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Abstract

Bathymetries of 17 previously unsurveyed lochs and computer methods for mapping and calculating morphometric parameters are described. Deposited sea salt is shown to have a major effect, that varies according to distance from the west coast, on water quality in these lochs. The ecological significance of water quality variation is assessed by diatom analysis of surface sediment from each site. Multi-variate methods of diatom community analysis indicate that the sites can be classified into five groups and that water conductivity and pH are the main determinants of diatom assemblage species composition.

INTRODUCTION.

Freshwaters on the Outer Hebrides islands of western Scotland have received scant attention from limnologists. This is particularly so for the island of South Uist, one of the few localities omitted from the extensive bathymetric survey of Scottish freshwater lochs carried out by Murray and Pullar (1910). Nevertheless, South Uist lochs are of particular interest for at least two reasons. First, the Outer Hebrides are included in an EEC sponsored Integrated Developement Programme (IDP) for the Scottish Western Isles (see Hanbury, 1984) and planned agricultural improvements such as better land drainage and increased use of manufactured fertilizers could have detrimental effects on the island's freshwater resources. Second, since frequent westerly storms distribute sea salt over the entire island, South Uist lochs offer the possibility of assessing the effect of variation in deposited salt on water qualty and its ecological significance in a geographically restricted area. Other important factors thought to affect water quality on the island are acid humic drainage water from extensive blanket peats and leaching of fertilizers from agricultural land.

Bathymetric data for South Uist are currently pertinent as proposed and already implemented drainage operations could cause a lowering of the water table detrimentally affecting wetlands and shallow lochs, particularly those in the western machair fringe ( a thinly vegetated ecologically sensitive sand dune system, cf. Jaatinen 1957, Richie 1979, Hambrey 1984). Measurement or calculation of morphometric characteristics such as area, volume, and depth, of a selection of these lochs should not only provide empirical data but possibly aid the formulation of management plans for conservation and preservation of the wetlands.

The ecological significance of water quality variation in South Uist lochs can be assessed inter alia by examining the distribution and abundance of diatoms. Diatoms are siliceous algae common in fresh and brackish water lakes that, at the species level, are good indicators of water acidity (cf. Hustedt 1937-39, Meriläinen 1967), salinity (cf. Kolbe 1927, Hustedt 1957) and eutrophication (Platt Bradbury 1975, Battarbee 1978). In this paper the surface sediment diatom assemblages of seventeen lochs are related to water quality and drainage basin characteristics and we attempt a natural classification of the sample sites. The relationship between the distribution of diatoms and water quality is examined using multi-variate methods of plant community analysis (Hill 1979).

Planned development of South Uist and other islands of the Outer Hedrides stimulated environmental concern in the 1970's and resulted in a series of papers on the region including descriptions of the aquatic macrophytes (Spence et al. 1979, Royal Botanic Gardens, 1983), aquatic invertebrates (Waterston & Lyster 1979) and of inland water chemistry (Waterston et al. 1979). There is however only one published account of the distribution of algae (mainly phytoplankton) in South Uist freshwaters made over 30 years ago by Lind (1953).

SITES DESCRIPTIONS.

The Atlantic island of South Uist is 32km by 13km and is situated some 65km from the west coast of mainland Scotland in the Outer Hebrides archipelago. It experiences a wet and cool climate with frequent strong winds from the west and southwest. The geology of the island is dominated by resistant siliceous Archaean rocks of mainly Lewisian gneiss that are uplifted along the eastern side of the island to form rugged hills up to 500m in altitude (Fig 1). The western slopes of these hills extend into the central lowlands or 'blacklands' and merge with the machair along the west coast (see Jaatinen 1957 for fuller descriptions of land type and use). The upland and central lowland soils are composed almost entirely of blanket peat usually overlying coarse glacial drift deposits or gneiss bedrock. The peat may be several metres deep on the less steep slopes in the eastern hills but according to Jaatinen (1957) extensive peat cutting in the lowlands has produced the unproductive 'blacklands', an area characterized by thin sandy peat with many boulders and bedrock exposures. The west coast is typified by a vegetated dune system or machair where good drainage has enabled subsistence agriculture to be practised on large areas of the shell-rich sandy soils, probably since pre-historical times (cf. Dickinson & Randall 1979).

Freshwater lochs are abundant on South Uist and can be broadly grouped into upland, blackland and machair lochs according to location. Lochs in the two latter areas are surrounded mainly by agricultural land, the upland lochs however have open moorland catchments managed for sheep grazing by burning. Most of the blackland and all of the machair lochs are maintained by ground water and are often

Table 1. Loaction and selected physical characteristics of the seventeen South Uist sample lochs. Sites 1 to 15 are ordered from south to north.

| SITE | | NATIONAL GRID REF. | ALTITUDE (m) | DISTANCE FROM WEST COAST (km) | DRAINAGE BASIN GEOLOGY | SEDIMENT † TYPE |
|---|---|---|---|---|---|---|
| 1. Briste | (B) | NF 747149 | < 10 | 0.9 | Drift | Organic detritus |
| 2. Nan Capull | (B) | 754161 | 10-20 | 1.5 | Rock | Sand & Silt |
| 3. Trosaraidh | (B) | 758170 | 10-20 | 2.3 | Rock | Silt |
| 4. Eilean | (B) | 746169 | < 10 | 0.6 | Rock | Organic detritus |
| 5. Hallan | (M) | 739222 | < 10 | 0.9 | Sand & Rock | Sand |
| 6. Cuith Moire | (B) | 738234 | < 10 | 1.3 | Rock | Silt & Organic Detritus |
| 7. Nighe | (B) | 740237 | < 10 | 1.5 | Rock | Organic detritus |
| 8. Liana Moire | (M) | 733248 | < 10 | 0.7 | Sand | Sand |
| 9. Aird na Sgairbh | (M) | 736266 | < 10 | 0.5 | Sand | Sand |
| 10. West Loch Ollay | (M) | 741326 | < 10 | 0.5 | Sand & Rock | Sand |
| 11. Mid Loch Ollay | (B) | 755315 | < 10 | 1.6 | Rock | Organic detritus |
| 12. East Loch Ollay | (B) | 766312 | < 10 | 3.1 | Rock | Organic detritus |
| 13. Ardvule | (M) | 713299 | < 10 | 0.01 | Rock | Organic detritus |
| 14. Cille Bhanian | (M) | 768414 | < 10 | 1.5 | Sand & Rock | Sand & Silt |
| 15. Duin Bhig | (M) | 761470 | < 10 | 0.4 | Sand | Organic detritus |
| 16. Kearsinnish | (U) | 798168 | 10-20 | 3.0 | Rock | Organic detritus |
| 17. Teanga | (U) | 818383 | 20-30 | 6.5 | Rock | Organic detritus |

† As sampled at the deepest point of each loch

( ) Indicate B = Blackland, M = Machair and U = Upland Loch.

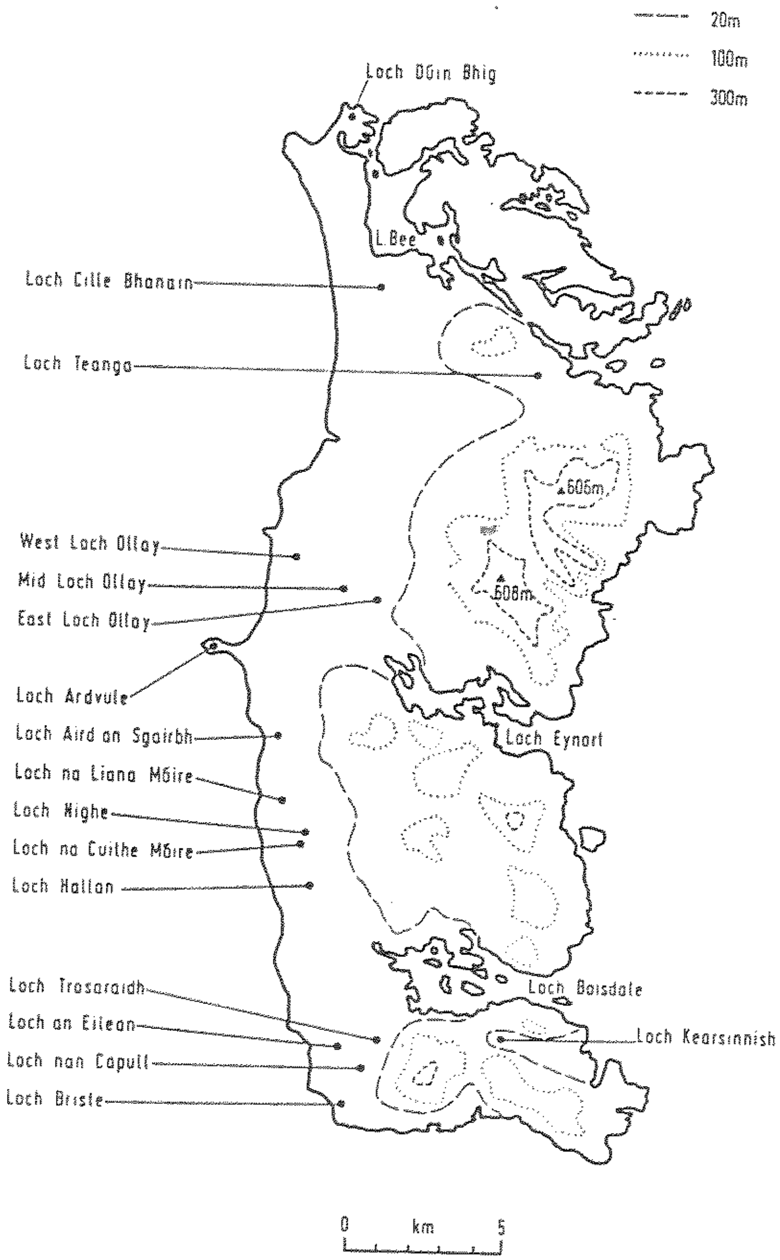


Figure 1. The island of South Uist showing the 17 sample lochs.

interconnected, so making description of the effective individual loch catchments virtually impossible. In collaboration with the Nature Conservancy Council we selected a range of seventeen sites for investigation, including upland, blackland and machair lochs (Table 1).

## FIELD METHODS

The seventeen lochs (Fig. 1) were visited in May 1983 and survey methods entailed making several traverses across a loch in an inflatable boat using a graphical echo-sounder to record depths. Depth transects were located by reference to easily identifiable map features such as inflows and promontories. In several of the very shallow machair lochs however, depths were simply measured using a graduated pole. In addition to the bathymetric survey, Secchi disc depths were determined where possible and water samples were collected for pH and conductivity measurements in the field and for further analysis in the laboratory. Surface sediment samples for diatom analysis were collected from the deepest point in each loch using a small Ekman grab.

## LABORATORY METHODS

Water samples selected for six contrasting sites were analysed for major cations and anions using standard spectrophotometric methods. Surface sediment samples for diatom analysis were cleaned using 30% hydrogen peroxide followed by concentrated hydrochloric acid and mounted on glass coverslips in Mikrops for microscopical examination. The specimens were identified at x1500 magnification and about 300 valves counted for each sample .

Contour maps and estimates of loch surface area and volume were produced using both proprietary mapping software (MAPICS 1985) and custom programs. Loch outlines were taken from 1:10000 maps and enlarged to a suitable scale. The outlines were superimposed on the surveyed depths and the following data were digitized for each site, loch outline detail, outlines of islands (if present), and surveyed depths including a sample of points from loch outlines recorded as zero depth.

