BASELINE WATER QUALITY INVESTIGATIONS ON LOUGH CARRA, WESTERN IRELAND, WITH REFERENCE TO WATER CHEMISTRY, PHYTOPLANKTON AND AQUATIC PLANTS

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ABSTRACT

Lough Carra is a shallow limestone lake in County Mayo in the west of Ireland. It is situated in the Corrib catchment. The lake has been managed as a brown trout fishery since the 1950s, initially by the Inland Fisheries Trust and more recently by the Western Regional Fisheries Board. The results from a number of studies carried out by the Inland Fisheries Trust and Fisheries Boards are presented, including the findings of a 1972 bathymetric survey; data from long-term monitoring of mid-lake samples for chlorophyll and nutrients, ongoing since 1975; a four-year study on phytoplankton composition and biomass (1983–6) and vegetation surveys carried out in 1975 and 1996, the latter as part of a study on littoral processes in the large western Irish lakes, funded by the Environmental Protection Agency. The findings show the lake to be a very shallow hard-water system with low levels of photoplankton primary production. Diatoms dominated the algal crop in the autumn–spring period with genera of green algae and dinoflagellates present in summer. The submerged vegetation was dominated by species of the genus *Chara*. Extensive reed-beds, dominated by *Phragmites australis* (Cav.) Trin. ex Steud. grew on sheltered and on east-facing shores.

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INTRODUCTION

Lough Carra is a brown trout fishery lake in County Mayo managed by the Western Regional Fisheries Board (WRFB). Fishery management work on the lake has been in progress since 1956. This programme of management involves controlling levels of fish species that predate or compete with brown trout and improving the spawning and nursery potential of the small tributary streams (O'Grady 1990). The lake and tributary streams are kept under surveillance by fishery staff for signs of nutrient enrichment. Investigations by the Inland Fisheries Trust (IFT) on Lough Carra included a detailed bathymetric survey in 1972, investigations on the lake's zooplankton (Fitzmaurice 1977), a survey of macrophyte distribution in 1975 and a detailed monthly study in 1975 that examined chlorophyll, water clarity, temperature–oxygen profiles, water chemistry and enumeration of phytoplankton crop from a deep open-water station (Champ 1977; J. Caffrey (unpublished data); W.S.T. Champ (unpublished data)). Since 1975, monthly water samples and water clarity data from this open-water station have been collected and analysed for chlorophyll, total and molybdate-reactive phosphorus and nitrite–nitrate in addition to alkalinity, conductivity, total hardness, colour and turbidity. The chlorophyll–nutrient relationships have been used in a recent comparative study of trophic status in Irish fishery lakes (Champ 1998). Subsamples of the monthly open-lake sample were examined between 1983 and 1986, inclusive, for phytoplankton speciation and enumeration.

The phytoplankton of the lake was previously described by Macan and Lund (1954) based on limited shoreline net-hauled samples from a single sampling date only. A more detailed study on water chemistry and plankton from open-lake stations was performed by Flanagan and Toner (1975). The lake's aquatic plants were described by Praeger (1906) and more recently in an unpublished report by the IFT in 1975 and by the Wildlife Service (Heuff 1984). In 1995 the Central Fisheries Board (CFB) was invited to participate in a study, partially funded by the Environmental Protection Agency (EPA), on littoral processes in the large western Irish lakes. The CFB brief involved repeating vegetation surveys on five lakes including Lough Carra.

