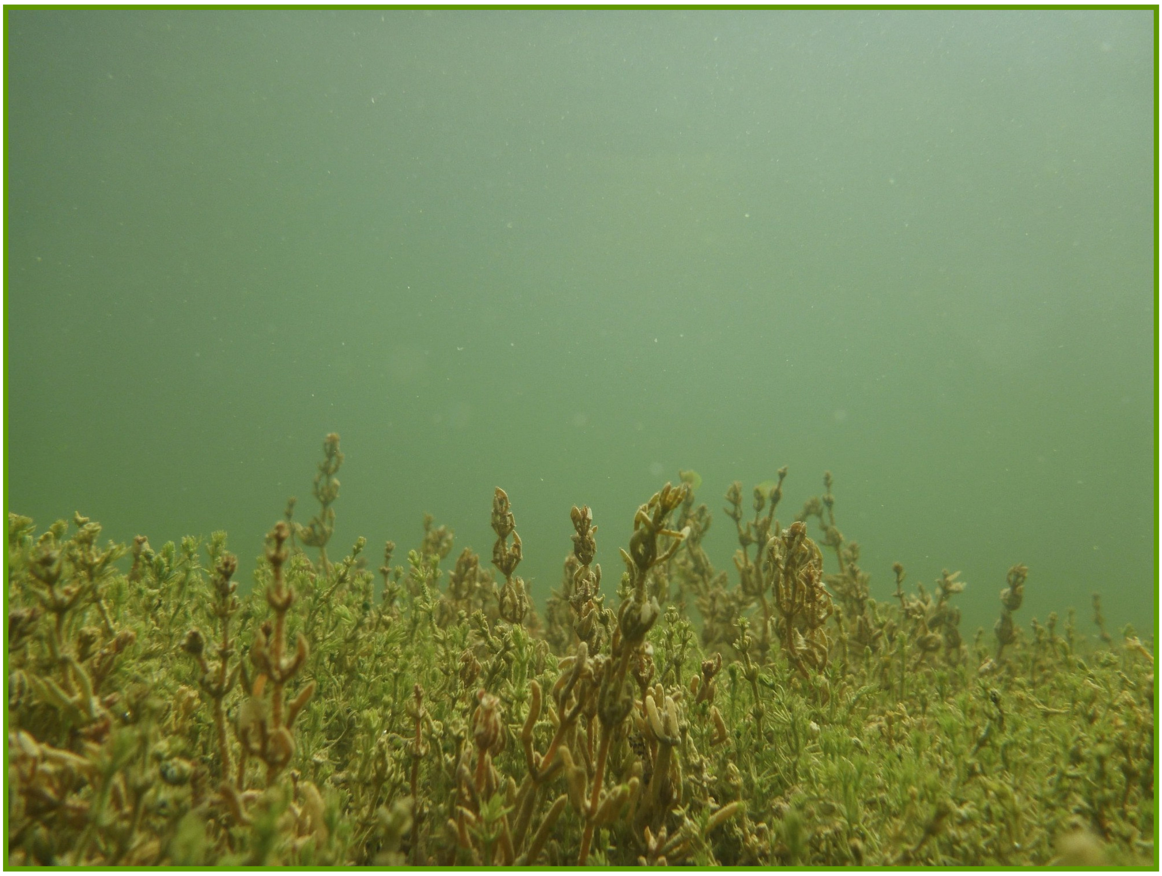
A survey of the benthic macrophytes of three hard-water lakes: Lough Bunny, Lough Carra and Lough Owel



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A survey of the benthic macrophytes of three hard-water lakes: Lough Bunny, Lough Carra and Lough Owel

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Cover photos: *Chara tomentosa* and *Chara curta* at 3m in Lough Owel. © NPWS

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Executive Summary

In 2011 the authors completed a sub-littoral vegetation survey of three limestone marl lakes: Lough Bunny (Co. Clare), Lough Carra, (Co. Mayo) and Lough Owel (Co Westmeath). The survey was done under contract to NPWS. Its purpose was to provide detailed maps of the lakes' vegetation and to assess their conservation importance and to determine if the habitat was under environmental threat.

All three lakes have a similar vegetation dominated by cyanobacterial crusts in shallow water giving way to extensive charophyte communities at depth. A depth zonation of plant communities was as follows: Cyanobacterial crust (termed krustenstein), *Chara curta*, *Chara rudis* and aquatic angiosperms, *Chara globularis* and/or *Chara virgata*, *Chara denudata* or *Nitella flexilis* agg. This type of vegetation is uncommon in the EU and some of the best European examples occur in Ireland. Therefore the conservation value of the lakes is very high and Ireland has a special responsibility to protect the habitat.

There are however obvious signs of ecological stress in one of the lakes, Lough Carra. These signs include a shallowing of maximum vegetation depth (6m in Carra, 8-9m in Bunny and Owel), a change in the nature of the deep water communities from charophyte to angiosperm dominance, the destruction of the cyanobacterial crust in the vicinity of inflowing streams and the rapid spread of an introduced species, *Chara tomentosa*. The causes of this stress are discussed and future monitoring methods based on the stress indicators noted above, suggested.

Acknowledgements

We wish to thank James King of the I.F.I. for allowing us to use his original survey data. Bryan Kennedy and Ruth Little let us examine EPA unpublished data. Áine O Connor and Jim Ryan of NPWS not only discussed the work but participated in the survey. Caroline Roche, Aquafact International, undertook the G.I.S. data processing. Chris Huxley provided much useful advice and guidance. Mr and Mrs Roberts, Partry not only welcomed us and looked after us during our fieldwork on Lough Carra but even rescued us when we ran out of fuel. Dr Klaus van de Wyer kindly arranged for Dr C. Roden to visit comparable sites in Bayern, Germany in September 2011 and permitted the use of the photo shown in plate 8. Sabine Springer helped in the long task of data input.

Plate 1: Lough Bunny, Lough Carra and Lough Owel (from top down)

Introduction

This study of three hard-water lakes in Ireland was commissioned by the NPWS. Hard-water lakes (EU Habitats Directive code 3140) are characteristic of the carboniferous limestone of the Irish midlands. Research over many decades has shown that they have a rich and distinctive flora and vegetation dominated by charophyte algae (Reynolds, 1998; King and Caffrey, 1998). Because they occur in lowland limestone areas, they are often adjacent to intensively farmed land and large towns and are consequently at risk from eutrophication due to agricultural run off and sewage (Pentecost, 2009).

Hard-water lakes are more common and larger in Ireland than in some neighbouring E.U. states, this abundance is reflected in the presence of species ranging from charophytes (*Chara tomentosa*), insects (*Ochthebiuis nilssoni*) and even fish, which are rare or absent from neighbouring countries. They are also the location of some of the countries finest brown trout fisheries (e.g. Lough Mask and Lough Corrib) (Reynolds, 1998). Thus, Ireland has a European responsibility to protect this habitat. However, there has been a steady erosion of habitat quality, including increasing chlorophyll levels, loss of unique populations of species such as Arctic char and some charophyte species and a possible decrease in water clarity with the consequence that the depth of the euphotic zone or the area covered by benthic vegetation is decreasing (Stewart and Church, 1992; NPWS, 2008). In addition, introduced species, especially *Lagarosiphon major*, are severely damaging certain lakes such as Lough Corrib.

While Irish hard-water lakes have been the subject of much research, accurate maps of sub-littoral vegetation based on snorkelling/scuba observation are not common (King and Caffrey, 1998). Heuff and Ryan did study a wide variety of lakes including the three proposed study sites in the 1970s (Heuff, 1984), while John *et al.* (1982) examined a number of hard-water Westmeath lakes. King and others (Krause and King, 1994; King and Champ, 2000) have studied sub-littoral vegetation of Lough Corrib and Lough Carra using grapnel samples. Roden (1999, 2000 and 2001) and Bruinsma *et al.* (2009) used snorkel/Scuba to map vegetation in hard-water lakes both on carboniferous limestone and calcareous machair. While all these surveys provide an outline of the vegetation of hard-water lakes and confirm the dominance of certain charophyte species, they were completed before the widespread use of GPS and are thus only approximate in positioning.

More recent work by the EPA lake survey teams has provided geo-referenced, grapnel data on vegetation. However, only the snorkel/Scuba surveys provide visual descriptions of *in situ* vegetation structure and components. Roden (2008, 2009) produced a detailed map of Lough Bane in Co. Westmeath, using snorkelling and GPS positioning of relevés and transects. It is noteworthy that this survey of the hard-water Lough Bane established both the presence of a previously un-described deep water bryophyte unit and a new station for the rare *Chara denudata*, thus illustrating the value of direct visual inspection.

Despite this body of work, it is not clear that sufficient data exist to make a satisfactory report (due every six years) to the European Commission under article 17 of the Habitats Directive. The last report in 2007 noted that hard-water lakes rated 'bad' under the headings 'Structure and Functions' and 'Future Prospects' (NPWS, 2008). Additional data and actions are required to support the implementation of both the Habitat and Water Framework Directives for hard-water lakes, including:

1. Description of the ecological characteristics of and internal variation in hard-water lakes
2. Maps of the distribution of the habitat and its variants
3. Assessment of the conservation value of the habitat and its variants
4. Determination of the elements of the habitat that ought be monitored and development of a monitoring methodology
5. Comparison of any proposed methodology to that used by the EPA for WFD monitoring and implementation of any necessary additional monitoring procedures
6. Proposals for restoration and protection methods

It is against this background that the present study was commissioned by the NPWS. The objectives of the study were as follows:

1. Collate and interrogate biological, physico-chemical and other relevant data for Lough Bunny (Co. Clare), Lough Carra (Co. Mayo) and Lough Owel (County Westmeath).
2. Produce benthic vegetation maps of these three hard-water lakes, through snorkel and/or scuba survey.
3. Report on the current conservation status and trend direction for the three lakes.
4. Make recommendations on future monitoring and assessment of the conservation status of these and other hard-water lakes.

Detailed field mapping is undertaken for three purposes:

1. to provide an accurate up to date baseline map of the vegetation that will describe within-habitat variation,
2. to establish if any changes, especially in depth of the vegetated zone (a good indicator of trophic status (Scheffer, 2004)) has occurred since any previous investigation,
3. to establish if benthic vegetation mapping is necessary for conservation management of these or other hard-water lakes.

Methods

Lough Bunny, Lough Carra and Lough Owel were surveyed between June and September 2011 by Dr Cilian Roden and Mr Paul Murphy. Survey dates were as presented in Table 1.

Table 1: Survey dates

Lake name	Survey dates
Lough Bunny	29th June, 01st July and 24th September 2011
Lough Carra	13th, 16th, 20th, 21st and 27th July; 03rd, 04th and 11th August and 29th September 2011
Lough Owel	17th, 18th and 31st August, and 1st September 2011

Sub-littoral vegetation was examined by snorkelling with boat cover. Depths were measured using a diver's depth gauge and position determined using a hand held GPS recorder (Garmin GPSmap 60CSx, accurate to +/- 5m). Vegetation relevés or quadrats (2 x 2m) were made by snorkelling and the data recorded by the boat-handler. In general fewer than five taxa occurred per quadrat, so recording was a simple exercise. Samples for later examination were stored in plastic bags and identified within three days of collection. On one occasion, scuba gear were used to explore an 18m submerged cliff in Lough Carra. In general sampling was conducted by swimming transects from the shore line to the limit of submerged benthic vegetation. Relevés were taken whenever changes in vegetation were detected. Consequently sampling density is greater along sharp gradients.

The location of each station (relevé), identified by waypoint number, is shown in the maps of each lake (Figures 6, 7 and 8). Maps were based on the 2005 OSi orthophoto series. The same waypoint numbers were used in Appendix II to tag each relevé. For a small number of relevés, it was not possible to take a GPS position: these were designated as 574.1, 574.2 etc., where 574 is the nearest waypoint. The distance involved never exceeded 20m.

Underwater photographs were taken with a Panasonic DMC FT3 underwater camera.

Identification guides used include Moore (1986), and John *et al*. (2002). Nomenclature for higher plants follows Stace (1999) and algae follow John *et al*. (2002).

Vegetation types were determined using the TWINSPAN programme, a final vegetation table was slightly modified by hand. For each transect, the depth range of each vegetation unit was calculated. Using aerial photographs and bathymetric maps of each lake the available ground within the depth range of each vegetation unit was mapped and assigned to that vegetation type.

Site descriptions

Lough Bunny

Lough Bunny is a small lake of about 1 km^2, 14m depth and 2km in length and 0.5km in width (Figure 1). Much of the lake is less than 3m but two deep basins occur, separated by a saddle, at a depth of about 5m. There are no inflowing streams and much of the surrounding land is hazel scrub or limestone pavement. In several places springs occur. In this study a spring was located in the northwest sector (Waypoint 333). In 2001, Roden (2001) saw a large depression or opening on the western side of the southern basin, but we could not re-locate this feature.

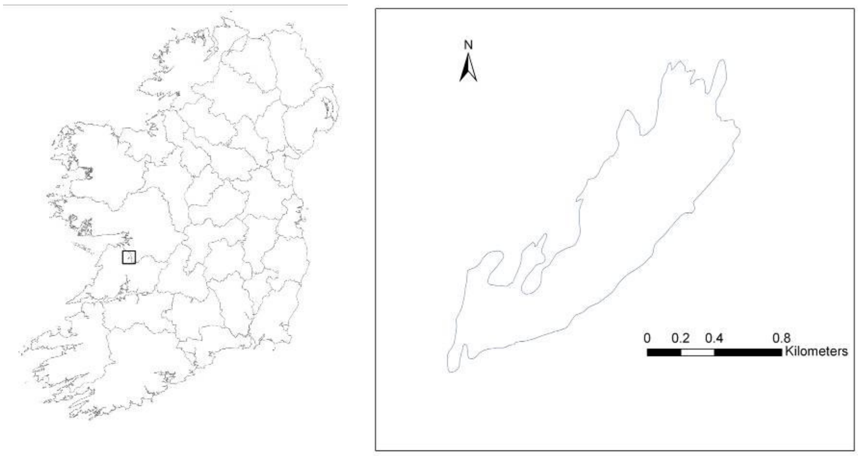

Figure 1: Lough Bunny

Lough Carra

Lough Carra is a large complex lake of 18 km^2, with eight separate deep holes of 15-20m depth separated by extensive shallows of 1-4m depth (Figure 2). It is divided into a lower and larger arm running north-east to southwest linked to a smaller northern arm running in the same direction by a narrow north—south basin. These three areas are referred to as the Twin island basin, the northern or Castle Burke basin and the Castle Carra basin. Several streams enter the northern and southern basins, but not the Castle Carra basin. A series of circular depressions at the south-west end of the northern basin at Gallagh (WP369-376) appear to be dolines which may act as sources or sinks. A similar feature occurs on the western shore of the Twin Island basin (WP 574).

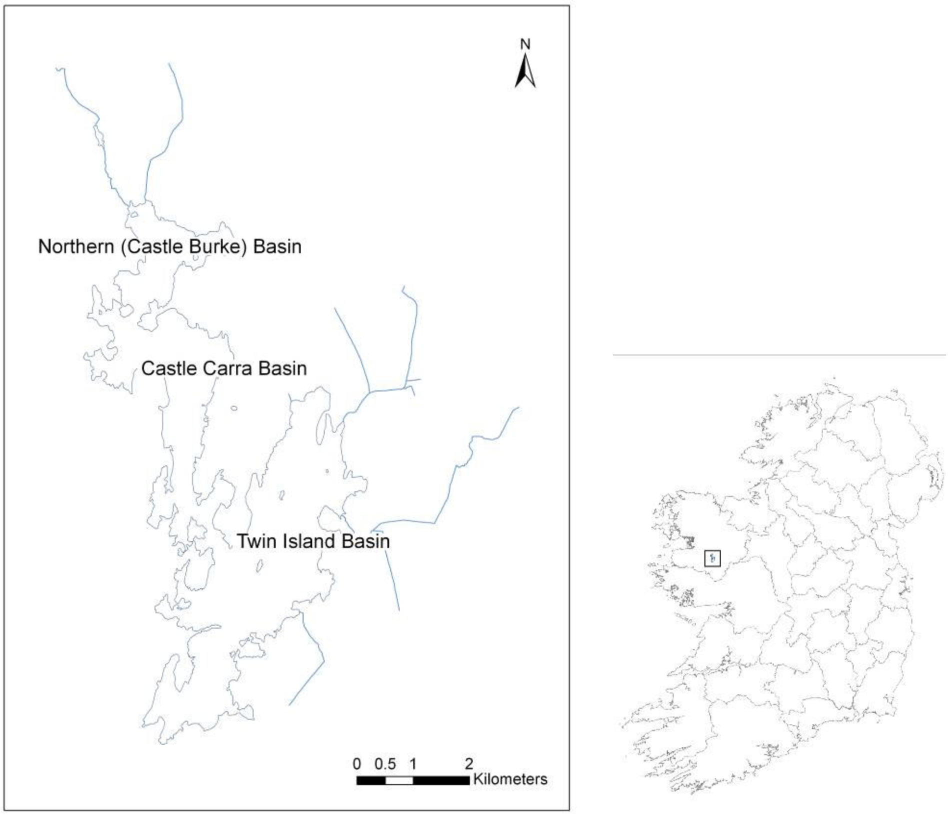

Figure 2: Lough Carra, showing main in-flowing streams

Lough Owel

Lough Owel is a large lake of 10 km^2 consisting of a single large basin running north-west—south-east (Figure 3). It is 24m deep at its deepest, 6.6km long and 3km wide. A river exits the lake at the northwest end and a feeder canal leaves the southeast corner. Doline like features occur in the south-west corner, in one of which we noted much colder water suggesting an inflowing spring (WP 692-698).

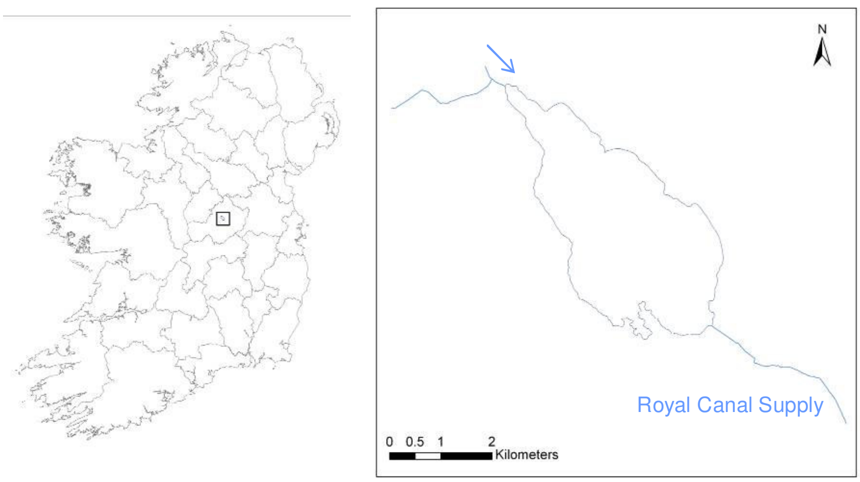

Figure 3: Lough Owel, showing main in-flowing stream and canal feeder

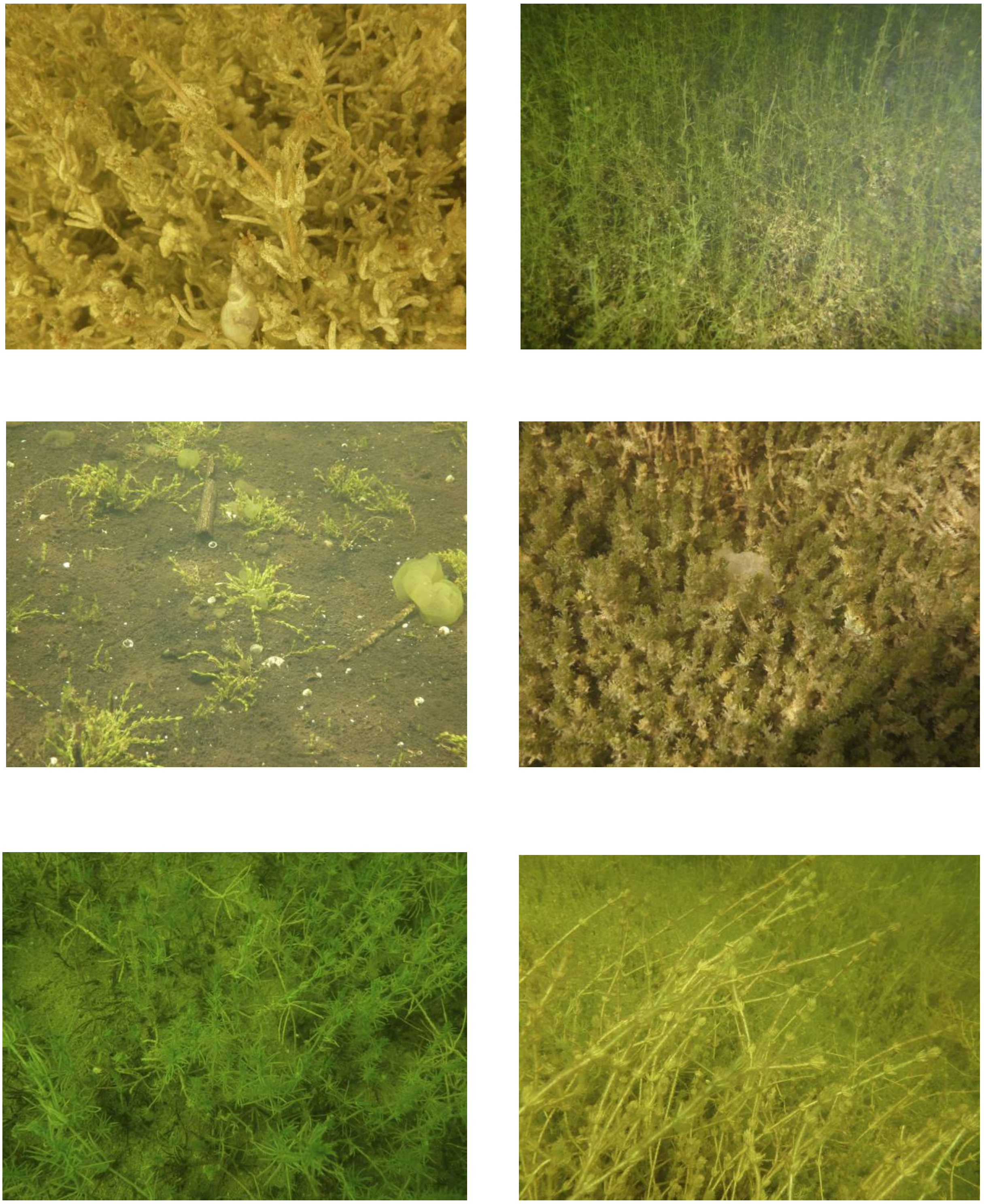

Plate 2: Typical Charophytes of marl lakes; from top left in clockwise order: *Chara tomentosa*, *Chara globularis*, *Chara curta*, long-form of *Chara aculeolata*, *Chara rudis* and *Chara virgata* var. *annulata.*

Vegetation classification and mapping

During fieldwork, it was quickly realised that all three lakes had a sub-littoral vegetation dominated by charophytes and that the distribution of different species was largely determined by depth (Plate 2). In order to map vegetation, however, it was necessary to first define the units to be mapped. In this chapter we describe our approach to defining vegetation units and our results; we then present maps of the vegetation of the lakes.

The nature of lake vegetation

Even though over 400 relevés were sampled, the total number of species encountered did not exceed 50. Figure 4 shows that sufficient relevés were taken to ensure that most species present in each lake were sampled. Of these taxa, only 17 occurred in all three lakes, while a further 16 occurred in two of the three lakes; the remainder only occurred in a single lake (Table 2). These figures suggest that each lake may differ substantially in its vegetation or alternatively that a small number of species dominate the vegetation.

