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A COMPARATIVE LIMNOLOGICAL SURVEY OF RATHLIN ISLAND, CO. ANTRIM, WITH PARTICULAR REFERENCE TO DIATOMS

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(Communicated by A. Macfadyen, M.R.I.A.)

[Received 21 August 1981. Read 1 March 1982. Published 30 June 1982.]

ABSTRACT

A number of freshwater sites on Rathlin Island, Co. Antrim, were visited in 1978 and 1979 and investigated for water chemistry, macroinvertebrates and algæ. Lough sites were found to be alkaline and had high water-conductivity values. Pool sites were acidic and had relatively lower water-conductivity values. The cation water chemistry of all the sites is shown to be strongly influenced by sea spray. Algæ at the sites indicated that the loughs were eutrophic and the pool sites oligotrophic. The influence of varying water quality on the distribution of macroinvertebrates and algæ, particularly diatoms, is discussed.

Introduction

Since the turn of the century there has been a number of biological surveys of freshwaters in the north of Ireland. Particular attention has been focused upon phytoplankton, possibly because of the ease of sampling and because of the wide range of species occurring in the region with its abundance of loughs and pools of varying water quality.

The first significant study of phytoplankton in the region was undertaken by West and West (1902, 1906) and centred upon Lough Neagh. This work was followed up by that of Dakin and Latarche (1913). Pearsall and Lind (1942) investigated the distribution of phytoplankton in twenty-six loughs in the north-west of Ireland and demonstrated large differences between the algal communities of acid peaty and calcareous waters. More recently, the water chemistry and phytoplankton succession in Lough Neagh (Gibson *et al.* 1971) and Lough Erne (Gibson *et al.* 1980) have been

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monitored as part of a study of cultural enrichment. Diatoms have been investigated by Round (1959) in the west and north of Ireland, and Foged (1977) has constructed species lists of diatoms for sites all over Ireland.

The aquatic macroinvertebrates and zooplankton in freshwaters in the north of Ireland have received less attention than the phytoplankton. Accounts of these groups are given by Macan and Lund (1954), Strange and Glass (1979), Taylor (1979) and others.

Water chemistry has a fundamental effect on the abundance and distribution of freshwater organisms. Gorham (1957) has shown that salt spray is a major influence on the ionic composition of coastal loughs in the west of Ireland. The present paper focuses attention on the influence of an extreme maritime climate on the distribution of freshwater organisms, particularly diatoms. Rathlin Island is an admirably suitable site for such an investigation, being situated in an exposed position about 5km north of the Antrim coast and possessing numerous loughs and pools. This paper describes the basic water chemistry, aquatic invertebrates and algæ at various sites on the island. Additionally, the bathymetry of the three largest loughs is described for the first time.

Previous biological surveys carried out on Rathlin include those of the Coleoptera (Hardy 1897), the Mollusca (Chaster 1897) and the flora (Praeger 1934).

Site descriptions

A general description of Rathlin Island

Rathlin is an L-shaped island situated 6·5km north of Ballycastle, Co. Antrim, and 21km east of Kintyre, Scotland. This strategic position, between Ireland and Scotland, has contributed towards a turbulent social history (Clark 1971). In recent times the population of Rathlin reached a peak of 1148 in 1813, declining to about 100 in the early 1970s (Brett 1974).

Geologically Rathlin is composed of Tertiary basalt overlying Cretaceous limestone. The latter only out-crops in Church Bay and in cliff sections. Glacial till is very local, being recorded only from the western tip of the island and on the beach at Church Bay. Typically the soils have formed *in situ* by weathering of the underlying basalt; they are generally thin and well drained. On lower ground in the central and southern parts of the island the vegetation is mainly improved pasture used for beef production. Elsewhere the vegetation is rough grassland with heathland in rocky places. There is a small conifer plantation on the island but otherwise there are few trees.

Small depressions, some filled with water, are dotted all over the island. These were probably scooped out by the passage of ice in glacial times. Examination of the Ordnance Survey map (1935, scale 1: 10560) reveals over 155 sites marked as loughs or pools. However, following recent visits to Rathlin (1978-80) most of the smaller sites were found to be marshy, *Sphagnum*-filled depressions. Even two of the larger loughs, Kinkeel and Craigmacagan, are now almost entirely covered with emergent macrophytic vegetation. Many of the loughs and pools on Rathlin are, therefore, in a state of senescence.

The climate of Rathlin is oceanic and cool, the daily mean temperature being 8·2°C (1961-78), and annual rainfall is 1280mm (1941-71) (Lenehan 1980). During the

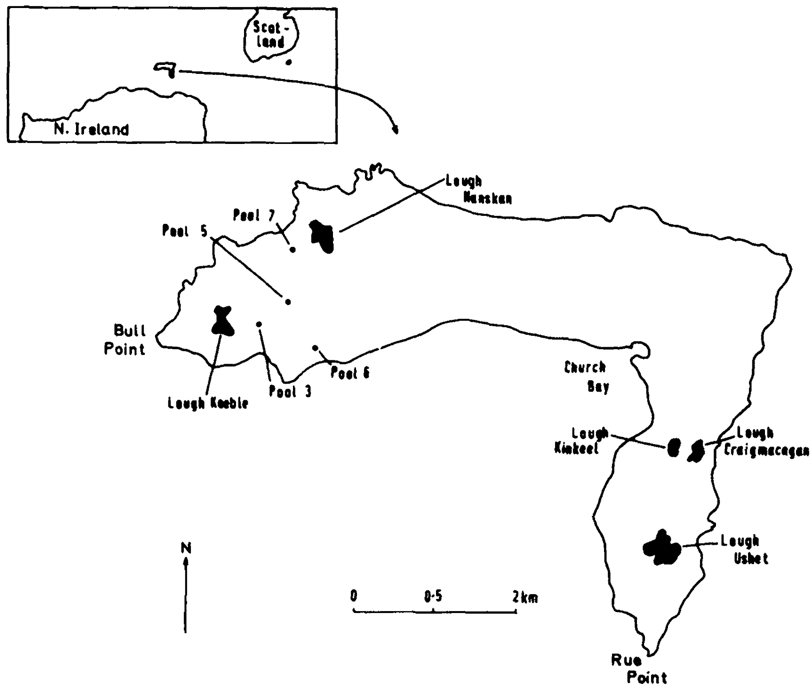

FIG. 1—Sketch of Rathlin Island showing its geographical location and distribution of sample sites.

frequent westerly storms which sweep in off the Atlantic the whole island can become covered with a fine salt spray.