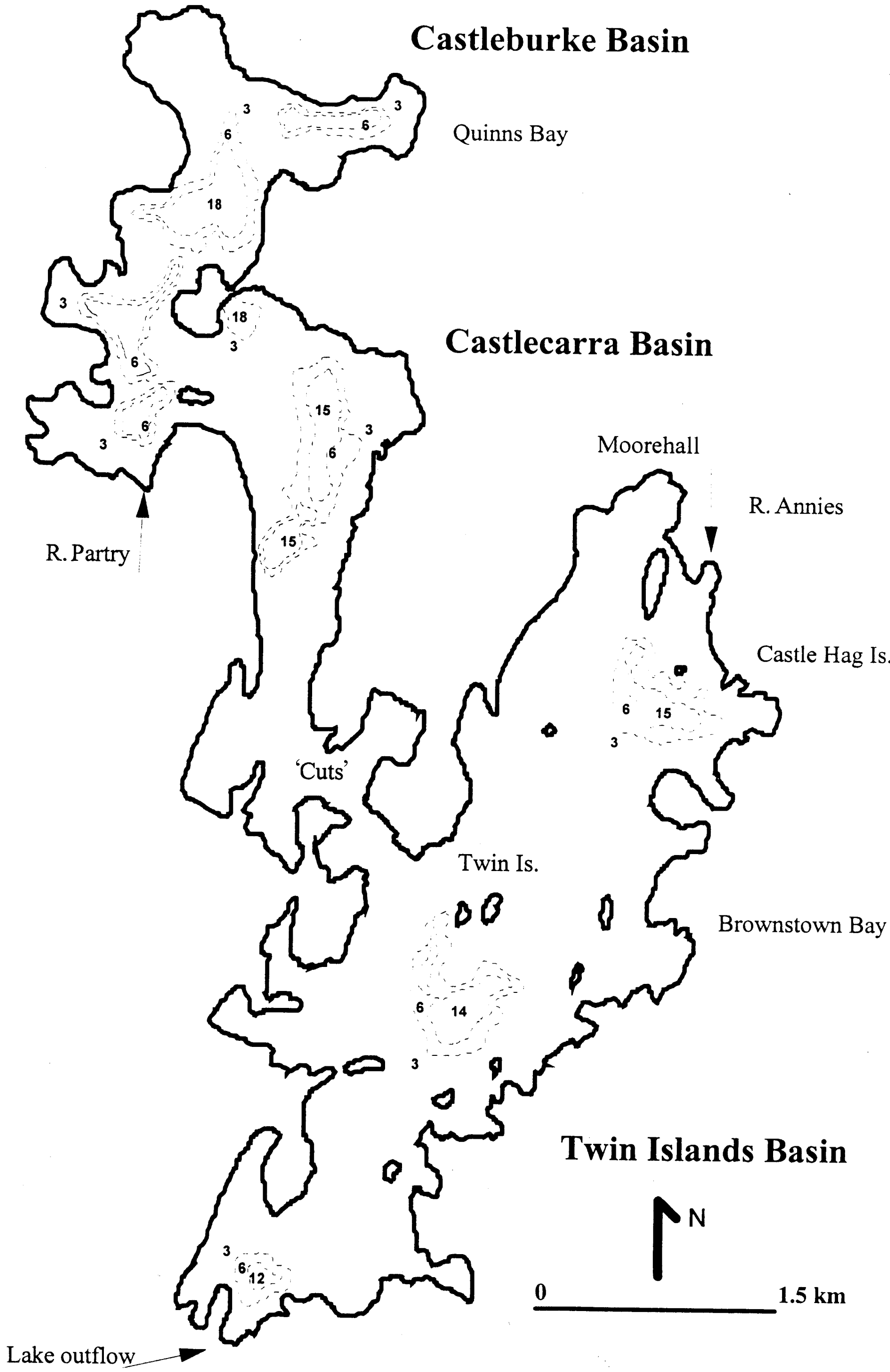

Fig. 1—Lough Carra bathymetric map (after IFT survey of 1972). Depth contours in metres.

This paper brings together recently compiled and previously unpublished archival material on Lough Carra and presents a broad picture, with a long time-base, of the water quality status of the lake in terms of water chemistry, phytoplankton and aquatic plants.

STUDY AREA

Lough Carra lies to the north-east of Lough Mask in the Corrib catchment. The lake shoreline is highly indented, enclosing three well-defined basins: Castleburke, Castlecarra and the Twin

Islands basin (Fig. 1). Both the lake and its small catchment area lie on carboniferous limestone. Soils in the catchment are an association of grey-brown podzolics (60%) with gleys (20%) and inter-drumlin peats (20%). These soils are of limestone glacial till origin (Gardiner and Radford 1980). Limited areas of blanket peat adjoin the lake at the north-east corner of the Twin Islands basin and to the south of the narrow 'Cuts' between the Twin Islands and Castlecarra basins. There are no major centres of population in the Lough Carra catchment. Land use consists primarily of grass production and sheep grazing. Data from the synoptic meteorological station at Claremorris, 15km due east across flat countryside, indicate an annual rainfall of 1113mm over the 30-year period 1951–80 (Rohan 1986). Wind records for this station indicate that approximately 60% of wind comes from westerly to southerly directions and that half of all such winds equal or exceed Beaufort force 4–5 (5.5–10.7m/s).

The bed levels of streams in the catchment were lowered as part of the Carra–Mask Arterial Drainage Scheme executed by the Office of Public Works (Drainage Division) during the period 1979–87. Investigations by the Wildlife Service indicated the importance of Lough Carra as a habitat for wildfowl and the rare vegetation types adjacent to the lakeshore (Lockhart 1982). This community included 19 of the 26 species of orchid recorded in Ireland. Following consultation between drainage and wildlife personnel it was agreed that the pre-drainage summer water surface level of Lough Carra would be retained as a minimum water surface level on completion of the drainage scheme (Howard 1980).

MATERIALS AND METHODS

ARCHIVAL MATERIAL

A detailed hydrographic survey of the lake was carried out by the IFT in 1972. This was used as the basis for determining the physical attributes of the lake basin (Table 1). The definitions of these attributes and the formulae for their computation followed Hutchinson (1957).

An unpublished vegetation survey, compiled in September 1975 by the late Mr N.J. Hackett of the IFT and taking the form of text and annotated six-inch Ordinance Survey maps, was available for comparison with the present findings.

ANALYSIS OF WATER SAMPLES

In the course of the 1996 vegetation survey, subsurface water samples of 2.5l were taken at ten locations within the areas examined. These samples and the mid-lake samples from the long-term monitoring programme were analysed for alkalinity (acid titration of sample for methyl-orange alkalinity), total hardness (compleximetric titration of sample with EDTA standard solution), conductivity (conductivity meter), colour (Nessleriser using Pt standards) and turbidity (Hach turbidimeter), and automated spectrophotometric analysis was carried out for nitrogen, phosphorus and silica species (Skalar Methods™, unpublished reference manual). In all cases analysis was performed on unfiltered water from the lake. Samples for total nitrogen and total phosphorus were subjected to acid digestion (digestion mixture of H_2SO_4 and K_2SO_4 added to the sample and heated to 360°C for two hours). The digested total phosphate material was analysed, as for molybdate-reactive phosphorus, by determination of a phosphomolybdic blue complex at 880nm. The digestion reduced total nitrogen to NH_4^+, which was measured at 660nm following complexation with salicylate anion. The autoanalyser reduced nitrate to nitrite, which was measured at 520nm after formation of a diazo complex. Silica was measured as a silicomolybdic blue complex at 810nm.

Determination of chlorophyll involved filtration of 600ml of the sample through glass-fibre filter paper followed by pigment extraction using hot methanol for three minutes (Youngman 1978). Absorbance was measured at 750nm and 665nm. Water clarity, as Secchi Disc transparency, was measured when sampling at open-lake stations.

PHYTOPLANKTON COLLECTION AND ENUMERATION

Water sampling took place by boat in the deep-water station south of Twin Islands, using the 6m tube composite sample method of Lund *et al.*

Table 1—Physical features of Lough Carra and its catchment

National Grid Reference	M 19 71
Altitude (m)	21.00
Lake catchment area (km^2)	104.00
Lake surface area (km^2)	14.38
Volume (m^3)	25.24×10^6
Shoreline length (km)	69.40
Shoreline development	5.16
Maximum length (km)	9.60
Maximum width (km)	2.50
Mean depth (m)	1.75
Maximum depth (recorded) (m)	18.00
Percentage of lake bed in depth zone:	
0–3m	86.80
3–6m	6.25
>6m	6.95

