., Little, R., Plant, C., Trodd, W. and Wynne, C. (2010) Water Quality of Lakes. In: M. McGarrigle, J. Lucey, and M. Ó Cinnéide (eds.) *Water Quality in Ireland 2007-2009*. EPA, Wexford.

van Groenendael, J.M., Hochstenbach, S.M.H., van Mansfeld, M.J.M. and Roozen, A.J.M. (1979) *The influence of the sea and of parent material on wetlands and blanket bog in west Connemara, Ireland*. Department of Geobotany, Catholic University, Nijmegen.

van Groenendael, J.M., Hochstenbach, S.M.H., van Mansfeld, M.J.M., Roozen, A.J.M. and Westhoff, V. (1982) The influence of the sea on the vegetation of lakes in southwest Connemara. In: *Studies on Irish Vegetation*. J. White (Ed.). *J. Life Sci. R. Dubli. Soc.* 3: 221-242.

van Groenendael, J.M., Hochstenbach, S.M.H., van Mansfeld, M.J.M. and Roozen, A.J.M. (1983) Soligenous influences on wetlands and blanket bog in western Connemara, Ireland. *J. Life Sci. R. Dubli. Soc.* 4: 129-137.

van Groenendael, J.M., van Mansfeld, M.J.M., Roozen, A.J.M. and Westhoff, V. (1993) Vegetation succession in lakes in the coastal fringe of West Connemara, Ireland. *Aquatic Conservation: Marine and Freshwater Systems* 3: 25-41.

Visser, G and Zoer, J.A. (1972) *Verslag van een botanisch/malacologische studiereis naar Z.W. Ierland*. Unpublished Report, Rijksinstituut voor Natuurbeheer, Leersum, the Netherlands.

Visser, G and Zoer, J.A. (1976) A*bbreviated report of a botanical and malacological study performed in the southwestern part of Ireland*. August 1976. Unpublished Report to National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

Wetzel, R.G. (2001) *Limnology: Lake and River Ecosystems*. Academic Press, London.

Wetzel, R.G. and Likens, G.E. (1991) *Limnological Analyses*. Second Edition. Springer-Verlag, New York.

Williamson, C.E., Morris, D.P., Pace, M.L. and Olson, O.G. (1999) Dissolved organic carbon and nutrients as regulators of lake ecosystems: Resurrection of a more integrated paradigm. *Limnol. Oceanogr*. 44 (3, part 2): 795-803.

Wingfield, R.A., Murphy, K.J., Hollingsworth, P. and Gaywood, M.J. (2004) *The Ecology of* Najas flexilis. Scottish Natural Heritage Commissioned Report No. 017 (ROAME No. F98PA02).

Wingfield, R.A., Murphy, K.J. and Gaywood, M.J. (2005) Lake habitat suitability for the rare European macrophyte *Najas flexilis* (Willd.) Rostk. & Schmidt. *Aquatic Conserv. Mar. Freshw. Ecosyst*. 15: 227–241.

Working Group on Characterisation and Risk Assessment (2005) WFD Lake Typology. Summary note of Irish lake typology to be applied in Ireland's River Basin Districts. March 2005 http://www.wfdireland.net/Documents/Characterisation%20Report/Background%20Information/Analaysis%20of%20Characters/Rivers/Lake_Typology_Summary_Guidance.pdf

Appendices

Appendix I

Examination of the lake habitats 3110 and 3130

Text from the interpretation manual of European Union habitats (CEC, 2013):

3110 Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*)

PAL.CLASS.: 22.11 x 22.31

1) Shallow oligotrophic waters with few minerals and base poor, with an aquatic to amphibious low perennial vegetation belonging to the *Littorelletalia uniflorae* order, on oligotrophic soils of lake and pond banks (sometimes on peaty soils). This vegetation consists of one or more zones, dominated by *Littorella*, *Lobelia dortmana* or *Isoetes,* although not all zones may not be found at a given site.

2) Plants: *Isoetes lacustris*, *I. echinospora*, *Littorella uniflora*, *Lobelia dortmanna*, *Deschampsia setacea*, *Subularia aquatica*, *Juncus bulbosus*, *Pilularia globulifera*, #*Luronium natans*, *Potamogeton polygonifolius*; in the Boreal region also *Myriophyllum alterniflorum*, *Drepanocladus* spp., *Warnstorfia* spp. and *Fontinalis* spp.

3) Corresponding categories

German classification : "24020201 kalkarmer, oligotropher See des Tief- und Hügellands", "24020301 kalkarmes, oligotrophes, sich selbst überlassenes Abbaugewässer".