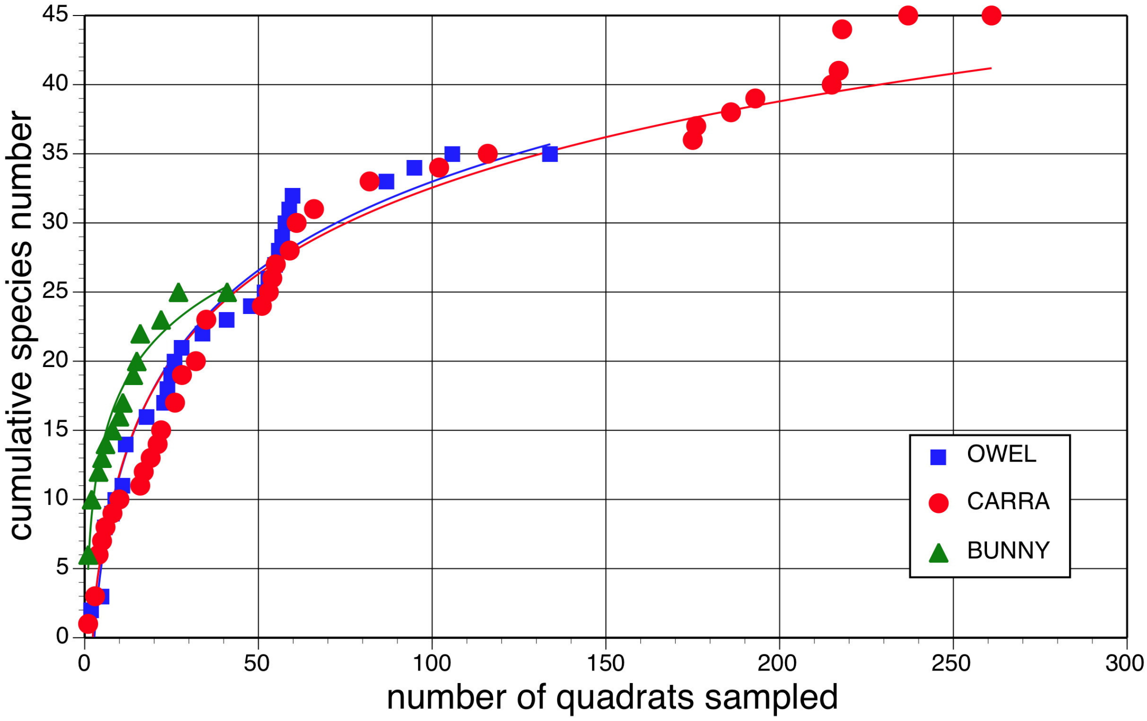

Figure 4: Cumulative species number versus number of relevés sampled

The matter can be resolved by examining the results of TWINSPAN analyses of each lake (Appendix I). These tables show that the vegetation is grouped into a number of units, which are mainly characterised by a dominant charophyte species, all of which occur in all three lakes or in two of the three lakes, as shown in Table 2. In the tables and maps, abbreviations are used for the vegetation units (Table 3). Associated with these dominant species are a variety of other aquatic macrophytes which have both low abundance and constancy. In other words much of the vegetation is composed of a few widespread species. In Appendix II the complete data sets of the vegetation survey of each lake are presented in spreadsheets. Species are arranged into the vegetation units derived from the TWINSPAN analysis. These data are summarised in Table 4 by grouping species into constancy classes (I = present in <20% of relevés, V= present in > 80% of relevés) and permits a comparison between the vegetation of the three lakes.

Table 2: A list of taxa recorded in the survey and the number of lakes in which each occurred

Taxa occurring in all 3 lakes	**Taxa occurring in 2 of the 3 lakes**	**Taxa occurring in only 1 lake**
Bryophytes	*Chara denudata*	*Alisma plantago-aquatica*
Chara aculeolata	*Chara hispida*	*Chara vulgaris*
Chara aspera	*Chara tomentosa*	*Hippuris vulgaris*
Chara contraria	*Cladophora*	*Juncus bulbosus*
Chara curta	*Elodea canadensis*	*Lemna minor*
Chara globularis	*Lemna trisulca*	*Myriophyllum verticillatum*
Chara rudis	*Myriophyllum alterniflorum*	*Potamogeton coloratus*
Chara virgata var. *annulata*	*Myriophyllum spicatum*	*Potamogeton crispus*
Krustenstein	*Nitella flexilis*	*Potamogeton filiformis*
Littorella uniflora	*Nuphar lutea*	*Potamogeton friesii*
Ophrydium versatile	*Nymphaea alba*	*Potamogeton natans*
Phragmites australis	*Potamogeton lucens*	*Potamogeton perpusillus*
Potamogeton gramineus	*Potamogeton pectinatus*	*Potamogeton zizii*
Potamogeton nitens	*Potamogeton praelongus*	*Ranunculus flammula*
Potamogeton perfoliatus	Red cyanobacterial mat	*Ranunculus sp.*
Schoenoplectus lacustris	*Utricularia minor*	*Ranunculus trichophyllus*
Utricularia vulgaris		*Sparganium erectum* agg.
		Utricularia intermedia
17 taxa	**16 taxa**	**18 taxa**

Table 3: Abbreviations used for vegetation units

Vegetation unit	**Abbreviation**
Krustenstein or cyanobacterial crust	CY
Chara virgata var. *annulata* variant of CY unit	ANN
Chara curta	CUR
Chara. .denudata	DENUD
Elodea and other angiosperm unit	ELOD
Chara globularis/Chara virgata unit	GLOB
Angiosperm communities with very low cover <10%	OPEN
Chara rudis or *Chara rudis* and *Nuphar* in case of Lough Bunny	RU
Chara tomentosa unit of Lough Chara	TOM
River mouth communities in Lough Carra	VULG
areas with no plant or krustenstein growth	Empty
Chara contraria unit in L. Owel	CONT
Nitella zone in Lough Bunny	NIT

Table 4: Vegetation types in each lake. Vegetation units were grouped using TWINSPAN. Roman numerals show % frequency of each species in each vegetation type. The complete data set is shown in Appendix II.

Lough Bunny						
depth	0.85	2.25	1.67	2.4	5.68	7.43
vegetation	cy	cur	op	ru	glob	nit
cyanophyte crust	V					
Ophrydium versatile	II					
Chara annulata	I					
Chara aspera	I					
Littorella uniflora	II					
Bryophytes	I					
Chara polyacantha	I					
Chara desmacantha	I	V	I			
Chara contraria		II				
Juncus bulbosus		I	II			
Schoenoplectrus lacustris		III	IV	II		
Numphar lutea		III	I	V		
Chara rudis		II		V		I
Potomageton gramineus			II	II		
Potomageton perfoliatus				II		
Potomageton praelongus				III		
Hippuris vulgaris				II		
Potamogeton niters			I	I		
phragmites			I			
Ranunculus ???			I			
Chara globularis					V	I
Nitella flexilis					II	V
U. minor	I	I	I	I		
U. vulgaris	I	I		I	II	

Lough Owel							
depth	1.18	1.4	3	2.84	4.44	4.63	5.5
vegetation	cy	cur	cont	ru	glob	denud	elod
U. vulgaris		I					
Potomageton gramineus		I					
Schoenoplectrus lacustris		I					
Nymphaea alba		I					
phragmites		I					
Bryophytes	I	I					
Ranunculus ???	I	I					
Littorella uniflora	II	I					
Myriophyllum alt	IV	I			I		
cyanophyte crust	V	II					
Ophrydium versatile	I	I	I				
Chara polyacantha	I	II		I			
Chara annulata	III	I	I	I			
Chara aspera	III	I	II	I		I	
Cladophora		I		I	I		
Chara tomentosa	I	IV		II	I	I	
Chara desmacantha	I	V	II	I	I	I	
Chara contraria	III	I	V	I	II		
Chara rudis	I	II	III	V		I	II
Potamogeton niters			I	I	I		
Chara globularis			II	I	V		
Nitella flexilis					II		I
Chara denudata					II	V	I
Elodea canadensis							V
Potamogeton friesii	I					I	IV
Potomageton praelongus							II
Potamogeton pectinatus				I			II
Myriophyllum spicatum							I
Potomageton perfoliatus							I
Chara hispida				I			
Potamogeton lucens				I			
Potomageton coloratus			I				

Lough Carra								
depth	1.09	1.26	1.53	2.12	3.41	5.08	4.94	6.33
substrate	ann	cy	cur	tom	ru	glob	elod	denud
R. flamula	I							
Bryophytes		I						
ranunculus trichophy		I						
Ophrydium versatile	I	I						
Chara annulata	V	I						
phragmites	II	II	I					
cyanophyte crust	IV	V	I					
Chara desmacantha		III	V					
Littorella uniflora	I	I	I					
Chara hispida			I					
Potamogeton filiformis	I		I					
Chara polyacantha	I	I	II	I				
Potamogeton pectinatus			I	I				
Nymphaea alba		I	I		I			
Myriophyllum alt		I	I		I			
Chara aspera	I	I	I		I			
Potomageton gramineus			I	I	I			
Potamogeton lucens		I	I	I	I	I		
Numphar lutea			I	I	I	I	I	
Chara contraria		I	I			I		
Potamogeton nitens	I	I	I		I	I	I	
Schoenoplectrus lacustris			I	II	I			
Chara tomentosa	I	I	I	V	I			
U. vulgaris	I	I	II	II	II	I		
Chara rudis	II	I	I	II	V	III		
Myriophyllum vert.	I	I	I	II	II	I	III	
Elodea canadensis		I		I	II	I	IV	
Potomageton perfoliatus			I		II	I	III	
Utricularia intermedia		I	I		I	I		
U. minor	I		I		I	I	I	
Potamogeton crispus			I		I	I		
Potamogeton zizii			I			I	I	
Lemna trisulcata					I	I		
Chara globularis		I	I		I	V	I	I
Myriophyllum spicatum						I		
Red cyanophyte						I		
Chara denudata								V

In the following section the major units identified using TWINSPAN analysis are described for each lake and then an attempt is made to relate these units to each other. See excel spreadsheets (Appendix II) for vegetation units.

Lough Bunny

Krustenstein

Visually this unit appears as a yellow-brown crust on exposed rock (Plate 3). Microscopic examination shows that the crust contains many species, but most of the crust consists of the cyanobacterium *Schizothrix fasiculata*. This unit is common in Irish Carboniferous marl lakes and has been equated to the krustenstein formation of sub-alpine lakes by Pentecost (2009). While the continental krustenstein may be found to differ from Irish examples following detailed comparisons, this unit is referred to as krustenstein in this report. It should be noted that the term includes not only the cyanobacterial layer but also the underlying etched rock. The commonest associated species is the colonial flagellate *Ophrydium versatile* (Muller) Ehrenberg, which contains symbiotic green algae. *Chara virgata* var. *annulata* and *Littorella uniflora* occur occasionally. This unit is extensive on exposed rocky shores down to a depth of 1.5 - 2.0m.

This unit is extensive in unpolluted Irish limestone lakes has been described by John *et al*. (1982) and Roden (2001). A variant crust that is much softer can form on hard submerged peat and occasionally on loose pebbles forming rounded 'oncoliths'.

Marl

In Bunny, there are very large areas of a similar colour to the krustenstein, but that consist of coarse shell sand without crust development.

Chara curta

These stands, which occur in water of 1-2m, are locally extensive. In general the species forms a dense, monospecific sward, but in slightly deeper water it grades into the following unit.

Chara rudis/Nupar lutea *community*

This unit occurs along the slope break of the lake's two basins. While *Chara rudis* has high cover values, *Nuphar lutea* frequently forms an upper layer along with *Potamogeton praelongus* and *Potamogeton perfoliatus*. This unit grades into pure stands of *Chara rudis* at slightly greater depths, but these quickly give way to more extensive *Chara globularis* stands. In other lakes such as Lough Bane

(Roden 2008), pure stands of *Chara rudis* can be separated from the angiosperm-dominated unit that is usually confined to the slope break.

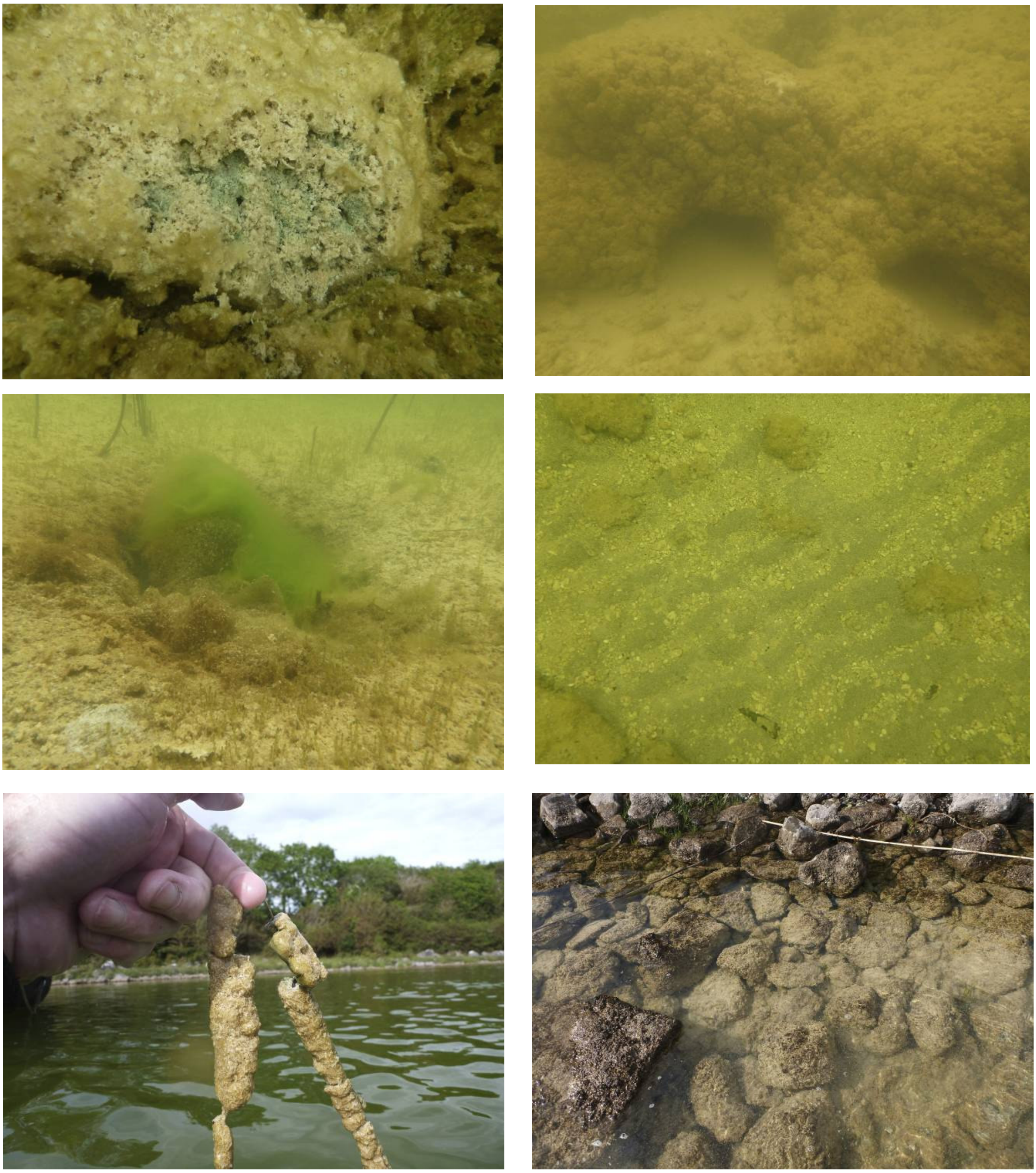

Plate 3: Cyanobacterial crust or krustenstein; clockwise from top left: 1) Stone with crust removed to show blue-green colour, 2) Encrusted rocks at 2m, 3) Wave-marked sandy-marl in Lough Bunny at 4m, krustenstein only on boulders, 4) Shore zone - reddish colour indicates different species in this zone, 5) krustenstein developed on old fishing line, Castle Carra Bay, 6) Small spring in the krustenstein zone with green filamentous algae, Lough Carra.

Schoenoplectus lacustris *stands*

This unit is characterised by the presence of the emergent species Bulrush, often growing on a coarse shell sand or silt bottom. In many relevés only the submerged form was recorded. It grades into the previous unit of *Chara rudis/Nuphar lutea*. Small stands of *Schoenoplectus lacustris* are scattered throughout the shallower (<2m) soft sediment areas of the lake, but do not form stands large enough to map.

Chara globularis

Chara globularis stands are well developed in deeper water but have few associates other than occasional *Utricularia vulgaris*.

Nitella *community*

At the limit of macrophyte vegetation below 7m very extensive beds of *Nitella flexilis* agg. occur.

Cyanobacterial mat community

Below the lower limit for macrophytes, the bottom is occasionally covered with dark red or green cyanobacterial mats 1 - 2 metres in size, consisting mainly of *Oscillatoria* species. Similar mats can occur interspersed with charophyte swards. Like the *Schoenoplectu*s stands, the cyanobacterial mat does not form units large enough to be mapped.

Vegetation of springs or depressions

Lough Bunny is fed and drained by underwater springs. The vegetation of the largest spring encountered is shown in relevé 334. The spring emerged from a crack at 7m amongst bedrock and boulders on the wall of a circular depression which extended from 8-3m below water level. *Potamogeton crispus* was abundant in the depression but was not encountered again during the survey.

Lough Carra

Lough Carra is a complex lake with eight deep holes greater than 8m depth, separated by extensive areas of shallow water.

A number of broad vegetation divisions can be recognised but these do not fully describe differences between basins.

Krustenstein

This unit is very extensive in Carra, covering huge areas of shallow water. It is remarkably thick in this lake with crust-depth sometimes exceeding 10cm. Several *Chara* species are associated with it, including a short thick form of *Chara rudis/hispida* not encountered in the other lakes. A sub-division of stands dominated by *Chara virgata* var. *annulata* is identified in the TWINSPAN analysis, but it is hard to separate from other relevés dominated by krustenstein.

Chara curta

This unit is very extensive in Carra, two variants are distinguished in the TWINSPAN analysis: a deeper water type with *Utricularia vulgaris* and *Potamogeton gramineus*, and a shallower water form with *Chara contraria* and *Chara aculeolata*.

Chara tomentosa

This species is confined to the southern basin of the lake, where it is extremely common forming mono-specific stands in water from 0.5 - 3.0m deep. It is also associated with *Utricularia vulgaris*, *Myriophyllum verticilliatum* and *Schoenoplectus lacustris*. In places, the species forms circular growths of up to 1.5m in diameter, suggesting recent colonisation.

Chara rudis

Chara rudis forms either pure stands or is mixed with angiosperms including *Elodea canadensis*, *Potamogeton perfoliatus*, *Potamogeton x nitens*, *Myriophyllum verticillatum* and *Utricularia vulgaris*.

Chara globularis

Monospecific stands of *Chara globularis* are infrequent in Carra, mainly occurring in the most southerly basin. It also occurs intermixed with *Chara rudis*

Elodea canadensis *and* Myriophyllum verticillatum

In some basins, *Elodea canadensis*, *Myriophyllum verticillatum* and *Potamogeton* species form the lowermost vegetation unit rather than charophyte dominated communities. In addition *Myriophyllum verticillatum* forms dense stands which break the surface in water depths of 5 - 6m (Plate 4).

Chara denudata

Chara denudata forms pure stands in two of the eight Lough Carra holes. All stands are at depths of 6 – 8m.

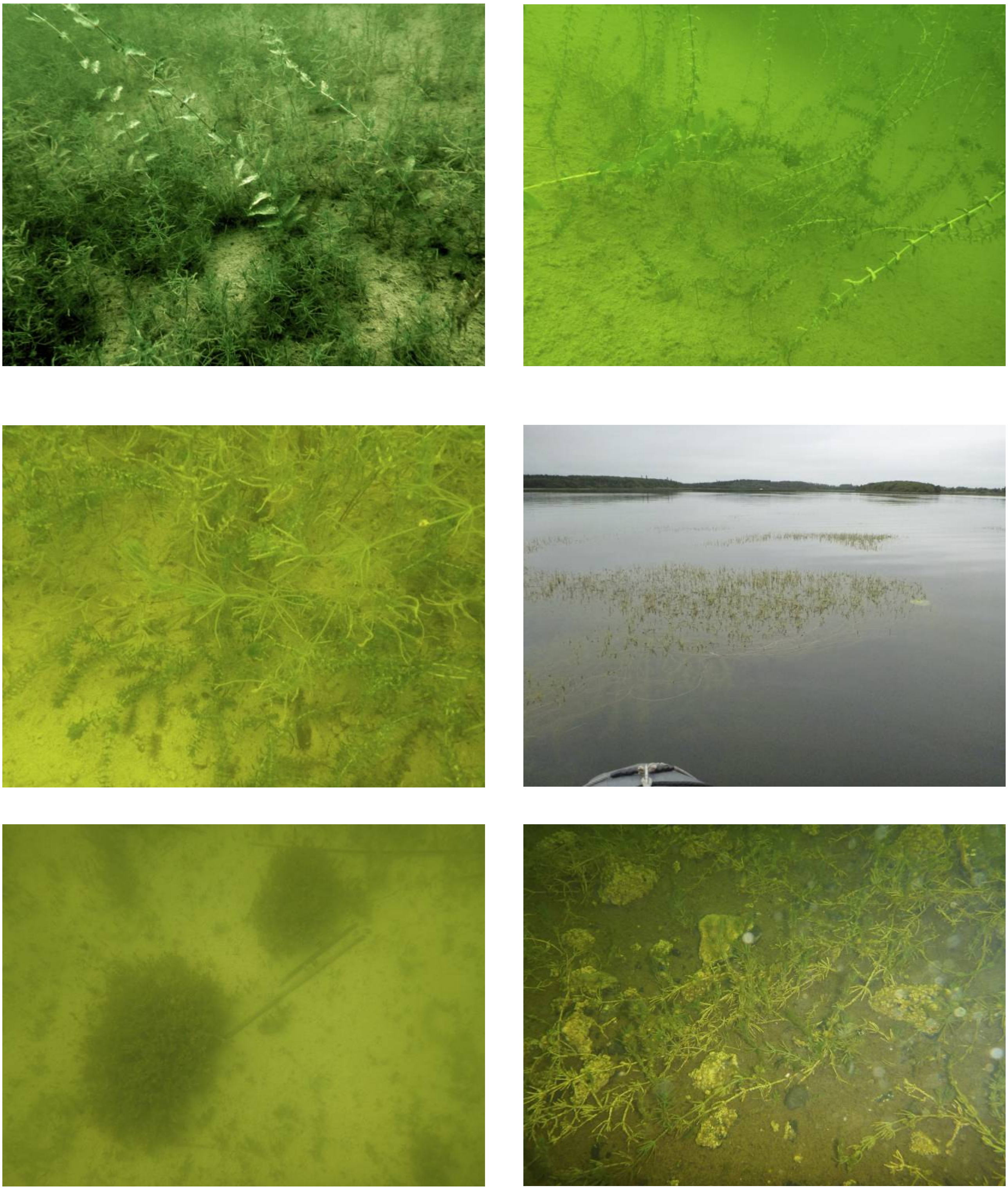

Plate 4: Possible indicators of stress. Clockwise from top left: 1) Base of euphotic zone, *Chara rudis* sward breaking up and presence of *Potamogeton perfoliatus*, 2) *Elodea canadensis* at base of euphotic zone, 3) Banks of *Myriophyllum verticillatum* in Lough Carra, 4) *Chara rudis* at base of euphotic zone, 5) New colonies of *Chara tomentosa* in Lough Carra, 6) *Chara rudis* and *Elodea canadensis* at base of euphotic zone.