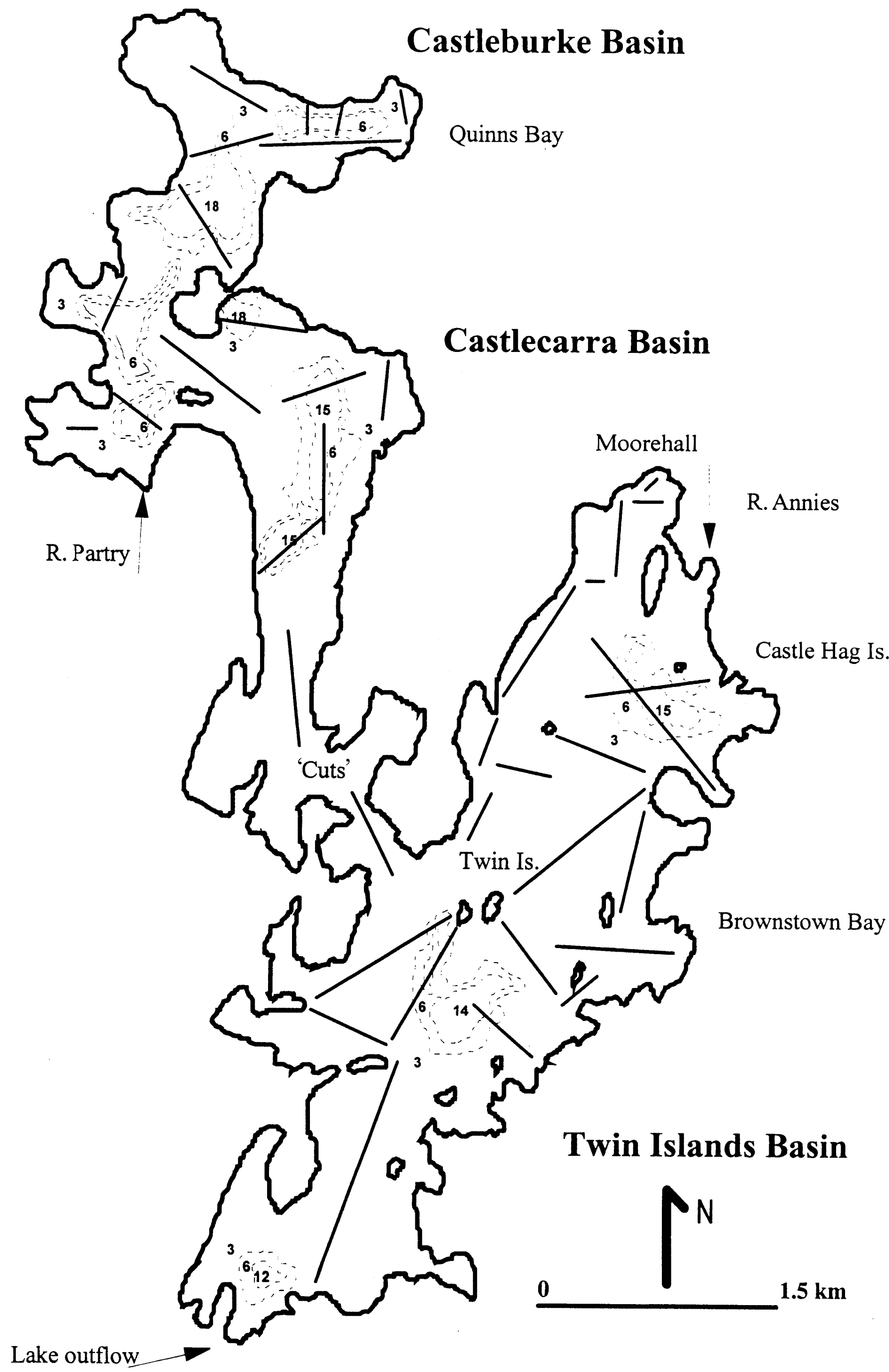

Fig. 2—Lough Carra, indicating the transects along which sampling of aquatic plants was carried out in 1996.

(1958) to collect a 2.5l sample. The sample bottle was covered in dark wrappings to reduce algal metabolism prior to water chemical analysis and phytoplankton enumeration.

Following sample agitation, a 10ml sub-sample was taken in a centrifuge tube. Eight to ten drops of Lugols Iodine were added and the mixture was allowed to stand overnight. Further concentration was achieved by centrifuging at high speed for five minutes. Removal of the upper 9ml of the solution further concentrated the algae into 1ml of liquid. The concentrated sample in each tube was agitated to redistribute the organisms evenly. A single drop was then placed on a clean microscope slide and covered with a 2.2×2.2cm coverslip before examination using a compound microscope. For counting purposes a modification of the Edmondson (1969) method was used, in which the complete field under the coverslip was examined for algae.

A graticule enabled the dimensions of cells, colonies and filaments to be measured for the purpose of calculating volumes. It was assumed that cells and colonies correspond roughly in form to geometrical figures or their derivatives, as proposed by Findenegg (1969). Where difficulty in measurement arose, such as obtaining valve and girdle view measurements of some diatoms, reference was made to the data of Willén (1976). Multiplication of cell numbers by average cell volume gave a biovolume per unit volume of water; this biovolume was converted to biomass by assuming unit cell density (Bostrom and Pettersson 1977). The nomenclature for phytoplankton followed that of Prescott (1971).

SAMPLING OF AQUATIC PLANTS

Samples were collected by boat, between 7 and 12 August 1996, using plant grapnels following the method of Krause and King (1994). Passes were made along specific transects, chosen to sample a wide range of locations and to include distribution related to shoreline orientation and lake bed topography, as indicated by the bathymetric study. A total of 38 transects was taken. These varied in length from short runs of approximately 100m to long cruises, such as that from the lake outflow to the Twin Islands (Fig. 2). In view of the shallowness of much of the lake and the clarity of the water, it was possible to assess the extent of cover visually over a wide area on both sides of the boat. In those areas with a littoral slope, transects were taken to the point of disappearance of plant cover. A graduated plumb-line was used to make depth soundings. All submerged, floating-leaved and emergent species encountered were noted. Most material was identified in the field. Difficult specimens were examined on-shore using a dissecting microscope. The nomenclature of Allen (1950) was adopted for charophytes, and that of Haslam *et al.* (1975), as modified by Preston and Croft (1997), was used for phanerogams.