Description of sample sites

Sites representative of the range of freshwater habitats on Rathlin were chosen for sampling. The distribution of the loughs and pools sampled on the island is shown in Fig. 1. Some physical characteristics of each sample site are given in Table 1 and Fig. 2.

Lough Keeble is probably the least sheltered of the lough sites; it is also the shallowest. Its water is noticeably brown and turbid (Secchi-disc depth *c.* 0·5m), doubtless caused by frequent wind-induced resuspension of bottom sediment. The sediment in Lough Keeble is a fine brown detritus mud composed largely of macrophyte remains. A palynological study of sediment cores from Keeble carried out by Lenehan (1980) suggests that the lough is artificial and was probably formed during the nineteenth century by the cutting of fen peat. Indeed, a map of Rathlin produced by Marshall (1836) makes no reference to Lough Keeble although the other major loughs are shown.

Loughs Nanskan and Ushet are probably a little more sheltered than Lough Keeble, higher ground immediately to the west of these two sites affording some wind protection. Also, the open water in Loughs Nanskan and Ushet is considerably clearer than in Keeble, Secchi-disc depth being about 2m at both sites. The profundal

TABLE 1—Some physical characteristics of each sample site on Rathlin Island

		Altitude (*m*)	*Length in longest axis* (*m*)	*Approximate area* (*ha*)	*Maximum depth* (*m*)
Loughs:	Keeble	85	410	3·8	1·8
	Nanskan	100	430	4·9	13·5
	Ushet	35	550	12·0	7·0
Pools:	3	90	28	0·07	0·28
	5	110	20	0·03	0·25
	6	60	150	0·60	—
	7	125	22	0·03	0·20

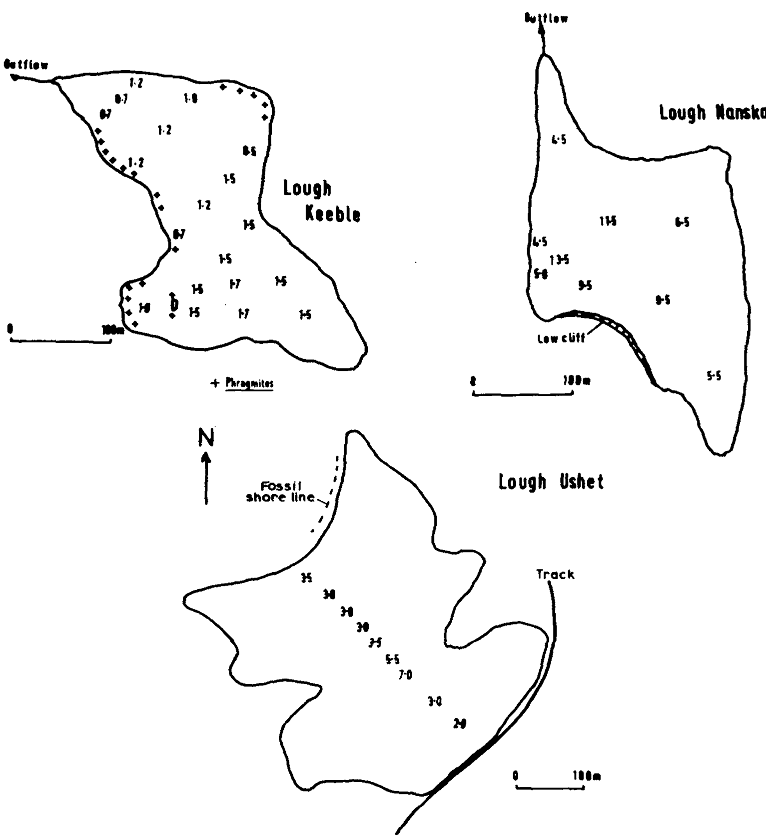

FIG. 2—Outline and bathymetry of Lough Keeble, Lough Nanskan and Lough Ushet (depths in metres).

sediments in these two loughs are black and considerably more minerogenic than that in Lough Keeble. Lough Nanskan (formerly known as Lough Cleggan) is the deepest lough on the island (13·5m) and supports a good population of brown trout. Lough Ushet (formerly known as Lough Roonivoolin) is the largest lough on Rathlin and is unusual in possessing a fossil shore-line (Fig. 2) suggesting that it was about 1m deeper some time in the past.

Except for a few patches of *Potamogeton* and *Carex* the rocky shores of both Nanskan and Ushet are devoid of emergent macrophytic vegetation. This is in marked contrast to the situation at Lough Keeble where soft littoral sediments have been extensively colonized by *Phragmites* (Fig. 2); *Menyanthes trifoliata* is common around the reed beds.

With the exception of Pool 6 all the pool sites are less than 30m in diameter and 30cm in depth. Maximum water depth in Pool 6 was not determined, as access to the central region was prevented by dense *Phragmites* cover. In addition to the *Phragmites*, *Hippuris vulgaris* and *Lemna* were common in this pool and, where macrophytes were absent, the sediment was covered with macro-algæ. Sediment in Pool 6 is black and organic and it liberated considerable quantities of gas during sampling. Pool 6 is regularly used by cattle and domestic ducks. Pools 3 and 7 were partically overgrown with emergent macrophytic vegetation consisting principally of *Carex rostrata*, *Eleocharis acicularis*, *Hydrocotyle vulgaris* and *Potamogeton*. The bottom sediments in these two pools are very organic and black being composed largely of macrophyte roots and remains; *Sphagnum* covered much of the sediment in Pool 3. Except for a small stand of *Potamogeton* in the centre, Pool 5 was devoid of macrophytic vegetation. The floor of this pool is composed of hard-packed reddish clay.

Field sampling methods

In May 1978 a preliminary visit was made to Rathlin and a basic bathymetric survey of the three major loughs, Keeble, Nanskan and Ushet, was carried out. Soundings were made from an inflatable dinghy which was transported from site to site by tractor. Samples of surface sediment were collected from the deepest point in each lough using an Ekman grab. Periphytic algæ were collected from submerged stones or vegetation in the littoral zone at each site.