Vegetation of dolines

As in Lough Owel, there are several circular, isolated inlets on the western side of the lake. They also contain a comparable vegetation of *Chara* species: *Chara curta*, followed by *Chara rudis* and the large form of *Chara aculeolata*, and then *Chara globularis* in Gallagh Bay. While in Cloonlagheen (WP 574), *Chara curta* and *Chara aculeolata* are followed by *Chara rudis*. In both cases, vegetation did not extend below 5m.

River-mouth communities

At three river mouths a distinctive vegetation has been recorded which is characterised by mineral sand replacing limey marl, an abundance of bryophytes especially *Fontinalis antipyretica*, the visible decay of krustenstein which is colonised by *F. antipyretica*. *Chara vulgaris* and true *Chara hispida* are present (Plate 5). A large form var *hedwigii* of *C. globularis* also occurred. *Lemna* species occur and *Cladophora* is common. This unit appears to be expanding by colonising the krustenstein, which is breaking down (due to shading of epiphytic bryophytes). As *Chara vulgaris* is an r-selected or opportunistic species, it appears that inflowing water results in the ongoing destruction of the cyanobacterial crust unit and its replacement by weed species and *Cladophora*.

Lough Owel

Krustenstein

This vegetation unit is similar to that in Lough Bunny, however a greater range of associated plants were recorded including several small *Chara* species and *Myriophyllum alterniflorum*. Along the north-eastern shore, the bottom is steep wave exposed and rocky and the krustenstein is well developed and descends several metres.

Chara curta

These stands that occur in water of 1 - 2m are very extensive throughout Owel. *Chara tomentosa* frequently occurs in this zone but rarely forms monospecific stands. *Chara contraria* also forms part of the unit and in a variant found on the west side of the lake it is dominant.

Chara rudis

This species occurs both in monospecific stands and associated with other charophytes including *Chara tomentosa*, *Chara contraria* and *Chara curta*. Few angiosperm species were recorded however.

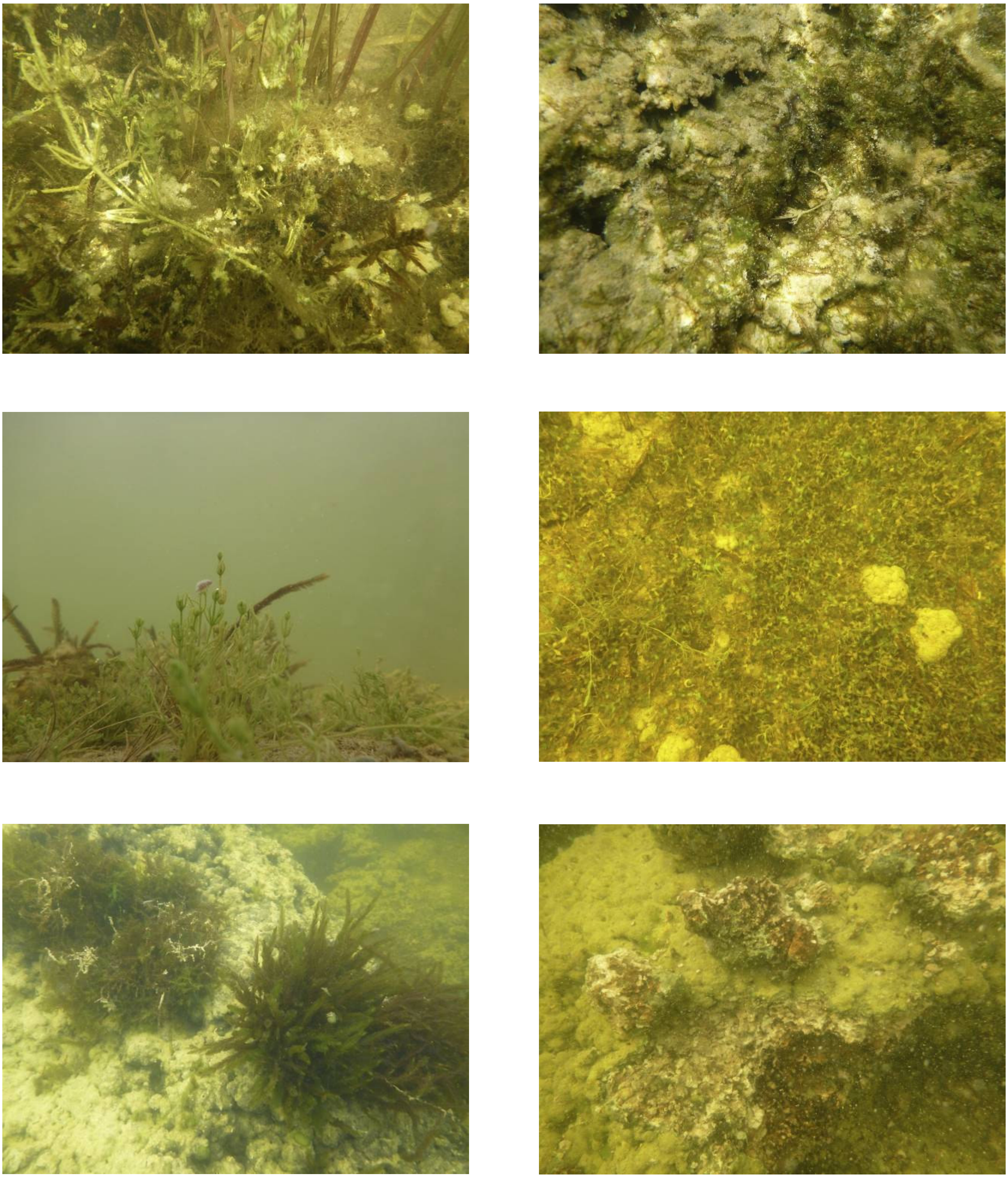

Plate 5: Colonisation of krustenstein at river mouths in Lough Carra: Clockwise from top left: 1) *Fontinalis antipyretica* and *Chara hispida* growing over krustenstein, 2) Liverwort (?*Jungermania* sp.) growing over krustenstein, 3) Mat of *Lemna trisulca*, 4) Krustenstein breaking down and producing red sand, 5) *Fontinalis antipyretica* growing on krustenstein, 6) *Chara vulgaris* and *Fontinalis antipyretica* on red sand.

Chara globularis

Unlike Bunny and Carra, Owel has only local beds of *Chara globularis*, mainly in the south-eastern area. *Nitella flexilis* sometimes also occurs in this area.

Chara denudata

This species is very abundant in Owel at depths greater than 5m. It mainly occurs in mono-specific stands.

Aquatic angiosperms

Angiosperms are remarkably scarce in Owel, with the introduced *Elodea canadensis* being the most frequently recorded form. *Elodea* tends to occur at the base of the euphotic zone along with *Potamogeton friesii* and *Potamogeton praelongus*, both species are very locally distributed, however.

Vegetation of dolines at the southern end of Lough Owel

While it is reported that there are springs in the south-eastern corner of Owel, they were not found in this survey. However, a series of doline-like structures forms the southern shore of the lake. Two of these were investigated and in one it was noted that the water temperature of 14˚C was 3 degrees colder than that of the adjoining open lake, leading one to suspect that colder water was emerging from these structures. Vegetation included a zone of true *Chara hispida* followed by *Elodea canadensis* and a dense coating of *Lemna trisulca* descending to 3.7m. No plants were found below this depth. The other doline had an equally shallow euphotic zone but *Chara rudis* replaced *Chara hispida*.

What is the characteristic vegetation of marl lakes?

Table 2 lists the species found in all three marl lakes. These may be regarded as the core species of marl lakes. It can be seen that all the major vegetation units noted above are represented and a "typical" marl lake's vegetation is outlined in Table 5. In Figure 5 the average depth of each vegetation unit is shown.

All three lakes also have more limited communities associated with possibly more nutrient rich environments. In Lough Carra, river mouth communities are dominated by bryophytes, *Chara hispida* and *Chara vulgaris*; in Lough Owel, a doline with cold water contains a *Lemna trisulca, Chara hispida* community, while springs in Lough Bunny support a *Potamogeton crispus* community. Lough Owel differs from many other marl lakes in the presence of *Chara tomentosa* and the abundance of *Chara* *contraria* and *Chara denudata*, as well as the smaller populations of *Chara rudis* and *Chara globularis*. The reason for these differences is not known.

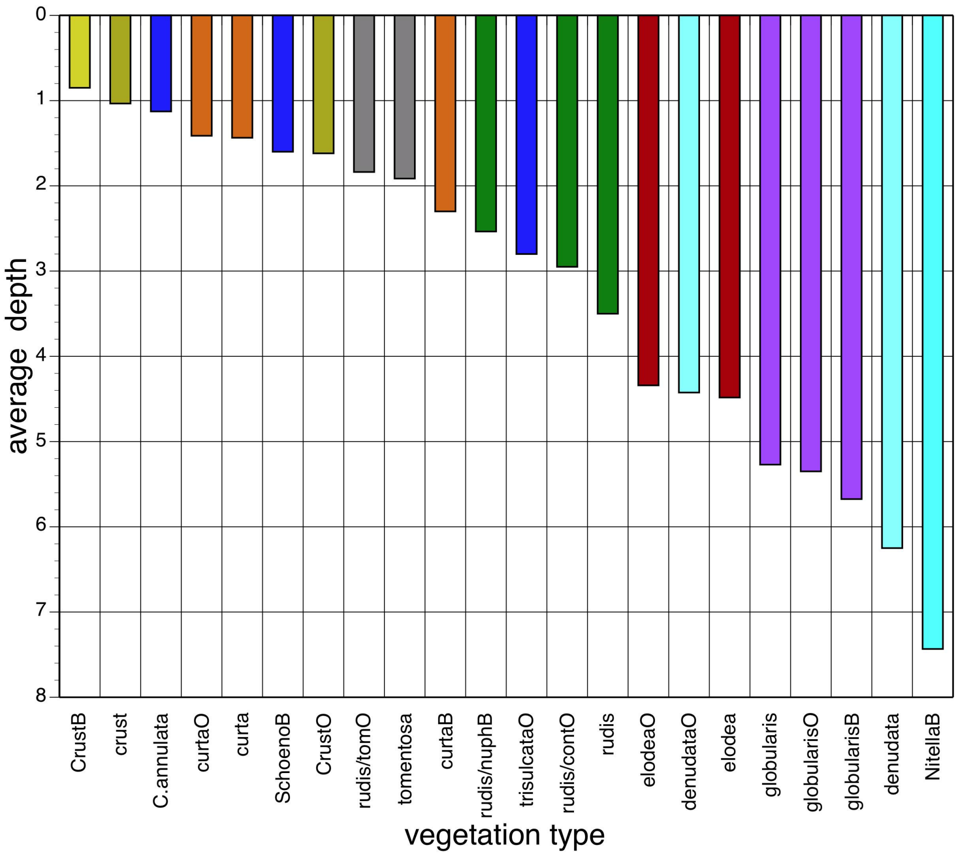

Figure 5: Average depth of vegetation types. Letter suffix: O is Lough Owel and B is Lough Bunny, no letter refers to communities from Carra

Table 2 lists the species found in all three marl lakes and these may be regarded as the core species of marl lakes. It can be seen that all the major vegetation units noted above are represented and a 'typical' marl lake's vegetation could be defined as per Table 5 (Plate 6). The characteristic angiosperms of marl lakes are showing in Plate 7.

Table 5: The characteristic vegetation of marl lakes

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* (and, in Lough Owel, also with *Chara tomentosa*). 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 nitens, Potamogeton perfoliatus, Schoenoplectus lacustris*
Chara globularis	Below the *Chara rudis* unit, *Chara globularis* or *Chara virgata* (see chapter on the flora of marl lakes, for discussion of *globularis* vs. *virgata*) can form extensive swards which extend to 8m below the surface. In the south-east of Lough Owel, *Chara globularis* grows close to the base of the euphotic zone, below *Chara denudata*.	*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*

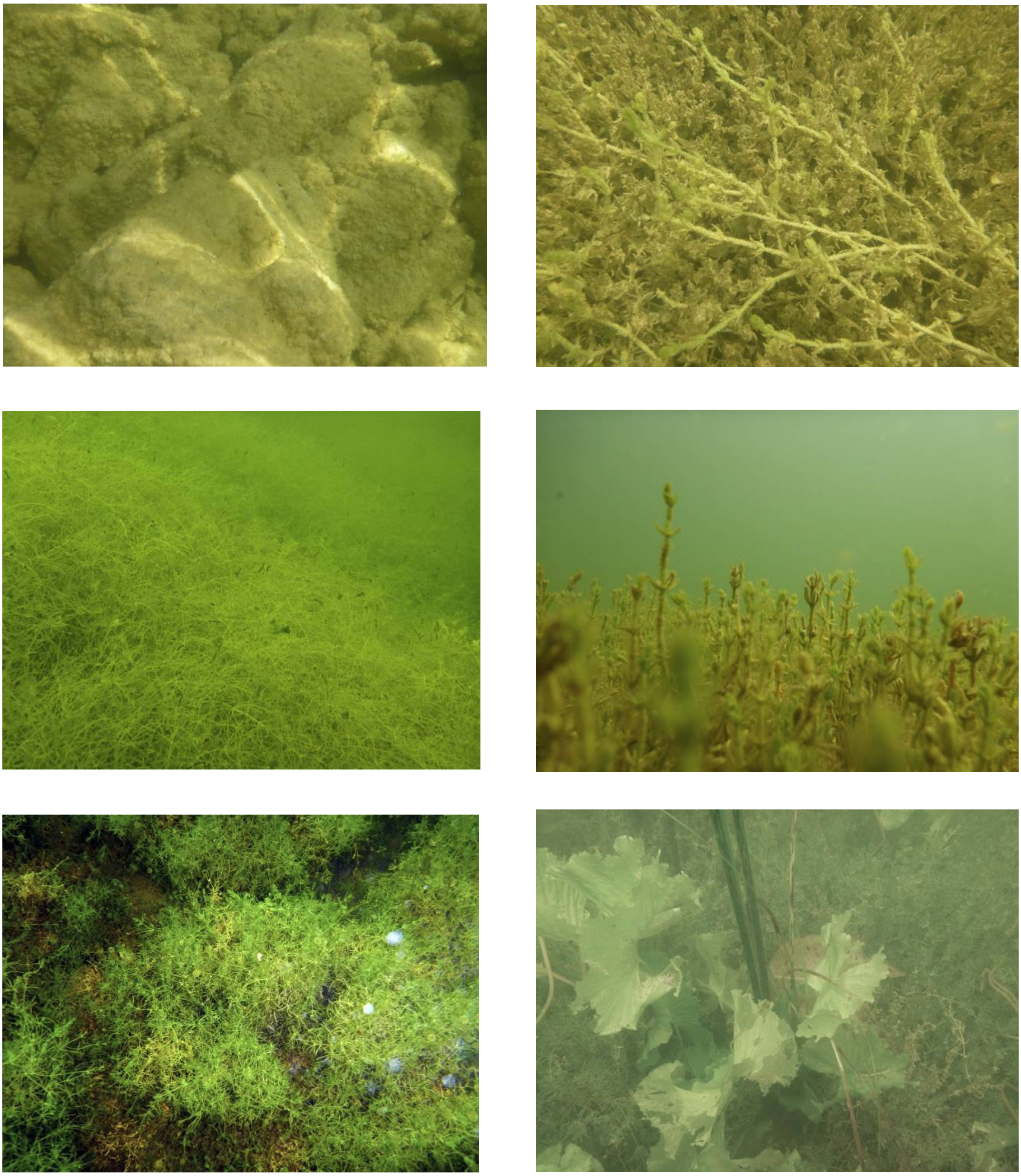

Plate 6: Marl lake vegetation zones, clockwise from left: 1) Krustenstein at 1m, 2) *Chara curta* with long-form of *Chara aculeolata* at 2m 3) *Chara curta* with *Chara tomentosa* at 3m, 4) *Chara rudis* with *Nuphar lutea* and *Schoenoplectus lacustris* at 4m, 5) *Chara globularis* at 7m, 6) *Chara denudata* at 7m

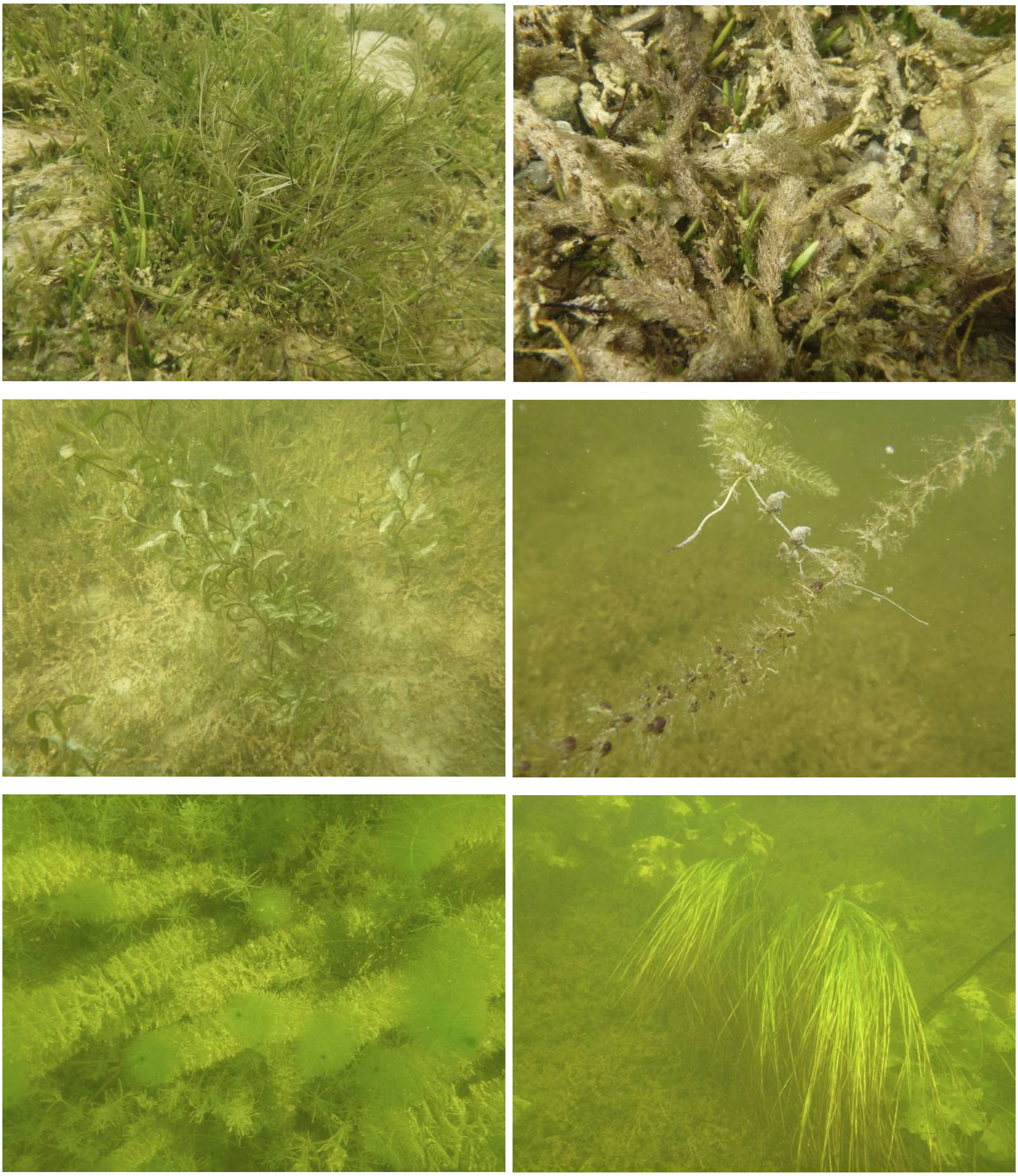

Plate 7: Angiosperms of the marl lakes. Clockwise from top left: 1) *Potamogeton filiformis* and *Littorella uniflora*, 2) *Myriophyllum alterniflorum*, 3) *Utricularia intermedia*, 4) Submerged forms of *Schoenoplectus lacustris* and *Nuphar lutea*, 5) *Myriophyllum verticillatum*, 6) *Potamogeton gramineus*

Vegetation maps

For each lake a series of maps is included, as follows:

1. Maps showing the location of all samples (relevés) denoted by waypoint (GPS) numbers (Figures 6, 7 and 8)
2. Maps showing the vegetation type of each sample derived from the TWINSPAN analysis as shown in Appendix II (Figures 9, 10 and 11)
3. Vegetation maps showing the extent of each vegetation type, extrapolated from the sample data (Figures 12, 13 and 14)

The units mapped correspond to those discussed above. It can be seen that in all lakes, the vegetation forms bands or rings contoured around the various basins. The effect of exposure to south-westerly winds can be seen in Owel and Bunny, where vegetation is less developed on the exposed north-eastern end than the sheltered south-western side. The situation in Carra is complicated by the presence of *Chara tomentosa* stands and a complex topography. In both Carra and Bunny, large areas of bare sand mud or marl occur in shallow (< 4m) water.

In the Castlecarra basin of Carra, the south-western basin of Bunny and the south-western side of Owel, a consistent sequence of communities (Krustenstein, *Chara curta, Chara rudis, Chara globularis, Chara denudata/Nitella flexilis*) can be recognised as depth increases. A similar pattern also occurs in Lough Bane (Roden 2008, 2009, 2010). However, in Lough Carra this pattern is not replicated in the other basins. In the southern deep, only *Chara. denudata* is absent, but in some north-western basins the *Chara rudis* zone is the final band or an *Elodea* unit is found. The Twin Island and Moore Hall basins do contain some *Chara denudata*, but an irregular pattern is seen due to the presence of possibly recently introduced *Chara tomentosa* stands.

Huxley (2007) has already documented the spread of emergent reeds in Lough Carra. In this study, the boundaries of reed beds in the north-west, centre and south-centre were mapped using GPS and compared to the distribution shown in King and Champ (2000). While our data showed an extension in reed bed area compared to King and Champ, our results were very similar to those of Huxley, so we cannot conclude that further reed growth has occurred in the last five years.