RESULTS

PHYSICAL ATTRIBUTES

The hydrographic map (Fig. 1) compiled from the bathymetric survey indicated the extent of shallow water, with 87% of the lakebed lying between the 0m and 3m depth contours (Table 1). The maximum depth indicated was 18m, recorded in the Black Hole in Castlecarra and in some of the basin areas of Castleburke. Apart from the extensive shallow areas, the lake bed descended in several locations to form local basins or 'holes' (Fig. 1). Castleburke had the greatest extent of deep water, while the Twin Islands basin had the

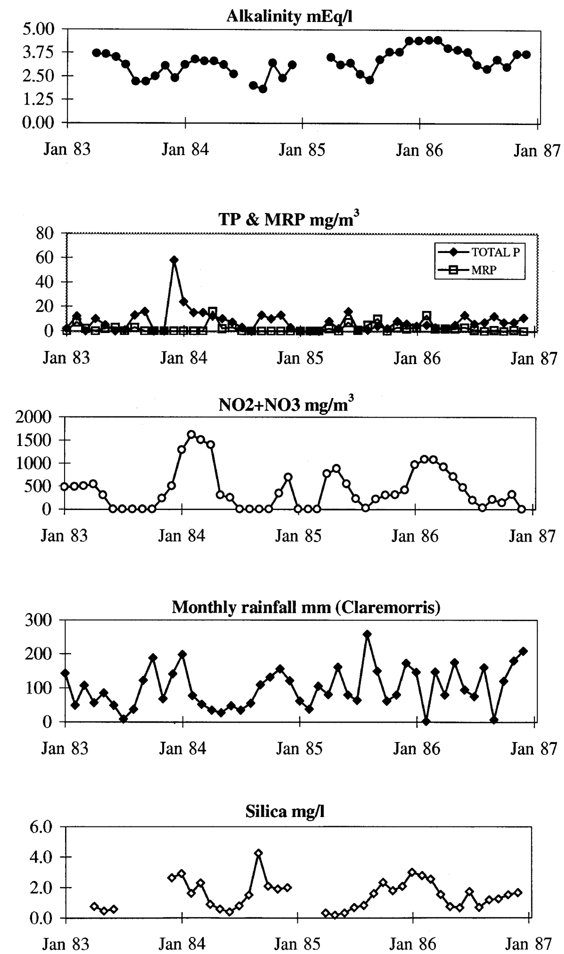

Fig. 3—Lough Carra (Twin Islands basin). Monthly values for selected nutrients from deep-water station and for rainfall, 1983–6.

greatest extent of shallows, i.e. between 0m and 3m.

The indented nature of the shoreline was indicated by the high values for shoreline length, 69.4km, and degree of shoreline development, 5.16. This latter figure is the ratio of measured shoreline length to the length of the circumference of a circle of area equal to that of the lake (Hutchinson 1957).

WATER CHEMISTRY

There was a cyclic pattern displayed by many of the water chemistry variables measured over the 1983–6 period (Fig. 3). Alkalinity showed seasonal maxima in the January–March period and minima in the July–August period. The silica record is rather fragmented over the four-year period. The 1983 data indicated low levels as early as April. This may be linked to the elevated levels of the diatom *Asterionella formosa* Hass., particularly in January. This species, as with all diatoms, requires silica for construction of its outer 'shell' or frustule.

The remaining data indicated rising levels in autumn, with winter peaks, and declining levels throughout spring into summer.

Nitrite–nitrate levels peaked in the January–April period and declined thereafter, with zero levels recorded in at least one summer month annually (Fig. 3). The nutrient level attained may be linked to rainfall events in the preceding months. The timing of rainfall in autumn in each of the three years 1983–5 preceded a rise in open-lake nitrate concentrations, and the highest nutrient levels were recorded following the rainfall events of greatest magnitude. There was exceptionally high rainfall in August 1985, a feature in many parts of the country, and nitrate levels began to rise from zero or trace levels in September, peaking in the period January–March 1986. Zero nitrate concentrations were recorded in September in 1983 and 1984, with low rainfall a feature of the preceding months in both years. Levels of total phosphorus (TP) rarely exceeded 20mg/m^3. Molybdate-reactive phosphorus (MRP) levels were low in all months. The low levels recorded for MRP and nitrate in summer months, frequently falling to trace or undetectable levels, may indicate that either or both were present at limiting levels.

Nine sub-surface water samples were collected at various points in the lake during the vegetation survey of 1996 (Table 2). These showed the lake to be an alkaline water body with high values of conductivity and total hardness. Values of colour and turbidity were low, indicative of a system with low inputs of humic material. The marked similarity between sites for the majority of variables measured is indicative of a well-mixed water body. Levels of nitrite–nitrate were higher in the Castleburke and Castlecarra basins than in the other open-water stations sampled. The sample from the mouth of the Annies River had substantially higher values of alkalinity, conductivity and hardness than those from open-lake stations. The River Partry sample was similar to the open-lake data.

PHYTOPLANKTON

Algal biomass was low on all occasions during the four-year sampling period, the maximum values never exceeding 1.5mg/l (Fig. 4). The peaks were due to diatoms in spring of 1983, 1984 and 1986, to dinoflagellates in summer 1985 and to combined dinoflagellates and blue-green algae in late summer 1986.

Diatoms were the principal contributors to the algal crop, in terms of percentage of total biomass (Fig. 4) and they were most prominent in the total crop in the autumn–winter–spring period, with low to zero presence in the summer months. *Asterionella formosa* Hass. was the most prominent

Table 2—Lough Carra: results of chemical analyses carried out on water samples from selected stations, August 1996.

Site	*Alkalinity (mEq/l)*	*Conductivity (uS/cm)*	*Total hardness (mg/l CaCO)$_3$*	*pH*	*Colour (Hazen units)*	*Turbidity (mg/l SiO_2)*	*Total phosphorus (mg/m^3 P)*	*Total nitrogen (mg/m^3 N)*	*Nitrite+nitrate (mg/m^3 N)*
Brownstown Bay	1.6	261	107	8.07	5	0.73	5	631	39
S. of Twin Islands	1.6	262	120	8.15	5	0.9	3	535	81
W. of Castle Hag	1.8	278	115	8.09	10	0.85	5	595	60
Outflow	1.4	245	102	8.24	10	0.7	4	609	6
Cuts W. of Twin Islands	1.55	245	101	8.16	15	1.25	7	608	69
Castlecarra basin	1.65	252	105	8.03	10	0.82	6	549	156
Castleburke basin	1.8	266	116	8.07	5	0.73	5	476	144
Mouth of Annies River	3.5	430	210	7.8	15	1.38	7	492	310
Mouth of Partry River	1.85	262	120	8	5	0.86	5	548	130