The MAPICS (1985) graphics system produces high quality bathymetric contour maps of the loch basins from height-gradient grids interpolated from the surveyed depths and loch/island outlines. Contour maps were drawn using a Hewlett-Packard vector plotter. Surface areas were estimated using a custom program based on a GAG (Geography

Table 2. Morphometric characteristics of the seventeen South Uist sample lochs, as sampled May 1983. Sites are numbered according to Table 1.

| SITE | MAX DEPTH (m) | MEAN DEPTH (m) | SURFACE AREA ($m^2$) | VOLUME ($m^3$) | SURFACE AREA: VOLUME RATIO |
|---|---|---|---|---|---|
| 1. | 1.50 | 1.12 | 5262.3 | 3892.3 | 1.352 |
| 2. | 0.60 | 0.42 | 28600.0 | 5647.0 | 5.065 |
| 3. | 0.50 | 0.32 | 23816.1 | 3542.0 | 6.724 |
| 4. | 1.60 | 0.73 | 109483.8 | 46921.7 | 2.333 |
| 5. | 1.20 | 0.52 | 320856.6 | 61163.3 | 5.246 |
| 6. | 2.00 | 0.99 | 81252.0 | 24182.9 | 1.292 |
| 7. | 0.80 | 0.55 | 13552.0 | 4994.2 | 2.714 |
| 8. | 0.35 | 0.19 | 77492.3 | 11163.2 | 6.942 |
| 9. | 2.30 | 0.63 | 259916.5 | 88850.8 | 2.925 |
| 10. | 1.40 | 0.74 | 328152.0 | 120619.2 | 2.721 |
| 11. | 5.20 | 2.17 | 325611.4 | 377428.3 | 0.863 |
| 12. | 5.00 | 1.92 | 326544.7 | 439042.9 | 0.744 |
| 13. | 1.80 | 1.14 | 63702.5 | 41767.8 | 1.525 |
| 14. | 1.40 | 0.5 | 65765.9 | 21312.6 | 3.086 |
| 15. | 1.10 | 0.73 | 25232.5 | 8676.5 | 2.908 |
| 16. | 10.50 | 2.51 | 141309.3 | 147202.9 | 0.960 |
| 17. | 21.00 | 9.38 | 77131.5 | 418793.6 | 0.184 |
| SUM | 58.25 | 24.56 | 2223681 | 1825201 | – |
| MEAN | 3.43 | 1.45 | 130805 | 107365 | – |

Algorithms Group) subroutine for calculating polygon areas. Volumes were estimated using an algorithm that automatically generates triangulations of the depth and outline sample points and sums the volumes of the individual triangles. This algorithm generates an optimal triangulation of the data points (the Delaunay Triangulation) by ensuring that triangles are as equiangular and equilateral as possible (Sibson and Green, 1978).

## RESULTS

### Loch bathymetries.

Bathymetries for the 17 surveyed lochs are presented in Figs. 2 to 5 and basic morphometric parameters of depth area and volume calculated for each site are given in Table 2. The machair group of lochs, Hallan, Liana Moire, Aird an Sgairbh, West Loch Ollay, Ardvule, Cille Bhanian and Duin Bhig, are all less than 2.5m deep and have hard sandy bottoms and littoral areas. Exceptions are Ardvule and Duin Bhig which contain soft detrital sediments composed largely of fibrous macrophyte remains. The bathymetries of the sandy lochs usually show several shallow sub-basins which are

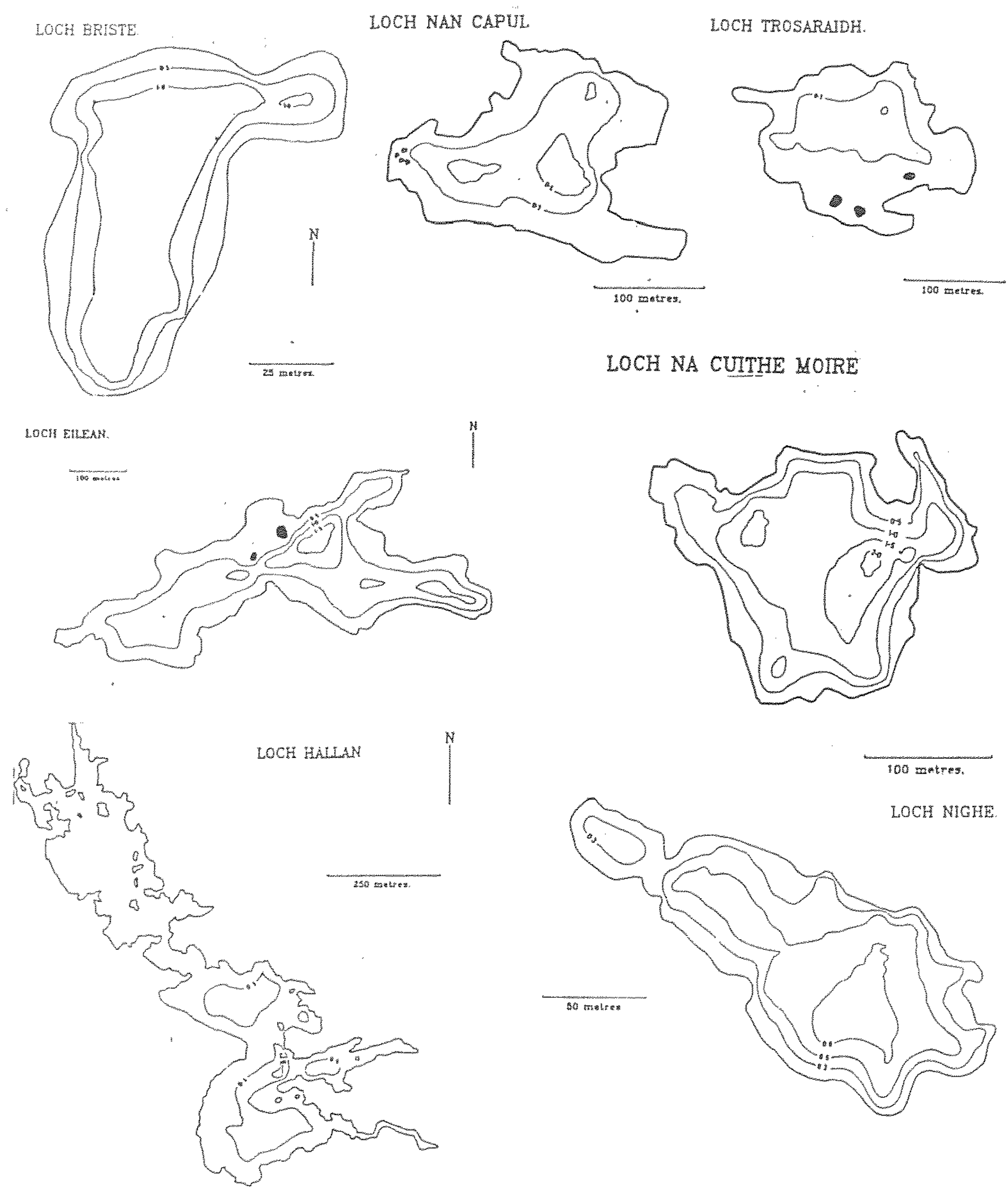


Figure 2. Bathymetric maps for Loch Briste, Loch nan Capull, Loch Trosaraidh, Loch Eilean, Loch Cuithe Moire, Loch Hallan, and Loch Nighe.

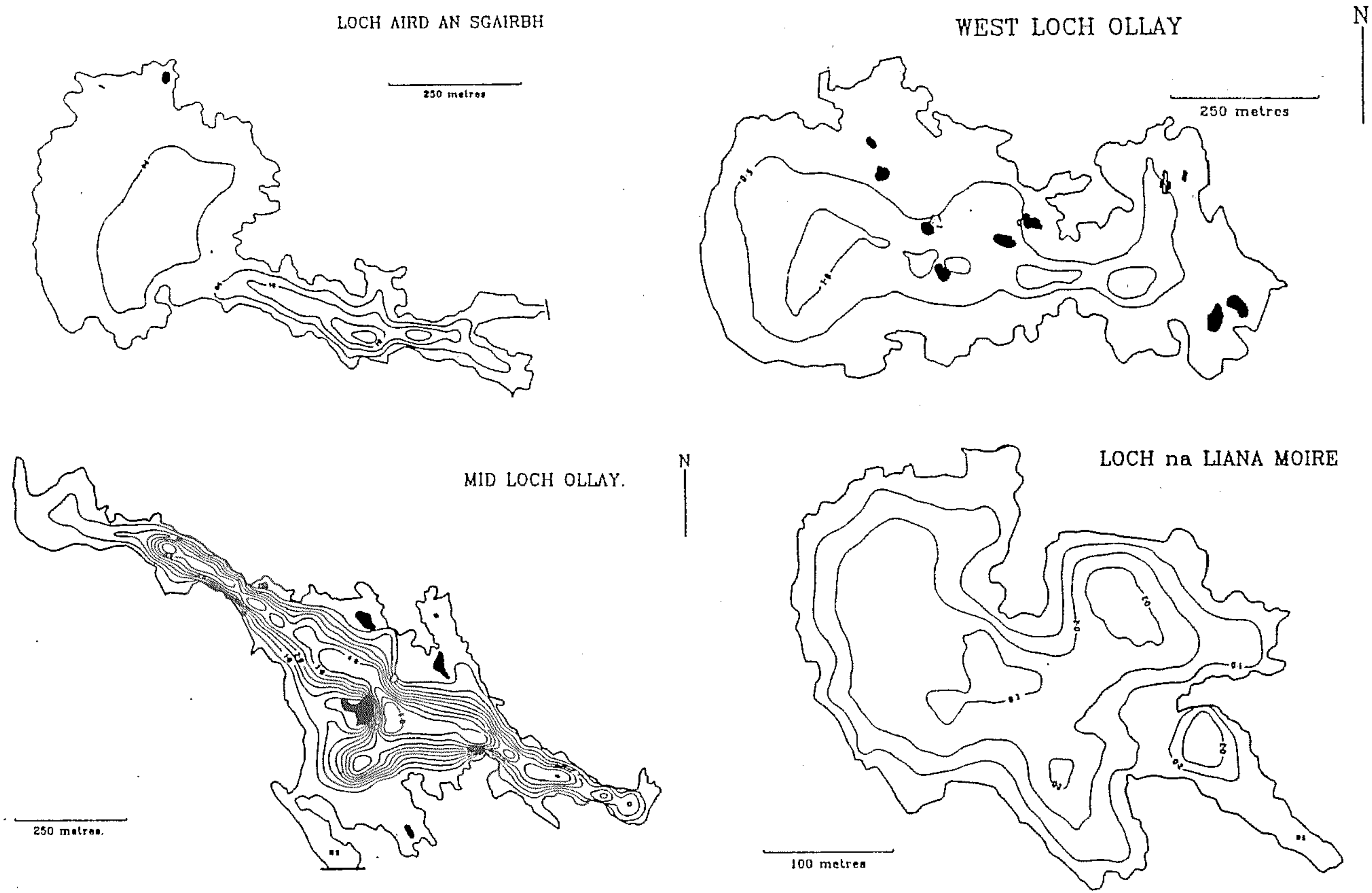


Figure 3. Bathymetric maps for Loch Aird na Sgairbh, West and Mid Loch Ollay, and Loch na Liana Moire.