In October 1978 the island was again visited and water samples for phytoplankton and chemical analyses were collected from both the lough and pool sites. Sampling for aquatic macroinvertebrates was also performed and surface sediment samples from the pool sites were collected by hand. Field measurements of water pH and conductivity were made.

Water chemistry

Field measurements of water pH and conductivity at each site are given in Table 1. Optical density (OD) measurements at $\lambda = 365\mu m$ were performed on the water samples on return to the laboratory some twelve hours after collection. Measurements were made before and after filtration through GF/C filters (Table 2).

TABLE 2—The pH, conductivity ($\mu S\ cm^{-1}$) and optical density (OD) measurements of water samples from Rathlin Island, October 1978

		pH	*Conductivity (at 15C°)*	OD_{365}	OD_{365} *(filtered)*
Loughs:	Keeble	7·8	601	0·368	0·168
	Nanskan	7·9	580	0·028	0·023
	Ushet*	7·4	385	0·010	0·006
Pools:	3	5·8	310	0·227	0·216
	5	6·0	299	0·188	0·178
	6	7·2	428	0·268	0·237
	7	6·7	350	0·520	0·493

* Sampled December 1979.

It is clear from Table 2 that the sites fall broadly into two groups, the loughs which are alkaline and have high conductivity values and the pools (3, 5 and 7) which are acid and have lower conductivity values. Pool 6 occupies an intermediate position between the two groups being slightly alkaline and having a fairly high conductivity value. Compared with data for twenty-four mainland Northern Ireland lakes (Gibson 1976) Rathlin freshwaters show a greater range of pH values and have a considerably higher mean conductivity value.

The unfiltered OD values of water from Loughs Nanskan and Ushet were lower than those from the other sites by a factor of at least 10. Filtering reduced the OD of Lough Keeble water by more than 50 %, showing that particulates contributed significantly to the colour of this water. After filtration the OD values of the pool samples were all higher than those of the lough samples, particularly for Pool 7, indicating higher concentrations of dissolved humic substances.

Cation analyses were carried out on the water samples according to the methods of Golterman and Clymo (1969). Results of these analyses are presented in Table 3. The most common cation was sodium, concentration ranging from 40 to 85mg l^{-1} The highest concentrations of sodium occurred in the lough sites. Except for Pool 7 the concentrations of magnesium showed a similar trend to that of sodium. The concentration of calcium was the most variable, the highest value being found in Pool 6. The least common cation was potassium which was also the least variable in concentration. As indicated by the water-conductivity measurements, Rathlin freshwaters are concentrated compared to other freshwaters, the levels of sodium, magnesium and potassium being considerably higher than those recorded for mainland Irish waters (of. Gorham 1957, Glass 1980).

TABLE 3—Cation analyses for water samples from Rathlin Island, October 1978 (concentrations in mg l^{-1})

		Na^+	K^+	Ca^{2+}	Mg^{2+}
Loughs:	Keeble	75	4·0	19·9	15·5
	Nanskan	85	3·3	23·3	13·7
	Ushet*	60	2·8	5·0	9·6
Pools:	3	40	2·9	14·2	6·8
	5	35	2·6	8·9	6·8
	6	45	2·2	31·0	10·9
	7	40	2·6	12·8	11·0
	mean	54·3 (36 %)	2·9 (20 %)	16·4 (54 %)	10·6 (31 %)

() Indicate coefficient of variation.

* Sampled December 1979.

Phytoplankton

Single preserved water samples from each site were concentrated and enumerated for phytoplankton using a Wild inverted microscope at ×400 magnification. Abundances of the commoner algæ are given in Table 4. The phytoplankton in Loughs Nanskan and Ushet was dominated by planktonic diatoms, notably *Melosira* spp. The blue-green alga *Gomphosphæria lacustris* was most common in Lough Keeble. This lough also supported a considerable number of green algæ, particularly *Crucigenia* spp and *Scenedesmus* spp. Algæ in the pool samples were sparse and consisted mainly of desmids and various flagellates.

According to Rawson (1956) certain diatoms and many blue-green algæ tend to be common in eutrophic waters and other diatoms, desmids and some flagellates are characteristic of oligotrophic waters. Applying this scheme to the Rathlin samples it is clear that the lough phytoplankton reflects fairly eutrophic conditions whilst that of the pools suggests oligotrophy. The presence of fungal hyphæ in Pools 3, 5 and 7 further emphasizes the acidic nutrient-poor nature of the water at these sites.

Aquatic macro-invertebrates

Sampling for invertebrates was carried out at each site using a hand net. Loughs Kinkeel and Craigmacagan were also sampled for invertebrates. Selected invertebrate

TABLE 4—The commoner phytoplankton in water samples from Rathlin Island, collected October 1978

	Lough Keeble	*Lough Nanskan*	*Lough Ushet**	*Pool 3*	*Pool 5*	*Pool 6*	*Pool 7*
Myxophyceæ							
Anabæna flos-aquæ		+	+				
Chroococcus sp.						++	
Gomphosphæria lacustris	+++						
Oscillatoria agardhii			++				
Bacillariophyceæ							
Asterionella formosa			+				
Cyclotella comta		+	+				
Fragilaria sp.	+					+	
Melosira granulata		+++					
M. italica subsp. subarctica	++	+	++				
Navicula sp.					+++		
Nitzschia acicularis		+	+				
Stephanodiscus astræa		++	+				
S. hantzschii			+				
Chlorophyceæ (general)							
Ankistrodesmus falcatus	+	+	+	+	+		
Crucigenia quadrata	++						
C. tetrapedia	++						
Oedogonium sp.	+			++		+	
Pediastrum duplex	+						
Scenedesmus abundans	+						
S. quadricauda	++						
Tetraëdron caudatum	+						
T. minimum	+						
Chlorophyceæ (desmids)							
Euastrum didelta							+
Closterium sp.		+			+		
Cosmarium sp.				+	+		+
'*Flagellates*'							
Dinobyron bavaricum			+				
Euglena sp.						+	
Gymnodinium sp.					++		+
Peridinium willei						+	
Rhodomonas minuta				+			+
Trachelomonas sp.	+			++	++		++
Others							
Fungal hyphæ				+		+	+

* Sampled December 1979.

+ = present, > 2 % of the total count.
++ = common, > 10 % of the total count.
+++ = very common, > 30 % of the total count.