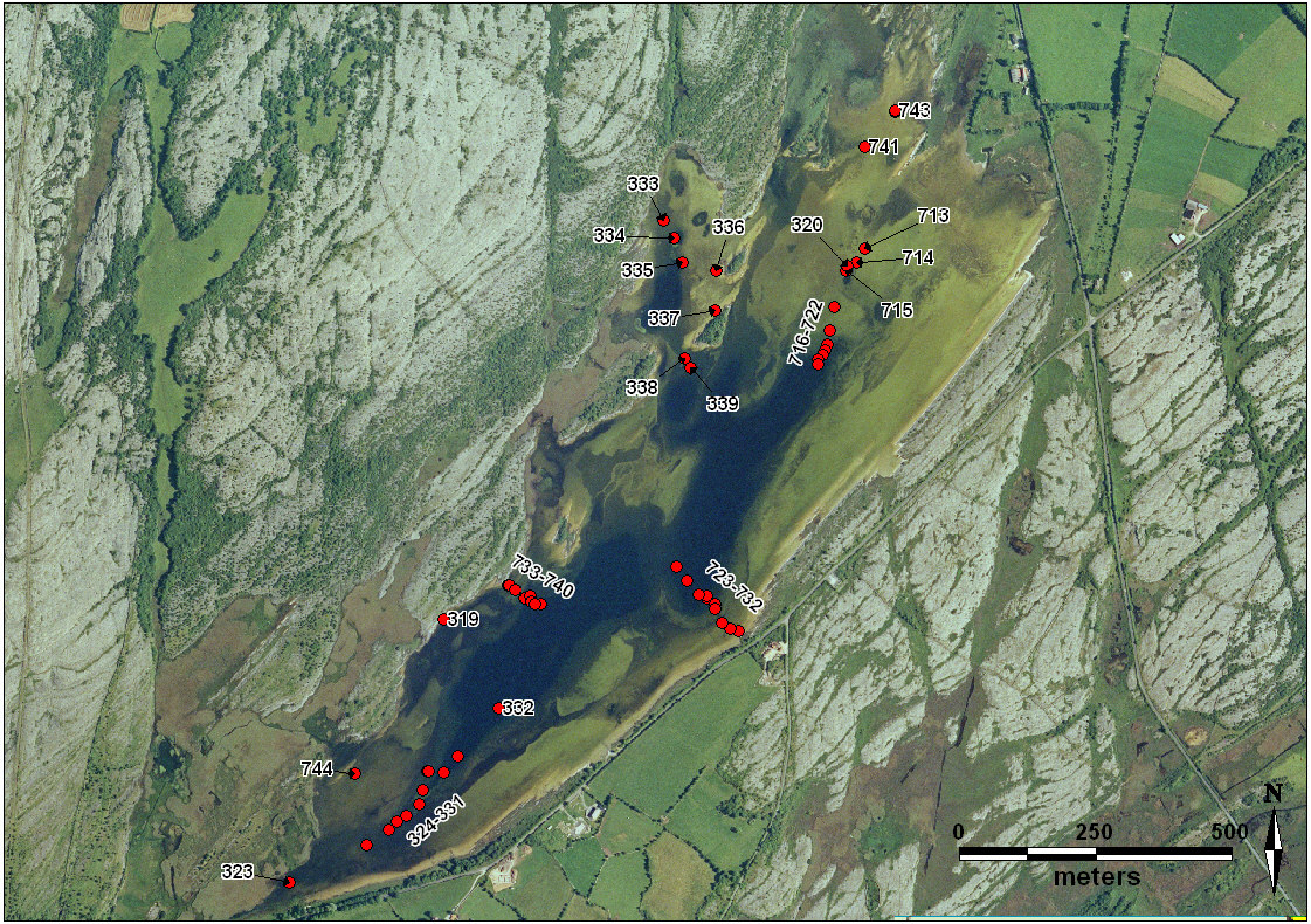

Figure 6: The location of all samples (relevés) in Lough Bunny denoted by waypoint (GPS)

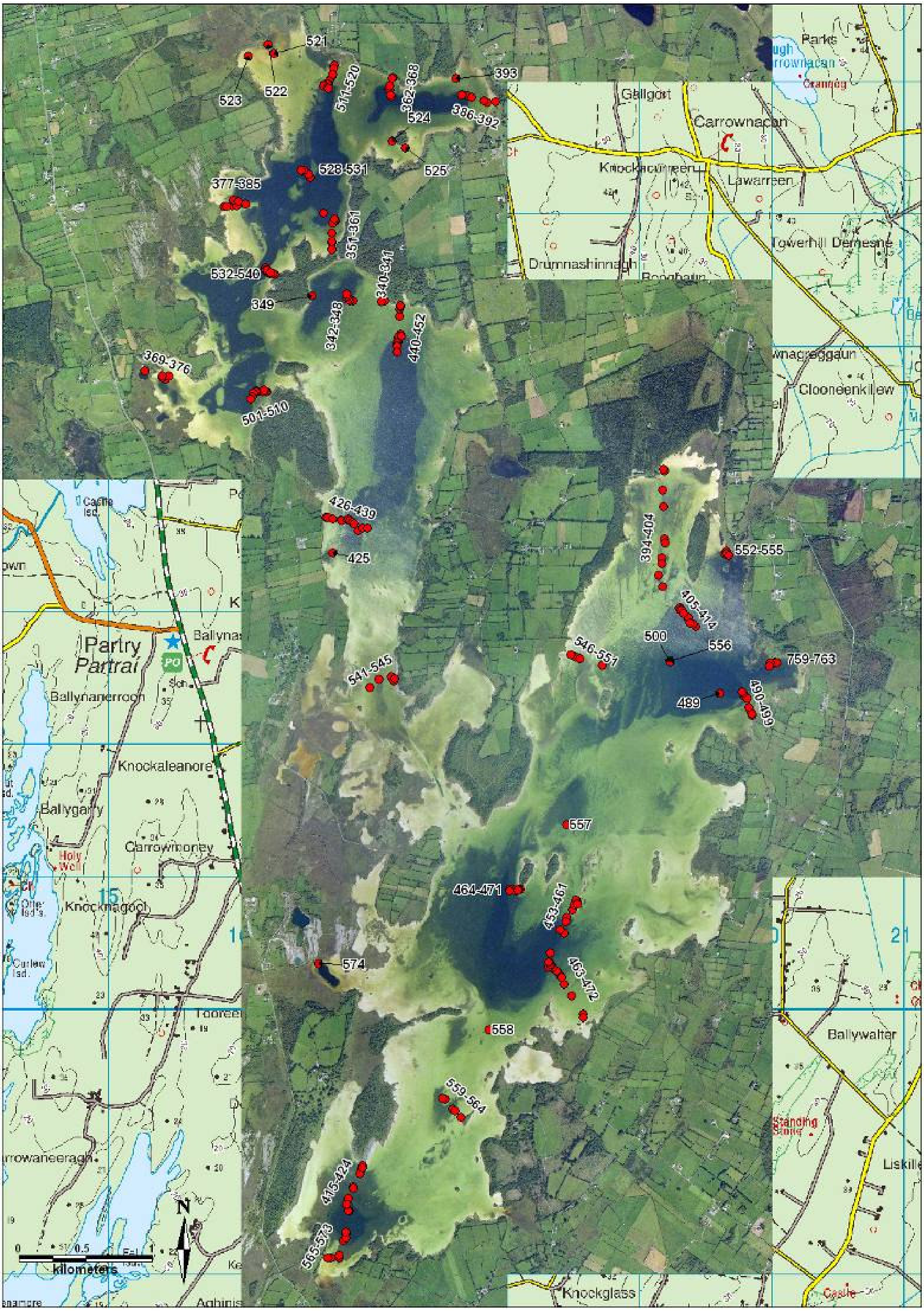

Figure 7: The location of all samples (relevés) in Lough Carra denoted by waypoint (GPS)

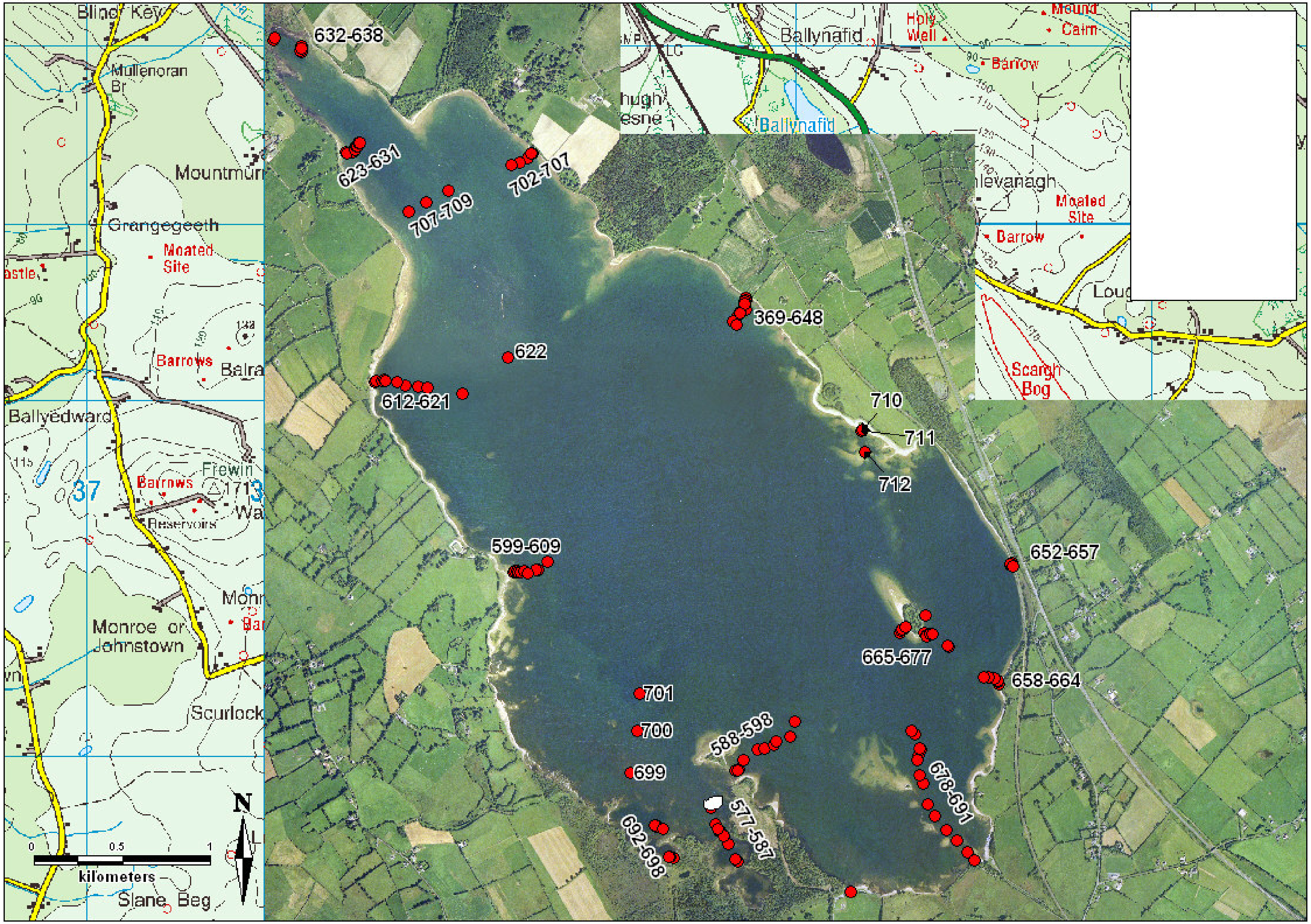

Figure 8: The location of all samples (relevés) in Lough Owel denoted by waypoint (GPS)

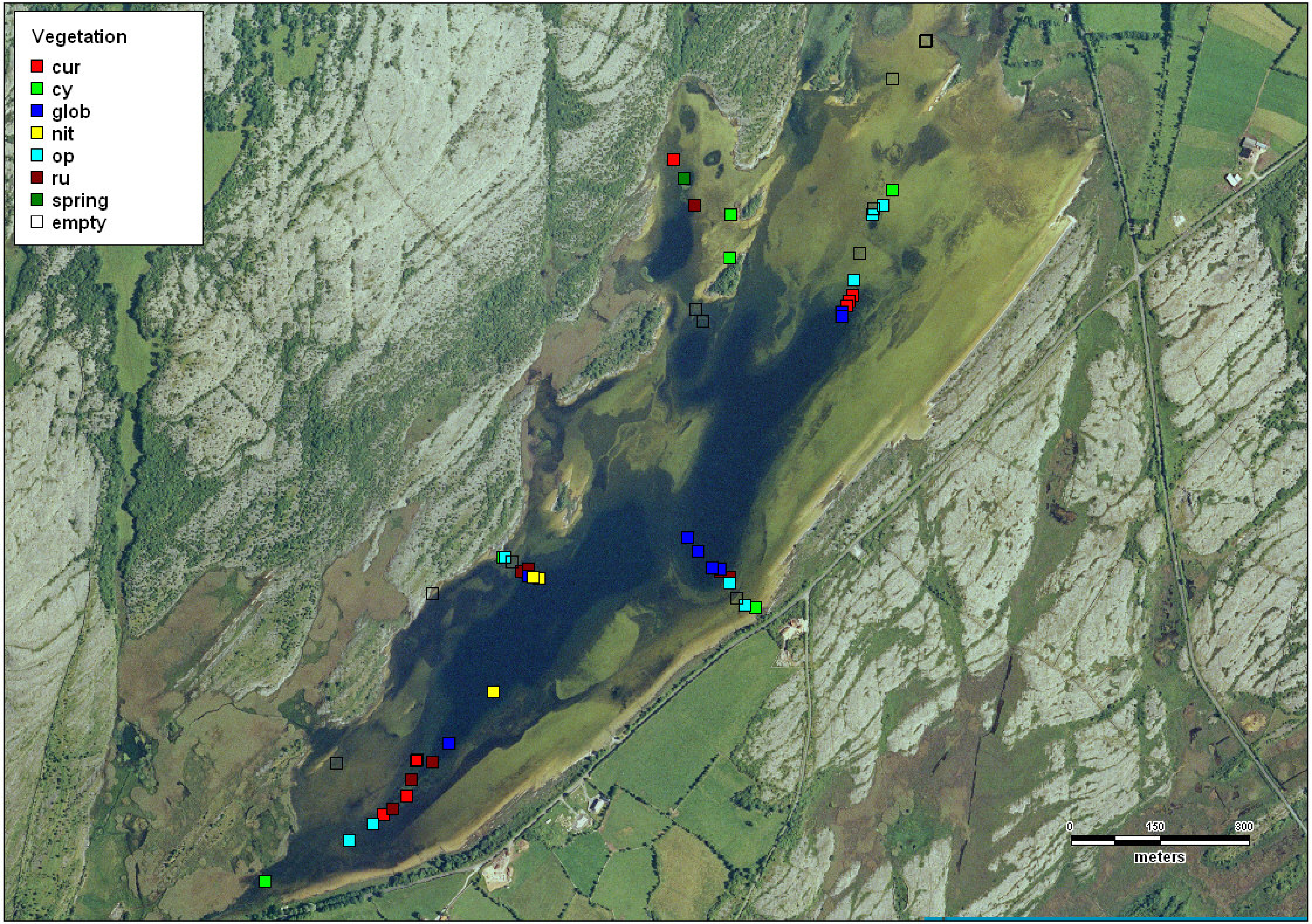

Figure 9: The vegetation type of each sample in Lough Bunny derived from the TWINSPAN analysis as shown in Appendix II

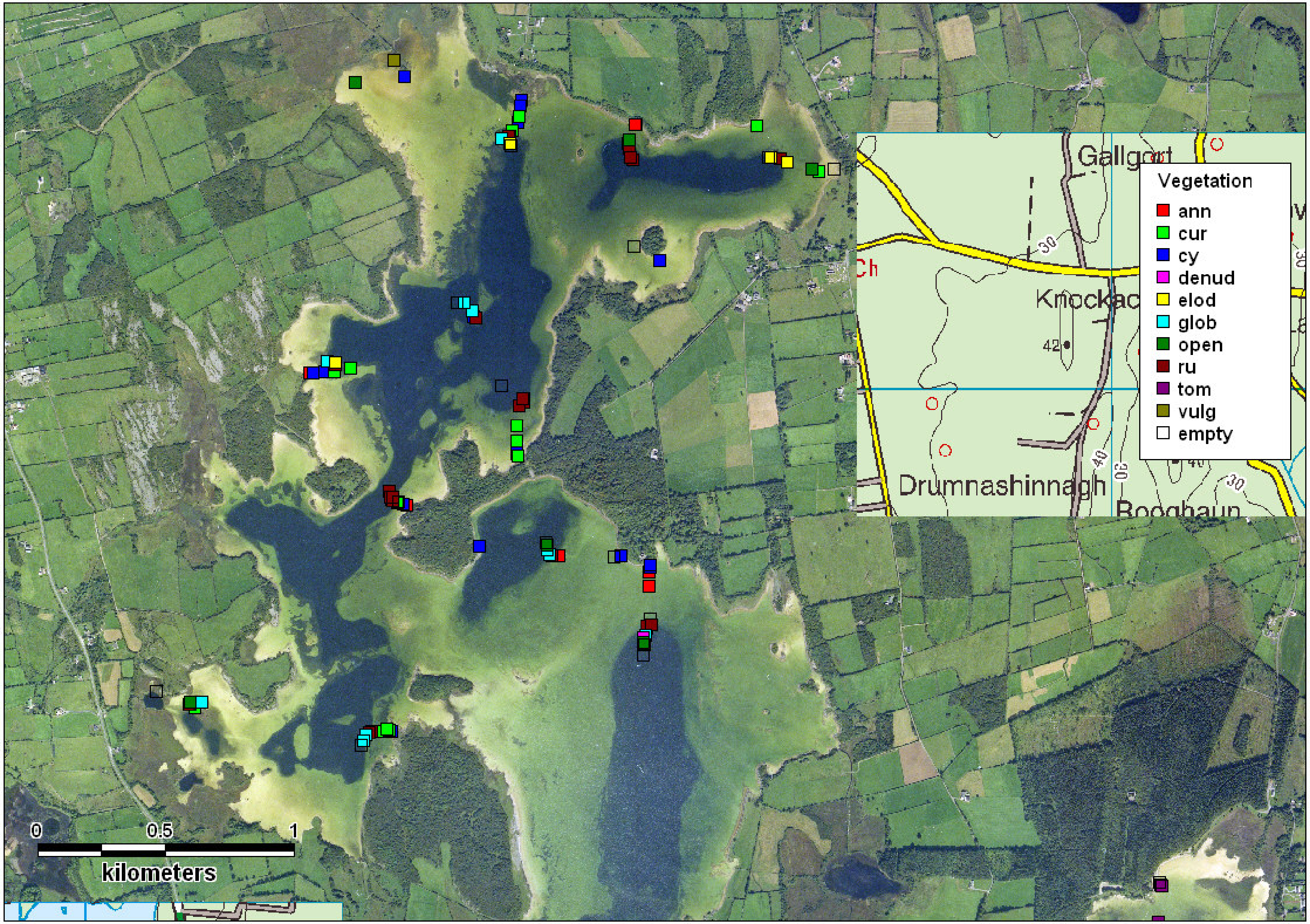

Figure 10a: The vegetation type of each sample in Lough Carra North derived from the TWINSPAN analysis as shown in Appendix II

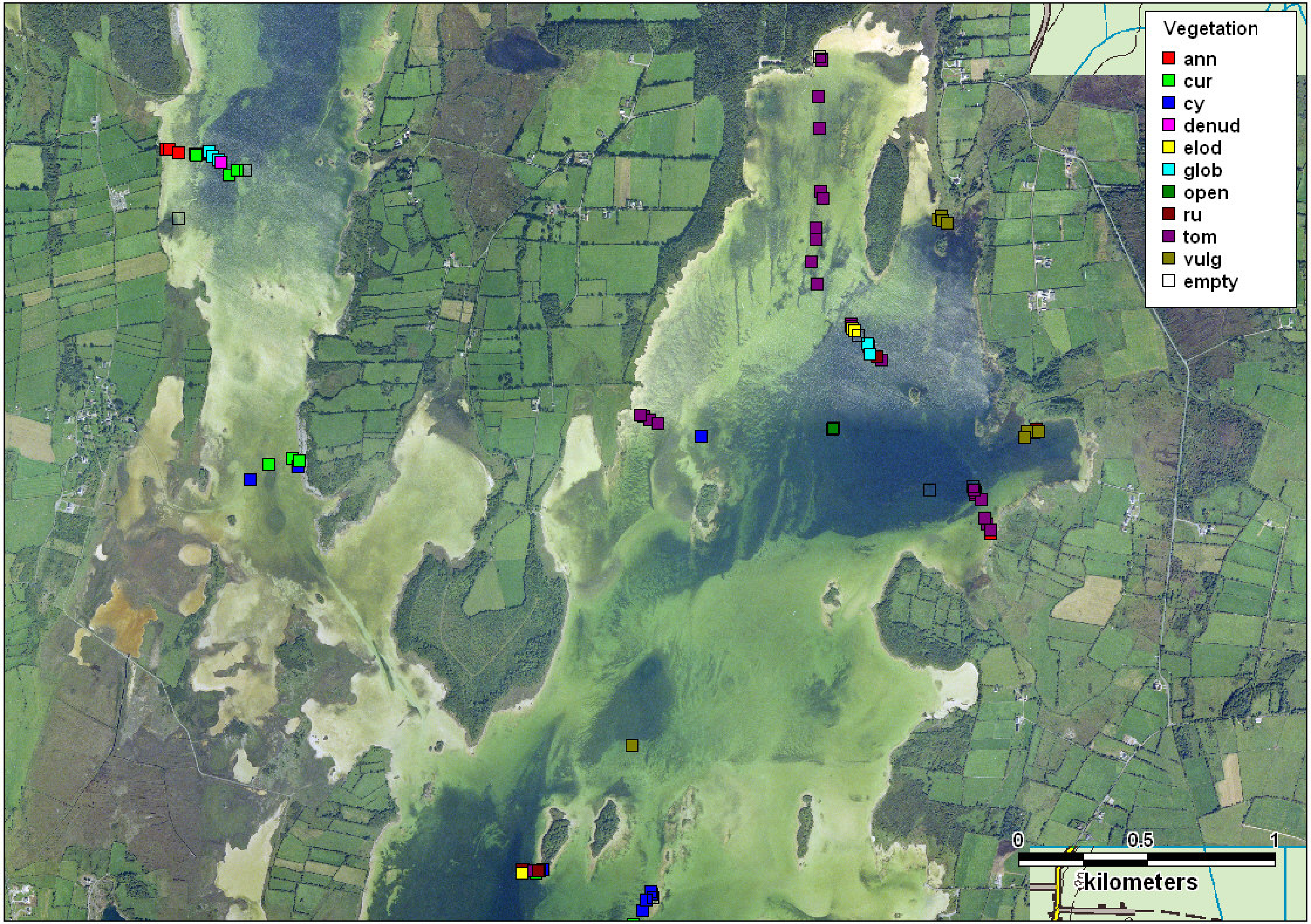

Figure 10b: The vegetation type of each sample in Lough Carra Middle derived from the TWINSPAN analysis as shown in Appendix II