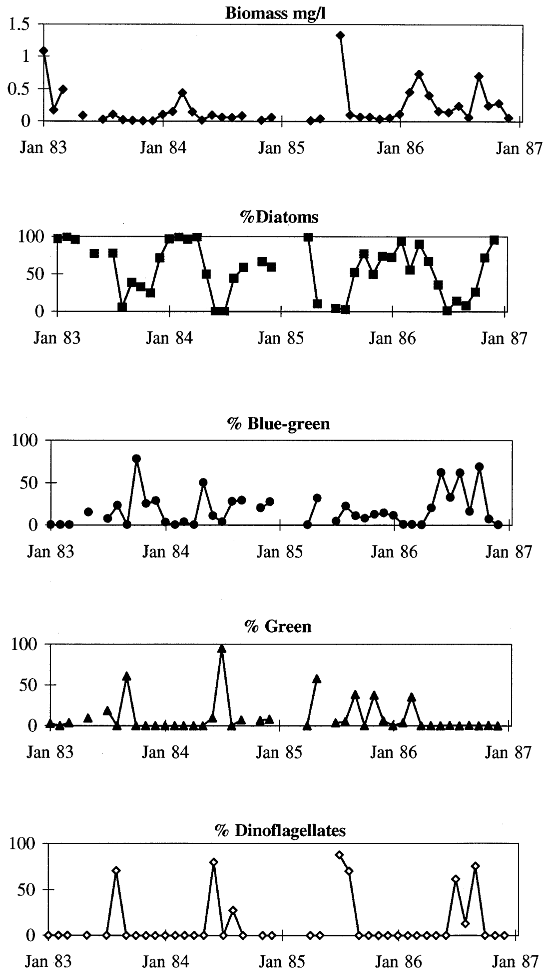

Fig. 4—Phytoplankton biomass (mg/l) and percentage composition in Lough Carra Twin Islands basin, 1983–6.

member of this group. Other diatoms present were centric forms (30µm diam) and species of *Synedra*, the small *S. actinastroides* type and a larger form of 200µm in length. The most common blue-green algae were *Anabaena flos-aquae* (Lyngb.) De Brebisson, present as occasional short segments with the characteristic chain-like form, and species of *Chroococcus*. The green algae were represented most commonly by small forms of the genera *Scenedesmus* and *Quadrigula*. Dinoflagellates were recorded in the summer months only. In addition to *Peridinium* sp., both *Ceratium hirundinella* O.F.M. and *C. cornutum* (Ehrenb.) Claparede & Lachmann were noted. During the four-year study the largest biomass peak was due to a crop of *C. cornutum* in July 1985.

AQUATIC PLANTS

The aquatic plants recorded in the 1996 survey are listed in Table 3 along with a summary of the depth range and maximum depth of colonisation for each species. Three assemblages (the term used by Krause and King 1994) of aquatic plants were identified in Lough Carra:

(i) an emergent flora dominated by *Phragmites australis* (Cav.) Trin. ex Steud.;
(ii) a shallow-water flora (0–2m) dominated by three species of *Chara*;
(iii) a more extensive and more species-rich flora colonising littoral slope areas (3–7m).

Emergent flora

This assemblage was dominated by *Phragmites australis*, which formed numerous extensive monospecific stands of cover each several hectares in extent (Fig. 5). These stands were most developed along east-facing shores. They developed along a shoreline but frequently extended out into open water for distances in excess of 100m and to

Table 3—Depth of colonisation of aquatic plants in Lough Carra, August 1996. Extreme values in parentheses.

	Depth (m)
Emergent flora	
Phragmites australis (Cav.) Trin. ex Steud.	0–1
Schoenoplectus lacustris (L.) Palla	0–1
Littorella uniflora (L.) Aschers	0
Shallow-water flora	
Chara aspera Deth. ex. Willd.	1
C. desmacantha J.Gr.&B.W.	1.5–3.5
C. tomentosa L.	1.75–2
Potamogeton filiformis Pers.	0.75–2
P. gramineus L.	(1) 2–4.5
Utricularia sp.	2
Littoral slope flora	
C. hispida L.	2–3.5 (6)
C. rudis (A.Br.) Leonh.	3–3.5 (6)
C. contraria A.Br. ex Kutz.	2–6
C. denudata A.Br.	4–7
C. delicatula C.A.Ag.	(1) 2–7
Elodea canadensis Michx.	3.5 (6)
P. perfoliatus L.	3.5 (6)
P. lucens L.	3.5–4
Myriophyllum verticillatum L.	3.5–5 (6)
Schoenoplectus lacustris (L.) Palla (submerged form)	2–3.5
Nuphar lutea (L.) Sm.	2–3.5
Other species	
Nymphaea alba L.	2
Menyanthes trifoliata L.	2