TABLE 5—Aquatic invertebrates sampled at various sites on Rathlin Island October 1978

	Lough Keeble	*Lough Craig-macagan*	*Lough Kinkeel*	*Pool 6*	*Lough Nanskan*	*Pools 3, 5 and 7 and Lough Ushet*
Flat worms						
Polycelis nigra	+					
Leeches						
Glossiphonia heterociliata	+					
Hæmopsis sp.	+					
Theromyzon tessulatum	+					
Snails						
Physa fontinalis	+					
Water bugs						
Corixidæ:						
Callicorixa præusta	+					
Cymatia bonsdorffi			+	+		
Hesperocorixa sahlbergi				+		
Sigara distincta	+++	+++	+	+		
S. dorsalis	++					
S. fossarum	+					
S. linnei		+				
S. scotti		++	++			
Others:						
Notonecta glauca	+	+				
Crustacea						
Gammarus duebeni	+	+			+	

\+ = present.
++ = common.
+++ = very common.

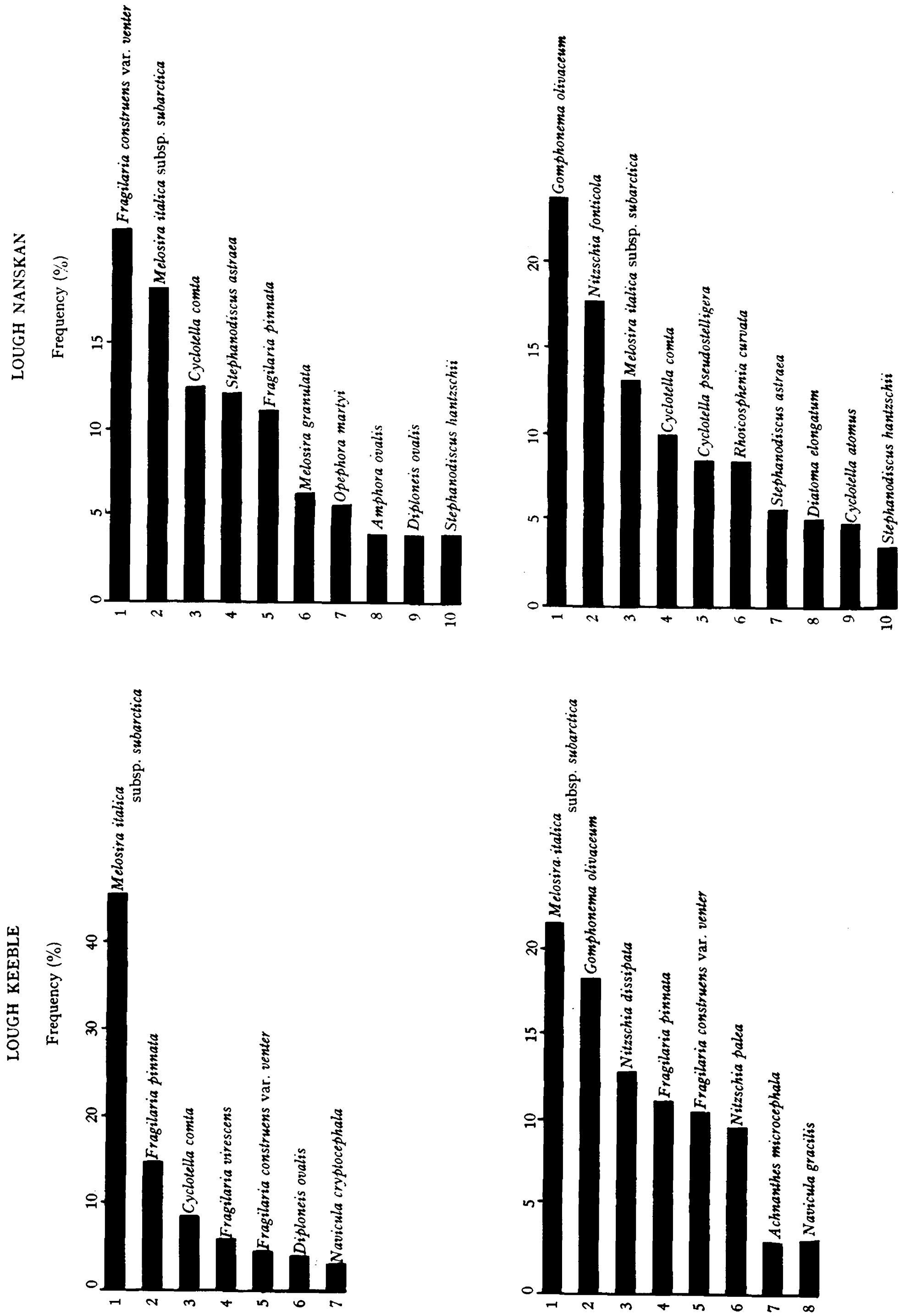

FIG. 3—(upper) Percentage frequencies of diatom taxas in the surface sediments of Lough Keeble (left) and Lough Nanskan (right).
(lower) Percentage frequencies of diatom taxa in the periphyton of Lough Keeble (left) and Lough Nanskan (right).

groups (Table 5) were identified as far as possible using the standard keys (Edmondson 1959, Macan 1965). Particular attention was given to the *Corixidæ;* nomenclature for this group follows Macan (1965).

Of the sites sampled Lough Keeble possesses the richest invertebrate fauna; chironomid larvæ (not shown in Table 5) were particularly numerous at this site. Aquatic snails appeared to be scarce on Rathlin: only one species was found in Lough Keeble and this was not common. A fairly diverse community of water-bugs occurred at the lough sites with extensive macrophytic vegetation and in Pool 6. As in many mainland Northern Irish loughs (Macan and Lund 1954), *Sigara distincta* was the most abundant species. The *Corixidæ* were apparently absent at the time of sampling in Loughs Nanskan and Ushet and at the pool sites, 3, 5 and 7.

Diatoms

Surface sediment samples from each site were prepared for diatom analysis. After oxidation of organic matter with 30 % hydrogen peroxide, 0·2ml quantities of sediment-diatom slurry were pipetted on to glass slides, dried and mounted in Mikrops resin. Relative diatom counts were carried out under oil immersion using a Wild microscope at ×1500 magnification. About 250 diatom values were counted in each sample. Identification of the diatoms was according to the standard floras of Hustedt (1930) and Cleve-Euler (1951-5). The percentage frequency of those taxa occurring above the 2 % frequency level are shown in Figs 3 and 4. In addition, the frequencies of taxa in periphytic assemblages from Loughs Keeble and Nanskan are shown in Fig. 3. Surface sediment samples from Lough Ushet were not collected. A list of all the diatom taxa found on Rathlin is given in the appendix.