Nordic classification: "6413 *Lobelia dortmanna-Isoetes* spp. typ", "6414 *Littorella uniflora-Lobelia dortmanna*-typ". In the Boreal region this habitat is particularly found on glacio fluvial soil and with usually dense isoetid vegetation, sparse reedbeds, helophytic vegetation and carpets of submerged bryophytes.

4) This habitat is found in association with heath (31.1) and *Nanocyperion* (22.32) communities. In France and Ireland this habitat occurs, in particular, in heathland of sandy plains on podzols, where the water table occurs at the surface

5) **Mäkirinta, U. (1978).** *Die Pflanzensoziologische Gliederung der Wasservegetation im See Kukkia, Südfinnland*. Acta Univ. Ouluensis Ser. A. Scientiae Rerum Naturalium Nr. 75, biologica Nr.5.
Thunmark, S. (1931). Der See Fiolen und seine Vegetation. *Acta Phytogeogr. Suecica*. II:1-198.

# denotes species listed on Annex II/IV

3130 Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea*

PAL.CLASS.: 22.12 x (22.31 and 22.32)

1) 22.12 x 22.31 - aquatic to amphibious short perennial vegetation, oligotrophic to mesotrophic, of lake, pond and pool banks and water-land interfaces belonging to the *Littorelletalia uniflorae* order.
22.12 x 22.32 - amphibious short annual vegetation, pioneer of land interface zones of lakes, pools and ponds with nutrient poor soils, or which grows during periodic drying of these standing waters: *Isoeto-Nanojuncetea* class.
These two units can grow together in close association or separately. Characteristic plant species are generally small ephemerophytes.

2) Plants: 22.12 x 22.31: *Littorella uniflora*, #*Luronium natans*, *Potamogeton polygonifolius*, *Pilularia globulifera*, *Juncus bulbosus* ssp. *bulbosus*, *Eleocharis acicularis*, *Sparganium minimum*.
22.12 X 22.32 : #*Lindernia procumbens*, *Elatine* spp., *Eleocharis ovata*, *Juncus tenageia*, *Cyperus fuscus*, *C. flavescens*, *C. michelianus*, *Limosella aquatica*, *Schoenoplectus supinus, Scirpus setaceus*, *Juncus bufonius*, *Centaurium pulchellum*, *Centunculus minimus*, *Cicendia filiformis*.

3) Corresponding categories

German classification : "240301 mesotropher See (Bleisee) (mit Zwergbinsenfluren -wechselnass-, P143)", "240306 meso- bis eutrophes, sich selbst überlassenes Abbaugewässer (mit Zwergbinsenfluren -wechselnass-, P143)".

Nordic classification : "6411 *Eleocharis acicularis*-typ", "6412 *Ranunculus reptans-Subularia aquatica*-typ".

in the Azores the corresponding association is *Isoetetum azorica* Lüp.

4) This habitat type could also develop in wet dune slacks (see 16.32 in 2190, included in Annex I).

In the Atlantic region, such lakes can shelter glacial relict species, e.g. fish such as *Selvelinus alpinus*. Areas with a variable hydrological system, periodically lacking vegetation due to trampling, should not be included.

5) **Jenssen, S. (1979).** Classification of lakes in southern Sweden on the basis of their macrophyte composition by means of multivariate methods. *Vegetatio* 39:129-146.

These two Annex I lake habitats are compared below, first using phytosociological classification (White and Doyle, 1982), then by CORINE biotope (CEC, 1991) and finally by plant species ecology (Webb *et al*., 1996, Preston and Croft, 1997, Stace, 1997, Cope and Gray, 2009).

Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) **3110**	**Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea*** **3130**
PHYTOSOCIOLOGY	**PHYTOSOCIOLOGY**
Class *Littorelletea uniflorae*	Class ***Littorelletea uniflorae***
Vegetation of rooted plants in and around oligotrophic and dystrophic pools and lakes, on sandy, loamy or peaty substrates. The communities are species poor, generally having fewer than ten species.	Vegetation of rooted plants in and around oligotrophic and dystrophic pools and lakes, on sandy, loamy or peaty substrates. The communities are species poor, generally having fewer than ten species.
Order ***Littorelletalia uniflorae***	Order *Littorelletalia uniflorae*
Diagnostic species for the **class** and **order** are *Littorella uniflora, Juncus bulbosus, Elatine hexandra, Myriophyllum alterniflorum, Potamogeton polygonifolius, Sparganium angustifolium, Scirpus fluitans, Deschampsia setacea, Carex serotina*.	Diagnostic species for the **class** and **order** are *Littorella uniflora, Juncus bulbosus, Elatine hexandra, Myriophyllum alterniflorum, Potamogeton polygonifolius, Sparganium angustifolium, Scirpus fluitans, Deschampsia setacea, Carex serotina*.
White and Doyle (1982) recognise four probable alliances and nine associations, of which those most relevant to lake habitat 3110 are detailed below.	White and Doyle (1982) recognise four probable alliances and nine associations, of which those most relevant to lake habitat 3130 are detailed below.
Alliance ISOETION LACUSTRIS	
Association *Isoetum echinosporae*	
Diagnostic species *Isoetes lacustris, I. echinospora, Subularia aquatica*	
Vegetation of nutrient-poor waters where few higher plants can survive; water temperature lower than that of the other alliances in the order; may grow in clear waters to 2 m deep.	
Alliance *LOBELION DORTMANNAE*	Alliance *LOBELION DORTMANNAE*
Character species: *Lobelia dortmanna*	
On sandy substrates along lake shores and on peaty substrates in bog pools, in water 50-120 cm deep	
Association *Isoeto-Lobelietum*	
Character species: *Lobelia dortmanna*	
Association *Eriocaulo-Lobelietum*	
Character species: *Eriocaulon aquaticum*	
The distinction between these two associations is based entirely on the occurrence of *Eriocaulon*, which has a restricted Irish distribution.	

Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) 3110	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea* 3130
Association *Pilularietum globuliferae*	Association *Pilularietum globuliferae*
Character species: *Pilularia globulifera*	Character species: *Pilularia globulifera*
Its largest single station is on the west shore of Lough Mask, where it grows with *Hypericum canadense* on boggy, sandy flats. Also recorded growing with *Mentha aquatica* and *Hydrocotyle vulgaris*.	Its largest single station is on the west shore of Lough Mask, where it grows with *Hypericum canadense* on boggy, sandy flats. Also recorded growing with *Mentha aquatica* and *Hydrocotyle vulgaris*.
Alliance *HYDROCOTYLO-BALDELLION*	Alliance *HYDROCOTYLO-BALDELLION*
Diagnostic species: *Baldellia ranunculoides, Hypericum elodes, Hydrocotyle vulgaris, Eleocharis multicaulis, Anagallis tenella*	Diagnostic species: *Baldellia ranunculoides, Hypericum elodes, Hydrocotyle vulgaris, Eleocharis multicaulis, Anagallis tenella*
Vegetation of mesotrophic to oligotrophic habitats, with periodic alternation between wet and dry phases. The strongly fluctuating water table is very distinctive.	Vegetation of mesotrophic to oligotrophic habitats, with periodic alternation between wet and dry phases. The strongly fluctuating water table is very distinctive.
Association *Eleocharitetum multicaulis*	Association *Eleocharitetum multicaulis*
Character species: *Eleocharis multicaulis, Deschampsia setacea*	Character species: *Eleocharis multicaulis, Deschampsia setacea*
Association *Hyperico-Potametum oblongi*	Association *Hyperico-Potametum oblongi*
Character spp.: *Hypericum elodes, Potamogeton polygonifolius, Eleogiton fluitans*	Character spp.: *Hypericum elodes, Potamogeton polygonifolius, Eleogiton flutians*
	White and Doyle (1982) do not consider that Class *Isoeto-Nanojuncetea* occurs in Ireland
Conclusion, phytosociology: The more aquatic associations of Class *Littorelletea uniflorae* (*Isoeto-Lobelietum* and *Eriocaulo-Lobelietum*) appear to be characteristic of habitat 3110. The amphibious communities are common in Ireland, particularly in the western third and likely associated with most/all Irish Annex I habitats.	**Conclusion, phytosociology:** Class *Isoeto-Nanojuncetea* is not considered to occur in Ireland. The more aquatic associations of Class *Littorelletea uniflorae* (*Isoeto-Lobelietum* and *Eriocaulo-Lobelietum*) appear to be more characteristic of 3110. The marginal amphibious associations is likely to be associated with both habitats (3110 and 3130). Phytosociological classification cannot be used at this time to classify habitat 3130 in Ireland.
CORINE BIOTOPES	**CORINE BIOTOPES**
22.11 x 22.31	22.12 x (22.31 and 22.32)
22.1 Fresh Waters – The water body itself, regardless of vegetation belts	22.1 Fresh Waters – The water body itself, regardless of vegetation belts
22.11 lime-deficient oligotrophic waters. Usually greenish to brownish clear waters poor in dissolved bases (pH often 5-6)	
	22.12 mesotrophic waters. Richer waters (pH often 6-7)

Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) **3110**	**Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea*** **3130**
22.3 Amphibious Communities – Temporarily exposed lake bottoms or lake shores and other periodically or occasionally inundated muddy, sand or stony basins colonized by phanerogamic vegetation (see also 22.432)	22.3 Amphibious Communities – Temporarily exposed lake bottoms or lake shores and other periodically or occasionally inundated muddy, sand or stony basins colonized by phanerogamic vegetation (see also 22.432)
22.31 Northern perennial amphibious communities. *Littorelletalia*. Carpets of perennials submerged for a considerable part of the year in oligotrophic or mesotrophic lakes, ponds and pools of the Euro-Siberian zone.	**22.31** Northern perennial amphibious communities. *Littorelletalia*. Carpets of perennials submerged for a considerable part of the year in oligotrophic or mesotrophic lakes, ponds and pools of the Euro-Siberian zone.
22.311 shoreweed lawns, lobelia ponds, quillwort swards	22.311 shoreweed lawns, lobelia ponds, quillwort swards
22.3111 shoreweed lawns – dense, almost monospecific *Littorella uniflora* lawns of lake shores subject to great annual variations of the water level and long emergence, and other *Littorella*-dominated associations.	22.3111 shoreweed lawns – dense, almost monospecific *Littorella uniflora* lawns of lake shores subject to great annual variations of the water level and long emergence, and other *Littorella*-dominated associations.
22.3112 *Lobelia* ponds – *Lobelia dortmanna* colonies of shallow oligotrophic, moderately acid ponds	22.3112 *Lobelia* ponds – *Lobelia dortmanna* colonies of shallow oligotrophic, moderately acid ponds
22.3113 Euro-Siberian quillwort swards – clear-water quillwort swards formed by the northern European and montane *Isoetes lacustris* and *I. echinospora*.	22.3113 Euro-Siberian quillwort swards – clear-water quillwort swards formed by the northern European and montane *Isoetes lacustris* and *I. echinospora*.
22.3114 Floating bur-reed communities – *Sparganium angustifolium* formations of, in particular, subalpine ponds.	22.3114 Floating bur-reed communities – *Sparganium angustifolium* formations of, in particular, subalpine ponds.
	22.32 Northern dwarf annual amphibious swards. *Cyperetalia fusci* (*Nancyperetalia*). Dwarf oligo-mesotrophic Euro-siberian annual communities of recently emerged muds and sands.
	22.321 Dwarf spike-rush communities, of 11 characteristic species, only four occur in Ireland –*Limosella aquatica*, *Lythrum portula*, *Elatine hexandra*, *E. hydropiper*, the latter being restricted to the northeast. Community may not occur in Ireland.
	22.322 Dune-slack pioneer

Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) **3110**	**Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea*** **3130**
	22.323 Dwarf toad-rush communities, associated with the drying phase of temporary pools flooded ruts of forest paths, wet heath paths, humid forest cuts, seeping mowed lawns and other sufficiently lit temporarily inundated, most often acidic, soils, characterized by *Juncus bufonius, Scirpus setaceus* (= *Isolepis setacea*), *Centunculus minimus* (= *Anagallis minima*), *Centaurium pulchellum, Blackstonia perfoliata, Samolus valerandi, Cicendia filiformis* and *Radiola linoides*
Conclusion, CORINE: the aquatic communities lack detail and 22.32 does not appear to occur in Ireland, therefore CORINE cannot be used to distinguish Irish lake habitats.	**Conclusion, CORINE:** the aquatic communities lack detail and 22.32 does not appear to occur in Ireland, therefore CORINE cannot be used to distinguish Irish lake habitats. Even if 22.32 did occur, it is not restricted to lakes and may be more characteristic of non-lentic temporary habitats.
Listed plant species (species considered aquatic by Preston and Croft (1997) indicated by *)	**Listed plant species** (species considered aquatic by Preston and Croft (1997) indicated by *)
Isoetes lacustris * Characteristic of oligotrophic lakes. Sensitive to eutrophication. Usually found over rock substrates with skeletal soils or base-poor sands or clays. Scattered plants occur in shallow water at lake edges, where frequently accompanied by *Littorella uniflora* and *Lobelia dortmanna*. It is usually more frequent at greater depths and can be the dominant/only macrophyte between 1.5 and 2.5 m. It can occur down to 6 m.	
Isoetes echinospora * While it appears to be less widespread in Ireland than *I. lacustris* it is most likely under-recorded. The two species can grow together. Found in oligotrophic lakes and at edges of slow-flowing rivers and pools. Occasionally found in eutrophic sites. Also occurs in dystrophic lakes, turbid water, and slightly brackish water. Occurs on a wide range of nutrient substrates including rocks and stones, base-poor sands and gravels, sandy mud or silt and peaty deposits.	

Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) **3110**	**Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea*** **3130**
Littorella uniflora * Found on a wide range of substrates (stones, gravel, sand, peat, marl and soft mud). Tolerates emersion and is often associated with draw-down zones. Is the most nutrient tolerant of isoetids, and occurs in a wider range of habitats, being the only isoetid that can be found on calcareous substrates and also less exclusively aquatic. It can be found down to 3-4 m depth. In Ireland, it is most frequent in areas of base-poor rocks and waters but can grow in base-rich habitats (limestone lakes and turloughs). Tolerant of sediment deposition, but not tolerant of acidification.	*Littorella uniflora* * Found on a wide range of substrates (stones, gravel, sand, peat, marl and soft mud). Tolerates emersion and is often associated with draw-down zones. Is the most nutrient tolerant of isoetids, and occurs in a wider range of habitats, being the only isoetid that can be found on calcareous substrates and also less exclusively aquatic. It can be found down to 3-4 m depth. In Ireland, it is most frequent in areas of base-poor rocks and waters but can grow in base-rich habitats (limestone lakes and turloughs). Tolerant of sediment deposition, but not tolerant of acidification.
Lobelia dortmanna * Characteristic of oligotrophic lakes. Vulnerable to eutrophication. A slow growing perennial with low competitive ability. Virtually confined to lakes, occurring in shallow water of <2 m on a wide range of substrates (from coarse sand to highly organic silts). At exposed sites, it is found with *Eleocharis palustris, Juncus bulbosus, Litorella uniflora, Myriophyllum alterniflorum* and *Ranunculus flammula*. At deeper sites, with *Callitriche hermaphroditica, Potamogeton gramineus* and *P. natans*. Tolerant of exposure. Intolerant of shade. Only over acidic substrates, but can be found in base-rich but nutrient poor water where the substrate is siliceous. Needs cold for seeds to germinate. Seed bank persistent for 30 years.	
Deschampsia setacea Wet bogs and lake margins. Frequent in south west Connemara. Unknown elsewhere. Scarce. Margins of lakes and pools and seasonally flooded hollows in heath and bogs. Open bare stony or peaty soils over a range of base-poor substrates. Mostly coastal and lowland. Appears to be very exacting in its ecological requirements, found in a narrow niche at the margins of water bodies which are drawn down in summer.	

Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) **3110**	**Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea*** **3130**
Subularia aquatica * Rare. Much less frequent than other typical isoetids, but probably under-recorded. May have declined significantly, but little evidence to support this. Has been lost from east of GB owing to eutrophication. Edge of acidic, oligotrophic lakes. A reliable indicator of oligotrophic conditions, but has been found in more eutrophic lakes. Not found on base-rich substrates. Occurs in shallow water, usually < 1 m, but can grow down to at least 1.5 m. Occurs as scattered individuals in open vegetation with *Isoetes* spp., *Littorella uniflora, Lobelia dortmanna, Juncus bulbosus, Myriophyllum alterniflorum* and *Potamogeton gramineus*. Also in emergent swamp. Can tolerate short periods of emersion. More ruderal than other isoetids. Mostly annual. Grows over fine silt, gravel and stones.	
Juncus bulbosus * A very variable species. As an aquatic, it is found in base-poor, clear or peaty waters in lakes, rivers etc. It extends to depths of 2 m or more. It is found in most oligotrophic and species-poor lakes. Occurs on a wide range of organic and mineral substrates. Occasionally in highly calcareous but nutrient poor waters. Can grow in such density it excludes other species. A winter-green perennial.	*Juncus bulbosus* * ssp. *bulbosus* Sub-species of this very variable species not generally recognised as occurring, in Ireland in line with Preston and Croft (1997) and Stace (1991). As an aquatic, it is found in base-poor, clear or peaty waters in lakes, rivers etc. It extends to depths of 2 m or more. It is found in most oligotrophic and species-poor lakes. Occurs on a wide range of organic and mineral substrates. Occasionally in highly calcareous but nutrient poor waters. Can grow in such density it excludes other species. A winter-green perennial.
Pilularia globulifera * Lowland, non-calcareous silty, gravely or peaty lake and pond margins, ditches and shallow pools. Also occurs on tracks. An opportunist, it can rapidly colonise open substrate exposed by falling water levels. A poor competitor. Perennial that dies back in winter. Endemic to western Europe. Decreasing in much of mainland Europe 'at an alarming rate'.	*Pilularia globulifera* * Lowland, non-calcareous silty, gravely or peaty lake and pond margins, ditches and shallow pools. Also occurs on tracks. An opportunist, it can rapidly colonise open substrate exposed by falling water levels. A poor competitor. Perennial that dies back in winter. Endemic to western Europe. Decreasing in much of mainland Europe 'at an alarming rate'.

Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) **3110**	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea* **3130**
Luronium natans * Its typical habitat is acidic, oligotrophic lakes. It occurs submerged up to 2m deep and on bare mud exposed by falling water-levels. It occurs with typical isoetids in these lakes. It is also found in a mesotrophic Welsh (slow) river. Appears generally to be sensitive to eutrophication. It was previously known from other habitats, such as ponds, ditches, canals etc. Some of the previous sites were on calcareous, nutrient poor substrates. A stoloniferous perennial, it can tolerate turbidity and shade. Endemic to W and C Europe, most frequent in west. Note the status of *Luronium natans* in Ireland is currently uncertain. The first published record was for Invermore Lough, in South-Connemara (Rich *et al.*, 1995) and it has since been recorded in a total of three lakes and two streams within 2 km of that lake (Roden and Murphy, 2012). It is as yet unclear whether the species is native to these sites, or was introduced there by man.	*Luronium natans* * Its typical habitat is acidic, oligotrophic lakes. It occurs submerged up to 2m deep and on bare mud exposed by falling water-levels. It occurs with typical isoetids in these lakes. It is also found in a mesotrophic Welsh (slow) river. Appears generally to be sensitive to eutrophication. It was previously known from other habitats, such as ponds, ditches, canals etc. Some of the previous sites were on calcareous, nutrient poor substrates. A stoloniferous perennial, it can tolerate turbidity and shade. Endemic to W and C Europe, most frequent in west. Note the status of *Luronium natans* in Ireland is currently uncertain. The first published record was for Invermore Lough, in South-Connemara (Rich *et al.*, 1995) and it has since been recorded in a total of three lakes and two streams within 2 km of that lake (Roden and Murphy, 2012). It is as yet unclear whether the species is native to these sites, or was introduced there by man.
Potamogeton polygonifolius * Generally considered a calcifuge, but has been found in highly calcareous flushes and fen pools. As an aquatic it occurs in oligo and mesotrophic waters, typically in water depths of < 1m at edge of lakes and in slow rivers, moorland streams and ditches. Also found in moist sub-terrestrial habitats. Most frequent over peat, but also on mineral substrates. In deep or rapidly flowing water the vegetative, submerged leaves only form occurs. Rhizomatous.	*Potamogeton polygonifolius* * Generally considered a calcifuge, but has been found in highly calcareous flushes and fen pools. As an aquatic it occurs in oligo and mesotrophic waters, typically in water depths of < 1m at edge of lakes and in slow rivers, moorland streams and ditches. Also found in moist sub-terrestrial habitats. Most frequent over peat, but also on mineral substrates. In deep or rapidly flowing water the vegetative, submerged leaves only form occurs. Rhizomatous.
	Eleocharis acicularis Submerged in shallow water or on damp ground (fluctuating). Submerged form usually found in mesotrophic to eutrophic, mildly acidic to strongly base-rich water < 0.5 m deep. Occurs in sheltered lakes, backwaters of rivers, slow-flowing streams, canals etc. Grows on damp silt at water body edges, or sandy shingle in areas that flood in winter. Found with wide range of species as aquatic form. On land, found in muddy annual dominated communities. Mainly a lowland species. Perennial, shallowly rooted rhizomes. Can grow through silt deposits. Can vary greatly in abundance year to year both aquatically and terrestrially. Frequent in the centre of Ireland, rare elsewhere. Found in turloughs, including in habitat 3270.

Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) **3110**	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea* **3130**
	*Sparganium minimum = S. natans ** Bogs, lakes, drains, canals and peaty pools; formerly frequent, now occasional. Sheltered bays at edge of lakes, slow streams, ditches, fen pools. Usually shallow water over peaty substrates. Most frequent at 10-50 cm. Also over chalk and limestone – highly calcareous waters. In more acidic areas found where the water or substrate is enriched by local outcrops of base-rich rocks. Mesotrophic habitats. Absent from eutrophic or turbid waters. Submerged and floating leaves. Can grow terrestrially.
	Elatine spp. *Elatine hexandra ** Edge of lakes, reservoirs etc. Damp mud exposed at water's edge or shallow < 50 cm, sometimes at depths of 2m or more. Tolerates a wide range of chemistry from oligotrophic upland lakes to eutrophic lowland sites. Absent from highly calcareous waters. Often with *Eleocharis acicularis and Littorella uniflora*, also *Baldellia ranunculoides* and *Juncus bulbosus* where water is peaty. Summer annual on mud or submerged, short-lived perennial. Varies in abundance year to year.
	Limosella aquatica Wet sandy mud by ponds. Often dries out in summer. Small pools especially on limestone or on wet mud at the margins of lakes. Western half only. Very local. Found in turloughs, including in habitat 3270.
	Scirpus setaceus (= *Isolepis setacea*) Damp, bare ground, especially on sandy or gravelly soils; frequent.
	Juncus bufonius All kinds of damp habitats, fresh and brackish. Damp muddy places. Abundant.
	Centaurium pulchellum Damp grassy and/or open ground. Especially near sea. Dune slacks, upper saltmarsh and margins of lagoons. Now confined to Wexford, Waterford and Dublin.
	Centunculus minimus (= *Anagallis minima*) Bare damp sandy ground on heaths and in woodland rides. Lake shores and damp sandy places. Occasional in Kerry and extreme North, rare elsewhere.
	Cicendia filiformis Damp sandy and peaty bare-ish ground mostly near coast. Damp peaty and sandy places. Frequent in Kerry and Cork, only one other location in west Mayo.

Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) **3110**	**Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea*** **3130**
Conclusion, species: Oligotrophic isoetid dominated lake habitat.	**Conclusion, species:** Amphibious species associated with many habitats from *Cheopodion rubri* (3270) and turloughs (3180) to coastal and brackish habitats, to damp tracks and ditches. All listed amphibious species very unlikely to co-occur anywhere in Ireland and certainly not around the edges of oligotrophic, circum-neutral or soft-water lakes. More aquatic species (*Elatine hexandra* and *Sparganium natans*) possibly more associated with habitat 3110. Nothing in list of species to distinguish 3130 from 3110 in Ireland.
Interpretation manual – geomorphological description	**Interpretation manual – geomorphological description**
Very few minerals. Of sandy plains. Shallow oligotrophic waters with few minerals and base poor. On oligotrophic soils of lake and pond banks (sometimes on peaty soils). In France and Ireland this habitat occurs, in particular, in heathland of sandy plains on podzols, where the water table occurs at the surface.	Lake, pond and pool banks and water-land interfaces/ Land interface zones of lakes, pools and ponds with nutrient poor soils, or which grows during periodic drying of these standing waters.
Conclusion, geomorphology: In Ireland, this habitat is frequently associated with peaty soils and commonly surrounded by peatland. The scenario described for Ireland of heathland of sandy plains on podzols does not actually occur, other than small pools found in the sandy plain of the Curragh, and possibly also in Co. Wexford. 3110 habitat is actually typical of peatland (blanket bog and wet heath), siliceous rock types in the West of Ireland or upland areas elsewhere.	**Conclusion, geomorphology:** Describes two marginal, amphibious communities that can grow in close association and require disturbance in the form of fluctuating water tables or anthropogenic activities. Species list does not support assertion that 22.12 x 22.32 is associated with nutrient poor soils and may be more typical of rich habitats in Ireland.
Overall: Describes the shallow water community, frequently associated with the fluctuating margins of oligotrophic, base-poor, isoetid-dominated lakes in Ireland. The community is also likely to occur along the shoreline of other lake types, including hard-water and circum-neutral lakes. The Isoetid-dominated lake is an important and declining lake type that is well represented in Ireland and frequently associated with blanket bog and wet heath.	**Overall:** Does not describe a discrete lake community or habitat in Ireland. The interpretation manual indicates two groups of communities, biotopes and species, the first of which appears identical to 3110, the second group does not appear to occur in Ireland and is anyway associated with a broad range of environmental scenarios: typically anthropogenic disturbance; infrequently lake edges. Given the broad range of habitats and communities covered by 3130, it could most usefully be re-interpreted as a submerged lake habitat of circum-neutral waters with more species rich communities than habitat 3110.

Appendix II

Special Areas of Conservation (SACs) with Annex I lake habitat Qualifying Interests

The table provides the list of SACs selected for the five lake habitats:

1. **3110** Oligotrophic isoetid lake habitat ('Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*)')
2. **3130** Mixed *Najas flexilis* lake habitat ('Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*')
3. **3140** Hard-water lake habitat ('Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.')
4. **3150** Rich pondweed lake habitat ('Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* — type vegetation')
5. **3160** Acid oligotrophic lake habitat ('Natural dystrophic lakes and ponds')

In addition, information is provided on SACs selected for:

6. **1833** *Najas flexilis*, the Slender Naiad

Emboldened blue text indicates that the qualifying interest was added in 2015. Qualifying interests that were removed at that time are also indicated.