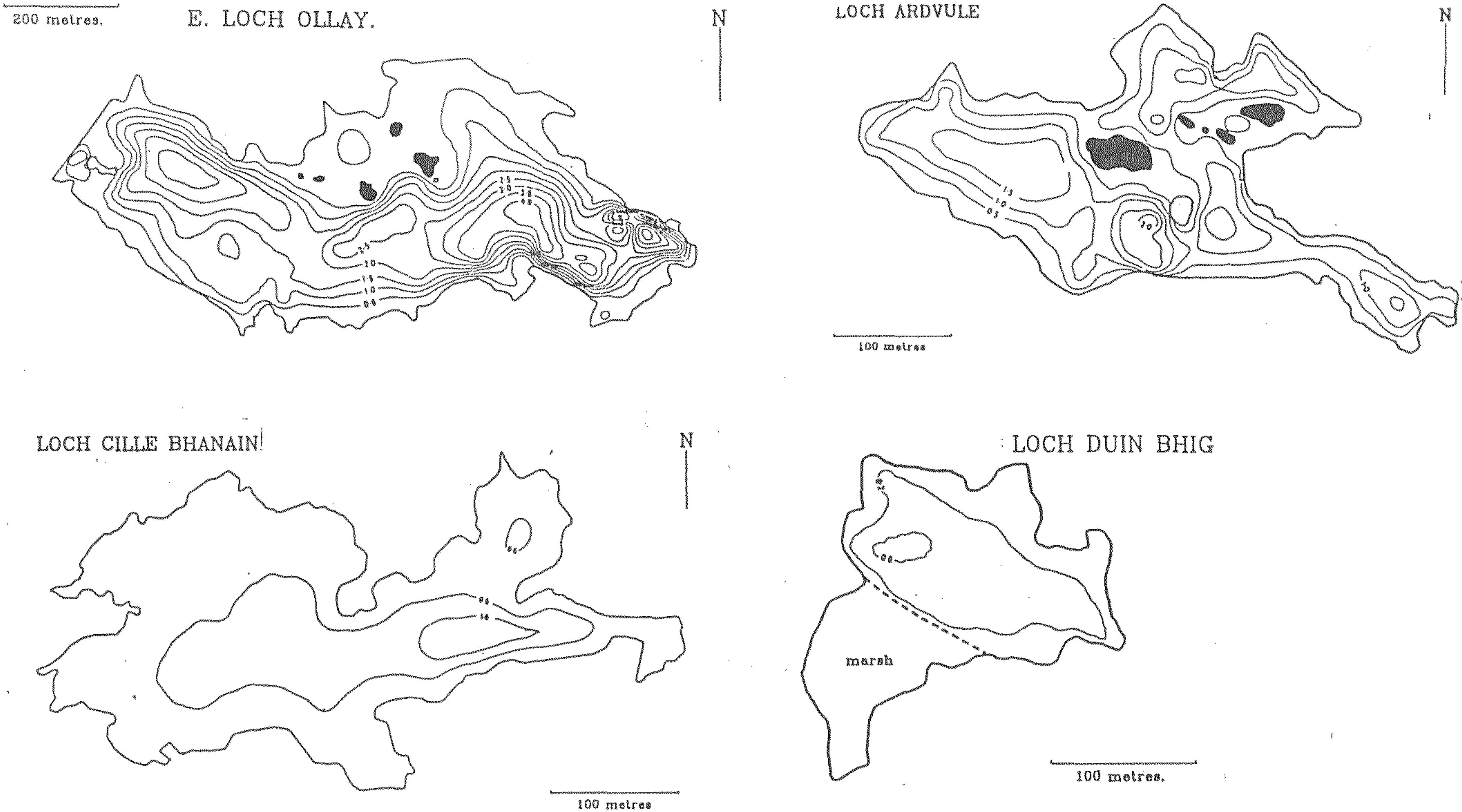


Figure 4. Bathymetric maps for East Loch Ollay, Loch Ardvule, Loch Cille Bhanain, Loch Duin Bhig.

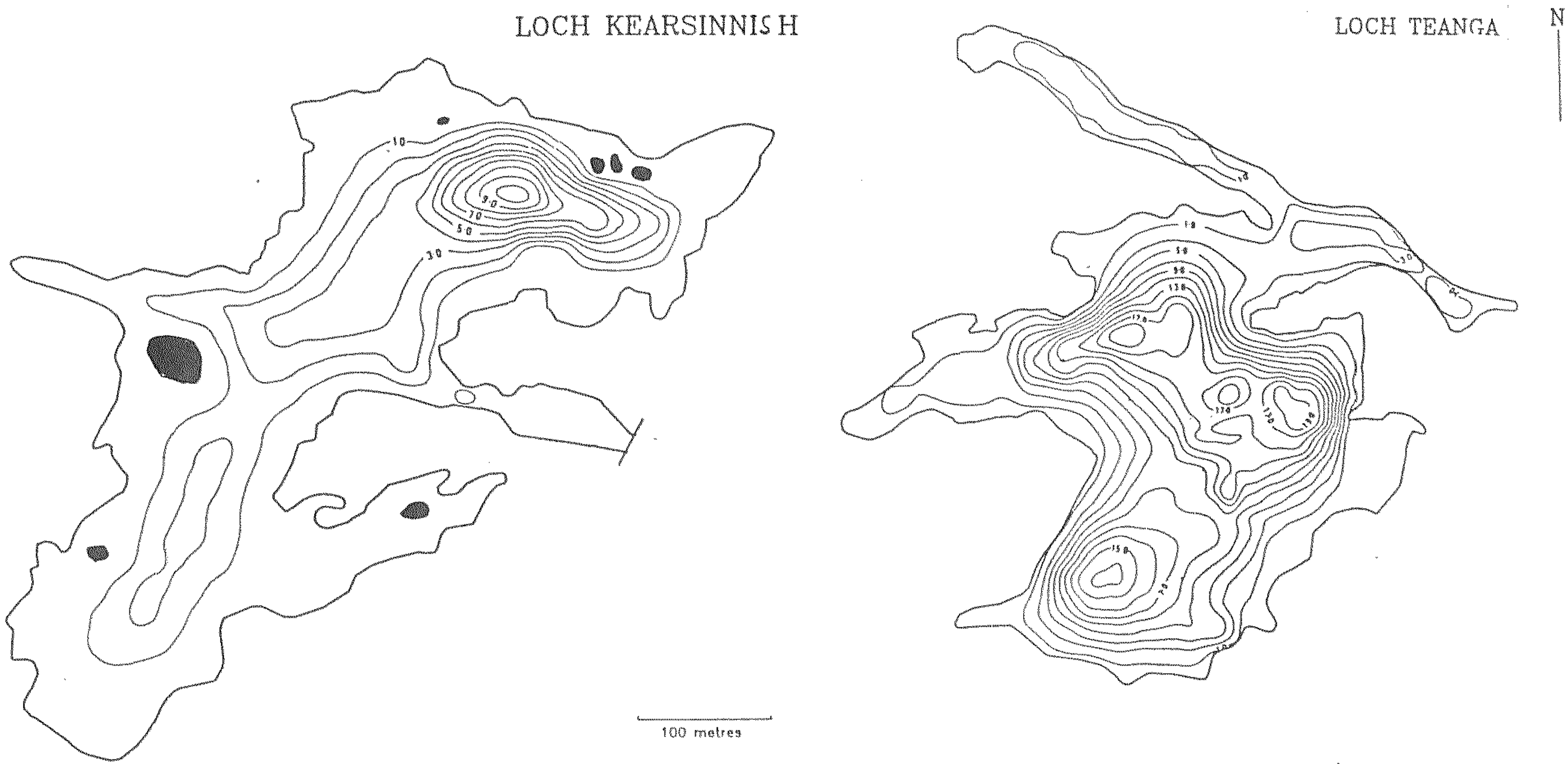


Figure 5. Bathymetric maps for Loch Kearsinnish and Loch Teanga.

formed by sand bars otherwise the basins are essentially simple in shape. In addition several lochs, eg. Hallan and Aird an Sgairbh have eastern arms that occupy rocky channels extending into the blacklands and at the latter site this channel forms a separate sub-basin. Small islands of rock or sand are typical of these lochs and are often host to breeding colonies of gulls during the spring.

Lochs Trosaraidh, Eilean, Nighe, Cuithe Moire, Mid Ollay and East Ollay occur on the blacklands or on land transitional to machair. They are usually less than 6m deep, have margins formed mainly of bedrock, contain fine black detrital sediment in the deeper parts, and usually lie in simple basins interrupted only by the occurence of islands. Lochs Briste and Nan Capull are exceptional sites in that the former is surrounded by a mat of floating vegetation and the latter contains sediment composed of sandy-micaceous silt.

The two upland lochs, Kearsinish and Teanga are more than 10m deep and both are linked to unusual rocky channels that occupy geological fault lines orientated NW-SE. The bed-rock margins of these lochs steeply shelve down to fine black sediments which appear to be derived mainly from eroding peat within the catchments. Loch Teanga is the deepest and possesses the most complex bathymetry of all the sites surveyed. It is divided into four sub-basins and sediment sampling indicated the presence of rock outcrops towards the loch centre.

Water quality.

Using water pH, alkalinity and conductivity (Table 3) as a simple index of water quality the sites can be roughly divided into two groups, the first characterized by high values for pH ( >7.5), alkalinity (>50 mg $CaCO_3$/l) and conductivity ( >350µS $cm^{-1}$), the second is characterized by considerably lower values of these variables. East Loch Ollay shows affinities with both groups having a relatively high pH but low conductivity. The highest alkalinities occur in the machair lochs and are probably due to the high abundance of shell fragments in the surrounding sand. Predictably the lowest alkalinities are found in the upland lochs which also have the lowest pH values. However only at one site, Loch Teanga, was the pH below 6. Loch Ardvule was easily the least dilute site having a water conductivity value of over 2000 µS $cm^{-1}$ and being less than 10m from the high tide mark must regularly receive direct inputs of sea salts from spray.

Ionic analysis of the selected six water samples shows

Table 3. Water quality measurements and sites distance from the west or southwest coast. Sites are numbered according to Table 1.

| LOCH | pH | ALKALINITY (mg Ca $CO_3$ $l^{-1}$) | CONDUCTIVITY ($\mu S$ (25°C)$CM^{-1}$ | SECCHI DISC DEPTH (m) |
|---|---|---|---|---|
| 1. | 7.5 | 40.0 | 502 | 1.0 |
| 2. | 7.4 | 23.7 | 310 | ND |
| 3. | 7.3 | 24.5 | 290 | ND |
| 4. | 7.4 | 20.0 | 330 | 1.3 |
| 5. | 8.2 | 04.0 | 510 | ND |
| 6. | 7.1 | 11.0 | 330 | ND |
| 7. | 7.1 | 15.5 | 340 | ND |
| 8. | 8.5 | 148.0 | 570 | ND |
| 9. | 8.0 (7.9) | 61.4 (53.2) | 540 (502) | ND (1.3) |
| 10. | 8.6 | 124.4 | 500 | ND |
| 11. | 8.1 | 52.0 | 360 | 2.0 |
| 12. | 7.7 | 24.2 | 290 | 2.3 |
| 13. | 8.2 | 52.0 | 2,100 | 0.4 |
| 14. | 8.0 | 52.8 | 370 | ND |
| 15. | 8.4 | 61.4 | 592 | 0.3 |
| 16. | 6.8 | 2.4 | 230 | 4.5 |
| 17. | 5.7 | 1.0 | 163 | 3.5 |

ND = Not determined where light penetration was > water depth.

( ) Indicate values from the east basin of Loch Aird na Sgairbh.

Table 4. Major cation and anion concentrations (in u eq⁻¹ ) in six South Uist lochs.

| LOCH | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $HCO_3^-$ | $Cl^-$ | $NO_3^-$ | $SO_4^{2-}$ |
|---|---|---|---|---|---|---|---|---|
| Aird na Sgairbh (East) | 2343 | 64 | 1095 | 644 | 1064 | 2980 | 140 | 280 |
| Briste | 2183 | 87 | 1100 | 594 | 794 | 3160 | 131 | 496 |
| Nighe | 1700 | 54 | 520 | 446 | 310 | 2360 | 30 | 310 |
| Cuithe Moire | 1739 | 55 | 380 | 437 | 220 | 2296 | 7 | 297 |
| Kearsinnish | 1209 | 28 | 180 | 363 | 120 | 1640 | 93 | 187 |
| Teanga | 981 | 23 | 110 | 255 | 20 | 1160 | 7 | 233 |

Table 5. Simple correlation coefficient matrix for morphometric characteristics estimated for each of the seventeen lochs and site distance from the west or southwest coast.

| | Max Depth (m) | Mean Depth (m) | Area ($m^2$) | Volume ($m^3$) |
|---|---|---|---|---|
| Mean depth (m) | $0.97^{xx}$ | | | |
| Area ($m^2$) | 0.07 | 0.01 | | |
| Volume ($m^3$) | $0.71^{x}$ | $0.70^{x}$ | $0.56^{x}$ | |
| Distance (Km) | $0.89^{xx}$ | $0.88^{xx}$ | 0.32 | $0.68^{x}$ |

$^{x}$ P = > 0.02 $^{xx}$ P = > 0.001

sodium, calcium, magnesium, chloride and bicarbonate to be the major ions present (Table 4). Corresponding with the conductivity and alkalinity values (see Table 3), these ions are present at relatively high concentrations in the coastal machair lochs and the lowest values occur in those lochs furthest from the west coast such as Loch Teanga. Sulphate concentrations are an exception showing no correspondence with conductivity or with the other variables listed in Table 3. Chloride is the predominant ion and is present at a concentration of more than 1000 $\mu$ eq l-1 in all six samples. Concentrations of calcium and nitrate are notably high in the two coastal lochs Briste and Aird na Sgairbh but nitrate shows the greatest variation.