The most common diatom genus in the surface sediment of Lough Keeble was *Melosira,* here represented by the single species *M. italica* subsp. *subarctica. Melosira* was also the most frequent genus in Lough Nanskan sediment where it is represented by the species *M. italica* subsp. *subarctica* and *M. granulata.* However, the most common taxon in Lough Nanskan was *Fragilaria construens* var. *venter.* It is noteworthy that *F. construens* var. *venter* was unrecorded in the phytoplankton sample collected from this lough later in the year (see Table 4). This demonstrates the greater value of surface sediment to single phytoplankton samples as a guide to the average composition of recent diatom phytoplankton communities. The presence of *Stephanodiscus astræa* and *S. hantzschii* in Lough Nanskan strongly suggests alkaline and eutrophic conditions. A few specimens of *Licomorpha tenuis* and *Nitzschia frustulum* var. *subsalina,* species characteristic of increased salinity, were recorded from this lough.

The periphytic diatom assemblage collected from the stems of *Phragmites* in Lough Keeble was dominated by *Melosira italica* subsp. *subarctica* as was the surface sediment assemblage. Without more data concerning phytoplankton succession it is impossible to say if the *M. italica* subsp. *subarctica* was growing *in situ* on the *Phragmites* or whether it had been deposited there after the decline of a planktonic population. In Lough Nanskan the stalked diatom *Gomphonema olivaceum* was most abundant in the assemblage collected from rock surfaces. It was, however, very infrequent (< 1 %) in the surface sediment assemblage in this lough. As in Lough Keeble, it is not clear whether the normally planktonic diatoms in the Nanskan

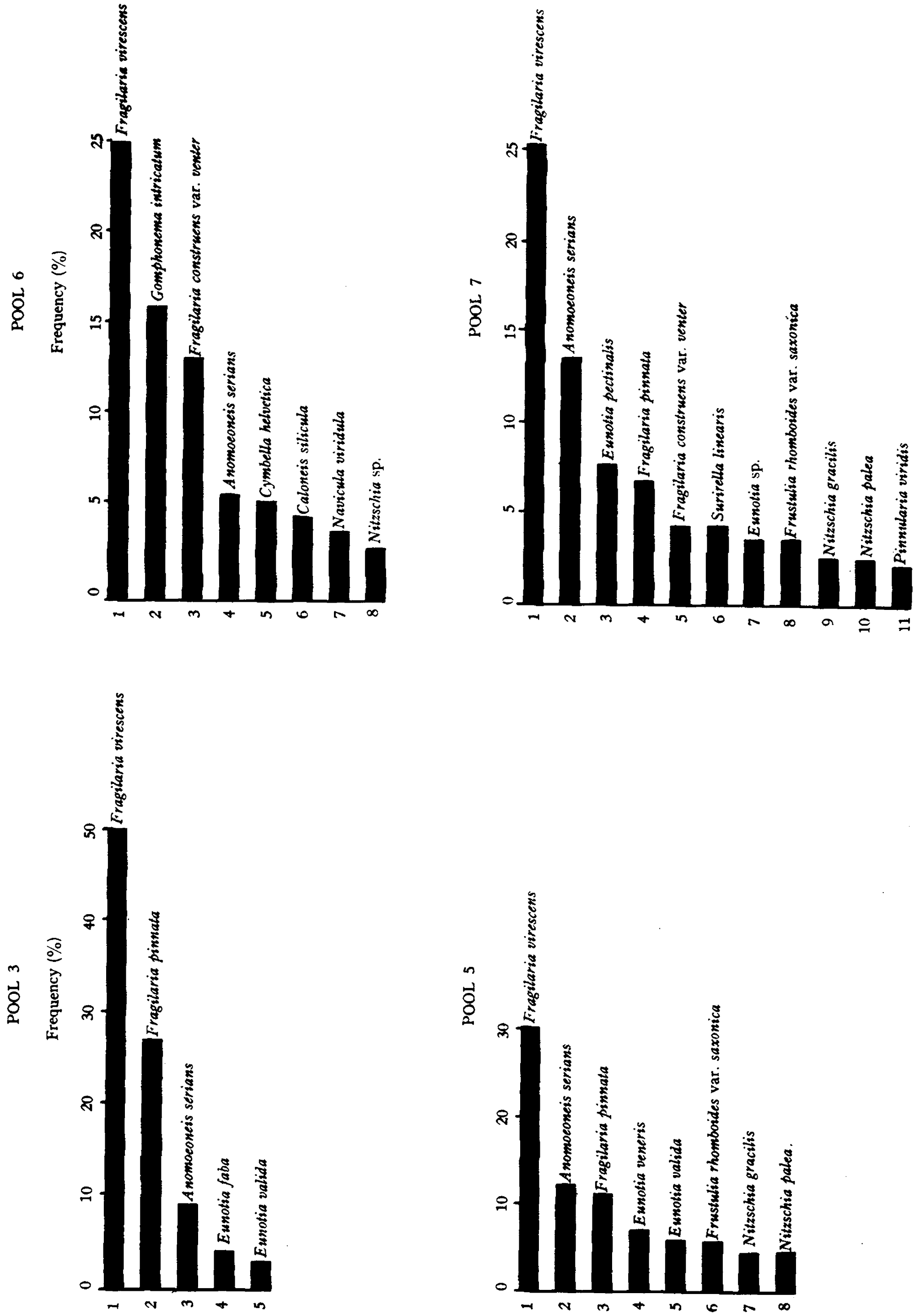

FIG. 4—Percentage frequencies of diatom taxa in the surface sediments from Pools 3, 5, 6 and 7.

periphyton sample, i.e. *Cyclotella, Melosira* and *Stephanodiscus*, were growing *in situ* or were deposited from the water column, but the latter is thought more likely.