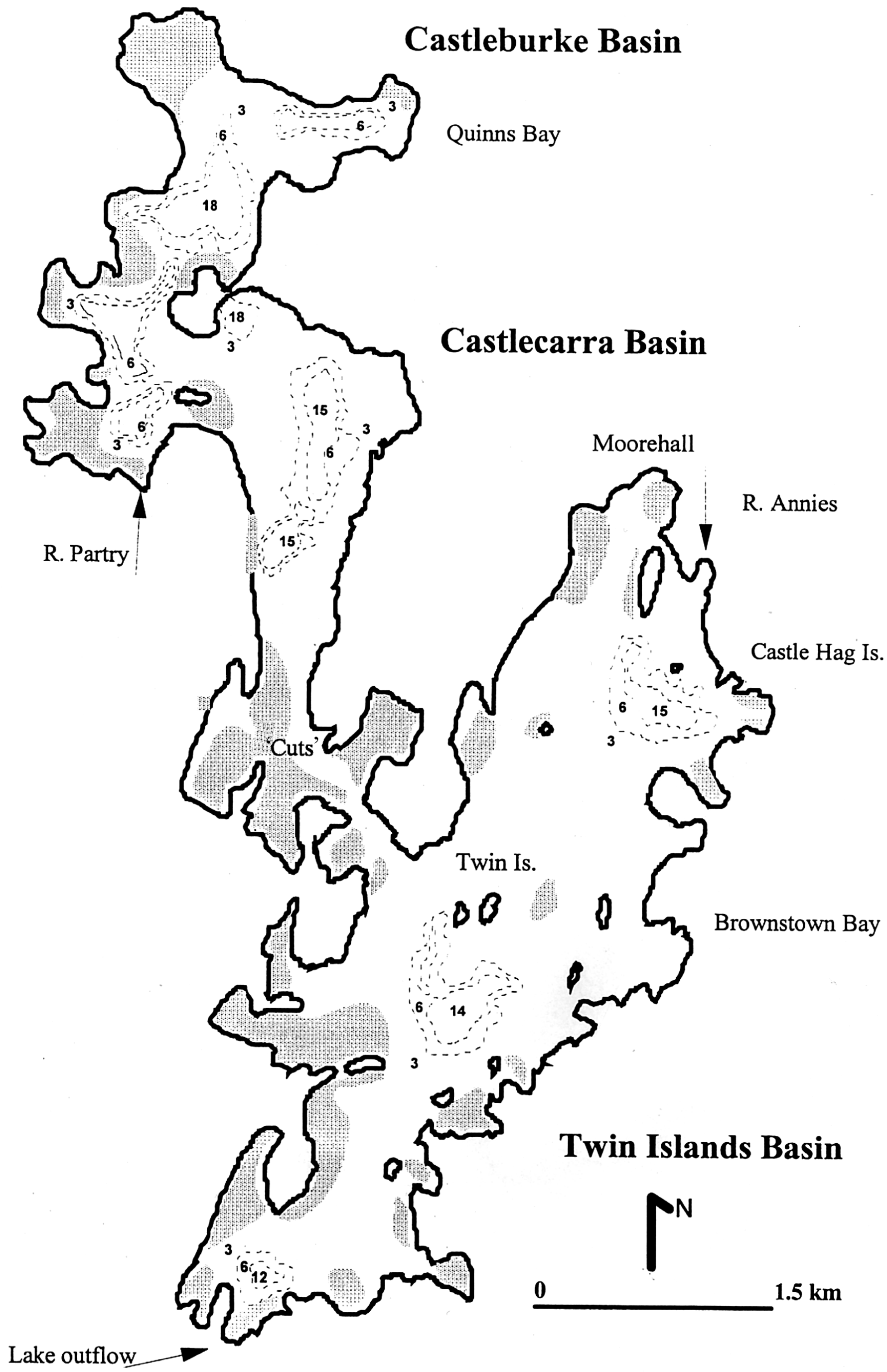

Fig. 5—Distribution of *Phragmites australis* beds (shaded areas) in Lough Carra, based on IFT survey of 1975 and vegetation survey of 1996.

a depth of 1m. In some areas, such as the north-west corner of Castleburke, the 'Cuts' and at Moorehall in the Twin Islands basin, the degree of development encroached considerably on the open-water area. In addition to *Phragmites*, *Schoenoplectus lacustris* (L.) Palla was recorded in its emergent form at a number of locations and *Littorella uniflora* (L.) Aschers was found at one location at the western shoreline of the Twin Islands basin.

Shallow-water flora

This flora had a patchy distribution at the majority of sites examined (see Fig. 2) in the large expanses of shallow water (<2m depth) in all

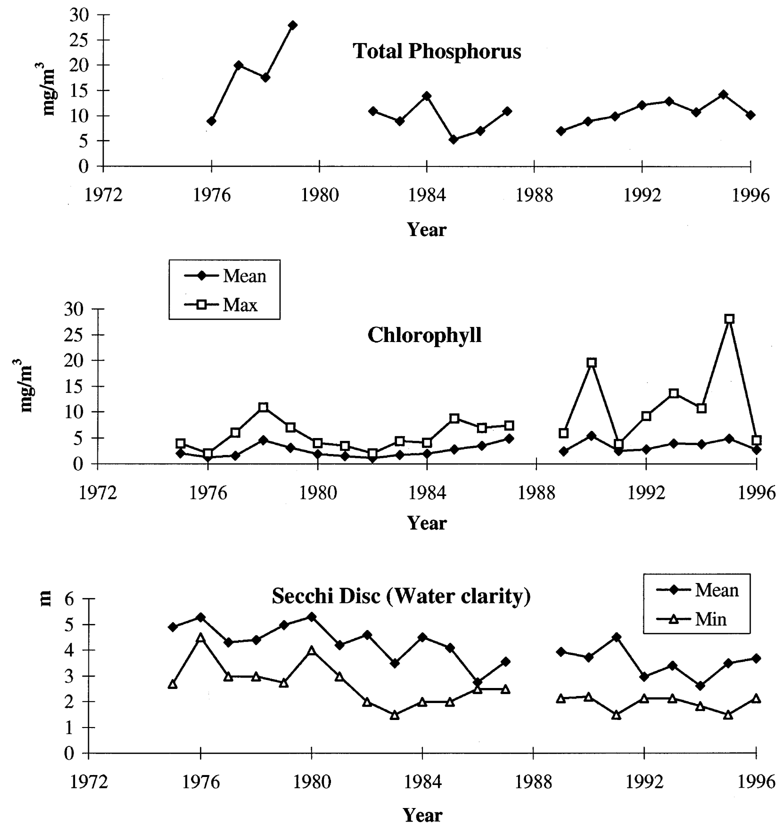

Fig. 6—Annual average data for Lough Carra (Twin Islands basin) for total phosphorus, chlorophyll and Secchi disc (after Champ 1998 and unpublished data) and OECD boundary criteria (OECD 1982).

three basins of the lake. Large portions of these shallow areas were devoid of any plant cover and the bare marl bed was clearly visible by boat. The flora was best exemplified in the Twin Islands basin. The shallow-water flora was dominated by three species of *Chara*. A further two species of *Chara* occurred in both shallow- and deep-water sites. *Chara aspera* Deth ex Wild. and *C. desmacantha* (H. & J. Gr.) J. Gr. & Bull.-Webst. were found predominantly at depths of 1.5–2m in mixed stands. *C. tomentosa* L. was also found in this depth range, but was only recorded in the Twin Islands basin. These 'shallow-water' *Chara* species formed small mixed stands of up to 0.5ha in a number of places in the Twin Islands basin. The closely related robust species *C. hispida* L. and *C. rudis* (A. Br.) Leonh. were found in slightly deeper water (2–3.5m). The most extensive areas of *Chara* cover lay in the southern portion of this basin, where large stands of *C. hispida* alternated with *C. desmacantha*, creating plant cover over several hectares in extent. *Potamogeton filiformis* Pers. and *P. gramineus* L. were generally recorded in shallow-water locations mixed with stands of charophyte species. *Potamogeton filiformis* was also found locally in the Twin Islands basin in small isolated stands in depths of less than 1m. *Utricularia* sp. was taken in a number of hauls in uniformly shallow areas, as well as on the upper portions of littoral slopes, and was generally associated with *Chara desmacantha*.