The diatoms

Diatoms valves in surface sediment samples from several blackland coastal lochs were very fragmented making identification of less common species difficult. In Loch Eileen for example virtually all the valves present were broken. This breakage is probably attributable to the exposed and shallow nature of these sites where vigorous wind induced surface sediment resuspension must be frequent. Interestingly, in the sandy deposits of machair lochs where light penetrates to the bottom sediment ( cf. Table 3) diatom valves were usually complete and undamaged. This indicates that here the sampled diatoms were present mainly as a living community whereas those diatoms sampled in the peaty blackland loch sediments were present as a dead assemblage.

The diatom taxa identified in each loch surface sediment sample, including an additional sample from Loch Aird na Sgairbh( East basin), are mainly periphytic in habit and are listed in the appendix. The distribution of the most frequent species are shown in Fig. 6 where sites are ordered according to water conductivity and pH. Sediment samples from ten coastal lochs with high water conductivity and pH values, Ardvule, Duin Bhig, Aird na Sgairbh, West Loch Ollay, Cuithe Moire, Cille Bhanian, Nighe, and Mid and East Loch Ollay are all dominated by one species, Fragilaria elliptica. The dominance of Fragilaria elliptica is displaced by Cocconeis placentula in three coastal lochs Hallan, Briste and Liana Moire. Achnanthes minutissima and A. microcephala occur in most samples but are particularly abundant in Loch nan Capul. Only in three of the coastal

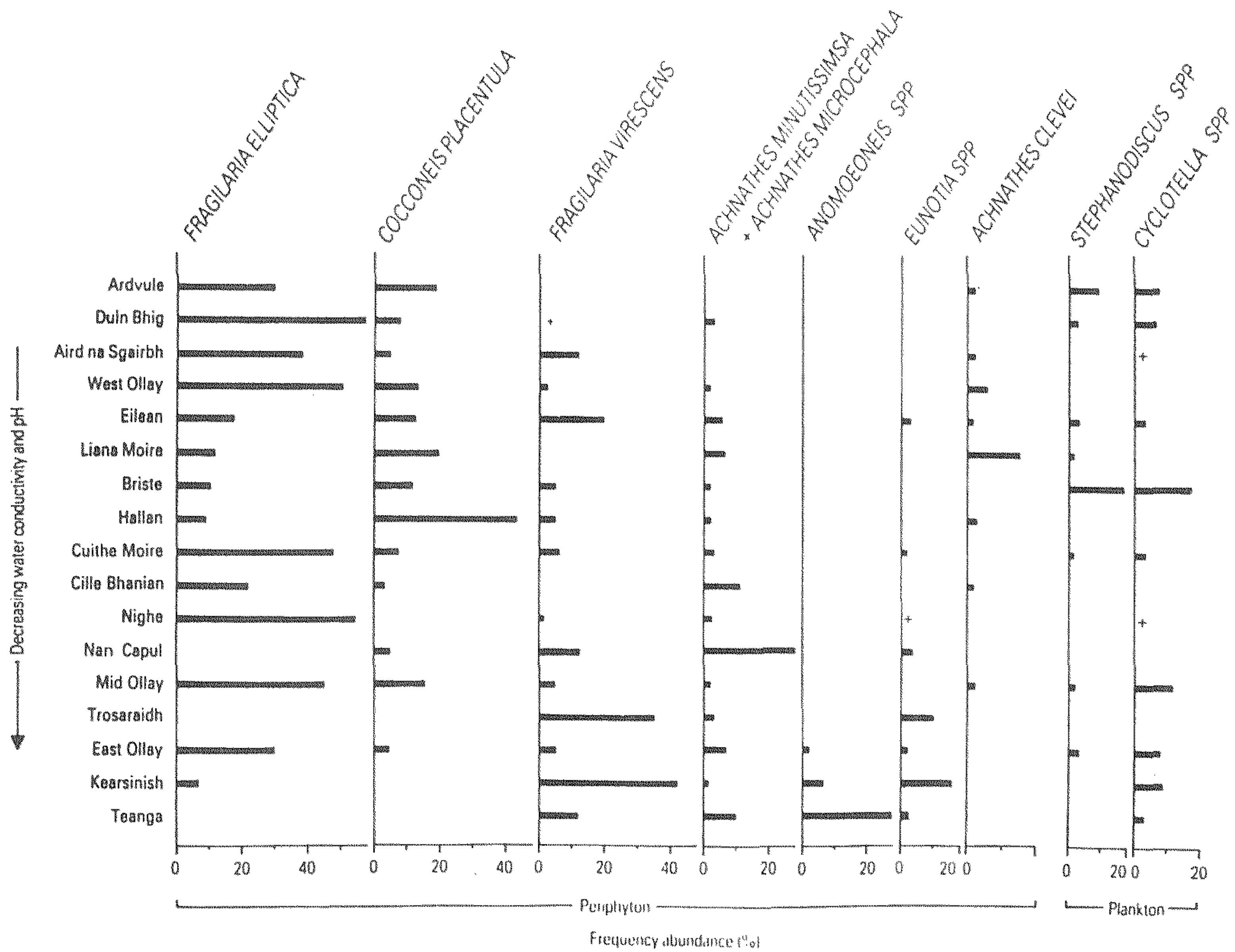


Figure 6. Percentage frequencies of the common diatom taxa in the surface sediments of the 17 South Uist lochs placed in order of increasing water conductivity and pH.

lochs, Liana Moire, Briste and Nan Capul, are the diatom assemblages not dominated by the Fragilaria-Cocconeis group but by A. clevei and C. placentula, by Cyclotella pseudostelligera and F. elliptica and by A. minutissima respectively. Fragilaria virescens was the most abundant diatom in the samples from lochs Trosraidh and Kearsinnish. The two eastern lochs of lowest conductivity and pH contained substantially different floras with Eunotia veneris common in Kearsinish and Anomoeoneis vitrea abundant in Loch Teanga. The planktonic diatoms, Cyclotella spp. and Stephanodiscus spp., only exceeded 10% total frequency abundances in two sites, Loch Briste and Mid Loch Ollay.

Although the most abundant diatom species are the same at all the coastal sites there are considerable differences between the less common diatoms. For example in lochs Trosaraidh, Cille Bhanian and Nan Capull the less frequent species include Tabellaria flocculosa and Frustulia spp. and Eunotia spp., all indicative of acid environments (cf Hustedt 1937-39). This effect is also demonstrable to a small degree within a site by comparing diatoms from the hard sand bottom of the west sub-basin with those in the black detrital mud of the rocky eastern sub-basin in Loch Aird na Sgairbh (see sites 9 and 9A, appendix ). Here many diatoms are common to both samples but, although rare, Eunotia spp. only occurred in the eastern sample (cf. water quality Table 3). However, the overall taxonomic similarity of these and all the machair loch samples is evident even though available periphytic habitats are often very different.

To produce an overview of the relationships between diatom species abundance and species occurrence at all the sites the multi-variate statistical programes DECORANA and TWINSPAN (Hill 1979) were employed. First to ordinate the species data, second to ordinate the sites using the species data, and third to construct a hierarchical classification of the sites according to differentiating or indicator species. The analysis produced clearest results when the percentage species data was transformed into abundance levels and no down-weightings given to rare species. The species ordination produced a good separation of the taxa along DECORANA axis 1 when plotted against axis 2 (Fig. 7). These two axes accounted for 66% of the total variance in the data. On axis 1 common diatoms such as Fragilaria elliptica, F. virescens and F. construens have intermediate scores whilst Cocconeis placentula and planktonic diatoms (Cyclotella pseudostelligera and Stephanodiscus spp.) have low scores. Diatoms charactersitic of acid water, Amonoeoneis vitrea, Eunotia veneris and Achnanthes recurvata, all have

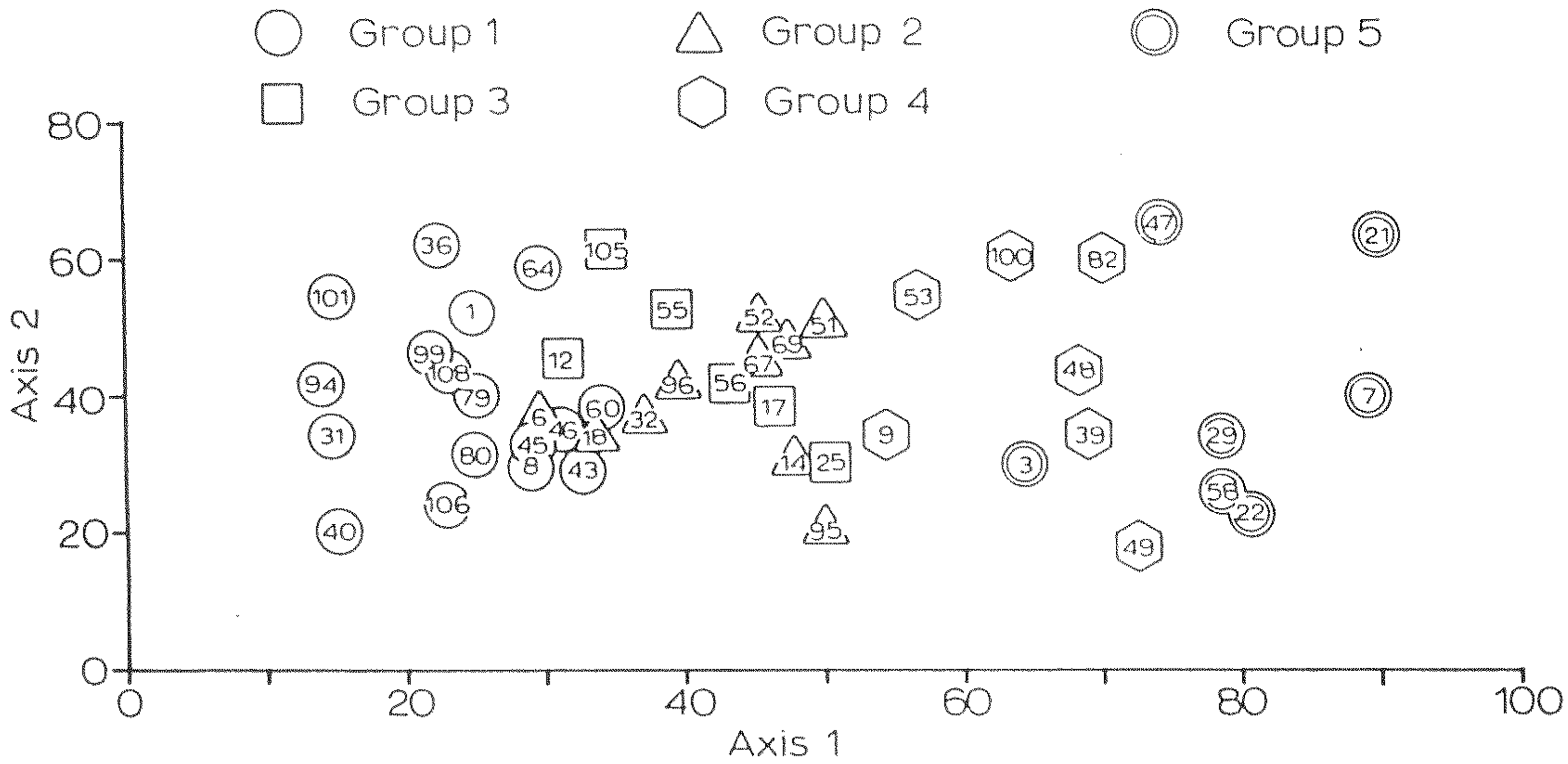


Figure 7. DECORANA ordination of diatom species occurring in the surface sediments of the 17 South Uist lochs. Individual species are indicated numerically and symbols are according to the TWINSPAN species classification (cf. Fig. 9 and see text).

high scores. Ordination of the sites according to the diatom assemblages also produced the best separation along axis 1 (Fig. 8) and are classified into five groups (see dotted enclosures, Fig. 8) by TWINSPAN (Fig 9), indicator species and abundance levels are also given in Fig. 9. The lochs Teanga and Kearsinish are removed first by the TWINSPAN classification, confirming that the diatom assemblages at these sites are substantially different from those at other sites. The next division occurs between those sites which have a high abundance of Fragilaria virescens or Cocconeis placentula. The final useful separations are made between those sites where planktonic species Stephanodiscus invisitatus and S. hantzschii are common (group 1) and those sites where periphytic forms occur viz. Achnanthes clevei (group 2), Fragilaria elliptica (group 3), and Tabellaria flocculosa (group 4), as indicator species. Applying results of the TWINSPAN site classification to the species ordination plot ( see symbols on Fig. 7) shows that species characteristic of site groups 1, 4 and 5 are clearly separated along axis 1 whereas those in groups 2 and 3 are not.