At all the pool sites *Fragilaria virescens* was the dominant diatom in the sediment, particularly in Pool 3 where it constituted more than 50 % of the total assemblage. The diatoms *Anomœoneis serians* and *Eunotia* spp, indicators of acidic oligotrophic conditions, were common in Pools, 3, 5 and 7; *Anomœoneis serians* also occurred in Pool 6. This diatom has been described as ' acidobiontic ' (Meriläinen 1969), which implies that it is restricted to waters of pH lower than 7 (see Hustedt, 1937-39). However, since Pool 6 was slightly alkaline (pH 7·2) *A. serians* is probably best described as ' acidophilous ' meaning that it ' prefers ' acidic conditions but can occur in alkaline waters.

Diatoms in the pool phytoplankton were scarce (see Table 4) and it is probable that most of those identified in the sediments had, in contrast to the loughs, arisen from periphytic growth on the sediment surface or on submerged vegetation. The shallowness of the pools—in contrast to the loughs—ensures that light is unlikely to be a factor limiting diatom growth on the sediment surface.

An interesting point concerning Pool 5 is that *Navicula* spp were very infrequent in the sediment assemblage but the phytoplankton was dominated by *Navicula* sp. (see Table 4). This genus is normally considered to be periphytic (e.g. Hustedt 1930); its occurrence in the phytoplankton of Pool 5 illustrates the difficulty, often encountered in diatom ecology, of making generalizations about whether a species is planktonic or periphytic, as the behaviour of a particular species can vary in different conditions (Bradbury 1973).

Discussion

Sea spray has been proposed as the major source of the common cations in freshwaters in the west of Ireland (Gorham 1957). The relatively high concentrations of sodium and magnesium ions in Rathlin freshwaters suggests that here sea spray is also the major source of the common cations. Further evidence for this suggestion can be seen in Table 6 which shows the correlation coefficients between various pairs

TABLE 6—Correlation matrix of water-chemistry variables from various sites on Rathlin Island

Variable	*Conductivity*	*OD*	*OD*†	Na^+	Mg^{2+}	K^+	Ca^{2+}
pH	0·94**	–0·06	–0·33	0·86*	0·94**	0·51	0·66
Conductivity		–0·20	–0·53	0·96***	0·99***	0·74	0·55
OD			0·90**	–0·38	–0·16	–0·11	–0·22
OD†				0·64	–0·51	–0·49	–0·29
Na^+					0·91**	0·77*	0·43
Mg^{2+}						0·71*	0·59
K^+							–0·03

* Denotes significance at P = < 0·05. ** Denotes significance at P = < 0·01.
*** „ „ at P = < 0·001. † OD of filtered water samples.

of chemical variables measured on Rathlin. Sodium is very significantly positively correlated with magnesium and also with potassium but to a lesser extent. This indicates that these ions originate from the same source. No significant correlation was found between calcium and the other variables, implying that calcium is derived from a source different from that of the other ions.

TABLE 7—Ratios of various cations in Rathlin freshwaters and other samples

	Lough Keeble	*Lough Nanskan*	*Lough Ushet*	*Pool 3*	*Pool 5*	*Pool 6*	*Pool 7*	*Basalt*[1]	*Sea water*[2]
Na:Mg	4·8	6·2	6·3	5·9	5·1	4·1	3·6	0·3	8·2
Na:K	18·8	25·6	21·3	13·8	13·5	20·5	15·7	0·6	27.8
Na:Ca	3·8	3·7	12·0	2·8	3·9	1·5	3·1	0·2	26·4

[1] Wilson and Manning (1978).
[2] Riley and Skirrow (1965).

Comparing the ratios of various ions in fresh water can also provide information concerning the origin of the ions (Douglas 1968). The ratio of sodium to magnesium, potassium and calcium at the Rathlin sites is compared with the ratios in seawater and basalt rock in Table 7. In all cases the ionic ratios in the freshwater samples are lower than in sea-water. However, this is much less so for sodium : magnesium and sodium : potassim than for sodium : calcium. The ratio of sodium to the other ions is very much less in basalt rock than in the water samples. These observations strongly suggest that most of the sodium, magnesium and potassium is derived from seawater. A terrestrial contribution is probably more important for calcium, particularly in the case of Pool 6. In general, the ionic ratios of the major cations in the lough waters show a closer correspondence to those in seawater than do those in pool waters. In other words, cations from terrestrial sources have a greater influence on the water chemistry at the pool sites than at the lough sites.

It is thought that there are two main water-chemistry characteristics that can influence aquatic organisms. Macan (1963) states that ' there is scarcely an animal group in which the distribution of some of its species . . . . has not been related to the calcium concentration '. The concentration of major ions, which is closely related to water conductivity and usually to nutrient concentration, exerts a strong influence particularly on phytoplankton communities (Moss 1980). It is of interest to examine the distribution of aquatic organisms at the Rathlin sample sites in relation to these two influences. The sites can be ordered in a series of increasing calcium concentration (Scheme A) and increasing water conductivity (Scheme B).

Scheme A
L. Ushet > Pool 5 > Pool 7 > Pool 3 > L. Keeble > L. Nanskan > Pool 6

increasing Ca^{2+}
⟶

Scheme B
Pool 5 > Pool 3 > Pool 7 > L. Ushet > Pool 6 > L. Nanskan > L. Keeble

increasing conductivity
⟶

Following a study of the ecology of the *Corixidæ* Macan (1954) showed that various species in the group were characteristic of high and low calcium levels:

S. dorsalis → *S. distincta* → *S. scotti*—base-poor conditions
S. dorsalis → *S. fossarium*
S. dorsalis → *S. linnei* → *H. sahlbergi*—lime-rich conditions.

The aquatic macroinvertebrate data (Table 5) from Rathlin must be treated with caution as samples were collected on one occasion only. The presence of *Hesperocorixa sahlbergi* in Pool 6 and of *Sigara distincta* and *S. dorsalis* in Lough Keeble, and the absence of *Corixidæ* in Pools 3, 5 and 7 and Lough Ushet do, however, indicate that calcium concentration might have some influence on the distribution of water-bugs on the island. The absence of *Corixidæ* in Lough Nanskan, a site where the calcium concentration was relatively high, suggests that some other factor, such as the presence of macrophytic vegetation, is also important.

As with the invertebrates, samples of phytoplankton were only collected on one occasion and inferences can only be tentative. Using the distribution of ' eutrophic ' and ' oligotrophic ' algæ (Rawson 1956, Palmer 1969) the Rathlin sites can be ordered into an ascending series which approximately corresponds to Scheme B, increasing water conductivity:

Pools 3, 5, 6 and 7 > Loughs Nanskan and Ushet > Lough Keeble.

