Phytoplankton Assemblages from 97 Headwater Lakes in Insular Newfoundland: an Assessment of Environmental and Morphometric Influences on Species Distributions and Associations

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PHYTOPLANKTON ASSEMBLAGES FROM 97 HEADWATER LAKES IN INSULAR NEWFOUNDLAND: AN ASSESSMENT OF ENVIRONMENTAL AND MORPHOMETRIC INFLUENCES ON SPECIES DISTRIBUTIONS AND ASSOCIATIONS

by

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ABSTRACT

Scruton, D. A., J. C. Earle, and H. C. Duthie. 1987. Phytoplankton assemblages from 97 headwater lakes in insular Newfoundland: an assessment of environmental and morphometric influences on species distributions and associations. Can. Tech. Rep. Fish. Aquat. Sci. 1585: v + 68 p.

Physical, chemical, and morphometric data, as well as phytoplankton samples, were collected from 109 headwater lakes throughout insular Newfoundland during a two-month period (August 16 to October 18) in 1981. These data were used as a basis for an evaluation of the environmental factors influencing phytoplankton species distributions and associations. A selected subset of 77 phytoplankton taxa from 97 lakes were clustered using a complete-linkage cluster analysis. The final twelve clusters represent the associations of species found occurring together in Newfoundland. Physical, chemical, and morphometric data collected with the phytoplankton served to characterize the environment. Factor analysis of a reduced subset of 23 parameters simplified the original variables into seven derived environmental factors: dystrophy, hardness, salinity, lake size, watershed influence, and orthophosphate enrichment. The resulting orthogonally rotated (VARIMAX) scores comprising these seven factors were correlated with the transformed species abundances. Spearman correlations showed several relationships between species distributions and the seven derived environmental factors. For the most part, the members from each of the cluster groups demonstrated similar relationships with the derived environmental factors. The evidence suggests that the cluster groups may represent species associations; groups of species that co-occur because of their common requirements for a specific set of environmental conditions.

The analyses identified a subset of naturally acidic, dystrophic water bodies but failed to reveal any evidence of anthropogenic acidification in the lake data (no LRTAP factor emerged) or in the species associations. Phytoplankton species numbers demonstrated a trend to decreased diversity with increasing acidity for both total species and in three algal classes (Cyanophyceae, Chlorophyceae, and Cryptophyceae), while algal biomass demonstrated no trend with lake pH. Lower species numbers in the acidic, highly coloured lakes were considered to demonstrate response and adaptation to natural conditions as phytoplankton communities in anthropogenically acidified lakes in other global regions demonstrated much more severely impoverished algal diversity.

RÉSUMÉ

Scruton, D. A., J. C. Earle, and H. C. Duthie. 1987. Phytoplankton assemblages from 97 headwater lakes in insular Newfoundland: an assessment of environmental and morphometric influences on species distriutions and associations. Can. Tech. Rep. Fish. Aquat. Sci. 1585: v + 68 p.

Du 16 août au 18 octobre 1981, on a recueilli des données physiques, chimiques et morphométriques ainsi que des échantillons de phytoplancton dans 109 lacs d'amont de l'île de Terre-Neuve. Ces données ont servi de base à une évaluation des facteurs environnementaux qui influent sur la répartition et l'association des espèces de phytoplancton. Un sous-ensemble de 77 taxons de phytoplancton provenant de 97 lacs ont été regroupés à l'aide d'une analyse typologique à liaison complète. Les douze grappes obtenues représentent des associations d'espèces que l'on a observés ensemble à Terre-Neuve. Les données physiques, chimiques et morphométriques recueillies en même temps que le phytoplancton ont servi à caractériser l'environnement. Une analyse factorielle d'un sous-ensemble réduit de 23 paramètres a réduit les variables initiales en sept facteurs environnementaux dérivés, soit la dystrophie, la dureté, la salinité, la superficie du lac, l'influence du bassin versant et l'enrichissement par orthophosphate. Les cotes obtenues introduites dans l'échantillon par renouvellement (VARIMAX) englobant ces septs facteurs ont été mises en corrélation avec les abondances spécifiques transformées. Les coefficients de corrélation de Spearman ont révélé plusieurs relations entre la répartition des espèces et les sept facteurs environnementaux dérivés. En général, les membres de chaque groupe typologique ont montré des relations semblables avec les facteurs environnementaux dérivés. Ceci porte à croire que les groupes typologiques peuvent représenter les associations spécifiques, c'est-à-dire des groupes d'espèces retrouvées ensemble à cause de leur besoin commun d'un ensemble précis de conditions environnementales.