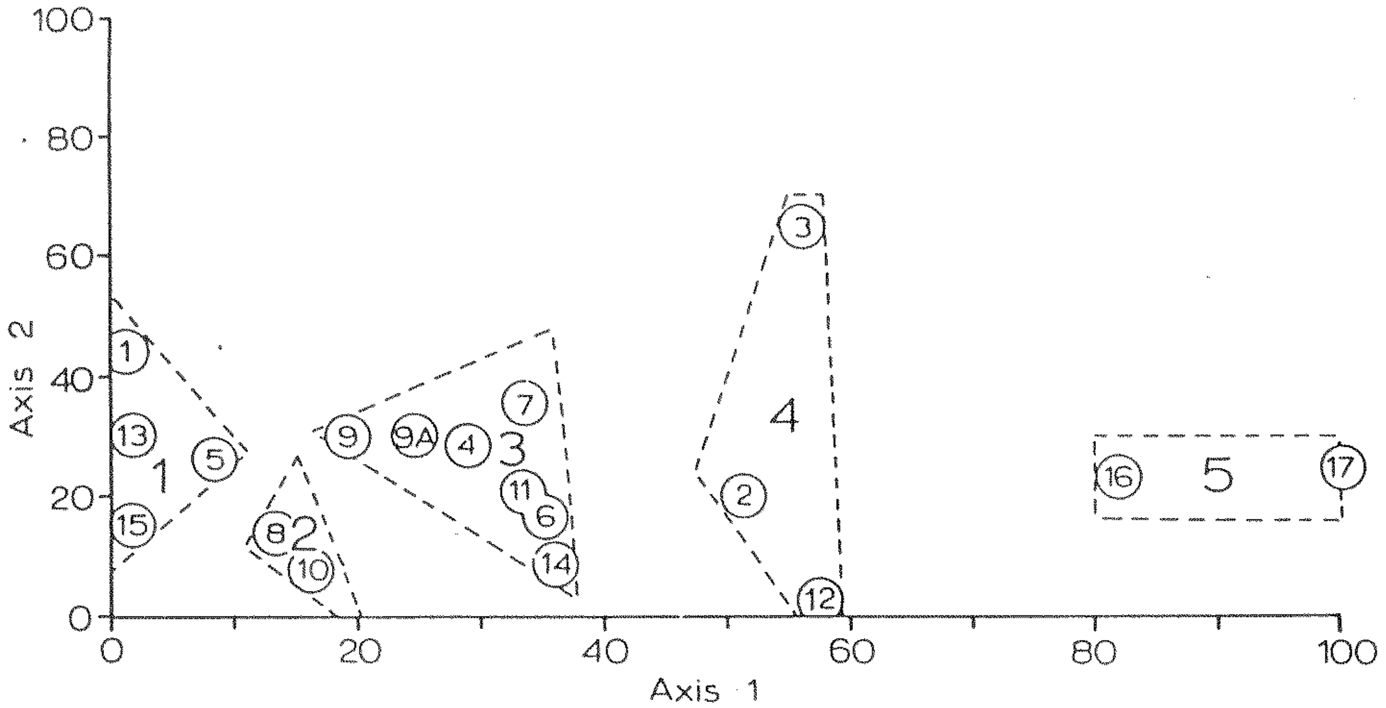


Figure 8. DECORANA ordination of the sites based on the diatom data. The loch sites are identified numerically (1 to 17) and enclosed by dotted lines into five groups according

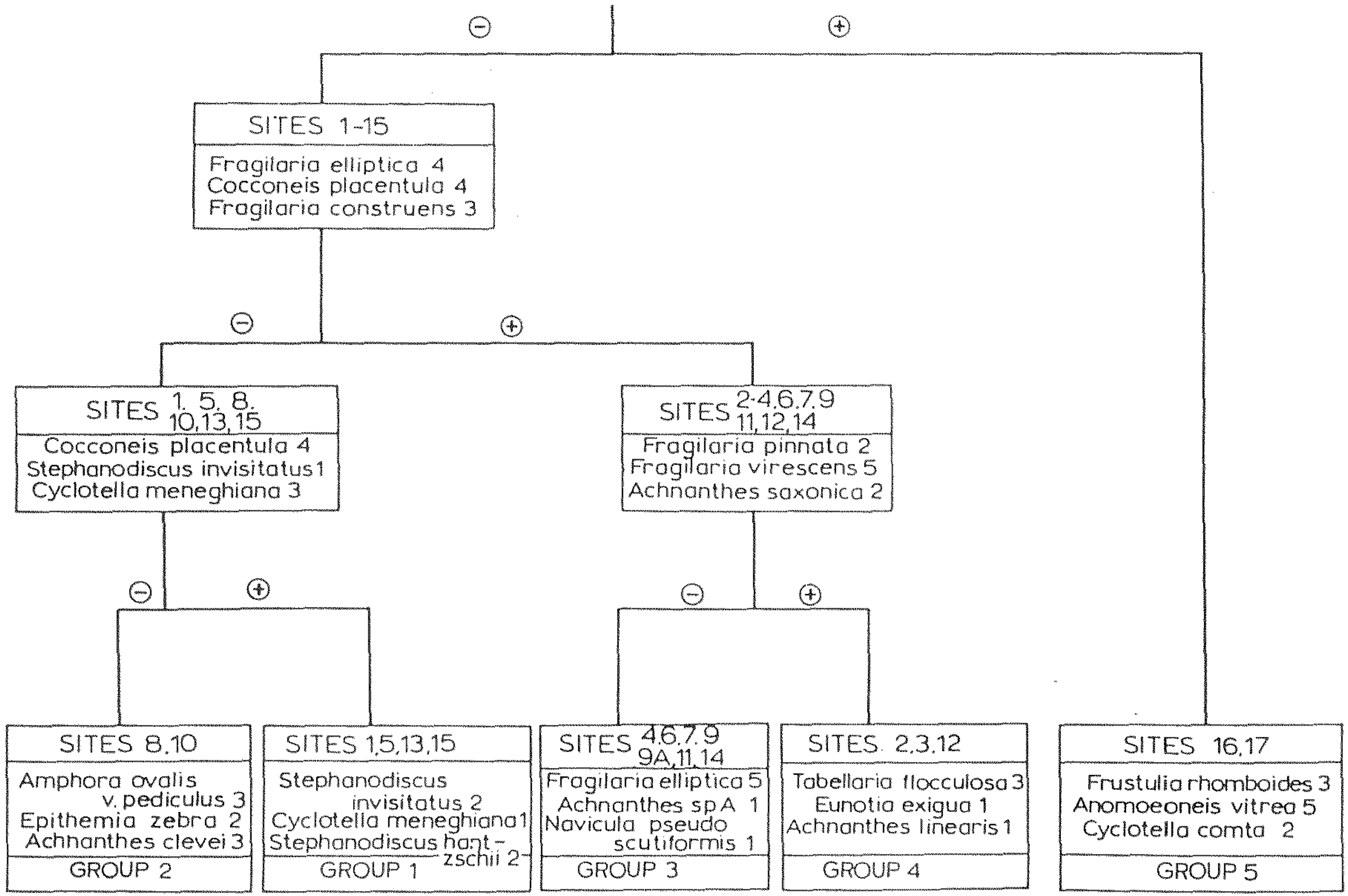


Figure 9. TWINSPAN classification dendrogram of the 17 sites South Uist lochs based on the surface sediment diatoms.

DISCUSSION.

Advanced digital mapping techniques were employed to produce high quality bathymetric contour maps of selected loch basins and reliable estimates of morphometric parameters such as loch volume, surface area and mean depth. The computational techniques are similar to those described by Battarbee et al. (1983) but an improved version of the contouring algorithm has been incorporated into a graphics software package that is now commercially available (MAPICS 1985). Despite the computational precision with which the morphometric calculations are made there are several sources of error in the results and all are a consequence of the field data. In several cases where a loch possesses one or more islands there are no depth points between the island and the shore-line so causing contour lines to be constrained to pass on one side of the island. This effect was particularly acute in West Loch Ollay and necessitated removal of all the zero depths for islands from the data set and re-computation of contours. Inaccessible bays and channels associated with several lochs were not surveyed and depths were assumed to fall within the first depth contour line. Perhaps the most serious critisims are not of the errors directly associated with computational methods but concern the representativity of morphometric parameters calculated from data collected on one occasion only. For example, depths, volumes, and surface areas of the ground water maintained shallow West coast lochs fluctuate considerably both seasonally and annually according to rainfall. Hence, without some knowledge of these changes it is difficult to comment on possible changes in loch water level caused by improved land drainage. However, it is evident from this survey that a substantial lowering of the water table in the machair region by 0.5m would cause several lochs, Nan Capull, Trosaraidh, Liana Moire to virtually disappear.

Several studies of relationships between various morphometric parameters of Scottish lochs generally (Gorham 1958) and lochs on Shetland (George & Maitland 1984) have been made. Despite doubts concerning seasonal fluctuations, relationships between estimated morphometric parameters of the South Uist lochs and distance from the west coast are examined in Table 5 using simple correlation analysis. Not surprisingly, mean and maximum depths are highly correlated and both are correlated with distance from the west coast. Unfortunately the number of sites surveyed is insufficient to attempt separation of the maximum/mean depth relationship according to basin type (cf. Gorham 1958). Loch volume is positively linked with the depth parameters but less strongly with loch area. More interestingly no significant correlation occurred between loch surface area and depth. This unusual feature of the data set arises from the abundance of machair and blackland lochs that vary greatly in area (0.5-32.8 ha) yet are all less than 2.5m deep. Consequently, the supposition that in studies of island lochs it should be possible to predict morphometric characteristics simply from map measurements of surface area (George & Maitland 1984) is not substantiated here.