The surface sediment diatom assemblages also indicate oligotrophic conditions at the pool sites and more eutrophic conditions at the lough sites.

The degree of similarity between the sedimentary diatom assemblages at each site was estimated by comparing the number of taxa in common at paired sites (Fig. 5). The sites separate in a manner which again corresponds to increasing water conductivity (Scheme B).

It is difficult to identify exactly what is causing the changes in diatom assemblage composition at each site. Diatoms have been shown to be good indicators of chloride concentration (Kolbe 1927), of pH (Hustedt 1937-9), and of nutrient levels (Lange-Bertalot 1979). Unfortunately, there are no data available on the nutrient chemistry of Rathlin fresh waters; it is, however, instructive to examine the correspondence between diatom floras and water pH and conductivity measured at each site. Meriläinen (1967) showed that the pH tolerances of diatoms, as defined by Hustedt (1937-9), can be used to calculate fairly accurately the pH of the water in which a particular assemblage originated. As used by Gasse (1978) the expression to calculate

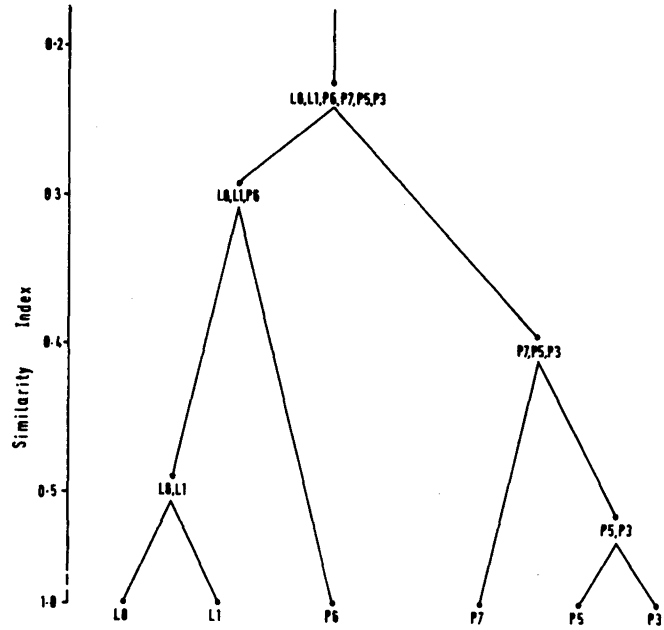

FIG. 5—Cluster analysis of similarity indices calculated from the diatom assemblages in the surface sediments at each pair of sites (according to Sørensen in Southwood 1966). Key: L8—Lough Nanskan; L1—Lough Keeble; P3-7—pool sites.

water pH from a particular diatom assemblage is:

$$\text{pH} = \frac{7{\cdot}16 - \text{Log index } \alpha}{1{\cdot}08}$$

$$\text{where index } \alpha = \frac{\text{Relative frequency of acidophilic diatoms} + 5 \text{ relative frequency of acidobiontic diatoms}}{\text{Relative frequency of alkaliphilic diatoms} + 5 \text{ relative frequency of alkalibiontic diatoms}}$$

Water pH for each Rathlin site was calculated from the respective sediments diatom assemblage and compared with the pH measured in the field (Fig. 6). The calculated pH tends to be higher than the measured pH, especially for Pool 6 and Lough Nanskan. This disagreement may indicate that caution is required in applying the pH calculation to assemblages that are strongly dominated by pH-indifferent diatoms (e.g. *Fragilaria virescens*), as in Pool 3, or where alkalibiontic diatoms (e.g. *Stephanodiscus* spp) are frequent, as in Lough Nanskan. It is to be noted that Meriläinen (1967) used mainly acid diatom floras to compute water-pH values.

Kolbe (1927) suggested that diatom assemblages were particularly sensitive to salinity changes, in particular to chloride ion concentration. He proposed a 'halobian' system of classifying diatom taxa according to their salinity preference (if any). Use of the halobian system in describing freshwater diatom communities has been

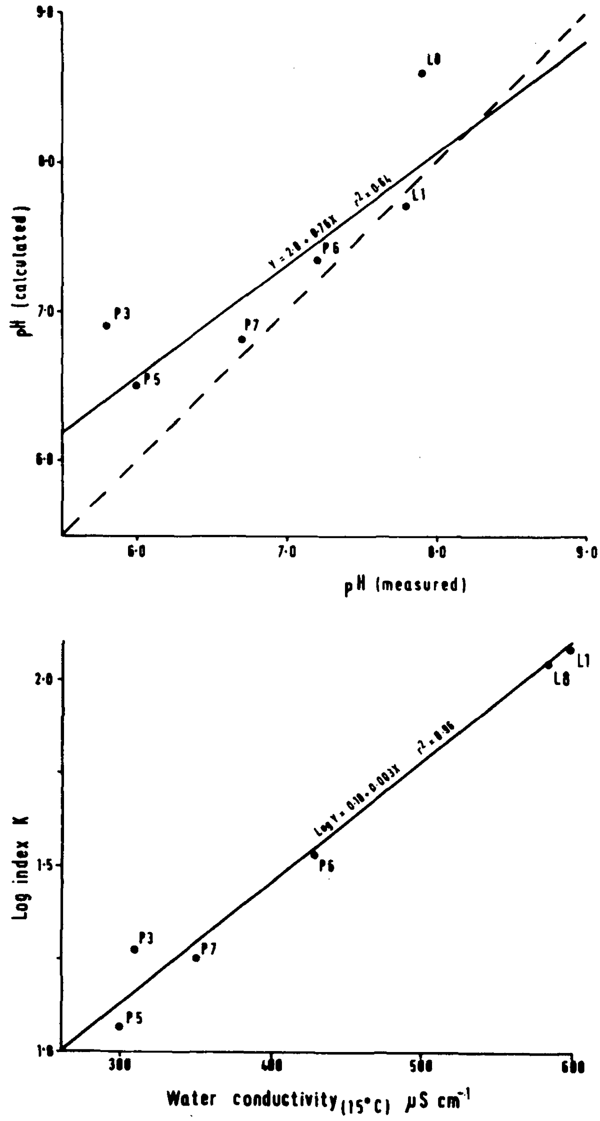

FIG. 6—(upper) Relationship between water pH calculated from the diatom assemblage and pH measured at each site.
(lower) Relationship between the measured water conductivity at each site and index K (see text). Symbols as for Fig. 5.