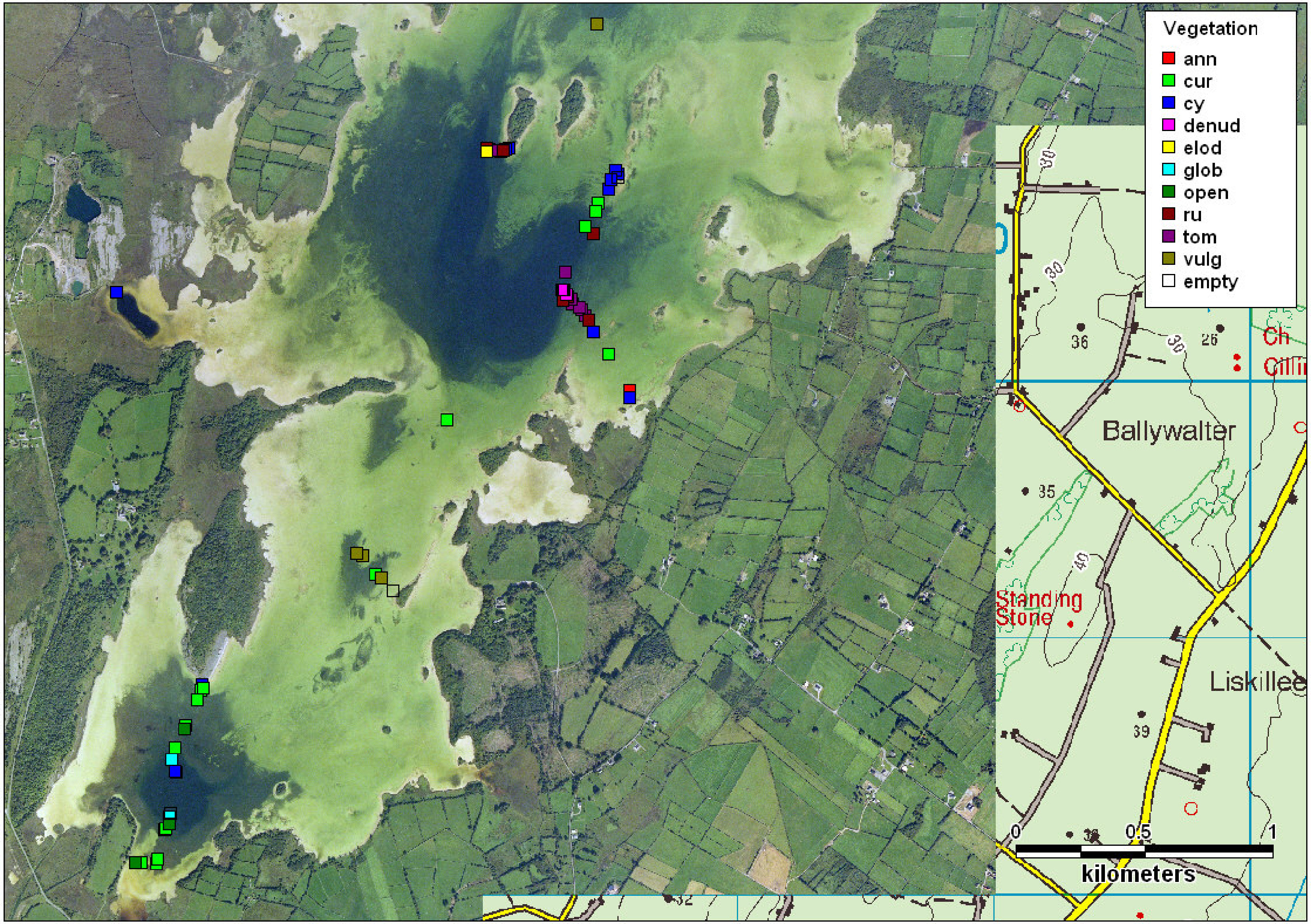

Figure 10c: The vegetation type of each sample in Lough Carra South derived from the TWINSPAN analysis as shown in Appendix II

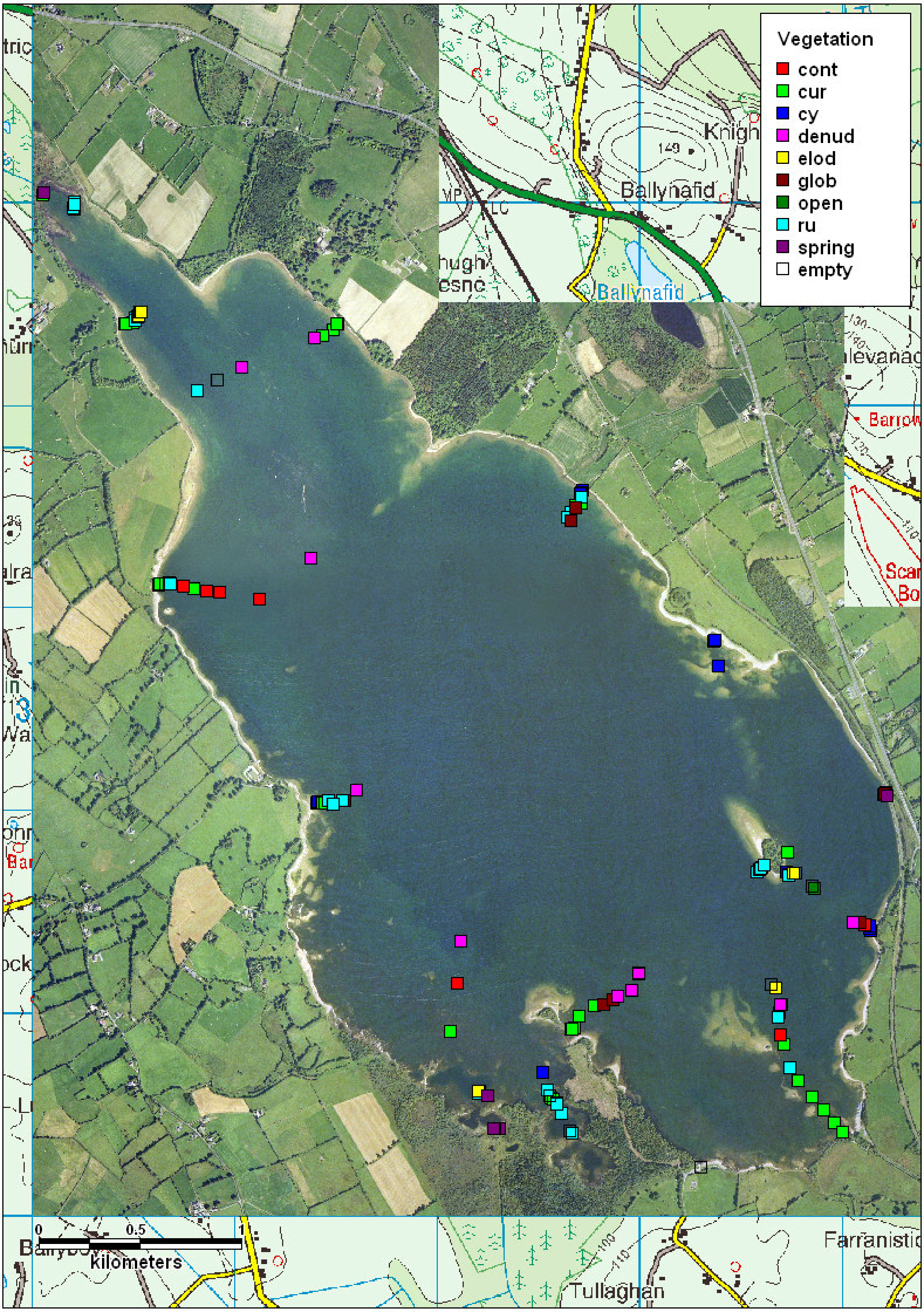

Figure 11: The vegetation type of each sample in Lough Owel derived from the TWINSPAN analysis as shown in Appendix II

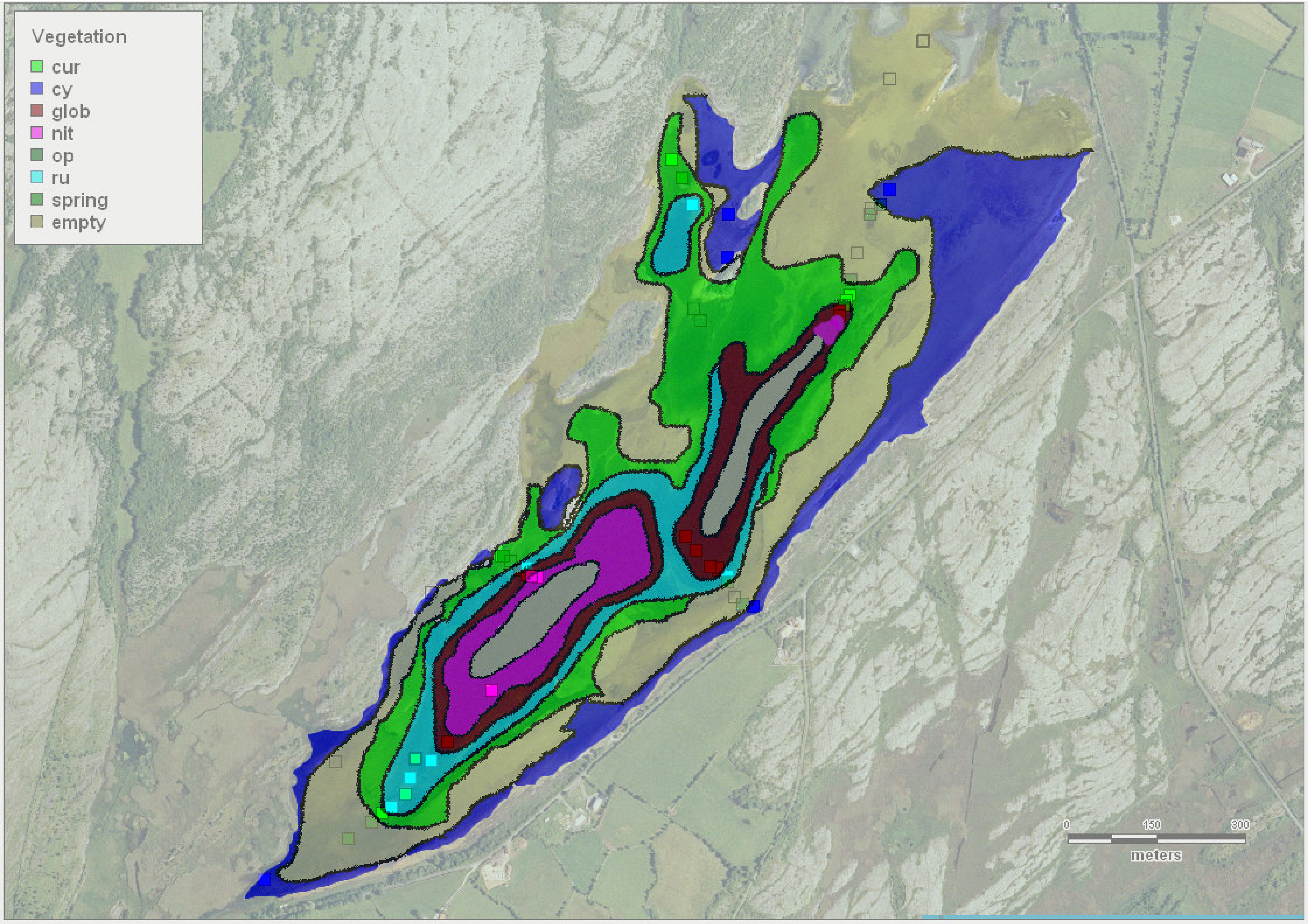

Figure 12: Vegetation map for Lough Bunny, showing the extent of each vegetation type, extrapolated from the sample data

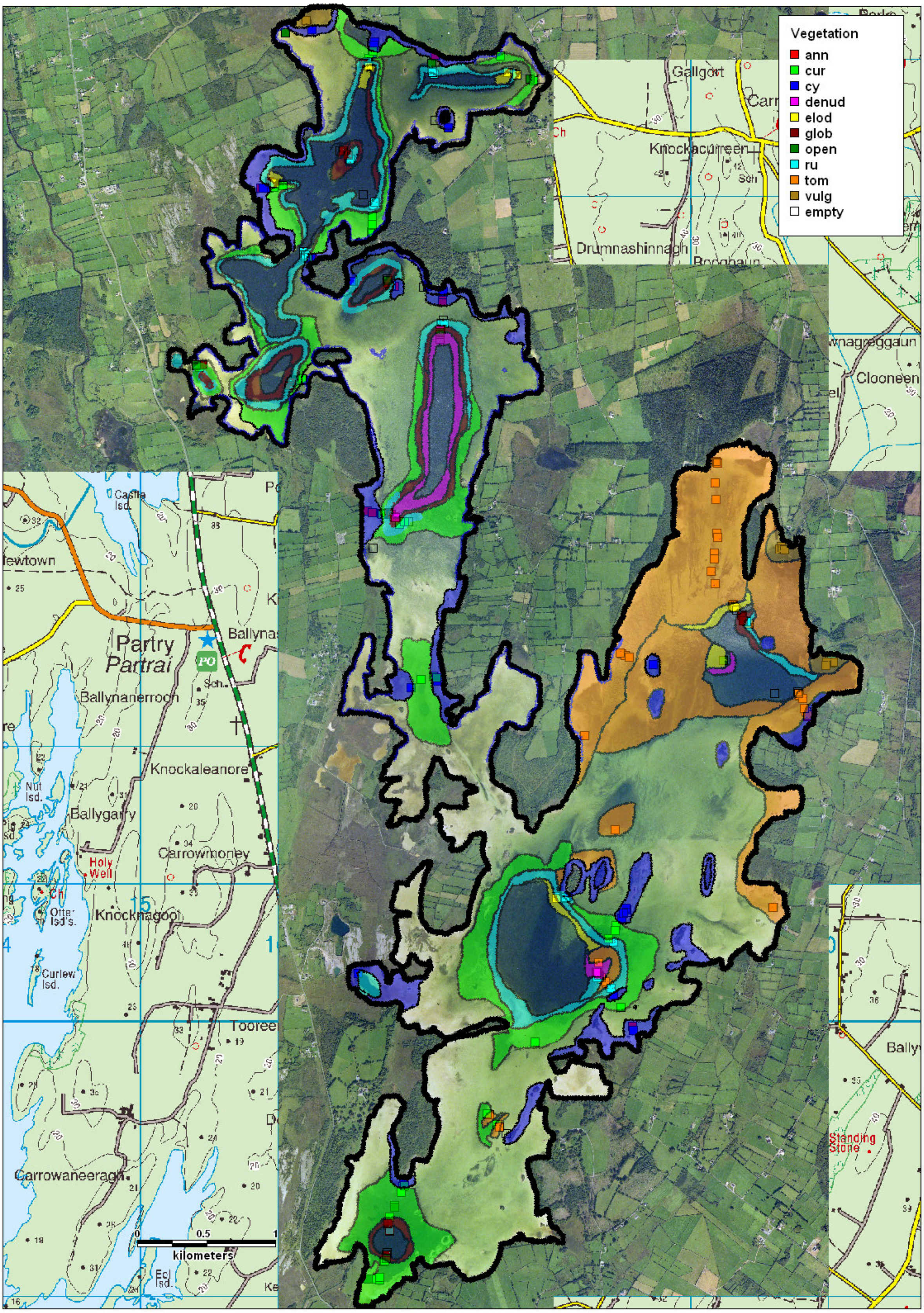

Figure 13: Vegetation map for Lough Carra, showing the extent of each vegetation type, extrapolated from the sample data

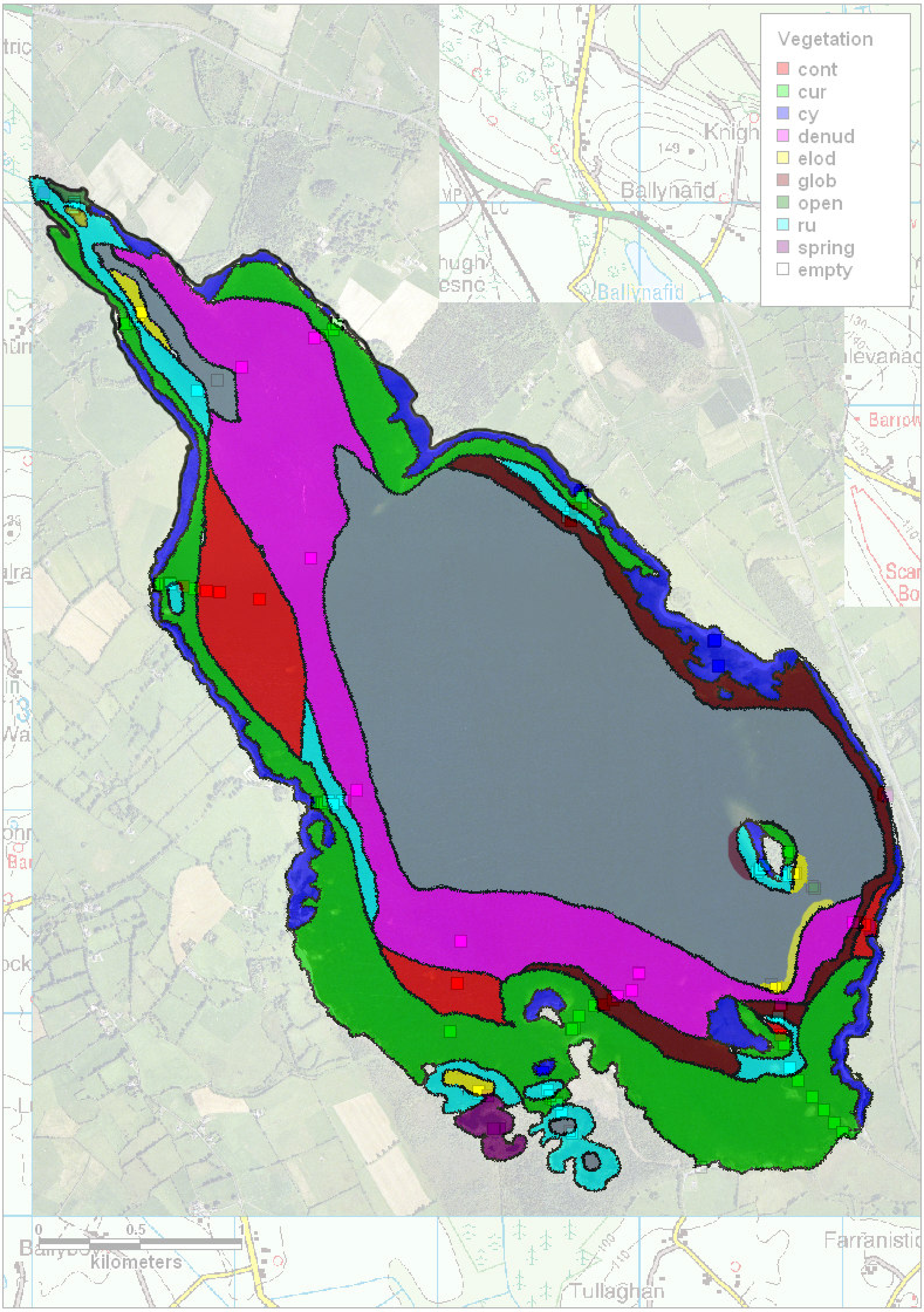

Figure 14: Vegetation map for Lough Owel, showing the extent of each vegetation type, extrapolated from the sample data

Maximum depth of macrophytes and community type

Figure 15 shows that a relationship exists between the species present at the euphotic limit and the maximum depth of benthic vegetation. When the maximum depth exceeds 7m, charophyte swards of *Chara denudata, Chara globularis or Nitella flexilis* occur, but when maximum depth is less than 6.5m the deepest species are angiosperms or angiosperm - *Chara rudis/Chara hispida* mixtures. An alternative pattern would be for the deeper communities to migrate towards the surface as light penetration decreases; this pattern was not observed, instead a shallower euphotic zone appears to result in the replacement of charophyte by angiosperm vegetation.

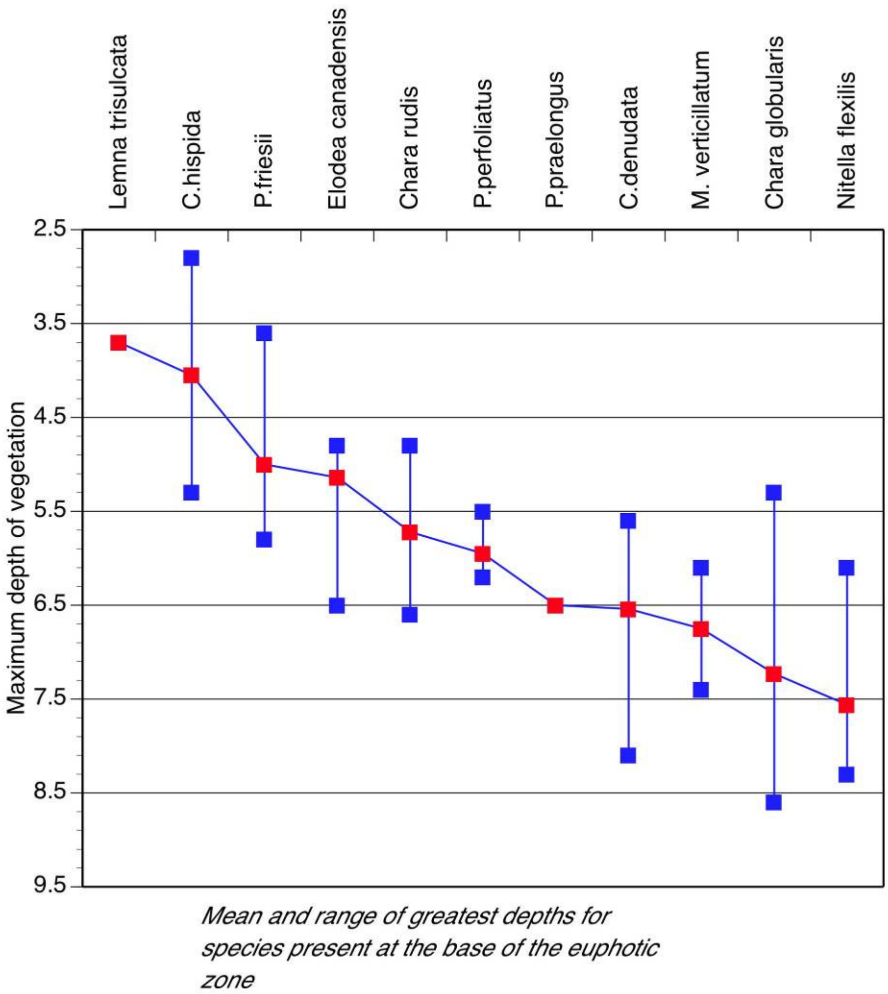

Figure 15: The species which occur at the base of the euphotic zone related to the maximum depth of vegetation. For each species data from all three lakes is used

The flora of marl lakes

The total number of species recorded consisted of 12 charophytes, two bryophytes and 34 angiosperms. There is a relationship between the numbers of species recorded and lake size (Table 6).

Table 6: Species number and lake area

	Bunny	**Carra**	**Owel**
Area (km^2)	1	18.6	10.4
Charophytes	7	11	11
Angiosperms	13	29	16
Other taxa	3	5	4

Full species lists are incorporated in the vegetation tables for each lake, here we discuss unusual or noteworthy forms.

Chara tomentosa

Believed to be threatened by Stewart and Church (1992), but abundant in both Carra and Owel. There are good grounds for thinking it is introduced recently in Carra. It was not recorded by Praeger in 1906 even though he was familiar with the plant and it now grows in shallow water close to the shore. It was first noted by King and Champ (2000) who only found it near the western shore of Moore Hall Bay. 20 years later it is abundant throughout this bay and in much of the Twin Islands Basin. Here it appears to have replaced a previous sward of *Chara curta*, to judge from field notes of King and Champ.

Chara aculeolata

In Ireland, this is usually a plant of shallow water especially in fen peat pools and shallow water of limestone lakes. In Lough Carra, an unusual large, deeper water form was noted in several stations. It was much larger than the 30cm noted in Moore (1986) and grows in depths of up to 3m amongst *Chara curta* and *Chara rudis*. It is especially abundant in the doline at Gallagh Bay. Krause (1997) however, notes a variety of forms on the continent including types greater than 1m and forms growing at depths greater than 10m.

Chara rudis

This taxon is sometimes included with *Chara. hispida*, but in this study it was noted that easily recognised *Chara hispida* with erect spines and an isostichous cortex were confined to nutrient enriched areas such as river mouths or springs. Some of the open-lake forms had some erect spines, but were clearly aulacanthous as is *Chara rudis*. Here *Chara hispida* is regarded as a plant of enriched waters while *Chara rudis* is regarded as the typical marl lake form. This treatment differs from that of John *et al*. (1982).

A very contracted and heavily encrusted *Chara* found growing in Carra amongst the krustenstein was identified as a form of *Chara rudis*.

Chara denudata

This plant is apparently confined to deep clear water in limestone lakes. Listed as rare by Stewart and Church (1992), its Carra populations were only discovered in the 1990s by King and Champ (2000). Krause (1997) records it in Lough Corrib. Roden (2000, 2008) found populations in Loch na Leibe in Sligo and Lough Bane (Meath/Westmeath), and it may be more widespread. Outside Ireland, it is extremely rare in Europe (e.g. it is not found in Britain and has only five stations in Germany); thus the Irish populations are of European significance.