Site Code	Site Name	3110	3130	3140	3150	3160	1833
000007	Lough Oughter and Associated Loughs SAC				3150		
000014	Ballyallia Lake SAC				3150		
000032	Dromore Woods and Loughs SAC				3150		
000093	Caha Mountains SAC	**3110**	removed			3160	
000142	Gannivegil Bog SAC	3110					
000147	Horn Head and Rinclevan SAC		**3130**				1833
000163	Lough Eske and Ardnamona Wood SAC	3110					
000164	Lough Nagreany Dunes SAC		**3130**				1833
000165	Lough Nillan Bog (Carrickatlieve) SAC	3110					
000185	Sessiagh Lough SAC	removed	**3130**				1833
000194	Tranarossan and Melmore Lough SAC			3140			
000197	West of Ardara/Maas Road SAC	3110	**3130**				1833
000252	Coole-Garryland Complex SAC				3150		
000278	Inishbofin and Inishshark SAC	3110					
000297	Lough Corrib SAC	3110	**3130**	3140			1833
000304	Lough Rea SAC			3140			
000365	Killarney National Park, Macgillycuddy's Reeks and Caragh River Catchment SAC	3110	3130				1833
000370	Lough Yganavan and Lough Nambrackdarrig SAC	3110					
000375	Mount Brandon SAC	**3110**	3130				
000428	Lough Melvin SAC		3130				
000440	Lough Ree SAC				3150		
000470	Mullet/Blacksod Bay Complex SAC				3150		
000500	Glenamoy Bog Complex SAC					3160	
000534	Owenduff/Nephin Complex SAC	3110	removed			3160	
000584	Cuilcagh - Anierin Uplands SAC	**3110**	removed			3160	
000607	Errit Lough SAC			3140			
000633	Lough Hoe Bog SAC	3110					
000636	Templehouse and Cloonacleigha Loughs			3140			

Site Code	Site Name	3110	3130	3140	3150	3160	1833
	SAC						
000688	Lough Owel SAC			3140			
000708	Screen Hills SAC	3110					
001141	Gweedore Bay and Islands SAC	removed	**3130**				1833
001151	Kindrum Lough SAC	removed	**3130**				1833
001228	Aughrusbeg Machair and Lake SAC	3110					
001309	Omey Island Machair SAC			3140			
001311	Rusheenduff Lough SAC	removed	**3130**				1833
001312	Ross Lake and Woods SAC			3140			
001342	Cloonee and Inchiquin Loughs, Uragh Wood SAC	3110					1833
001571	Urlaur Lakes SAC			3140			
001673	Lough Arrow SAC			3140			
001774	Lough Carra/Mask Complex SAC	3110	**3130**	3140			
001786	Kilroosky Lough Cluster SAC			3140			
001810	White Lough, Ben Loughs and Lough Doo SAC			3140			
001818	Lough Forbes Complex SAC				3150		
001879	Glanmore Bog SAC	3110					
001919	Glenade Lough SAC				3150		1833
001922	Bellacorick Bog Complex SAC					3160	
001926	East Burren Complex SAC			3140			
001932	Mweelrea/Sheeffry/Erriff Complex SAC	3110	3130			3160	1833
001952	Comeragh Mountains SAC	**3110**	removed				
001975	Ballyhoorisky Point to Fanad Head SAC	removed	**3130**	3140			1833
001976	Lough Gill SAC				3150		
002006	Ox Mountains Bogs SAC	3110				3160	
002008	Maumturk Mountains SAC	3110					1833
002031	The Twelve Bens/Garraun Complex SAC	3110	**3130**				1833
002032	Boleybrack Mountain SAC					3160	
002034	Connemara Bog Complex SAC	3110	**3130**			3160	1833
002047	Cloghernagore Bog and Glenveagh National Park SAC	3110					
002074	Slyne Head Peninsula SAC	3110	**3130**	3140			1833
002111	Kilkieran Bay and Islands SAC		**3130**				1833
002118	Barnahallia Lough SAC	removed	**3130**				1833
002119	Lough Nageeron SAC	removed	**3130**				1833
002120	Lough Bane and Lough Glass SAC			3140			
002121	Lough Lene SAC			3140			
002122	Wicklow Mountains SAC	**3110**	removed			3160	
002130	Tully Lough SAC	removed	**3130**				1833
002176	Leannan River SAC	3110	**3130**				1833
002301	River Finn SAC	3110					

Two additional SACs are selected for *Najas flexilis* only:

Site Code	Site Name	3110	3130	3140	3150	3160	1833
001251	Cregduff Lough SAC						1833
002177	Lough Dahybaun SAC						1833