Flora of littoral slopes

This flora was recorded in those areas where littoral slopes descended from the shoreline and in those depressions or 'holes' of limited area in open water that are a feature of all three basins in Lough Carra. Macrophyte colonisation occurred down the littoral slope to a depth of 7m (Table 3). Repeated hauls in depths of 9–10m failed to yield plant material. The flora contained five species of *Chara* (Table 3), which were distributed broadly in relation to depth, and which frequently grew in mixed stands with phanerogams, principally *Elodea canadensis* Michx., *Myriophyllum* cf. *verticillatum* and broad-leaved species of *Potamogeton*. *Chara contraria* A. Br. ex Kutz and *C. delicatula* C.A. Ag. sensu Groves & Bull.-Webst. non Desv. colonised a range of depths from 2m to 7m while *C. denudata* A. Br., a form with reduced external features and closely associated with *C. contraria*, was found at the deeper end of this depth spectrum. Extensive charophyte cover occurred in the southern portion of the Castlecarra basin, where a continuous meadow of *C. delicatula* was recorded in 5m depth.

A unique feature of the flora in the Twin Islands basin was the presence, primarily in the submerged form, of both *Nuphar lutea* L. and *Schoenoplectus lacustris* (L.) Palla on the upper contours in several 'hole' areas growing in 2–3.5m depth in open-water locations of the lake.

Substantial discrete beds of submerged phanerogams were not commonly recorded due to the virtually ubiquitous presence of charophytes in all plant stands. One exception was the large stand

Table 4—Fixed state classification for trophic state conditions (after OECD 1982).

Category	*[T.P.] mean (mg/m^3)*	*[Chl] mean (mg/m^3)*	*[Chl] Max. (mg/m^3)*	*S.D. mean (m)*	*S.D. min. (m)*
Oligotrophic	<10.0	<2.5	<8.0	>6.0	>3.0
Mesotrophic	10–35	2.5–8	8–25	6–3	3–1.5
Eutrophic	35–100	8–25	25–75	3–1.5	1.5–0.7

of *Potamogeton lucens* in 3.5–4m at the Black Hole in Castlecarra.

An isolated area of *P. australis* to the west of the Partry stream inflow contained two pool areas of 6m depth. The innermost had a marginal flora of *P. australis*, *Carex* spp. and *Juncus* sp., an understorey of *Menyanthes trifoliata* L. *Nymphaea alba* L. formed a floating-leaved fringe with an understorey of *Chara desmacantha*, and *Chara delicatula* colonised the open water along with isolated *Potamogeton lucens*.

TROPHIC STATUS

The fixed-boundary criteria for trophic state classification of the OECD (1982) include annual mean values of TP, chlorophyll and Secchi Disc as well as annual maximum chlorophyll and annual minimum Secchi Disc (Table 4). Data from the Twin Islands station in Lough Carra indicated that the lake lay within the mesotrophic category for the variables measured (Fig. 6), with annual mean chlorophyll levels less than 5mg/m^3 for the 21-year period 1975–96.

Chlorophyll values below 2.5mg/m^3 lie within the oligotrophic range. The levels of chlorophyll measured, placed in the OECD context, indicated a low level of phytoplankton primary production in the lake over the period 1975–96. Mean water clarity, as Secchi Disc transparency, lay within the mesotrophic range for 18 of the 21 years. The mean value fluctuated widely from year to year but did appear to indicate an underlying trend of decreasing water clarity. Little emphasis can be placed on TP data for the period 1976–9, as the dataset in each year was small and the methodology used differed from that used in the 1982–96 period.

DISCUSSION

The annual sequence of changes in the phytoplankton composition, with diatom dominance in the autumn–winter–spring period, greater representation of green and blue-green algae in summer, and the seasonal appearance of the genus *Ceratium* in late summer, are characteristic of lakes in the temperate zone (Reynolds 1982). In 1974, diatoms dominated in February in Lough Carra, represented primarily by *Asterionella* with lesser amounts of *Tabellaria* and *Synedra*, while in July the blue-green *Anabaena* was the dominant form, with *Ceratium* and *Pediastrum* also noted (Flanagan and Toner 1975). Reporting on the phytoplankton of net-hauled shore samples from 33 Irish lakes, sampled during July–August 1951, Macan and Lund (1954) considered Lough Carra to be 'relatively poor in species and numbers'. They recorded a total of eight species, two blue-green algae, one diatom, one desmid and four 'flagellates' (including Chloro-, Chryso- and Dinophyceae). Those algae identified as the more important from the Lough Carra sample were *Gomphosphaeria aponina*, *Staurastrum dejectum* and *Ceratium hirundinella*. Heuff (1984) examined phytoplankton material from Lough Carra in the course of her vegetation study. The algal sample was taken in August 1977, and ten principal taxa were recorded. The sample was dominated by Pyrrophyta, while 'common' forms included *Ceratium hirundinella*, *Chroococcus* and *Coelosphaerium*. Mooney (1989) showed a seasonal pattern in adjacent Lough Corrib similar to that observed in Lough Carra in the period 1983–6. The spring crop in Lough Corrib peaked in April, dominated by diatoms including *Asterionella formosa*. These were replaced by colonial blue-green forms in summer, with the blue-green *Oscillatoria* and the filamentous green form *Mougeotia* forming autumn peaks (Mooney 1989).

There is some disparity in the literature with regard to the ecological tolerances of *Ceratium cornutum*. Hutchinson (1967) reported it as being eurytopic, and West and Fritsch (1927) found it to be widely distributed in the plankton of British lakes. Bourelly (1970) described it as being abundant in acid waters, whereas Morling (1979), during a ten-year study of acidified lakes in western Sweden, recorded *Ceratium carolinianum* in all of the waters examined but found *C. cornutum* in only one of them. Prescott (1971) referred to *C. cornutum* as being rare in the plankton of soft-water lakes. This latter observation is rather ambiguous but is taken here to mean that the species is present in small numbers and only in soft water. The limited record of this species in Ireland indicates a distribution in soft-water lakes, in some cases with an associated high humic content, on the hard rock strata of the west coast (Pearsall and Lind 1942; Round and Brook 1959; Heuff 1984; Bowman 1991; J. Bowman, pers. comm.). It has not been recorded in lakes examined in Northern Ireland (C. Gibson, pers. comm.). The occurrence of *C. cornutum* in Lough Carra may be seen as an 'outlier' in the context of its known Irish distribution, although the finding would conform to its 'eurytopic' status as reported by Hutchinson (1967). There is obviously considerable scope for further investigation of the distribution of this species in Irish lakes.