somewhat neglected in the literature, where favour has been given to classifying diatoms according to their pH preference (of. Hustedt 1937-9). This came about because the chloride ion is not usually the most common anion in fresh waters (Hutchinson 1957). The high concentrations of sodium and consequently chloride ions in Rathlin freshwaters suggests that salinity might have some influence on the species composition of the diatom floras. Using known salinity preferences (see

Kolbe 1927, Peterson 1943, Cleve-Euler 1951-5, Lowe 1974, Haworth 1976, Gasse 1978) for diatoms recorded at the Rathlin sites an index ' K ' was computed for each assemblage using the following expression:

$$\text{index K} = \frac{\%\ \text{indifferent forms} + 10\ (\%\ \text{mesohalobes} + \%\ \text{halophiles})}{\log\ (\%\ \text{halophobes} + 10)}.$$

Plotting the log of the calculated index K against measured conductivity at each site (Fig. 6) gives a strong positive correlation ($r^2 = 0{\cdot}96$, $P = < 0{\cdot}001$). It is likely, therefore, that in more saline freshwaters diatoms may be a better guide to water conductivity than to pH. If further work shows index K to be a reliable estimate of water conductivity then the possibility exists of calculating palæo-salinities for lakes exposed to different climates in the past.

Conclusions

Compared with mainland freshwaters those on Rathlin Island show higher levels of cations, notably sodium and magnesium ions. The main source of these ions is sea spray which is often dispersed over the island during storms. The phytoplankton indicate oligotrophic conditions at the pool sites and more eutrophic conditions at the lough sites. The diatom assemblages in the surface sediments appear to correspond more closely to water conductivity than to pH.

Information concerning the nutrient supply and the nutrient status of the sites examined in this paper is essential for a fuller understanding of the ecology of these habitats. A programme of water sampling for cation analysis is currently being planned for Rathlin. In addition, examination of dated sediment cores for algal remains would, it is hoped, show if the loughs on Rathlin have always been fairly biologically rich or whether these conditions are the result of post-agricultural enrichment, caused by intensive crop cultivation on the island in the last two centuries.

ACKNOWLEDGEMENTS

I am indebted to Professor A. Macfadyen for providing the data on invertebrates presented in this paper. I thank Dr A. C. Hamilton for twice reading the manuscript critically, the first draft having been lost in a laboratory fire, and Dr R. W. Battarbee for his constructive comments. This work was carried out with financial assistance from the Department of Health and Social Security (N.I.).

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Appendix

List of diatom taxa found on Rathlin Island

Achnanthes microcephala (Kützig) Grunow
A. lanceolata (Brébisson) Grunow
A. lanceolata var. *elliptica* Cleve
A. microcephala (Kutzing) Grunow
A. minutissima Kützing
Amphora ovalis Kützing
Amphora ovalis Kützing
Anomoeoneis serians (Brébisson) Cleve
A. serians var. *brachysira* (Brébisson) Cleve
Asterionella formosa Hassal

Caloneis bacillum (Grunow) Mereschkowski
C. silicula (Ehrenberg) Cleve
Cocconeis pediculus Ehrenberg
C. placentula var. *euglypta* (Ehrenberg) Grunow
C. thumensis Mayer
Cyclotella atomus Hustedt
C. comta (Ehrenberg) Kützing
C. meneghiniana Kützing
C. pseudostelligera Hustedt
Cymatopleura elliptica (Brébisson) Smith
Cymbella helvetica Kützing
C. turgida Gregory
C. ventricosa Agardh

Diatoma elongatum (Lyngbye) Agardh
Diploneis ovalis (Hilse) Cleve
D. puella (Schumann) Cleve

Epithemia zebra (Ehrenberg) Kützing
Eunotia pectinalis var. *minor* (Kützing) Rabenhorst
E. valida Hustedt
E. veneris (Kützing) Müller
E. sp.

Fragilaria brevistrata Grunow
F. capucina Demazieres
F. construens (Ehrenberg) Grunow
F. construens var. *binodis* (Ehrenberg) Grunow
F. construens var. *venter* (Ehrenberg) Grunow
F. lapponica Grunow
F. pinnata Ehrenberg
F. pinnata var. *subrotunda* Mayer
F. virescens Ralfs
F. virescens var. *subsalina* Grunow
Frustulia rhomboides var. *saxonica* (Rabenhorst) de Toni

Gomphonema abbreviatum (Agardh) Kützing
G. intricatum Kützing
G. olivaceum Hustedt
G. parvulum Kützing
Gyrosigma attenuatum (Kützing) Rabenhorst

Licomorpha tenuis (Kützing) Grunow

Melosira ambigua Müller
M. granulata (Ehrenberg) Ralfs
M. italica var. *subarctica* Müller

Navicula cryptocephala Kützing
N. gracilis Ehrenberg
N. hungarica Grunow
N. minima Grunow
N. minuscula Grunow
N. pseudoscutiformis Hustedt
N. pupula Kützing
N. radiosa Kützing
N. rhyncocephala Kützing
N. seminulum Grunow
N. viridula Kützing
N. sp. 1
N. sp. 2
Neidium productum (Smith) Cleve
Nitzschia acicularis Smith
N. dissipata (Kützing) Grunow
N. fonticola Grunow
N. frustulum var. *subsalina* Hustedt
N. palea (Kützing) Smith
N. sp.

Opephora martyi Héribaud

Pinnularia abaujensis (Pantocsek) Ross
P. episcopalis Cleve
P. major (Kützing) Rabenhorst
P. microstauron (Ehrenberg) Cleve
P. viridis (Nitzsch) Ehrenberg

Rhoicosphenia curvata (Kützing) Grunow

Stauroneis legumen (Ehrenberg) Kützing
S. phoenicenteron (Nitzsch) Ehrenberg
Stephanodiscus astraea (Ehrenberg) Grunow
S. astraea var. *minutula* (Kützing) Grunow
S. hantzschii Grunow
S. tenuis Hustedt
Surinella linearis Smith
S. tenera Gregory
Synedra ulna (Nitzsch) Ehrenberg

CORRIGENDA

Page 11, line 12 from foot, and page 20, line 17. For *Licomorpha* read *Licmophora*.

Page 64, Fig. 5. *For* CO *read* CI.