For freshwaters in a maritime climate, the effect of distance from the coast in the direction of the prevailing winds on water quality (particularly conductivity and pH), is well known (e.g. Gorham 1955, Mackereth 1957, Sugawara 1961, Flower 1982, Sutcliffe & Carrick 1983, 1984). This distance effect on water quality in the South Uist lochs is clearly evident from the water chemistry data and is further supported by correlation analysis (Table 6), where pH, alkalinity, and conductivity are significantly and negatively related to site distance from the west

Table 6. Simple correlation coefficient matrix for water quality variables measured in the seventeen lochs and distance from the west or southwest coast.

| | pH | ALKALINITY | CONDUCTIVITY |
|---|---|---|---|
| Alkalinity | $0.96^{xx}$ | | |
| Conductivity | $0.70^{xx}$ | $0.66^{xx}$ | |
| Distance | $-0.56^{x}$ | $-0.51^{x}$ | $-0.96^{xx}$ |

$^{x}$ $P = < 0.05$ $^{xx}$ $P = < 0.01$

coast. Log transformation of the data improved correlation coefficients considerably, indicating that within the coastal fringe water quality, particularly conductivity, changes exponentially with distance from the coast. As expected, pH and alkalinity are closely correlated and the small variance of the correlation is probably attributable to photosynthesis effects. Water conductivity is weakly related to pH and alkalinity but shows the strongest negative correlation with distance, where:

$$\log \text{conductivity}(\mu S_{25°} cm^{-1}) = 2.8 - 0.38 * \log \text{distance(km)}$$

$$S.E. = +/-0.07, \; r^2 = 0.92, \; n = 17$$

Over one hundred years ago, Smith (1872) recognised that the proportion of sea salts increased in precipitation towards the coast and additionally that chlorides and sulphates also increased in areas of industrial pollution. The sources of major ions in South Uist water samples can be indicated by comparing their ionic ratios with those in seawater (Table 7). It is clear that the sodium:chloride ratios in the loch waters are very similar to that in seawater and as the gneiss rock or sand lake basins preclude significant catchment sources of these ions their presence can be reasonably attributed to the deposition of wind-borne sea salts. The ionic ratios of sodium:magnesium and

Table 7. Ionic ratios of sodium with other ions in six South Uist lochs compared with those in seawater.

| ION RATIO | LOCH BRISTE | LOCH AIRD NA SGAIRBH | LOCH LIANA MOIRE | LOCH NIGHE | LOCH KEARSINISH | LOCH TEANGA | SEA WATER* |
|---|---|---|---|---|---|---|---|
| Na:Mg | 3.7 | 3.6 | 4.0 | 3.8 | 3.3 | 3.5 | 4.3 |
| Na:K | 25.1 | 36.6 | 31.6 | 31.5 | 43.2 | 38.7 | 46.8 |
| Na:Ca | 2.0 | 2.1 | 4.6 | 3.3 | 6.7 | 8.1 | 22.8 |
| Na:$SO_4$ | 4.4 | 8.4 | 5.9 | 5.5 | 6.5 | 3.8 | 8.3 |
| Na:Cl | 0.7 | 0.8 | 0.8 | 0.7 | 0.7 | 0.8 | 0.8 |
| Na:$NO_3$ | 16.7 | 16.7 | 248.4 | 56.7 | 13.1 | 127.0 | > 5000 |

*from Riley & Skirrow (1965).

sodium:potassium also indicate a predominantly marine source for these ions, the ratios are however all less than in the sea indicating small terrestrial contributions of magnesium and potassium (cf. Gorham 1955), significantly so for potassium in Loch Briste. The sodium:calcium ratio is very low in the coastal lochs due to high concentrations of calcium (see Table 4). The large quantity of wind-blown bivalve shell debris on the South Uist west coast and in the machair is well known (Richie 1979) and doubtless accounts for the relatively high calcium levels in these sites. Similarly Gorham (1961) attributed high calcium levels in dune slacks on the north English coast to the presence of calcareous shell fragments. Calcium then is, like sodium, largely supplied to these coastal freshwaters from the sea but indirectly so through the dissolution of biogenic calcium carbonate. This abundance of calcium carbonate is largely responsible for the high pH and alkalinities of the coastal lochs. In the eastern lochs of South Uist however biogenic calcium is scarce so that the sodium:calcium ratio is correspondingly higher and acid drainage from blanket peat produces waters with low pH and alkalinity. Interestingly, in the Shetland Islands where shell rich soils are less common the lochs are predominantly acid, have low alkalinities and are highly coloured (Carter & Bailey-Watts 1981).

The sodium:sulphate ratio varies similarly to that of sodium:calcium, being considerably lower than in seawater in five of the six lochs sampled. The sulphate concentration appears to be unrelated to distance from the sea and, in the absence of anv known major soures of atmospheric pollution on South Uist, the excess over the marine contribution appears to be derived from catchment sources. It is noteworthy that lowest sodium:sulphate ratios occur in sites containing a considerable quantity of decaying vegetation (Loch Briste) or where blanket peat erosion is occurring (Loch Teanga). The sodium:nitrate ratios in the lochs are strikingly different from that in seawater and are caused by relatively high concentrations of nitrate in the loch water. This indicates very significant catchment contributions of nitrate, possibly arising from leaching of agricultural fertilizers applied to the sandy soils.

Most of the species of diatoms found in the surface sediment samples are periphytic in habit and planktonic forms were generally uncommon. Also, species diversity was low, particularly in the shallow machair lochs, where over 50% of the diatom assemblages was accounted for by between one and three species. This, together with the absence of frustule breakage, indicates that the diatoms in these samples consisted predominantly of living cells attached to the sandy sediment. Planktonic diatoms were only common at Loch Briste and Mid Loch Ollay and the occurrence of Stephanodiscus spp. and Cyclotella pseudostelligera at both these sites may indicate agricultural enrichment (cf. Platt Bradbury 1976). However the occurrence of these species in Ardvule is more probably linked to nutrients leached from decomposing seaweed at the seaward end of the loch.

DECORANA ordination of the species abundance and occurrence data produced good separation of species according to site indicating that the diatom assemblages are related to one or more environmental factors. The possible relationships between the first three axes of the site ordination with water quality and with drainage basin morphometric characteristics were examined using Rank-Spearman correlation (Table 8). The three water quality variables pH, alkalinity and conductivity, are all significantly related to DECORANA axis one only and the rank correlation with conductivity was the most significant (at $P= < 0.001$). No significant correlations (at $P=>0.05$) occurred between the ordination axes and the morphometric characteristics, depth and loch area. The frequency of at least the diatom phytoplankton might be expected to increase with loch size, however, it also

Table 8. Matrix of Spearmann's coefficients of rank correlation for water quality variables, bathymetric characteristics and DECORANA scores for axes one, two and three.

| | AXIS 1 | AXIS 2 | AXIS 3 |
|---|---|---|---|
| pH | $-0.71^{xx}$ | 0.23 | 0.24 |
| Alkalinity | $-0.57^{x}$ | 0.12 | 0.19 |
| Conductivity | $-0.75^{xxx}$ | 0.02 | 0.04 |
| Max. Depth | 0.41 | -0.25 | -0.02 |
| Mean Depth | 0.29 | -0.38 | 0.06 |
| Area | 0.16 | 0.32 | -0.02 |

$^{x}P =< 0.02$ $^{xx}P = < 0.01$ $^{xxx}P = < 0.001$

appears to be unrelated to morphometric factors. In fact for South Uist lochs the frequency of planktonic diatoms is highest in one of the smallest lochs (Loch Briste) for which high nutrient inputs seem the most likely explanation. The environmental significance of DECORANA scores on axes two and three is unknown although nutrient concentrations and substrate variation may be of some importance.

Considerable variation in diatom communities can occur within a site according to substrate (Jørgensen 1948, Jones and Flower 1986). However species composition of the surface sediment diatoms in the South Uist lochs seems remarkably independent of substrate type as little floristic difference occurs between sites lying in sand or in rock basins where water quality is similar. An exception may be the abundance of Cocconeis placentula over Fragilaria elliptica in several samples, particularly in lochs Hallan and Liana Moire. This could possibly be explained, not from water quality variation, but by an over-representation of diatoms supplied from locally abundant stands of Potomogeton at these sites where the epiphyton was dominated by C. placentula (Flower, unpub.). Water transparency appears to be unimportant in determining species composition of the surface sediment diatom assemblages in South Uist lochs.

Despite the highly significant correlation of DECORANA axis 1 with water conductivity it is not possible to separate the effects of conductivity from those of pH and alkalinity as all three variables are co-related in in these waters (cf. Table 6). Nevertheless, water quality seems to be of primary importance in controlling the distribution of diatoms in South Uist freshwaters even where large differences in substrates occur. As diatoms are good indicators of both salinity and pH it is likely that, over a range of sites such as occurs on South Uist, the resulting distribution of diatom taxa is a response to an ecologically effective combination of these water quality variables. The changes in species occurence, according to the water quality gradient across the island, is important and allows the sites to be classified ecologically into five groups (where group 5 sites are of relatively low conductivity and pH). However, whether this classification of the lochs of South Uist is more or less appropriate than one based on physical (cf. George & Maitland 1984) or chemical attributes (Gorham et al. 1983) awaits evaluation according to the possible ways in which the sites may respond to future disturbances.

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# APPENDIX

LISTS OF DIATOM SPECIES AND FREQUENCIES IN SURFACE SEDIMENTS OF THE 17 SOUTH UIST SAMPLE LOCHS.

SITE 1 LOCH BRISTE

| SPECIES | FREQUENCY (%) |
|---|---|
| Cocconeis plancentula Ehr. | 11.7 |
| Cyclotella pseudostelligera Hust. | 11.7 |
| Fragilaria elliptica Schum. | 10.0 |
| Stephanodiscus invisitatus Hohn & Hellerman | 10.0 |
| Stephanodiscus hantzschii Grun. | 6.7 |
| Achanthes lanceolata Breb. | 5.0 |
| Cyclotella meneghiniana Kutz. | 5.0 |
| Fragilaria virescens Ralfs. | 5.0 |
| Fragilaria vaucheriae (Kutz) Boye Peterson | 5.0 |
| Navicula seminulum Grun. | 5.0 |
| Synedra pulchella Kutz. | 5.0 |
| Fragilaria construens (Ehr.) Grun. | 8.8 |
| Navicula pupula Kutz. | 8.8 |
| Nitzschia palea (Kutz.) W. Smith | 3.3 |
| Achnanthes minutissima Kutz. | 1.7 |
| Achnanthes hungarica Grun. | 1.7 |
| Cyclotella sp. | 1.7 |
| Diatoma tenue v. elongatum Lyngc | 1.7 |
| Navicula trivialis Lange-Bertalot | 1.7 |
| Navicula viridula Kutz. | 1.7 |

SITE 2 LOCH NAN CAPULL

| | |
|---|---|
| Achnanthes minutissima Kutz. | 40.5 |
| Fragilaria virescens Ralfs. | 12.2 |
| Achnanthes saxonica Krasske | 6.8 |
| Fragilaria vaucheriae (Kutz.) Boye Peterson | 5.4 |
| Cocconeis placentula Ehr. | 4.1 |
| Gomphonema intricatum Kutz. | 4.1 |
| Achnanthes linearis W. Smith | 2.7 |
| Cymbella gracilis (Rabh) Cleve | 2.7 |
| Opephora martyi Heribaud | 2.7 |
| Tabellaria flocculosa (Roth.) Kutz. | 2.7 |
| Amphora ovalis v. libyca (Ehr.) Cleve | 1.4 |
| Cymbella microcephala Grun. | 1.4 |
| Cymbella gaeumanni Meister | 1.4 |
| Eunotia veneris (Kutz.) O. Muller | 1.4 |
| Eunotia exigua (Breb.) Rabh. | 1.4 |
| Fragilaria construens (Ehr.) Grun. | 1.4 |
| Fragilaria pinnata Ehr. | 1.4 |
| Navicula sp. | 1.4 |
| Navicula pseudoscutiformis Hust. | 1.4 |
| Navicula hungarica Grun. | 1.4 |
| Navicula pupula Kutz. | 1.4 |
| Pinnularia sp. | 1.4 |