Chara globularis/ Chara virgata

These species are very similar in appearance and some difficulty was found in deciding whether *Chara globularis* or *Chara virgata* occurred. No satisfactory ecological pattern could be determined and it appears both taxa can grow at depth. Much of the material from depth in Lough Carra was *Chara virgata* but *Chara globularis* also occurred. *Chara globularis* was the dominant form in Lough Bunny and Lough Owel. These findings agree with those of the previous surveys of the lakes.

Myriophyllum alterniflorm

A form of this species with short leaves and internodes may be the var. *americium*. It is known from Lough Beg, Lough Neagh and Lough Ree.

Ranunculus *sp.*

An aquatic *Ranunculus*, found in Lough Owel, with long, few-segmented leaves is being grown to allow identification to species.

Historical comparison

Flora and vegetation

Lough Bunny

In 1993, Pybus *et al*. (2003) briefly examined the charophytes of Lough Bunny by dredging. They recorded many of the species noted in this survey, but omit *Chara curta*. However they found *Chara hispida* (*sensu stricta*) in shallow water near the western shore, a species not seen in Bunny during this survey. They also found *Chara vulgaris* in the northern part of the lake, but did not record *Chara contraria*. Their limited distribution data agree with the present survey. In 2001, Roden (2001) examined the vegetation in the central part of the lake by snorkelling and again recorded the species and vegetation recorded in this survey, but did not note *Nitella flexilis*, however the species was recorded in 2009 (Roden unpublished). Further examinations by snorkel or Scuba by Roden, Van De Wyer, Bruinsma, Ryan and O Connor in 2009-2010 also noted a similar vegetation (unpublished data). These studies suggest that there has been no notable change in the lake's vegetation in the last twenty years and probably for many years previously.

Lough Carra

Several previous accounts contain good data on the benthic macrophytes of Lough Carra. In 1906, Praeger spent several days with a boat exploring the lake and its surroundings (Praeger, 1906). He notes very clear water, a few starved plants and deeper vegetation of *Chara hispida/rudis*, *Potamongeton perfoliatus* and *Potamogeton nitens*. He does not mention *Chara tomentosa*.

In 1977, Heuff (1984) reported clear water (secchi = 6.5m vs. 5.0m in 2011) with *Chara curta* and *Chara contraria* descending to 7m near the Twin Islands. There is no mention of *Chara tomentosa*, even though the species is abundant in this area in 2011. In 2011, the limit of vegetation off the Twin Islands was at 6m and *Chara rudis* and *Elodea canadensis* were at the base of the euphotic zone (WP 464-471). This shift in depth and species composition suggests a decreasing light intensity.

In 1996, a detailed grapnel survey of the benthic macrophytes was undertaken by King and Champ (2000). They record most of the species and communities noted in the present report, with the exception of the river mouth *Chara hispida/Chara vulgaris* vegetation. They record *Chara tomentosa* for the first time in the lake including near the Twin Islands and part of the western shore of Moorehall Bay. However, they do not report the species from the Moorehhall Castle Island transect nor from other places shown in the vegetation map.

To summarise:

- In 1906 the lake was nearly devoid of macrophytes, other than at depth. Shallower water had extensive crust development (which Praeger sent for analysis of its cyanobacterial flora). This situation is close to that of the Burren lakes described in Roden (2001).
- By 1977, the situation appears not to have changed.
- By 1996, *Chara tomentosa* had appeared and has increased its range since then. Its formation of monospecific stands that have displaced previous *Chara curta* vegetation in the Moorehall basin between 1996 and 2011, and the occurrence of small circular colonies of the species in new locations, indicate it is a new arrival brought in perhaps by anglers from the Shannon Basin. *Myriophyllum verticillatum* formed huge banks not noted by Heuff or Praeger.
- *Potamogeton filiformis*, which was 'generally' recorded by King and Champ was only noted in two relevés, besides the river-mouth stations.
- Depth of colonisation - the maximum depth of colonisation noted in King and Champ in 1996 is broadly similar to records made in this survey. However, King and Champ do not give figures for individual basins.

Lough Owel

Heuff (1984) reports that in September 1977 the depth of colonisation in Owel was 7m and communities of *Chara rudis*, *Chara contraria* and *Chara aculeolata* occurred. The benthic macrophytes of Lough Owel were mapped by John *et a*l. in 1981, who also summarised previous unpublished work (John *et al.* 1982). Surprisingly, the detailed survey by John *et al*. record maximum macrophyte depth of only 5.5m in 1980-81, while in this study depths of greater than 7m were recorded. Depths of 7 and 7.3m were recorded in the early 1970s by the Central Fisheries Board (John *et al.* 1982). This difference may be due to differences in technique or may record an improvement in the lake's light climate since 1982. Maximum depths of different species are greater in this report than in the 1982 report also. A map of the horizontal distribution of macrophyte communities in 1981 is very similar to that produced in this survey. Some additional species were also recorded in the present survey, but a few species noted in 1982 were not seen in 2011, these included: *Zanichellia palustris*, *Utricularia intermedia*, and some *Ranunculus* species. Species seen over a century ago by Levinge, Bullock Webster, Groves and Linton (see John *et al*. 1982 for references) but not recorded by John *et al*. and rediscovered in the present survey, including *Chara aspera* and *Chara rudis* (but see comments above in flora of marl lakes chapter). Heuff (1984) did record *Chara rudis* in 1977.

Water chemistry

Water chemistry data were gathered from several published sources and data were also very kindly provided by the EPA. Over several decades methods of analysis have changed. Therefore, comparisons should be treated with caution. Much of the published data are presented as graphs, and data were read from these and are less precise than data presented in tables in the source material. Chlorphyll a values are for the growing season (March to October) only.

Lough Bunny

Table 7 shows the annual range of selected environmental variables from 1992 to the present. Changes can be seen in the increase in Chlorophyll in 2010-11. This high value (8.3µgl^{-1}) occurred in spring, presumably due to a spring-bloom. D.I.N. was also higher in 2011 than in 1992-3. A similar increase was noted by Roden (2008) in Lough Bane. A similar increase is seen in total P. Secchi disc measurements taken during the present survey in July and September were 6m.

Table 7: Water chemistry data for Lough Bunny

Source		**Pybus *et al.***	**EPA**	**Allot *et al.***	**Roden**	**EPA**
Year		1992/3	1996/7	1996/7	2001*	2010/11
Secchi (m)	Ave.	6.5	6.2	-	7	-
	Range	6 – 9	5 – 8.6	-		-
	n	12	10	-		-
DIN (mgl^{-1})	Ave.	0.058 †	0.68	-	0.009 †	0.47
	Range	0.0021 – 0.192	0.37 – 0.94	-	0.001 – 0.016	0.25 – 0.91
	n	8	10	-	6	7
Total P (mgl^{-1})	Ave.	-	<0.005	0.002	-	0.013
	Range	-	All <0.005	-	-	<0.01 – 0.027
	n	-	10	4-9	-	7
MRP (mgl^{-1})	Ave.	<0.001	<0.005	-	0.001	<0.005
	Range	0 – 0.004	All <0.005	-	0.001 – 0.001	<0.005
	n	8	10	-	3	7
Chlorophyll *a* (µgl^{-1})	Ave.	1.3	1.7	0.002	3.0	3.5
	Range	0.54 – 2.7	0.8 – 2.1	-	2.9 – 3.17	0.5 – 8.3
	n	8	8	4-9	3	7

* July and September.

† No NH_3 data.

Lough Carra

Table 8 suggests that chlorophyll concentrations are rising in Lough Carra, a trend already visible in data presented by King and Champ (2000). The unusually high value of 58μgl^{-1} was considered to be a true reading by EPA staff. D.I.N. appears to vary with peaks in 1984 and again 2011. Secchi depth was not available in the EPA database, as there were some problems with methodology. Again, King and Champ show a gradual decline in Secchi depth since 1976. In the present survey Secchi depth ranged from 3.5-5m. The work of Irvine *et al*. (2008) showed that the middle or Castle Carra Basin has the lowest values for the parameters presented.

A more long term view of Lough Carra's evolution is given in sediment core samples analysed by Irvine *et al*. (2008). These data shows the eutrophication of the lake over the last 50 years.

Table 8: Water chemistry data for Lough Carra

Source		Flanagan and Toner	King and Champ*	King and Champ*	King and Champ ‡	Irvine *et al*. (2008)	EPA	EPA
Year		1973/4	1984	1995	1996	2001-03	2008	2011
Secchi (m)	Ave.	-	4.5	3.0	-	-	-	-
	Range	1 - 4	-	-	-	-	-	-
	n	-	-	-	-	-	-	-
DIN (mgl^{-1})	Ave.	-	0.5 †	-	0.11 †	0.18 †	0.38	0.56
	Range	0.06 – 1.15	0 – 1.5	-	0.006–0.31	0 – 0.9	<0.04 – 1.7	0.4 – 0.9
	n	-	12	-	9	120	88	83
Total P (mgl^{-1})	Ave.	-	0.015	0.015	0.012	0.012	0.01	0.013
	Range	0.02 – 0.32	-	-	0.003-0.007	0.005-0.04	<0.01–0.02	0.01 – 0.09
	n	-	-	-	9	123	88	83
MRP (mgl^{-1})	Ave.	-	<0.01	-	-	-	0.01	-
	Range	<0.01 – 0.05	-	-	-	-	<0.01–0.018	-
	n	-	-	-	-	-	5	-
Chlorophyll *a* (μgl^{-1})	Ave.	-	2.5	5.0	2.5	2.7	1.9	5.4
	Range	1 – 2.2	0 - 5	0 – 30	-	1 – 9	0.2 – 7	<2 – 58
	n	-	-	-	-	123	61	69

* Mean annual values.

† No NH_3 data.

‡ August only.

Lough Owel

The figures in Table 9 do not show any notable changes over the last 30 years. Secchi depths in the present survey ranged from 4 - 5.5m.

Table 9: Water chemistry data for Lough Owel

Source		Flanagan and Toner	John *et al.**	EPA	EPA
Year		1973/4	1973-78	1996/7	2011
Secchi (m)	Ave.	-	-	5.3	-
	Range	7 – 8	7.0 - 8.9	4.1 – 7.6	-
	n	-	-	18	-
DIN (mgl^{-1})	Ave.	-	-	0.076 †	0.081
	Range	0.06 – 0.16	0.08 – 0.20 †	0 – 0.26	<0.01 – 1.75
	n	-		18	149
Total P (mgl^{-1})	Ave.	-	-	0.01	0.012
	Range	0.06 – 0.23	0.03 – 0.043	0.005 – 0.016	<0.01 – 0.09
	n	-	-	18	149
MRP (mgl^{-1})	Ave.	0.02	-	0.005	0.001
	Range	-	0.01 – 0.026	0.005 – 0.007	0.001 – 0.002
	n	-	-	18	149
Chlorophyll *a* (μgl^{-1})	Ave.	-	-	6.38	4.46
	Range	1.6 – 4.7	4.6 – 15.8	3.0 – 10.4	1.42 – 6.47
	n	-	-	16	79

* Maximum annual values.

† No NH_3 data.

The current conservation status of the lakes

The conservation status of natural habitats is a balance between their intrinsic value, present condition and probable future. Here we evaluate the three lakes under these headings.

Intrinsic ecological value

All three lakes are protected SAC designated as Habitats Directive Annex I habitat Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp. (habitat code 3140). Such lakes typically contain a diverse charophyte flora but only occur on limestone bedrock or other calcareous material, usually in areas with moderate to high rainfall. In Northern Europe they occur very locally, being concentrated in the Alpine region, eastern Germany, Poland and Ireland. The vegetation described in this report is typical of Irish marl lakes on limestone, and has three major characteristics:

- Charophytes form a major part of the vegetation
- Krustenstein or cyanobacterial crusts are very extensive in shallow water
- Angiosperms only constitute a small part of the vegetation

These lakes are the most extensive habitat for many of the species present such as *Chara rudis*, *Chara denudata* (only found in such lakes) and *Chara curta*. Equally the krustenstein, dominated by *Schizothrix* species, is confined to these lakes.

The fauna is less well researched, but the recent discovery of an aquatic beetle *Ochthebius nilssoni* (O'Callaghan *et al*., 2009), which appears to be associated with the crust, shows that a distinctive invertebrate fauna may occur. This species was discovered in Lough Carra in 2011 (Nelson and O'Connor pers. com.). The Crayfish *Austropamobius pallipes* is abundant in some lakes, such as Lough Owel and Lough Carra. Equally, as these lakes were never linked to continental rivers, the fish fauna is derived from anadromous ancestors and a range of salmonid species occur (or used to occur) (Reynolds, 1998). Many of these taxa have a northern distribution and Irish marl lakes could be seen, like raised bogs, as one of the few Irish habitats that extend in time back to the early post glacial.

To summarise, the marl lake or hard-water habitat has a most unusual flora, vegetation and fauna, which is very restricted in Europe as a whole, and Ireland contains a large proportion of the total European habitat.

Present condition

Compared to the extremely poor state of some water bodies in Ireland, the transparency and developed benthic vegetation noted in this survey might lead one to believe that the lakes are in reasonable condition. As noted above, however, marl lakes are an unusual type of water body and condition must be measured against the optimum for the marl lake category, rather than for lowland lakes in general. Based on this survey and previous surveys of Lough Bane (Roden, 2008, 2009) and the lakes of the south-east Burren (Roden 2001), the following characteristics are proposed for the vegetation of Irish marl lakes in good to excellent ecological condition:

1. Maximum vegetation depth > 8m
2. A full development of charophyte vegetation, including zones of the following species: *Chara curta, Chara rudis, Chara globularis* and optimally a final zone of *Chara denudata/Nitella flexilis*
3. An extensive krustenstein zone on exposed rocks
4. Submerged angiosperm vegetation confined to *Chara rudis* zone
5. Secchi transparency > 6m.

Using these characteristics as a standard, it is possible to evaluate the present condition of the lakes surveyed. The results are shown in the Table 10. For Lough Owel and Lough Bunny the evaluation is based on the main lake basin, in the case of Lough Carra, with eight separate deeps, the evaluation is based on the least favourable deep in each basin of the lake.

Table 10: A comparison of the vegetation condition in the three lakes

	Lough Bunny	**Lough Carra: Twin Islands Basin**	**Lough Carra: Carra Castle Basin**	**Lough Carra: Northern Basin**	**Lough Owel**
Vegetation depth (m)	8.5	6	8.5	6	7.7
Complete *Chara* zones	Yes	No	Yes	No	Yes
Krustenstein	Yes	Declining locally	Yes	Declining locally	Yes
Angiosperms confined to *Chara rudis* zone	Yes	No	Yes	No	Yes
Secchi transparency	5 – 6	3 - 4	5	4	4 – 5.5
Evidence of vegetation change since 1900	No	Yes	No	Yes	No (but char now extinct)

The evaluation shows that, at present, Owel, Bunny and the Castle Carra or central basin of Lough Carra are in good condition, however the other two Carra basins show clear signs of deterioration. Hobbs *et al*. (2005) have shown that sediment phosphorus is increasing in Lough Carra and noted that the increase is greatest in the northern basin and least in the central basin. These results exactly mirror the vegetation changes noted in this report. Hobbs *et al*.'s work is one of a number of papers resulting from studies by Dr K. Irvine's research group in T.C.D. which point to declining environmental quality in Lough Carra. Equally reports in Huxley and Irvine (2008) discuss the declining environment of Lough Carra.

Future prospects

Pentecost (2009) is pessimistic about the future prospects for marl lakes in Britain or Ireland, stating their often shallow depth and proximity to agricultural land makes eutrophication inevitable and very difficult to prevent. Is such an assessment reasonable in the case of the three marl lakes described here? While the use of N and P fertilisers is widespread on Irish grasslands and many septic tanks may be inefficient, it cannot be taken for granted that all Irish marl lakes are at risk.

The shallow lake models outlined by Scheffer (2004), in which the balance between light limited or nutrient limited photosynthesis governs the balance between growth in the plankton versus growth of bottom communities and water clarity, help in predicting the future evolution of the lakes. Decline in transparency and increase in planktonic algae is regarded as deterioration of the habitat, leading to the collapse of benthic vegetation, turbid water and very large plankton blooms.

An additional complication is that marl lakes can buffer phosphorus enrichment for some time, and only after buffering capacity is largely exhausted will phosphorus enrichment directly drive plant growth. The future prospects for each lake is estimated in Table 11.

Based on Table 11 it must be concluded that Lough Carra is under considerable ecological stress and the assumption that it is Ireland's best example of a marl lake may cease to be true in the near future. Its gradual decline should be compared to the similar fate of Lady's Island Lake, Co. Wexford, for a long time assumed to be Ireland's largest and most diverse lagoon, it is now extremely stressed and has lost much of its vegetation (Roden and Oliver, 2010, 2011).

Table 11: The ecological status of the three lakes, based on available data

	Lough Bunny	**Lough Carra**	**Lough Owel**
Increasing Chlorophyll	Possibly, 1 recent value of 8µg^{-1}	Yes, recent value of 58µg^{-1}	No
Increasing sediment P	?	Yes (Hobbs *et al.* (2005)	?
Decreasing Transparency	No	Yes (King and Champ 2000)	Perhaps. 8.9m in 1982 vs. 5.5m this study
Changes from optimal marl lake vegetation (from Table 10).	No	Yes, this study	No
Evidence of vegetation change since 1900	No	Yes	No
Large watershed	No	Yes	No
Introduced macrophyte species	None	*Elodea canadensis, Chara tomentosa*	*Elodea canadensis*
Prospects	Good	Unfavourable	Good

Future monitoring

Possible measurements

The present study shows that some marl lakes in Ireland are under environmental stress. Consequently, they need to be monitored for further habitat deterioration, and adequate management plans must be implemented if the lakes are to maintain their conservation value. Table 10 lists the signs of environmental deterioration, but it also suggests methods of monitoring and evaluating the status of other marl lakes.

Sampling should take place between June and September. Each lake basin should be sampled individually. Lake basins might be distinguished from individual deep holes (a common feature of marl lakes) by the presence of narrow straights separating each basin. We recommend that the following variables be measured once every three years:

- 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 6.5m.
- Presence of all major *Chara* zones, (*Chara curta, Chara rudis, Chara globularis and Chara denudata/ Nitella flexilis*), especially the *C.globularis* and *C.denudata* zones.
- The krustenstein zone should be intact and not colonised by bryophytes. Some monitoring sites should be close to inflowing rivers. As this zone can be sampled from the shore, ten or more relevés should be examined.
- 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).
- Secchi transparency should on average exceed 6m.
- As the EPA carry out extensive plankton and water chemistry surveys on the three lakes studied in this report, we do not suggest additional measurements. However, in the case of marl lakes not monitored by the EPA, we recommend as a minimum that total phosphorus, chlorophyll a and Secchi transparency be sampled in lakes of conservation value, at least four times per year, every third year.

The vegetation survey should be done by snorkelling or scuba-diving, as grab sampling does not provide sufficient data on vegetation below about 2 metres, especially about depth of colonisation.

(e.g. the data on depth of colonisation in King and Champ (2000), based on grapnel sampling, is sometimes shallower than the observations in this report. Compare depths of colonisation in our Figure 15 for *Chara rudis* or *Myriophyllum verticillatum* with maximum depths shown in Table 3 of King and Champ).

Using this methodology, certain Burren lakes would pass all tests or criteria, while none of the south Clare lakes examined by Bruinsma *et al.* (2009) would do so. However, it is not certain that such lakes ever fully resembled those in the Burren. Some allowance for natural variation is desirable, but at present there is insufficient knowledge (due mainly to a lack of historical data) to achieve this distinction. Provisionally, we suggest that decay of the krustenstein, disappearance of the *Chara globularis* or the lower charophyte zones, or secchi transparency less than 3m should result in unfavourable-bad status for marl lakes on carboniferous limestone. Spring fed lakes on drift, e.g. Lough Meelagh see Bruinsma *et al.* (2009) may not fit this classification.

A comparison with the EPA methodology

At present, the EPA monitors benthic macrophytes in many Irish lakes. So inspection of the data obtained during their survey work gives rise to the following points

- It is very important that charophyte taxa be identified to species level, as they constitute the great bulk of macrophyte vegetation and define the major depth zones. By 'lumping' all charophytes into a single category, one loses nearly all useful data on marl lake macrophytes.
- All transects should extend to depths greater than the euphotic zone, rather than being a fixed length such as 100m or 200m. This approach is now standard with the EPA (R. Little, pers. comm..), but earlier sampling by the EPA did not always provide these data.
- If monitoring using grapnels is being undertaken, as is current practice with the EPA, the presence or absence of *Chara denudata* or *Nitella flexilis*, if known to have occurred previously, is very important to ascertain. The disappearance of this lowest charophyte zone indicates a worsening light climate at depth and is likely to occur before changes in the upper sub-littoral, such as the decay of the krustenstein, occur. As the work of King and Champ demonstrate, grapnel sampling does provide good presence/absence data for most marl lake charophytes. An exception is *Nitella tenuissima,* which is too small to be collected by grapnel; it occurs in some Burren lakes.
- The exact depth of grapnel samples is difficult to ascertain, thus it is hard to know the precise depth of each charophyte zone. Soundings by plumb line or echo sounder should be taken at the location where the deepest charophyte zone is located.

- It is probably more informative to carry out these extra measurements on a smaller number of transects than to sample more transects with less exact data on depth and species composition.
- While other data, such as chlorophyll a or total phosphorus concentrations, do indicate a lake's trophic status, they cannot indicate whether the characteristics of a typical marl lake are present, absent or under threat.

Surveying additional marl lakes

It should also be possible to evaluate the ecological status of other marl lakes by measuring the features noted above. Data could be collected along two transects running towards the deepest part of the lake. In single basin lakes this would provide sufficient data for an assessment based on macrophytes. In Table 12, two other marl lakes: Lough Bane Co. Meath/Westmeath (Plate 8), and Rossroe Lough, Co. Clare (Plate 9), surveyed by Roden (2008) and Bruinsma *et al.* (2009), are assessed using the proposed monitoring parameters.

Table 12: A comparison between two marl lakes surveyed prior to 2011 by Roden and others

	Lough Bane	**Rossroe Lough**
Vegetation depth (m)	9	4.7
Complete *Chara* zones	Yes, including *Chara denudata*	No, *Chara rudis* is last complete zone
Krustenstein	On exposed rock	Present, but angiosperm colonisation and some bryophytes.
Angiosperms confined to *Chara rudis* zone	Yes	No, *Elodea canadensis* and *Lemna trisulca* at base of euphotic zone

This comparison demonstrates that the relationships between vegetation depth and charophyte zones summarised in Figure 15 also apply to other marl lakes and could serve as a basis for their ecological evaluation.

Plate 8: Krustenstein zone in Lough Bane, charophytes growing amongst boulders

Plate 9: Krustenstein zone in Rossroe Lough, growth of angiosperms amongst boulders

Conclusions

This report has demonstrated that a typical Irish marl lake type exists with low nutrient and chlorophyll concentrations, high pH and alkalinity and a very characteristic charophyte and angiosperm flora and vegetation summarised as follows:

- Krustenstein with some small charophytes growing on rock and gravel.
- Communities dominated by *Chara curta* (and in Lough Owel with *Chara tomentosa*). These communities often extend into areas with sparse beds of *Phragmites* or *Schoenoplectus*, and other angiosperms may occur.
- *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*.
- Below the *Chara rudis* unit, *Chara globularis* or *Chara virgata* can form extensive swards which extend to 8m below the surface.
- The deepest macrophyte vegetation units consist of ecorticate charophyceae, either *Nitella flexilis* or *Chara denudata*; these communities extend to 9m depth.
- Mats of purple red *Oscillatoria* grow below the ecorticate charophyte zone close to the base of the euphotic zone.