A recent review of studies on Irish macrophytes (King and Caffrey 1998) indicated the predominance of two main lake types in terms of vegetation. In the larger lakes examined in the Republic of Ireland, soft-water systems were dominated by isoetid forms and hard-water systems by charophytes. These two types broadly conform to the '*Lobelia*' lakes and '*Chara*' lakes, respectively, referred to by Forsberg (1965). The present study places Lough Carra in the category of the '*Chara*' lakes, based on its water chemistry and aquatic flora. Many of Ireland's large limestone brown trout fishery lakes are of this lake type (Champ 1998; McGarrigle and Champ 1999). This lake type is susceptible to eutrophication and consequent decline in the dominant charophyte flora —a phenomenon recorded both in Ireland (John *et al.* 1982; Champ 1993, 1998) and in Europe (Lachavanne 1977; Best *et al.* 1984; Blindow 1992a). The unique nature of these calcareous waterbodies, with the fish communities and aquatic plants that they harbour, has been recognised at a political level by being listed in Annex 1 of the European Union's 'Habitats Directive' (CEC 92/43/EEC). This annex lists those habitat types within member states 'whose conservation requires the designation of special areas of conservation' (CEC 92/43/EEC). The finding of *Chara tomentosa* (confirmed by Werner Krause, pers. comm.) and *C. denudata* is of particular significance in this regard. Both are Red Data Book species within Britain and Ireland, which are considered to be rare in Ireland and unrecorded in Britain (Stewart and Church 1992). Both represent new records for this lake and this vice county (East Mayo vc H 26). *Chara tomentosa* was long considered to have a distribution limited to lakes in the Shannon catchment (Groves and Bullock-Webster 1924), but has recently been reported from locations in east Clare and south Galway (Stewart and Church 1992). Its habit in Lough Carra, growing in shallow water in mixed stands, principally with *C. desmacantha*, is similar to that observed for this species in Lough Ennell in the Irish midlands (John *et al.* 1982; King 1988). It has been reported from similar shallow-water locations in Sweden (Lundegardh-Ericson 1972; Blindow 1992b), although Stewart and Church (1992) comment that 'it usually grows in depths of up to 8 metres'. *Chara denudata* has been recorded from four of the major limestone brown trout fishery lakes in the Irish midlands (John *et al.* 1982) and, more recently, from Lough Corrib (Krause and King 1994). It is possible that it is under-recorded in Ireland, its known distribution being related to the extent to which it has been sought after rather than to any biological preferences. Its habit of growing in deeper water in the outer zones of depth colonisation renders it unlikely to be collected by shoreline sampling.

The *Chara* species recorded, and the depth zonation patterns observed, are similar to those reported for the neighbouring Lough Corrib (Krause and King 1994) and for other Irish lakes with a large component of limestone geology in their catchments (John *et al.* 1982; King 1988). The localised development of *Chara* cover in the 0–2.5m depth range, with very extensive areas devoid of cover, may be due to the impact of wave action in both uprooting young plants and re-suspending the fine marl sediment, which may then deposit on and smother young *Chara* plants. The wide range of water clarity values (measured as Secchi Disc transparency) recorded in the 1975–96 period (Champ 1998; T. Champ, unpublished data) in this lake with low colour values is considered to reflect the degree of disturbance and re-suspension of the fine marl sediment. A similar paucity of macrophyte growth in shallow littoral areas of less than 2m depth has been reported for other alkaline waters (Rich *et al.* 1971; Spence *et al.* 1984). Washout of the *Chara* meadows has been reported in the shallow littoral slopes of the highly alkaline Lough Ennel in the Irish midlands (Hodnett and King 1988). In contrast, extensive meadows of *Chara* vegetation have developed in 3m depth in Lough Sheelin (Champ 1993) and in the lower basin of Lough Corrib (King and Champ 1997). In Lough Carra the more continuous cover of *Chara* species at greater depth and the extensive meadow areas, such as that of *C. delicatula* in the southern end of Castlecarra, conform to a pattern characteristic of lacustrine Charophyta both in Ireland (John *et al.* 1982; Krause and King 1994), Scotland (Spence *et al.* 1984), the USA (Stross 1979) and New Zealand (Howard-Williams *et al.* 1986).

The overall findings of the Lough Carra vegetation survey reported here concur with those compiled in 1975 by the IFT in terms of species composition and depths of colonisation. That survey identified large expanses of lakebed in the 0–2.5m depth range as being devoid of vegetation. It did not identify individual *Chara* species, but discriminated between 'heavy/coarse' *Chara* (possibly conforming to *C. hispida* type) and 'fine' *Chara* (possibly conforming to *C. contraria/delicatula/denudata* type). It recorded *Chara* to depths of 24ft (7.3m), much as in the current study. Colonisation of the shoulders of deeper holes was a significant feature of the 1975 survey, with submerged *Schoenoplectus* present in some of the same locations as in 1996 and *Utricularia* recorded in many locations. Heuff (1984) examined selected relevés (5 × 5m) using SCUBA, confirming the dominance of *C. desmacantha* in more shallow water (2.75m) and of finer forms (*C. contraria* in that case) in deeper water (5m). That study also noted the absence of cover over a wide expanse in shallow areas (<2m) and confirmed the absence of *Chara* below 7m depth, where 'bright green algal mats grew on the marly bed'. The blue-green alga *Phormidium* was identified as a major constituent of these mats. Such algal material may not have been amenable to collection using the method employed in the 1996 survey. The findings of these three surveys differ from those of Praeger (1906), who spent three days on the lake sampling by boat. He considered that the lime deposition, most prevalent in the Twin Islands basin, had a deleterious effect on macrophyte growth and recorded only *Chara* and *P. perfoliatus*, both scant and in poor condition, in this basin. The lime deposits were not as pronounced in the other basins where he noted expanses of pale green and of dark green, as noted by the present authors in all basins of the lake. Praeger (1906) recorded the dark areas as representing large beds of *Chara hispida* with some *C. aculeolata* and *P. perfoliatus*. Given Praeger's familiarity with aquatic plants and his use of a boat and dredge for sampling, it is surprising that the variety of species and extent of cover reported by him was so limited when compared to the present study. These differences may point to some factor or factors that have had an impact on the lake in the intervening period, facilitating the development of a more diverse flora that has been colonising larger areas of the lake.

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