SITE 3 LOCH TROSARAIDH

| SPECIES | FREQUENCY (%) |
|---|---|
| Fragilaria virescens Ralfs. | 87.5 |
| Fragilaria elliptica Schum. | 15.8 |
| Eunotia veneris (Kutz.) O. Muller | 8.8 |
| Fragilaria construens (Ehr.) Grun. | 5.6 |
| Opephora martyi Heribaud | 5.6 |
| Tabellaria flocculosa (Roth.) Kutz. | 5.6 |
| Fragilaria pinnata Ehr. | 4.2 |
| Achnanthes minutissima Kutz. | 2.8 |
| Achnanthes linearis W. Smith | 1.4 |
| Achnanthes marginulata Grun. | 1.4 |
| Achnanthes sublaevis Hust. | 1.4 |
| Anomoeoneis vitrea (Grun.) Ross | 1.4 |
| Cymbella sp. | 1.4 |
| Diatoma tenue v. elongatum Lyngb. | 1.4 |
| Frustulia vulgaris v capitata Krasske | 1.4 |
| Navicula trivialis Lange-Bertalot | 1.4 |
| Navicula bryophila Petersen | 1.4 |
| Navicula hassiaca Krasske | 1.4 |
| Nitzschia fonticola Grun. | 1.4 |

SITE 4 LOCH AN EILEAN

| | |
|---|---|
| Fragilaria virescens Ralfs. | 19.2 |
| Fragilaria elliptica Schum. | 17.8 |
| Cocconeis placentula Ehr. | 12.3 |
| Fragilaria pinnata Ehr. | 8.2 |
| Achnanthes conspicua A. Mayer | 5.5 |
| Achnanthes microcephala Kutz. | 4.1 |
| Fragilaria construens (Ehr.) Grun. | 4.1 |
| Eunotia pectinalis v minor (Kutz.) Rabh. | 2.7 |
| Fragilaria vaucheriae (Kutz.) Boye Peterson | 2.7 |
| Stephanodiscus parvus Stoermer & Håkansson | 2.7 |
| Achnanthes minutissima Kutz. | 1.4 |
| Achnanthes sp. | 1.4 |
| Achnanthes clevei Grun. | 1.4 |
| Achnanthes saxonica Krasske | 1.4 |
| Achnanthes lanceolata Brèb. | 1.4 |
| Cyclotella meneghiniana Kutz. | 1.4 |
| Cymbella microcephala Grun. | 1.4 |
| Gomphonema intricatum Kutz. | 1.4 |
| Mastogloia smith Thwaites | 1.4 |
| Navicula veneta Kutz. | 1.4 |
| Navicula pseudoscutiformis Hust. | 1.4 |
| Navicula viridula Kutz. | 1.4 |
| Nitzschia palea (Kutz) W. Smith | 1.4 |
| Tabellaria flocculoca (Roth.) Kutz. | 1.4 |

SITE 5 LOCH HALLAN

| | |
|---|---|
| Cocconeis placentula Ehr. | 42.8 |
| Fragilaria elliptica Schum. | 9.1 |

SITE 5 LOCH HALLAN Contd..

| SPECIES | FREQUENCY (%) |
|---|---|
| Fragilaria construens (Ehr.) Grun. | 6.8 |
| Fragilaria virescens Ralfs. | 5.7 |
| Achnanthes clevei Grun. | 3.4 |
| Achnanthes conspicua A. Mayer | 3.4 |
| Navicula veneta Kutz. | 3.4 |
| Fragilaria vaucheriae (Kutz.) Boye Peterson | 2.3 |
| Mastogloia smithii Thwaites | 2.3 |
| Navicula radiosa v. tenella (Brèb.) Grun. | 2.3 |
| Achnanthes minutissima Kutz. | 1.1 |
| Achnanthes sp. | 1.1 |
| Achnanthes lanceolata Breb. | 1.1 |
| Anomoeneis sp. | 1.1 |
| Cymbella ventricosa Kutz. | 1.1 |
| Diatoma tenue v elongatum Lyngb. | 1.1 |
| Diploneis ovalis (Hilse) Cleve | 1.1 |
| Diploneis oculata (Brèb.) Cleve | 1.1 |
| Fragilaria brevistriata Grun. | 1.1 |
| Navicula sp. | 1.1 |
| Navicula seminulum Grun. | 1.1 |
| Navicula clementis Grun. | 1.1 |
| Navicula viridula Kutz. | 1.1 |
| Nitzschia amphibia Grun. | 1.1 |
| Nitzschia microchphala Grun. | 1.1 |
| Synedra pulchella Kutz. | 1.1 |
| Synedra rumpens Kutz. | 1.1 |

SITE 6 LOCH NA CUITHE MOIRE

| | |
|---|---|
| Fragilaria elliptica Schum. | 48.1 |
| Cocconeis placentula Ehr. | 8.6 |
| Fragilaria virescens Ralfs. | 7.4 |
| Acananthes hungarica Grun. | 3.7 |
| Fragilaria construens (Ehr.) Grun. | 3.7 |
| Achnanthes microcephala Kutz. | 2.5 |
| Cyclotella comta (Ehr) Kutz. | 2.5 |
| Navicula indifferens Hust. | 2.5 |
| Achnanthes minutissima Kutz. | 1.2 |
| Achnanthes rostrata Ostrup | 1.2 |
| Achnanthes linearis W. Smith | 1.2 |
| Caloneis silicula (Ehr.) Cleve | 1.2 |
| Diploneis ovalis (Hilse) Cleve | 1.2 |
| Epithemia zebra (Ehr.) Kutz. | 1.2 |
| Eunotia pectinalis v.minor (Kutz) Rabh. | 1.2 |
| Fragilaria pinnata Ehr. | 1.2 |
| Mastogloia smithii Thwaites | 1.2 |
| Melosira sp. | 1.2 |
| Navicula pseudoscutiformis Hust. | 1.2 |
| Navicula hungarica Grun. | 1.2 |
| Navicula trivialis Lange-Bertalot | 1.2 |
| Navicula dicephala (Ehr) W. Smith | 1.2 |
| Nitzschia terrestris (Petersen) Hust. | 1.2 |
| Stauroneis producta Grun. | 1.2 |
| Stephanodiscus minutula (Kutz) Round | 1.2 |

SITE 7 LOCH NIGHE

| SPECIES | FREQUENCY (%) |
|---|---|
| Fragilaria elliptica Schum | 54.9 |
| Fragilaria pinnata Ehr. | 26.2 |
| Navicula indifferens Hust. | 2.5 |
| Achnanthes minutissima Kutz. | 1.6 |
| Achnanthes sp. | 1.6 |
| Achnanthes saxonica Krasske | 1.6 |
| Fragilaria virescens Ralfs. | 1.6 |
| Fragilaria construens (Ehr) Grun. | 1.6 |
| Navicula pseudoscutiformis Hust. | 1.6 |
| Achnanthes microcephala Kutz. | 0.8 |
| Achnanthes umara Carter | 0.8 |
| Achnanthes lanceolata v. elliptica Cleve | 0.8 |
| Cyclotella meneghiniana Kutz. | 0.8 |
| Diatoma tenue v. elongatum Lyngb. | 0.8 |
| Eunotia pectinalis v. minor (Kutz) Rabh. | 0.8 |
| Fragilatia vaucheriae (Kutz) Boye Peterson | 0.8 |
| Navicula trivialis Lange-Bertalot | 0.8 |

SITE 8 LOCH NA LIANA MOIRE

| | |
|---|---|
| Cocconeis placentula Ehr. | 19.3 |
| Fragilaria elliptica Schum. | 12.0 |
| Amphora ovalis v. pediculus Kutz. | 8.4 |
| Achnanthes minutissima Kutz. | 4.8 |
| Epithemia zebra (Ehr.) Kutz. | 4.8 |
| Gomphonema intricatum Kutz. | 4.8 |
| Mastogloia smithii Thwaites | 4.8 |
| Achnanthes hungarica Grun. | 2.4 |
| Fragilaria brevistriata Grun. | 2.4 |
| Navicula radiosa v. tenella (Breb.) Grun. | 2.4 |
| Synedra pulchella Kutz. | 2.4 |
| Achnanthes linearis W. Smith | 1.2 |
| Achnanthes microcephala Kutz. | 1.2 |
| Achnanthes lanceolata Breb. | 1.2 |
| Caloneis sp. | 1.2 |
| Cocconeis pediculus Ehr. | 1.2 |
| Diatoma tenue v. elongatum Lyngb. | 1.2 |
| Fragilaria construens (Ehr.) Grun. | 1.2 |
| Navicula veneta Kutz. | 1.2 |
| Navicula trivialis Lange-Bertalot | 1.2 |
| Navicula cincta (Ehr.) Kutz. | 1.2 |
| Navicula rhynchocephala Kutz. | 1.2 |
| Nitzschia amphiba Grun. | 1.2 |
| Stephanoidscus minutula (Kutz.) Round | 1.2 |

SITE 9 LOCH AIRD AN SGAIRBH (West Basin)

| | |
|---|---|
| Fragilaria elliptica Schum. | 39.1 |
| Fragilaria virescens Ralfs. | 11.6 |
| Fragilaria construens (Ehr.) Grun. | 7.2 |
| Navicula veneta Kutz. | 5.8 |

SITE 9 LOCH AIRD AN SGAIRBH (WEST BASIN) Contd.

| SPECIES | FREQUENCY (%) |
|---|---|
| Cocconeis placentula Ehr. | 4.3 |
| Navicula gregaria Donkin | 4.3 |
| Navicula trivialis Lange-Bertalot | 4.3 |
| Epithemia zebra (Ehr.) Kutz. | 2.9 |
| Fragilaria pinnata Ehr. | 2.9 |
| Fragilaria vaucheriae (Kutz.) Boye Peterson | 2.9 |
| Achnanthes haukiana Grun. | 1.4 |
| Achnanthes clevei Grun. | 1.4 |
| Achnanthes saxonica Krasske | 1.4 |
| Cocconeis disculus Schum. | 1.4 |
| Cyclotella meneghiniana Kutz. | 1.4 |
| Navicula pseudoscutiformis Hust. | 1.4 |
| Navicula hungarica Grun. | 1.4 |
| Navicula graciloides A. Mayer | 1.4 |
| Nitzschia capitellata Hust. | 1.4 |
| Tabellaria flocculosa (Roth.) Kutz. | 1.4 |

SITE 9A LOCH AIRD AN SGAIRBH (EAST BASIN)

| | |
|---|---|
| Fragilaria elliptica Schum. | 36.4 |
| Fragilaria virescens Ralfs. | 22.2 |
| Fragilaria construens (Ehr.) Grun. | 6.1 |
| Cocconeis placentula Ehr. | 4.0 |
| Amphora ovalis v pediculus Kutz. | 3.0 |
| Cocconeis pediculus Ehr. | 3.0 |
| Fragilaris pinnata Ehr. | 3.0 |
| Navicula trivialis Lange-Bertalot | 3.0 |
| Achnanthes clevei Grun. | 2.0 |
| Achnanthes saxonica Krasske | 2.0 |
| Navicula hungarica Grun. | 2.0 |
| Nitzschia amphibia Grun. | 2.0 |
| Achnanthes haukiana Grun. | 1.0 |
| Achnanthes sp. | 1.0 |
| Achnanthes lanceolata Bréb. | 1.0 |
| Cyclotella meneghiniana Kutz. | 1.0 |
| Eunotia pectinalis v minor (Kutz.) Rabh. | 1.0 |
| Eunotia praerupta-nana Berg | 1.0 |
| Fragilaria brevistriata Grun. | 1.0 |
| Melosira italica v subarctica O. Muller | 1.0 |
| Navicula pseudoscutiformis Hust. | 1.0 |
| Stephanodiscus parvus Stoermer & Håkansson | 1.0 |
| Tabellaria flocculosa (Roth.) Kutz. | 1.0 |

SITE 10 LOCH OLLAY-WEST BASIN

| | |
|---|---|
| Fraglaria elliptica Schum. | 51.5 |
| Cocconeis placentula Ehr. | 12.9 |
| Achnanthes clevei Grun. | 5.9 |
| Amphora ovalis v pediculus Kutz. | 5.0 |
| Navicula radiosa v tenella (Bréb.) Grun. | 5.0 |
| Achnanthes haukiana Grun. | 3.0 |
| Cymbella microcephala Grun. | 3.0 |
| Navicula graciloides A.Mayer | 3.0 |

SITE 10 LOCH OLLAY - WEST BASIN CONTD...