Typically, these lakes occur on exposed carboniferous limestone, a rock type more extensive in Ireland than other EU states. Such lakes, other than the 65ha Malham tarn, scarcely occur in Britain (Pentecost 2009). Pentecost (2009) notes that only in Scandinavia are comparable shallow marl lakes recorded. Langangen (2007) states such lakes are rare and many typical Irish species (*Chara rudis*, *Chara curta*, *Chara denudata*) are very scarce. Other marl lakes do occur in Europe e.g. Starnbergersee and Walchensee in Bayern, Germany, but these differ from Irish examples in rock type, development of krustenstein and species composition (Roden, personal observation). Quite clearly the Habitats Directive definition of hard-water lakes is very broad and several variants may be recognised within it. Marl lakes on Irish Carboniferous limestone is such a variant.

Even within Ireland, however, it is known that other marl lakes, as defined in the EU Habitats manual (European Commission, 2007) occur on sea-sand or calcareous drift. Previous work (Roden, 1999; Bruinsma *et al*., 2009) suggests that these lakes have distinct features not encountered in the present survey. A comprehensive description of marl lakes in Ireland must provide an estimate of the total number of marl lakes, the number of variant types and where they occur, as well as some estimate of the ecological status of, at a minimum, the most important examples of each type.

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Appendix I

TWINSPAN Table – Lough Bunny

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 21  Ophrydiu  ---1-2-----------------------------------  001
 14  P. niten  -------------2---------------3-----------  010000
 18  Ranuncul  -----------------------------3-----------  010000
 24  C. annul  -----2-----------------------------------  01000100
 25  C. asper  -----2-----------------------------------  01000100
 19  U. minor  -----11------------2--1------------------  01000101
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 23  phragmit  ----------2------------------------------  0100011
  1  C. desma  ----3-------5-64-366----6-66-------------  01001
  4  Nuphar l  ------------3444322-44353---4------------  01001
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 10  Hippuris  ------------2-------24-------------------  01001
 12  C. contr  ---------------3--------2----------------  01001
 13  P. crisp  ------------4----------------------------  01001
 15  Cladopho  ------------4----------------------------  01001
 17  C. polya  ------------3----------------------------  01001
  3  C. rudis  ----2-------362155125363-6-----1-2-------  0101
  8  P. perfo  -------------3-32--2---2---------3-------  011
 16  U. vulga  -----1--------1--2---------------211-----  100
  2  C. globu  -------------------------------2265666665  101
  7  Nitella   ------------------------------554-2-1----  11

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TWINSPAN Table – Lough Carra 1

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3---233444--------------------------------------------------------------11--------1-1-----22--222-11
---2------22--4--1------1----3-----2-----13---2-2---------------33---2--1----------------2----2122--
-6--233444-------2------2-2------------------311--------------1-------------------------------------
---6233444------11----1----1---422------------1-----------------1---24------------------------------
3----1--2---1332------2--1---1----6---3--1-34---23--------1-----12-22----1----------------1----1----
--------------2-------------------------------------------------------------------------------------
------------44---------------------------------3------------------------------------1---------------
------3------65-------------------------------------------------------------------------------------
-----------------------------------------------3----------------------------------------------------
2---------------------------1------------------32---------------------------------------------------
---1-1-12----1-2224555434556645466266554566546545635546565646264-22212-------------1--2----2---1-4--
----2-3444---------------------------------3--3-----------------------------------------------------
--1-2-2--3----6-------------------------------2------------------------------------------1----------
--2---1--2---3------------------------------------3-------2-36-2------------------------------------
2---2---------1-2------------------------------------1----------------------------------------------
3-------------1-------------------------------------------------------------------------------------
-2----------------------------------2--------3------------------------------------------------------
1----------------------1----------------4------------------------1----------------------------------
-----2-2---1-------------------------1-------------12--2---3122----1-----------------2-------2-3----
------------------------------2---------------------------------------------------------------------
1------------13---2-----------------------------2-11----------1-------------------------------------
-------1------3--------3--------------1---21--2-----------------------------------------------------
----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
----22--2----------------------------------1--1--31-------------------------------------------------
-------------------------------------------------------------------------1-------------------4------
---------------------------------------------------------1------------------------------1-----------
--------------------------------------------------------------2-------------------------------------
-----------------------------------------3----1--4-------------------------------4------------------
--------------------------------------------------------2--3----------------------------------------
-------------------------1-----------------1-----------2--------------------------------2---------1-
---------------------------------------------------------------------------------------2------------
----------------------------------------------------------------------------------------------------
-------------------------------------------------------------1--------------------------------------
----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
-------------------------1----2----------1--4--122-1---------------------1----------12----1-----22--
------1----------------------------------------------32--3-----5------------------------------------

0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000111111111111111111111111111111111111
0000000000111111111111111111111111111111111111111111111111111111000000000000000000000000000000000011
01111111110000011111111111111111111111111111111111111111111111110000001111111111111111111111111111
 011111111     00000000000000000000000000000000000111111111111111001111
```

TWINSPAN Table – Lough Carra 2

```
                     11    11       111                        111111111111111111111111122          111111111111
          1212336666625789956  12233019 111233444555577788899000111222244455577777779900 122345889001112345566
          4453370567904042511469092589410177097891569237789064691233579136569012367838795818822037036786483834

C. denud  ----------------------------------------------------------------------------------------------------
R.flamul  ----------------------------------------------------------------------------------------------------
Ophrydiu  ----------------------------------------------------------------------------------------------------
cyan cru  12---------3----------------------------------------------------------------------------------------
C. annul  22--------------------------------------1----------------------------------------------2------------
phragmit  ----------------------------------------------------------------------------------------------------
C. contr  ------------1----------------------------------------------------------------1----------------------
C. asper  ------------------------------------------------------------------------------1--------2------------
C. polya  ----------------------------------------------------------------------------------1-----------------
L. minor  ----------------------------------------------------------------------------------------------------
Littorel  ----------------------------------------------------------------------------------------------------
Cladopho  ----------------------------------------------------------------------------------------------------
R. trich  ----------------------------------------------------------------------------------------------------
Myriophy  ------------------------------------------1---------------------------------------------------------
C. desma  --------------------------------1------------3----------------------------------------------------3-
C. vulga  ---------------------1----3-------------------------------------------------------------------------
Bryophyt  ----------------------------------------------------------------------------------------------------
P. grami  ----------------------------------3----1----------------------2----------2--------------------------
P. filif  ---------------------------------------------------------------------------------------2------------
L. trisu  ------------------------1------2--------------------------------------------------------------------
P. pecti  -------------------------------------------------------------------------------1-----------2--------
Urt. Int  --------------------------------------------------------------------4--------1----------------------
U. vulga  -----------------1-1------------1-1------1-22-----2--122---23--------3-----2---1--1------------1122-
P. zizii  ------------------2---------------------------------------------------------------------------------
Myr vert  -----11--------------------42------1---2-112---------1-2--------2--------1---51--1-----21-3---------
C. hispi  ---------------------1--------------------------------------------------5---------------------23----
alisma    ----------------------------------------------------------------------------------------------------
spargani  ----------------------------------------------------------------------------------------------------
P. natan  ----------------------------------------------------------------------------------------------------
Schoenop  ---------------------2-------------------------------------------------2----4-------1-----3--3--23--
C. tomen  -----------------------------------------------------------2---------------2--123345566255-645651544
P. lucen  ---------------11----┼------2-1-------1----------------------1---------------------------2---------2
Nuphar l  ------1-------------------1-4------------3--------------------1---------------------------------4---
Nymphaea  ---------------------1----3--------------------------------------------3----4-----------------------
U. minor  --1-----------2------------2------------2--------------------------2-------------------1------------
P. niten  -----------------1---------------1----2----22------------22-----------------------------------------
Elodea c  -------------------1213122222---------------------1111-2---4---1222---2--2----------------------3---
Red cyan  ------------2---------------------------------------------------------------------------------------
P. perfo  ---2-------------------3-2-2------11------2-------------2------2-2-2--2--2-2------------------------
P. crisp  --------------------------------2---------------------2-------------------3-------------------------
Myriophy  -----------------------------------------------------------------------------3----------------------
C. rudis  ------------1232334--1--2----121-3-45544434344666656665466525566554556654544431---------213-4-----24
C. globu  --224456666565354541----12--3-----------------------------2--3--2242------43-3----------------------

          0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
          0011111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111
          1100000000000000000000000000000000000000000000000000000000000000000000000000001111111111111111111111
          1100000000000000000111111111111111111111111111111111111111111111111111111111110000000000000000000000
            0000000000011111100000000001111111111111111111111111111111111111111111111110000000000000000000000
```

TWINSPAN Table – Lough Carra 3

```
           111111111112 2   1
           666688888991112844889
           567823789055382625128

C. denud   -----------------5666
R.flamul   ---------------------
Ophrydiu   ---------------------
cyan cru   ---------------------
C. annul   ---------------------
phragmit   -------2-------------
C. contr   ------2-----1--------
C. asper   ---------------------
C. polya   --------1----1-------
L. minor   ---------------------
Littorel   ---------------------
Cladopho   ---------------------
R. trich   ---------------------
Myriophy   ---------------------
C. desma   ---------------------
C. vulga   -------------2-------
Bryophyt   -------------5-------
P. grami   ---------1-----------
P. filif   ---------------------
L. trisu   ---------------------
P. pecti   ---2-----------------
Urt. Int   ---------------------
U. vulga   ---2--1-3-21---------
P. zizii   ----------------3----
Myr vert   --3-12-12122-1363----
C. hispi   ------22-----4-------
alisma     -------------2-------
spargani   -------------3-------
P. natan   -------------2-------
Schoenop   -2--34---3-422-------
C. tomen   656662665665---------
P. lucen   -----3-----2---------
Nuphar l   33--------24----3----
Nymphaea   ---------------------
U. minor   ---------------------
P. niten   ----------------1----
Elodea c   -----1---------------
Red cyan   ---------------------
P. perfo   ---------------------
P. crisp   ---------------------
Myriophy   ---------------------
C. rudis   -----------1---------
C. globu   --------------------1

           000000000000000001111
           11111111111111111
           11111111111111111
           00000000000000111
           00000000000011
```

TWINSPAN Table – Lough Owel 1

```
               1     111111          1    111                            11111111                1               1
              6139347001112256788999901899112 12233455566666667777888888900011122   11122224445691 113344557777890
              6385321462463969401146894903594452805845702345780378234568201801712678138015606981982676917022569773

21  P. perfo  ----------------------------------------------------------------------------------------------------
26  C. denud  ---------2---526666666646------4--------------------------------------------------------------------
30  P. fries  ------1--2221---1-----------------------------------------------------------------------------------
33  P. natan  3---3-----------------------------------------------------------------------------------------------
32  Elodea c  2-3-233432221---------------------------------------------------------------------------------------
22  P. prael  --1---4-3-------------------------------------------------------------------------------------------
15  Numphar   --2-5-----------------------------------------------------------------------------------------------
13  M. spica  ------------1---------------------------------------------------------------------------------------
35  Lemna tr  44--------------------------------------------------------------------------------------------------
 8  C. hispi  --46-----------------------------------2------------------------------------------------------------
31  P. pecti  -----4-2------------------------------------------------2-------------------------------------------
23  Schoenop  --2-------------------------------------------------------------------------------------------------
34  Nymphaea  ----1------------------------------------------------------------------2----------------------------
14  Nitella   -----------1-------------4---2----------------------------------------------------------------------
 7  C. globu  -------------54----------2663214---------22--3-------------3--2--2----------------1-----------------
19  P. color  ------------------------------------------------------------1---------------------------------------
18  P. niten  ----------------------------1----3--3---------------------------------------------1-----------------
17  P. lucen  -----------------------------------3-------------1--------------------------------------------------
10  C. rudis  -----31---2-------------5-------426466664-22556256656---5663252-32224543--442421323---2-------------
 5  C. contr  --------------3----------2-----443-4132-42223-2621---666---12-24------1-------------24---2-1--------
24  U. vulga  --------------------------------------------------------------------------------------------1-------
20  P. grami  -------------------------------------------------------------------3-----------------1--------------
 2  C. tomen  ---------------1------------1---1-1-------------1------------------44533444444453433242322-22-11----
25  Cladopho  ---------------------------------------------------------------------4--------------6-2-------------
 9  C. polya  ----------------------------------4---------------------------------1-434------1----2-2-2-3--1------
 6  C. desma  ------------------------2------445-------5-3----1-----------2------26-334444424333--4456666666666665
 1  phragmit  ----1------------------------------------------------------------------2--------------2------1------
29  Bryophyt  -------------------------------------------------------------------5-----4--------------------------
27  Littorel  ----------------------------------------------------------------------------------------------------
16  Ophrydiu  ------------------------------------------2--------------------------------------------1------------
11  cyanophy  ----------------------------------------------------------------------------3-----------------------
28  Ranuncul  ----------------------------------------------------------------------------------------------------
12  M. alter  -------------------------------------------------------------------1--------------------------------
 3  C. annul  ------------------------------------------22--------------------1-----------------1-2---------------
 4  C. asper  ---------------1--------------------------22-------2--------2---------------------------------------

              0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
              0000000000000000000000000111111111111111111111111111111111111111111111111111111111111111111111111111
              0000000000000111111111111000000000000000000000000000000000000000000000000000000000000000000000000000
              0011111111111001111111111000000000000000000000000000000000000000000111111111111111111111111111111111
                00111111111  0000000001000000111111111111111111111111111111111111000000000000000001111111111111111
```

TWINSPAN Table – Lough Owel 2

```
           1       1           1  1
           0 1123350   122334450452
           792941232135037473415590

P. perfo   -----------------------3
C. denud   ------------------------
P. fries   ---------------1--------
P. natan   ------------------------
Elodea c   ---------------------2--
P. prael   ------------------------
Numphar    ------------------------
M. spica   ------------------------
Lemna tr   ------------------------
C. hispi   ------------------------
P. pecti   ------------------------
Schoenop   ------1-----------------
Nymphaea   ------------------------
Nitella    ----------------------2-
C. globu   ----------------------2-
P. color   ------------------------
P. niten   ------------------------
P. lucen   ------------------------
C. rudis   -------------------3----
C. contr   -2---1-----332322-------
U. vulga   ------------------------
P. grami   ------------------------
C. tomen   -3--311-1---------------
Cladopho   --2------------------32-
C. polya   -------62---------------
C. desma   525445412--3------------
phragmit   ------------------------
Bryophyt   ---3---------------1-4--
Littorel   -2----1--2232-----3-----
Ophrydiu   -22---2-----2-----------
cyanophy   -55554422534565556635---
Ranuncul   ---------2-3------------
M. alter   --------2362222112---24-
C. annul   -2-------43--21-2--3----
C. asper   -----1---43-322322------

           000000000000000000000001
           11111111111111111111111
           01111111111111111111111
           10000000000000000000011
           100000000111111111111
```

Appendix II

Relevés by site

vegetation type	cy	cy	cy	cy	cy	cy		cur	cur	cur	cur	cur	cur	cur		ru	ru	ru	ru	ru	ru	ru	ru		op	op	op	op	op	op	op	op		glob	glob	glob	glob	glob	glob	glob	glob		nit	nit	nit		spring		empty	empty	empty	empty	empty	empty	empty	empty	empty	empty	empty	empty
substrate		marl	rock		peat				marl		silt/marl	marl				marl	marl		silt/marl	silt/marl			soft silt		peat	rock/marl	silt/peat	marl	peat	peat									soft silt						soft silt									marl		marl				
depth (m)	1	2	1	1	1	1		1	3	2	2	2	3	4		2	2	3	2	2	2	2	5		2	2	2	2	2	2	2	2		3	5	5	6	6	7	5	8		8	6	8		5							2	2	2				
cover	100	100	100	100	50	100		100	100	100	100	100	100	100		100	100	100	100	100	100	100	100		50	50	30	20	10	10	50	40		100	100	100	100	100	100	100	100		30	100	80				0	0	0	0	0	0	0	0	0	0	0	0
Krustenstein	5	5	5	5		4																																																						
Ophrydium versatile				0.1	1																																																							
Chara annulata					1																																																							
Chara aspera					1																																																							
Littorella uniflora	1					0.1																																																						
Phragmites australis																													1																														
Bryophytes						0.1																																																					
Chara polyacantha						1																																									2													
Chara desmacantha						2		5	5	5	5	5	5	3		2																															4													
Schoenoplectrus lacustris										0.1	3	1							3			0.1			3	3	1		0.1	1																	1													
Potomageton gramineus																			0.1			1			0.1			2																															
Utricularia minor					0.1							1										0.1			0.1																																		
Juncus bulbosus														0.1													1		0.1																														
Chara contraria													1	2																																													
Numphar lutea										3	1		2	3		1	3	4	2	3	3	2									3																2													
Chara rudis										1	0	1		0.1		4	2	2	4	4	5	5	5											1										0.1			2													
Potomageton perfoliatus												1		2				1	1		2													2																										
Potomageton praelongus										1						2	1	1		1																											2													
Hippuris vulgaris																	3			1																											1													
Potamogeton crispus																																															3													
Potamogeton nitens																					1											2																												
Utricularia vulgaris					0.1					0.1						1																		1	0.1						0.1																			
Chara globularis																																		5	5	5	5	5	4	5	4		1	1																
Nitella flexilis																																								0.1	1		3	4	4															
Cladophora																																															3													
Ranunculus ?																																2																												

vegetation type	ann	ann	ann	ann	ann	ann	ann	ann	ann	ann	ann	ann	ann	ann	ann
substrate		marl oncolith	marl		boulder/sediment	stone/marl	rock/marl	crust/marl	marl	marl	boulder	marl/shell	gravel/marl	marl	gravel/marl
depth (m)	1	2	1	3	1	0	0	2	1	1	0	2	2	1	2
cover	15		15	60	100		100		100		100	100	10		
Chara annulata	1	0.1	0.1	0	0.1	0.1		1	1	1	0.1	0	1		1
cyanophyte crust					4	4	4	5	5	5	5	5	0	1	1
Chara desmacantha															
Phragmites australis						0.1			1	1				2	
Ophrydium versatile			0.1						0.1	1					
Chara polyacantha					0.1			0.1						0.1	
Chara aspera	1													0.1	
Utricularia vulgaris							1								
Chara tomentosa	1				0.1										
Schoenoplectrus lacustris															
Chara rudis				3	0.1		1	0.1		1	0.1				
Chara globularis															
Chara denudata															
Myriophyllum verticillatum	1														
Elodea canadensis															
Potamogeton lucens															
Potomageton perfoliatus															
Potamogeton nitens		0.1													
Numphar lutea															
Potomageton gramineus															
Chara contraria															
Utricularlia minor	0.1			1											
Utricularia intermedia															
Potamogeton pectinatus															
Nymphaea alba															
Myriophyllum alterniflorum															
Chara hispida															
Potamogeton filiformis	1														
Potamogeton crispus															
Littorella uniflora											0.1				
Potamogeton zizii															
Cladophora															
Bryophytes															
Ranunculus flamula											0.1				
Ranunculus trichophyllus															

vegetation type	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy
substrate	marl	marl	sand/rock	soft marl	rock/marl	boulders/bedrock	rock	boulders	boulder	boulder	marl	crust/boulder	crust/marl	firm marl	rock	marl	silt/marl		boulder	boulder			rock			marl	silt/marl		rock/marl	marl
depth (m)	1	1	1	1	1	1	1	0	2	2	1	3	2	1	1	2	2	1	0	1	1	1	1	1	0	1	2	2	1	5
cover	10		50			100	100	100			100					15	100	100		100	100				100	100	100			
Chara annulata																		1								1				
cyanophyte crust	1	1	2	3	5	5	5	5	5	5	5	5	5	5	5	2	4	5	5	5	5	2	3	4	5	5	2	0	2	2
Chara desmacantha																1	3	1	0.1	1	0.1	1	4	1	3	0.1	4	4	3	
Phragmites australis														1								2	1	1	1	0.1				
Ophrydium versatile							2															1								
Chara polyacantha																					1	1	1			0.1				
Chara aspera																					1			3						
Utricularia vulgaris				1																						2	0.1			
Chara tomentosa				3																										
Schoenoplectrus lacustris																														
Chara rudis																							1		1				0.1	
Chara globularis																														4
Chara denudata																														
Myriophyllum verticillatum																							1							
Elodea canadensis															1															
Potamogeton lucens						0																								
Potomageton perfoliatus																														
Potamogeton nitens						1																								
Numphar lutea																														
Potomageton gramineus																														
Chara contraria																													0.1	
Utricularlia minor																														
Utricularia intermedia																						0.1						3		
Potamogeton pectinatus																														
Nymphaea alba			3																											
Myriophyllum alterniflorum																							1						2	
Chara hispida																														
Potamogeton filiformis																														
Potamogeton crispus																														
Littorella uniflora																													2	
Potamogeton zizii																														
Cladophora																														
Bryophytes														0.1																
Ranunculus flamula																														
Ranunculus trichophyllus																													2	

vegetation type	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur
substrate	marl	soft marl	marl	soft marl	soft marl			soft marl	silt/marl				rock/marl		marl			crust	silt/marl			silt	
depth (m)	1	1	2	1	1	1	2	1	2	1	1	1	1	2	2	1	2	2	3	2	2	3	3
cover		100		50	60	100	80	100	15	100	100	100	100	100	80	100	20	10	80	100	100		100
Chara annulata																							
cyanophyte crust																		3					
Chara desmacantha	5	5	0.1	3	3	5	4	5	1	0.1	4	5	3	1	4	5	0.1	1	4	4	1	5	2
Phragmites australis	2	1	1	0	2	0.1																	
Ophrydium versatile																							
Chara polyacantha					0.1	0.1	0.1	0.1	1	2	2	2	3	5				1					
Chara aspera			5																				
Utricularia vulgaris															0.1	0.1	0.1	0.1	1	1	1	1	1
Chara tomentosa																							3
Schoenoplectrus lacustris												2											
Chara rudis						0.1	0.1					1	3		0.1								1
Chara globularis																							
Chara denudata																							
Myriophyllum verticillatum										0.1					0.1							0.1	
Elodea canadensis																							
Potamogeton lucens																							
Potomageton perfoliatus																					0.1		
Potamogeton nitens							0.1													1			
Numphar lutea																						1	
Potomageton gramineus								1		2						2					5		
Chara contraria				1																		0.1	
Utricularlia minor																							
Utricularia intermedia																							
Potamogeton pectinatus																							
Nymphaea alba						2						3											
Myriophyllum alterniflorum																							
Chara hispida	1										0.1												
Potamogeton filiformis																							
Potamogeton crispus																	1						
Littorella uniflora										3													
Potamogeton zizii																							
Cladophora										5													
Bryophytes																							
Ranunculus flamula																							
Ranunculus trichophyllus																							

vegetation type	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur
substrate		sand	marl	marl	marl		marl	marl			marl	marl			soft marl	soft marl	marl					marl	
depth (m)	2	1	2	1	2	2	1	2	1	2	2	1	1	1	1	2	1	3	1	2	2	2	3
cover	60	10	60	80		100	25		100		100		50	50	100	100		100	100	100	100		100
Chara annulata																							
cyanophyte crust																							
Chara desmacantha	3	1	3	4	4	4	2	4	5	5	4	3	5	5	5	5	2	3	5	5	4	3	2
Phragmites australis																							
Ophrydium versatile																							
Chara polyacantha																							
Chara aspera		0.1							0.1			3	1	1									
Utricularia vulgaris	2																						
Chara tomentosa																							
Schoenoplectrus lacustris																	0.1						
Chara rudis											1												3
Chara globularis																		2	1		2	4	
Chara denudata																							
Myriophyllum verticillatum			1														0.1						
Elodea canadensis																							
Potamogeton lucens																					0.1		
Potomageton perfoliatus																							
Potamogeton nitens																							
Numphar lutea																							
Potomageton gramineus																	2					1	
Chara contraria								1								2							
Utricularlia minor	2																			1			
Utricularia intermedia							0.1																
Potamogeton pectinatus															1	2							
Nymphaea alba																							
Myriophyllum alterniflorum										0.1													
Chara hispida							2																
Potamogeton filiformis		1																0.1					
Potamogeton crispus																							
Littorella uniflora																							
Potamogeton zizii											1												
Cladophora																							
Bryophytes																							
Ranunculus flamula																							
Ranunculus trichophyllus																							

vegetation type		tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom	tom
substrate				sandy marl	marl	white marl	marly sand						sand/marl	marl		marl	marl	marly sand	marl sand		sandy marl	marl					silt		marl	marl	marl	marl	
depth (m)	1.57		3.5	3	1.6	1.4	0.65	2.2	2.6	2.5	2	0.8	1.2	1.5	1.2	1.6	1.6	0.64	1.4	2.6	2.9	1.9	2	3.2	2.6	2.6	3.3	4.7	0.6	0.9	1.2	1	1.5
cover			80	70		100		70		20	100	70	100		30	100				100	90	100	100	70	100	100		60	100	100	80	10	
Chara annulata																																	3
Chara desmacantha																																	1
Phragmites australis																																1	
Chara polyacantha												0.1			0.1																		1
Chara aspera																																	3
Utricularia vulgaris			0.1				1				1	2		0.1	0.1	1							0.1					1		0.1	0.1		
Chara tomentosa		4	0.1	4	5	5	4	4	1	2	5	4	5	1	3	5	2	4	5	5	5	5	4	4	4	3	3	1	5	5	4	5	4
Schoenoplectrus lacustris		0.1	1	1	2	2	2	2	3														3										1
Chara rudis																							0.1	0.1	1	3	3	1					
Chara globularis																																	
Myriophyllum verticillatum					0.1	0.1			1	0.1	1	1	2										1		0.1							0.1	
Elodea canadensis			2						0.1																			3					
Potomageton lucens									2														1	1			1						
Potomageton perfoliatus																																	
Potomageton nitens																																	
Numphar lutea			3	2							1										2		3										
Potomageton gramineus					0.1																												
Chara contraria																														1			3
Utricularlia minor																																	
Utricularia intermedia																																	
Potomageton pectinatus														0.1		1			1														
Nymphaea alba																																	
Myriophyllum alterniflorum																																	
Chara hispida																													1	1	2	1	
Potomageton crispus																																	
Lemna trisulcata																																	
Hippuris vulgaris												0.1																					

vegetation type	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru
substrate					boulder/marl						marl		silt/marl				shell/marl		soft marl		marl					marl	marl	soft marl	marl	marlmarl	marl	gravel/	sand/silt		marl	marl	silt		
depth (m)	4.5	2.5	6.7	2.3	2.1	0.9	2.1	7.6	1.4	1	3.5	3	4.1	2	3	4	3.5	3.5	2	3.3	4	2.7	4	5	5	4.6	2.3	4.7	2.5	2.4	3.8	2.4	2.6	2.4	6	5.5	5	4.2	2.7
cover			2	5		60			70	100	100	100	100				55	100			100	70	100	100		60	70		70		60	40	30	60	80	70	100	80	80
Chara annulata																																							
Chara desmacantha																																							
Phragmites australis																																							
Chara polyacantha																																							
Chara aspera		0.1																																					
Utricularia vulgaris	1																1	1	2	2	0.1	1					1		0.1			1							
Chara tomentosa	1	0.1																																					
Schoenoplectrus lacustris						3			1																									2					
Chara rudis	3	0.1	0.1	0.1	2	3	4	4	4	4	5	5	5	5	5	5	3	4	4	5	5	4	5	5	5	4	3	5	2	3	3	2	3	2	4	4	4	4	4
Chara globularis	2																																		1	1	1	1	2
Myriophyllum verticillatum		0.1																			0.1					0.1	1		0.1	0.1	0.1	1	1	2	1				
Elodea canadensis																					0.1	0.1	0.1	0.1	0.1	1	1	1							1	1			
Potomageton lucens																																							0.1
Potomageton perfoliatus	1										1													1		1		1		0.1	1					1		1	
Potomageton nitens					0.1								1				1															1					1		
Numphar lutea												0.1																	2										
Potomageton gramineus												1														1							0.1						
Chara contraria																																							
Utricularlia minor																																						1	
Utricularia intermedia							3																																
Potomageton pectinatus																																							
Nymphaea alba						3			2																														
Myriophyllum alterniflorum																															0.1								
Chara hispida																																							
Potomageton crispus																	1																						
Lemna trisulcata			1																																				
Hippuris vulgaris																																							

vegetation type	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob		elod	elod	elod	elod	elod	elod	elod	
substrate											mud						marl	mud	mud			grey marl	marl/sand	mud	marl	silt/marl	mud	
depth	5	4.2	3.2	5.5	3	3.2	5	5	6.4	6.5	5.3	6	7.3	4.1	7	4.6	3.7	8	4		6	6.1	5.2	4	5	2.3	6	
cover	100	80	100	60			100	70	80	80	5				100	100			40		40	30	10	60	20	20	20	
Chara annulata																												
Chara desmacantha																												
Phragmites australis																												
Ophrydium versatile																												
Chara polyacantha																												
Chara aspera																												
Utricularia vulgaris							0.1											0.1										
Chara tomentosa																												
Schoenoplectrus lacustris																												
Chara rudis	3	3	3	2	2	2	2	1	1	0.1																		
Chara globularis	3	3	3	2	2	3	4	0	4	5	1	1	3	4	5	5	5	0.1	2		1							
Chara denudata																												
Myriophyllum verticillatum					4								0.1	0.1					1					3		2	2	
Elodea canadensis		1						1										0.1	1		1	0.1	1	1	2			
Potamogeton lucens						0.1													1									
Potamogeton perfoliatus											1										1	2		1				
Potamogeton nitens							0.1																			0.1		
Numphar lutea														0.1					3							2		
Potomageton gramineus																												
Chara contraria					0.1					0.1																		
Utricularlia minor				1								0.1												1				
Utricularia intermedia					0.1																							
Potamogeton pectinatus																												
Nymphaea alba																												
Myriophyllum alterniflorum																												
Chara hispida																												
Potamogeton filiformis																												
Potamogeton crispus	2																											
Littorella uniflora																												
Potamogeton zizii			1																							2		
Lemna trisulcata								0																				
Hippuris vulgaris																												
Myriophyllum spicatum					2																							
Red cyanophyte										1																		
Cladophora																												
Bryophytes																												
Potamogeton natans																												
Lemna minor																												
Chara vulgaris																												
Potamogeton perpusillus																												
Sparganium																												
Alisma plantago-aquatica																												

vegetation type	denud	denud	denud	denud		open	open	open	open	open	open	open	open	open	open		empty	empty	empty	empty	empty	empty	empty	empty	empty	empty	empty	empty
substrate	grey silt						marl	marl	grey silt	loose marl		marl			sand				shell/marl		sand	marl/sand	sand	marl			gravel/marl	
depth	6	7.5	5.6	5.9		8.2	2.1	1.6	9	0.7		0.7	2.4		0.7		11	14	2		0.5	7.7	0.3	7.1			2.2	
cover	100			100		80	20						100		10		0				0	0					10	
Chara annulata																												
Chara desmacantha																												
Phragmites australis										1		1																
Ophrydium versatile																												
Chara polyacantha														0.1														
Chara aspera																												
Utricularia vulgaris							0.1					0.1																
Chara tomentosa																												
Schoenoplectrus lacustris								1																				
Chara rudis																												
Chara globularis	0.1																											
Chara denudata	5	4	5	5																								
Myriophyllum verticillatum											5																	
Elodea canadensis																												
Potamogeton lucens																												
Potamogeton perfoliatus							0.1																					
Potamogeton nitens																												
Numphar lutea																												
Potomageton gramineus							2								1													
Chara contraria								0.1					5															
Utricularlia minor																												
Utricularia intermedia																												
Potamogeton pectinatus													1															
Nymphaea alba																												
Myriophyllum alterniflorum																												
Chara hispida																												
Potamogeton filiformis																												
Potamogeton crispus																												
Littorella uniflora														3														
Potamogeton zizii																												
Lemna trisulcata									0																			
Hippuris vulgaris						4																						
Myriophyllum spicatum																												
Red cyanophyte									0							2												
Cladophora																												
Bryophytes															0													
Potamogeton natans																												
Lemna minor																												
Chara vulgaris																												
Potamogeton perpusillus																												
Sparganium																												
Alisma plantago-aquatica																												

vegetation type	empty	empty	empty	empty	empty	empty	empty	empty	empty	empty	empty	empty	empty	empty	empty		vulg	vulg	vulg	vulg	vulg	vulg	vulg	vulg	vulg	vulg	vulg	vulg
substrate		sand/marl	marl	marl	mud		marl					marl		marl			red solid sand	coarse sediment		coarse sediment		sand	coarse sediment			marl		
depth		1.6	7.6	7.4	7.9			6.7		9.1	6.1	1.5	8.5		7.9		1.2	0.4	0.6	0.8	1	1	0.8	1	0.7	2	1.5	1.5
cover																	100	15	100	20	80	40	100		100		100	60
Chara annulata																		1		2			3	2		3		
Chara desmacantha																					4					0.1	4	1
Phragmites australis																					1				3			
Ophrydium versatile																					1							
Chara polyacantha																			0.1					2	2		2	1
Chara aspera																		1		2	0.1		3			3		
Utricularia vulgaris																										1		
Chara tomentosa																			3									
Schoenoplectrus lacustris																	1	1	1		0.1						0.1	1
Chara rudis																	0.1											
Chara globularis																				0.1								
Chara denudata																												
Myriophyllum verticillatum																			0.1					0.1	2			
Elodea canadensis																	0.1		1			1						
Potamogeton lucens																												
Potamogeton perfoliatus																												
Potamogeton nitens																											0.1	
Numphar lutea																						0.1						
Potomageton gramineus																				0.1			1					
Chara contraria																		1		2	0.1		3			3		
Utricularlia minor																												
Utricularia intermedia																								0.1				
Potamogeton pectinatus																												
Nymphaea alba																	0.1				0.1	2						
Myriophyllum alterniflorum																								1				
Chara hispida																	0.1		3		1				2	0.1	0.1	
Potamogeton filiformis																		1						1	0.1			
Potamogeton crispus																												
Littorella uniflora																												
Potamogeton zizii																												
Lemna trisulcata																								2	0.1			
Hippuris vulgaris																												
Myriophyllum spicatum																												
Red cyanophyte																												
Cladophora																				2					4			
Bryophytes																		1	4	1	1		2		5			
Potamogeton natans																			1									
Lemna minor																									1			
Chara vulgaris																	0.1	1	1	2	2	2	3					
Potamogeton perpusillus																			0.1				0.1					
Sparganium																			2									
Alisma plantago-aquatica																			1									

Vegetation	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy	cy
	3	2	16	8	9	6	8	7	7	7	9	16	15	16	9	3	9	5	3
substrate		gravel	cobble/gravel	boulder/cobble	boulders/gravel		boulder/cobble	cobbles/gravel	cobbles/gravel	cobbles/gravel	boulders/gravel	cobble/gravel		cobble/gravel			boulders/gravel	cobble/gravel	
depth	0.5	0.2	0.8	1	0.8	3.6	0.5	0.4	1	2.6	1.6	1.8	0.5	1	0.8	1.1	2.2	0.3	0.8
cover		70			20					20					70		50	95	
Krustenstein	4	2	4	5	4	4	4	5	5	2	4	1	4	1	3	4	4	3	4
Myriophyllum alterniflorum	2	5	1	1	1	0.1	0.1	1						1	1				
Chara annulata	3	2		1	0.1		1			2			1						
Chara aspera	3	2	2	1	1	2	1	1											
Littorella uniflora	1	1	1						2				1		2			0.1	
Chara desmacantha												0.1	1	1	2	3	3	3	4
Chara tomentosa													2	0.1			2	0.1	
Chara polyacantha												5		1					
Chara rudis										2									
Chara contraria			2	1	2	1	1						1		2				
Chara globularis																			
Chara denudata																			
Elodea canadensis																			
Potamogeton friesii						0.1													
Ophrydium versatile			1										1					1	1
Cladophora																			1
Bryophytes										0.1						2			
Nitella flexilis																			
Potamogeton nitens																			
Phragmites australis																			
Potamogeton praelongus																			
Potamogeton pectinatus																			
Chara hispida																			
Numphar lutea																			
Potamogeton lucens																			
Potamogeton gramineus																			
Schoenoplectrus lacustris																		0.1	
Ranunculus ?	1														2				
Potamogeton natans																			
Nymphaea alba																			
Lemna trisulca																			
Myriophyllum spicatum																			
Potamogeton coloratus																			
Potamogeton perfoliatus																			
Utricularlia vulgaris																			

Vegetation	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur
	4	2	3	2		4	5	2	4	11	4	11		5	11	2	6
substrate	cobbles/sand	gravel			peat	silt	silty marl	silt	cobbles/sand	silty marl	silt		mud			sand marl	
depth	0.4	0.8	1.8		0.8	2.4	1.7	0.7	1	0.6	1.5	2.3	0.5	1.5	2	2.2	1
cover	100	100				90	100	100	100	100	100	100		100	100	100	
Krustenstein	3																
Myriophyllum alterniflorum																	
Chara annulata					1												
Chara aspera	0.1																
Littorella uniflora																	
Chara desmacantha	4	3	3	0.1	3	3	5	5	5	5	5	5	5	5	5	5	5
Chara tomentosa	0.1	3	3	2	1	3	2	1	1		1	1		0.1	0.1		
Chara polyacantha		3			1			1		2			0.1				
Chara rudis																	
Chara contraria	0.1				1	3			1		0.1						
Chara globularis																	
Chara denudata																	
Elodea canadensis																	
Potamogeton friesii																	
Ophrydium versatile							0.1										
Cladophora					5												
Bryophytes			3														
Nitella flexilis																	
Potamogeton nitens																	
Phragmites australis													0.1				
Potamogeton praelongus																	
Potamogeton pectinatus																	
Chara hispida																	
Numphar lutea																	
Potamogeton lucens																	
Potamogeton gramineus						0.1											
Schoenoplectrus lacustris																	
Ranunculus ?																	
Potamogeton natans																	
Nymphaea alba																	
Lemna trisulca																	
Myriophyllum spicatum																	
Potamogeton coloratus																	
Potamogeton perfoliatus																	
Utricularlia vulgaris											0						

Vegetation	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur	cur
	15	2	15	11	11		6	9	3	15	11	9	7	7	4	14	3
substrate		sand marl			peat	mud		cobble/gravel			silt	silt	sand/gravel	sand/gravel	silt		
depth	2.7	1.5	3.9	1.4	1.2	0.5	0.8	0.8	2.3	1.5	0.6	3	4	4.7	1.8	1.5	2.2
cover	100	100	80	100	100			100			100	100	6030	5	100		100
Krustenstein										2							
Myriophyllum alterniflorum									0.1								
Chara annulata														0.1			
Chara aspera																	
Littorella uniflora																	
Chara desmacantha	5	4	4	2	5	4	2	2	1	3	3	2	2		3	3	1
Chara tomentosa				4	3	1	2	2	3	3	3	3	2	2	3	3	3
Chara polyacantha				0.1	0.1	1	2	3									
Chara rudis				0.1	3	1	2	3	1	1	1	1	2	2	3	3	3
Chara contraria								0.1									
Chara globularis														0.1			
Chara denudata																	
Elodea canadensis																	
Potamogeton friesii																	
Ophrydium versatile																	
Cladophora						1											
Bryophytes									4								
Nitella flexilis																	
Potamogeton nitens														0.1			
Phragmites australis						1	1										
Potamogeton praelongus																	
Potamogeton pectinatus																	
Chara hispida																	
Numphar lutea																	
Potamogeton lucens																	
Potamogeton gramineus									2								
Schoenoplectrus lacustris																	
Ranunculus ?																	
Potamogeton natans																	
Nymphaea alba							1										
Lemna trisulca																	
Myriophyllum spicatum																	
Potamogeton coloratus																	
Potamogeton perfoliatus																	
Utricularlia vulgaris																	

Vegetation	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru
		11		11			3	5	6	9	15	7	10	10	4
substrate	peat		peat		mud	mud				mud		cobbles/sand	cobble/silt	cobble/silt	silt
depth	1	1.6	1.3	4.1	2.7	1	3	4	3	3.8	5	3.5	5.2	3.5	2.6
cover		100		100			100	100		100					100
Krustenstein															
Myriophyllum alterniflorum															
Chara annulata												0.1			
Chara aspera						1									
Littorella uniflora															
Chara desmacantha															
Chara tomentosa	4	0.1													
Chara polyacantha		3													
Chara rudis	4	5	5	4	5	4	5	4	5	5	4	2	1	1	5
Chara contraria															0.1
Chara globularis				2									1		
Chara denudata															
Elodea canadensis															
Potamogeton friesii															
Ophrydium versatile															
Cladophora	3														
Bryophytes															
Nitella flexilis															
Potamogeton nitens															2
Phragmites australis															
Potamogeton praelongus															
Potamogeton pectinatus								1							
Chara hispida			1												
Numphar lutea															
Potamogeton lucens															
Potamogeton gramineus															
Schoenoplectrus lacustris															
Ranunculus ?															
Potamogeton natans															
Nymphaea alba															
Lemna trisulca															
Myriophyllum spicatum															
Potamogeton coloratus															
Potamogeton perfoliatus															
Utricularlia vulgaris															

Vegetation	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru	ru
	6		13	13	5	11	3	6	3	7	10	10	10	7
substrate								grey silt			cobble/silt	cobble/silt	cobble/gravel	
depth	1	1	2.9	1	3	3.8	2.7	1.6	3	5.6	1.2	2.1	0.5	6.4
cover		100			100	100			80	5				1
Krustenstein														
Myriophyllum alterniflorum														
Chara annulata											1	1		
Chara aspera											1	1	1	
Littorella uniflora														
Chara desmacantha					0.1		3					2	1	
Chara tomentosa					0.1		0.1							
Chara polyacantha														
Chara rudis	5	5	5	5	4	4	3	3	3	2	1	1	1	1
Chara contraria	0.1	1	1	2	1	2	3	3	3	0.1	1	1	1	1
Chara globularis										2	1			1
Chara denudata														
Elodea canadensis														
Potamogeton friesii														
Ophrydium versatile											1			
Cladophora														
Bryophytes														
Nitella flexilis														
Potamogeton nitens														
Phragmites australis														
Potamogeton praelongus														
Potamogeton pectinatus														
Chara hispida														
Numphar lutea														
Potamogeton lucens	0.1							2						
Potamogeton gramineus														
Schoenoplectrus lacustris														
Ranunculus ?														
Potamogeton natans														
Nymphaea alba														
Lemna trisulca														
Myriophyllum spicatum														
Potamogeton coloratus													0	
Potamogeton perfoliatus														
Utricularlia vulgaris														

Vegetation	cont	cont	cont	cont	cont	cont	cont	glob	glob	glob	glob	glob	glob	glob	glob	glob	glob
	4	14	9	4	4	4	11	9	11	7	7	2	8	8	8	3	2
substrate	silt		sandy gravel	silt	silt	silt	silt	sandy mud					sandy mud	sandy mud	boulder clay		
depth	2.4	2.2	4	3	3.2	4	4	4.5	4.2	5	7.6	3.3	6.1	4.7	2.2	3.5	3.3
cover	100		100	100	100	100	100	100	100	10		80				100	100
Krustenstein																	
Myriophyllum alterniflorum															3		
Chara annulata																	
Chara aspera																	
Littorella uniflora																	
Chara desmacantha	4		4									3					
Chara tomentosa										0.1							
Chara polyacantha																	
Chara rudis	1	1															
Chara contraria	2	5	1	5	5	5	3					3		1			2
Chara globularis			1					5	5	2	0.1	3	1	1	1	4	3
Chara denudata												3				4	1
Elodea canadensis																	
Potamogeton friesii																	
Ophrydium versatile																	
Cladophora															1		
Bryophytes																	
Nitella flexilis													1	3	1		
Potamogeton nitens	2									0.1							
Phragmites australis																	
Potamogeton praelongus																	
Potamogeton pectinatus																	
Chara hispida																	
Numphar lutea																	
Potamogeton lucens																	
Potamogeton gramineus																	
Schoenoplectrus lacustris																	
Ranunculus ?																	
Potamogeton natans																	
Nymphaea alba																	
Lemna trisulca																	
Myriophyllum spicatum																	
Potamogeton coloratus																	
Potamogeton perfoliatus																	
Utricularlia vulgaris																	

Vegetation	denud	denud	denud	denud	denud	denud	denud	denud	denud	denud	elod	elod	elod	elod	elod	elod	elod	elod	open
	4	3	2	2	9	11	14	15	2	15	5	5	5	9	11	13	5	5	9
substrate	silt				sandy mud								grey silt/sand	mud		fine mud	grey silt	mud	mud
depth	4.7	5.6	3.3	3.3	3.2	4.3	6	4.5	7.2	4.2	4.5	5.1	5.1	6.4	5.6	4.6	5.8	6.6	5.5
cover		100	100	100	100	100		100		80	60		60	40	20		20	1	
Krustenstein																			
Myriophyllum alterniflorum																			
Chara annulata																			
Chara aspera	0.1																		
Littorella uniflora																			
Chara desmacantha										1									
Chara tomentosa	0.1																		
Chara polyacantha																			
Chara rudis										4	2	0.1				1			
Chara contraria																			
Chara globularis																			
Chara denudata	5	5	5	5	5	5	5	5	3	5					1				
Elodea canadensis											2	2	3	2	1	1	1	0.1	
Potamogeton friesii		0.1										0.1			1	1	1	0.1	
Ophrydium versatile																			
Cladophora																			
Bryophytes																			
Nitella flexilis																	0.1		
Potamogeton nitens																			
Phragmites australis																			
Potamogeton praelongus												3		2					
Potamogeton pectinatus											3		1						
Chara hispida																			
Numphar lutea																			
Potamogeton lucens																			
Potamogeton gramineus																			
Schoenoplectrus lacustris																			
Ranunculus ?																			
Potamogeton natans																			
Nymphaea alba																			
Lemna trisulca																			
Myriophyllum spicatum																		0.1	
Potamogeton coloratus																			
Potamogeton perfoliatus																			2
Utricularlia vulgaris																			

Vegetation	spring	spring	spring	spring	spring	spring	empty	empty	empty	empty	empty	empty	empty	empty	empty
	12	12	12	8	6	12	2		3	4	9	9	11	15	
substrate				sandy mud				silt			mud	mud			peat
depth	3.6	2	2	3.4	1.4	0.7	7.5	2.9	5.8		5.8	7	5.7	5.7	0.8
cover								0	0	100			0	100	
Krustenstein															
Myriophyllum alterniflorum				1											
Chara annulata															
Chara aspera															
Littorella uniflora															
Chara desmacantha															
Chara tomentosa															
Chara polyacantha															
Chara rudis															
Chara contraria															
Chara globularis															
Chara denudata															
Elodea canadensis		1	2	1	1										
Potamogeton friesii															
Ophrydium versatile															
Cladophora				2											
Bryophytes				3											
Nitella flexilis															
Potamogeton nitens															
Phragmites australis					0.1										
Potamogeton praelongus			0.1												
Potamogeton pectinatus															
Chara hispida			3			5									
Numphar lutea			1		4										
Potamogeton lucens															
Potamogeton gramineus															
Schoenoplectrus lacustris			1												
Ranunculus ?															
Potamogeton natans		2			2										
Nymphaea alba					0.1										
Lemna trisulca	3	3													
Myriophyllum spicatum															
Potamogeton coloratus															
Potamogeton perfoliatus															
Utricularlia vulgaris															