| SPECIES | (FREQUENCY%) |
| --- | --- |
| Epithemia zebra (Ehr.) Kutz. | 2.0 |
| Navicula exilis Kutz. | 2.0 |
| Achnanthes minutissima Kutz. | 1.0 |
| Achnanthes sp. | 1.0 |
| Achnanthes rostrata Ostrup | 1.0 |
| Fragilaria virescens Ralfs | 1.0 |
| Navicula scutelloides W. Smith | 1.0 |
| Navicula phyllepta Kutz. | 1.0 |
| Navicula trivialis Lange-Bertalot | 1.0 |

SITE 11 LOCH OLLAY - MIDDLE BASIN

| | |
| --- | --- |
| Fragilaria elliptica Schum. | 45.5 |
| Cocconeis placentula Ehr. | 15.2 |
| Cyclotella comta (Ehr.) Kutz. | 7.1 |
| Fragilaria virescens Ralfs | 5.1 |
| Fragilaria pinnata Ehr. | 5.1 |
| Cyclotella comensis Grun. | 4.0 |
| Achnanthes minutissima Kutz. | 2.0 |
| Achnanthes clevei Grun. | 2.0 |
| Cocconeis pediculus Ehr. | 2.0 |
| Fragilaria construens (Ehr.) Grun. | 2.0 |
| Achnanthes haukiana Grun. | 1.0 |
| Achnanthes lanceolata Brėb. | 1.0 |
| Amphora ovalis v libyca (Ehr.) Cleve | 1.0 |
| Asterionella formosa Hassall | 1.0 |
| Cocconeis disculus Schum. | 1.0 |
| Cyclotella pseudostelligera Hust. | 1.0 |
| Fragilaria vaucheriae (Kutz.) Boye Peterson | 1.0 |
| Pinnularia viridis (Nitzsch.) Ehr. | 1.0 |
| Stephanodiscus minutula (Kutz.) Round | 1.0 |
| Stephanodiscus parvus Stoemer & Håkansson | 1.0 |

SITE 12 LOCH OLLAY - EAST BASIN

| | |
| --- | --- |
| Fragilaria elliptica Schum. | 30.1 |
| Achnanhes minutissima Kutz. | 7.5 |
| Achnanthes linearis W. Smith | 6.5 |
| Cyclotella comta (Ehr.) Kutz. | 6.5 |
| Achnanthes microcephala Kutz. | 5.4 |
| Cocconeis placentula Ehr. | 5.4 |
| Fragilaria virescens Ralfs. | 5.4 |
| Fragilaria pinnata Ehr. | 5.4 |
| Cyclotella kutzingiana Thwaites | 3.2 |
| Stephanodiscus minutula (Kutz.) Round | 3.2 |
| Denticula tenuis Kutz. | 2.3 |
| Eunotia exigua (Brėb.) Rabh. | 2.2 |
| Fragilaria construens (Ehr.) Grun. | 2.2 |
| Gomphonema intricatum Kutz. | 2.2 |
| Tabellaria flocculosa (Roth.) Kutz. | 3.2 |
| Achnanthes rostrata Ostrup | 1.1 |
| Achnanthes saxonica Krasske | 1.1 |
| Anomoeoneis brachysira v thermalis Nov. Comb. | 1.1 |
| Cymbella helvetica Kutz. | 1.1 |
| Fragilaria brevistriata Grun. | 1.1 |
| Frustulia rhomboides V saxonica (Rabh.) De Toni | 1.1 |

SITE 12 LOCH OLLAY - EAST BASIN Contd..

| SPECIES | (FREQUENCY %) |
|---|---|
| Navicula sp. | 1.1 |
| Navicula phyllepta Kutz. | 1.1 |
| Nitzschia fonticola Grun. | 1.1 |
| Rhopalodia gibberula (Ehr.) O. Muller | 1.1 |

SITE 13 LOCH ARDVULE

| | |
|---|---|
| Fragilaria elliptica Schum. | 28.7 |
| Cocconeis placentula Ehr. | 17.8 |
| Cyclotella meneghiniana Kutz. | 8.5 |
| Diatoma tenue v. elongatum Lyngb. | 7.6 |
| Navicula trivialis Lange-Bertalot | 5.1 |
| Stephanodiscus hantzschii Grun. | 5.1 |
| Achnanthes lanceolata Brèb. | 4.2 |
| Stephanodiscus invisitatus Hohn & Hellerman | 4.2 |
| Achnanthes sp. | 2.5 |
| Caloneis sp. | 2.5 |
| Achnanthes clevei Grun. | 1.7 |
| Navicula veneta Kutz. | 1.7 |
| Navicula hungarica Grun. | 1.7 |
| Achnanthes haukiana Grun. | 0.8 |
| Achnanthes saxonica Krasske | 0.8 |
| Achnanthes delicatula Kutz. | 0.8 |
| Cymbella helvetica Kutz. | 0.8 |
| Navicula radiosa v. tenella (Brèb.) Grun. | 0.8 |
| Nitzschia palea (Kutz.) W. Smith | 0.8 |
| Nitzschia amphibia Grun. | 0.8 |
| Nitzschia microcephala Grun. | 0.8 |
| Opephora martyi Heribaud | 0.8 |

SITE 14 LOCH CILLE BHANIAN

| | |
|---|---|
| Fragilaria elliptica Schum. | 22.3 |
| Achnanthes minutissima Kutz. | 9.6 |
| Fragilaria construens (Ehr.) Grun. | 6.4 |
| Navicula seminulum Grun. | 6.4 |
| Achnanthes sp. | 4.3 |
| Amphora ovalis v. pediculus Kutz. | 3.2 |
| Cocconeis placentula Ehr. | 3.2 |
| Eunotia pectinalis v. minor (Kutz.) Rabh. | 3.2 |
| Navicula indifferens Hust. | 3.2 |
| Achnanthes microcephala Kutz. | 2.1 |
| Achnanthes saxonica Krasske | 2.1 |
| Cocconeis disculus Schum. | 2.1 |
| Cymbella microcephala Grun. | 2.1 |
| Fragilaria pinnata Ehr. | 2.1 |
| Mastogloia smithii Thwaites | 2.1 |
| Navicula radiosa v. tenella (Brèb.) Grun. | 2.1 |
| Navicula pseudoscutiformis Hust. | 2.1 |
| Achnanthes rostrata Ostrup. | 1.1 |
| Achnanthes linearis W. Smith | 1.1 |
| Achnanthes clevei Grun. | 1.1 |

SITE 14 LOCH CILLE BHANIAN Contd..

| SPECIES | (FREQUENCY %) |
|---|---|
| Achnanthes flexella (Kutz.) Grun. | 1.1 |
| Asterionella formosa Hassall | 1.1 |
| Caloneis sp. | 1.1 |
| Cocconeis sp. | 1.1 |
| Cyclotella comta (Ehr.) Kutz. | 1.1 |
| Cymbella helvetica Kutz. | 1.1 |
| Cymbella hebridica (Gregory) Grun. | 1.1 |
| Diploneis ovalis (Hilse) Cleve | 1.1 |
| Fragilaria brevistriata Grun. | 1.1 |
| Frustulia rhomboides v. saxonica (Rabh.) De Toni | 1.1 |
| Navicula gregaria Donkin | 1.1 |
| Navicula clementis Grun. | 1.1 |
| Nitzschia capitellata Hust. | 1.1 |
| Nitzschia terrestris (Petersen) Hust. | 1.1 |
| Nitzschia fonticola Grun. | 1.1 |
| Opephora martyi Heribaud | 1.1 |
| Tabellaria flocculosa (Roth.) Kutz. | 1.1 |

SITE 15 LOCH DUIN BHIG

| | |
|---|---|
| Fragilaria elliptica Schum. | 63.7 |
| Cocconeis placentula Ehr. | 5.8 |
| Cyclotella meneghiniana Kutz. | 4.4 |
| Stephanodiscus hantzschii Grun. | 3.5 |
| Achnanthes minutissima Kutz. | 2.7 |
| Cyclotella atomus Hust. | 2.7 |
| Navicula gregaria Donkin | 2.7 |
| Caloneis sp. | 1.8 |
| Diploneis ovalis (Hilse) Cleve | 1.8 |
| Fragilaria virescens Ralfs. | 1.8 |
| Fragilaria construens (Ehr.) Grun. | 1.8 |
| Navicula sp. | 1.8 |
| Achnanthes haukiana Grun. | 0.9 |
| Achnanthes sp. | 0.9 |
| Navicula exilis Kutz. | 0.9 |
| Navicula pygmaea Kutz. | 0.9 |
| Stephanodiscus invisitatus Hohn & Hellerman | 0.9 |
| Synedra pulchella Kutz. | 0.9 |

SITE 16 LOCH KEARSINNISH

| | |
|---|---|
| Fragliara virescens Ralfs. | 42.4 |
| Eunotia veneris (Kutz.) O. Muller | 9.8 |
| Fragilaria elliptica Schum. | 7.6 |
| Achnanthes linearis W. Smith | 5.4 |
| Cyclotella comta (Ehr.) Kutz. | 5.4 |
| Anomoeoneis vitrea (Grun.) Ross | 4.8 |
| Frustulia rhomboides v. saxonica (Rabh.) De Toni | 4.8 |
| Cyclotella comensis Grun. | 3.3 |
| Cymbella helvetica Kutz. | 2.2 |
| Eunotia pectinalis v. minor (Kutz.) Rabh. | 2.2 |
| Achnanthes minutissima Kutz. | 1.1 |
| Achnanthes flexella (Kutz.) Grun. | 1.1 |
| Anomoeoneis brachysira v. thermalis Nov. Comb. | 1.1 |
| Cymbella gracilis (Rabh.) Cleve | 1.1 |
| Cymbella cesatii (Rabh.) Grun. | 1.1 |
| Eunotia robusta Ralfs. | 1.1 |

SITE 16 LOCH KEARSINNISH Contd...

| SPECIES | (FREQUENCY %) |
|---|---|
| Fragliara construens (Ehr.) Grun. | 1.1 |
| Navicula scutelloides W. Smith | 1.1 |
| Navicula cocconeiformis Gregory | 1.1 |
| Nitzschia romana Grun. | 1.1 |
| Pinnularia abujensis (Pant.) Ross | 1.1 |
| Pinnularia sp. | 1.1 |

SITE 17 LOCH TEANGA

| | |
|---|---|
| Anomoeoneis vitrea (Grun.) Ross | 27.3 |
| Fragliara virescens Ralfs. | 10.9 |
| Achnanthes microcephala Kutz. | 10.0 |
| Frustulia rhomboides v. saxonica (Rahb.) De Toni | 9.1 |
| Cymbella gracilis (Rahb.) Cleve | 6.4 |
| Anomoeoneis brachysira v. thermalis Nov. Comb. | 4.5 |
| Eunotia pectinalis v minor (Kutz.) Rabh. | 4.5 |
| Achnanthes recurvata Hust. | 2.7 |
| Cyclotella comensis Grun. | 2.7 |
| Tabellaria flocculosa (Roth.) Kutz. | 2.7 |
| Achnanthes pseudoswazi Carter | 1.8 |
| Cymbella perpusilla A. Cleve | 1.8 |
| Nitzschia sp. | 1.8 |
| Peronia fibula (Brèb. ex Kutz) Ross | 1.8 |
| Achanthes minutissima Kutz. | 0.9 |
| Achnanthes sp. | 0.9 |
| Anomoeoneis serians (Brèb.) Cleve | 0.9 |
| Cyclotella comta (Ehr.) Kutz | 0.9 |
| Cymbella cesatii (Rabh.) Grun. | 0.9 |
| Eunotia veneris (Kutz.) O. Muller | 0.9 |
| Eunotia exigua (Brèb.) Rabh. | 0.9 |
| Eunotia diodon Ehr. | 0.9 |
| Nitzschia fonticola Grun. | 0.9 |
| Nitzschia angustata v acuta Grun. | 0.9 |
| Pinnularia abujensis (Pant.) Ross | 0.9 |
| Pinnularia undulata Gregory | 0.9 |
| Surirella delicatissima Lewis | 0.9 |

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