Les analyses ont identifié un sous-ensemble de nappes d'eau dystrophe naturellement acide mais n'ont pu révéler de signes d'acidification entropogène à partir des données sur les lacs (absence d'un facteur LRTAP) ou dans les associations spécifiques. L'abondance des espèces phytoplanctoniques a montré une tendance vers une diversité diminuée par rapport à une acidité à la hausse pour ce qui est du nombre total d'espèces et des trois familles d'algues (Cyanophyceae, Chlorophyceae et Cryptophyceae) tandis que la biomasse algale n'a pas varié en fonction du pH lacustre. Le plus faible nombre d'espèces dans les lacs acides très colorés a été interprété comme une réaction et une adaptation aux conditions naturelles étant donné que des communautés phytoplanctoniques peuplant des lacs acides d'origine antropogène ont montré une diversité algale de loin beaucoup plus appauvrie.

INTRODUCTION

Studies of the freshwater phytoplankton of the island of Newfoundland are extremely limited. Many of the published contributions to date are either taxonomic descriptions or lists of species (e.g. Taylor 1934, 1935). A number of environmental assessments in the region have also generated species lists (and in some cases quantitative data) as part of pre-development baseline data collection (Airphoto/Beak 1976, Newfoundland and Labrador Hydro 1980 a and b, for example). Recently, whole water phytoplankton collections were made from 34 lakes on the island of Newfoundland as part of Environment Canada's (Inland Waters Directorate, Water Quality Branch) baseline characterization of lakes selected for long-term trend monitoring in relation to acidic precipitation and related long range transport (LRTAP) pollutants (Lakshminarayana et al. 1985). Palmer (1965) published a brief quantitative study of the phytoplankton periodicity in Clarks Pond, on the Avalon Peninsula, and Davis (1972, 1973) investigated the phytoplankton succession in Hogan's Pond and Bauline Long Pond. A long term (~10 year) data series from two lakes in the Experimental Ponds Area (EPA) in Central Newfoundland is currently being evaluated (P. Ryan, pers. comm.). O'Connell and Andrews (1977) have published a seasonal quantitative study of phytoplankton in Long Pond (Rennies River, St. John's) in which seasonal variation in species composition and density are examined in relation to pollution, grazing, and flushing rate. In the only other studies of an ecological nature carried out to date, Kerekes (1975, 1977) investigated the effects of several abiotic factors on phytoplankton primary production in five small oligotrophic lakes in Terra Nova National Park.

In 1981, a comprehensive limnological and fisheries survey was conducted on 109 lakes throughout the island of Newfoundland, as part of Fisheries and Oceans' national lake survey program, entitled the 'National Inventory Survey' (or NIS). This program was intended primarily to determine the status of freshwater fisheries and their habitat in relation to anthropogenically derived pollution. Additionally, this data was to serve as baseline information against which future change in response to acidic deposition could be evaluated. Detail on the scope and approach of this survey program, from both a national and a regional perspective, is available in Kelso et al. (1986) and Scruton (1983), respectively. This survey program, which included lake characterization (morphometry and physical/chemical analysis of water) and phytoplankton sampling, made it possible to investigate relationships between phytoplankton associations and their physical and chemical environments throughout insular Newfoundland.

Ecological studies frequently deal with large numbers of highly correlated and interdependent variables which make environmental interpretations difficult. Multivariate statistics are well suited to the synthesis of variability in a complex data set and for presentation in a more interpretable form. Consequently, multivariate approaches to data analysis are increasingly more common, especially in the aquatic and biological sciences (e.g. Allen et al. 1977; Green and Vascotto 1978; Pinel-Alloul et al. 1982; Earle and Duthie 1985). Among the methods of analysis available, clustering has proven to be a useful tool that can be used for partitioning of objects, such as species, into discrete groups based on some measure of similarity between the objects. Factor and correlation analysis can be employed to investigate relationships between these biotic groups of 'species associations' and their physical and chemical environments. In this report we attempt to identify the structure of the freshwater phytoplankton communities of Newfoundland and then determine the critical environmental factors responsible for the organization observed. Multivariate statistical approaches are also used to investigate the effect of lake water pH on phytoplankton distributions and to separate pH regimes resulting from natural circumstances from suspected anthropogenically induced changes in acidity and other variables.

This report is a companion publication to Earle et al. (1987), which focused on the multivariate approach to the evaluation and interpretation of the physical, chemical, and biological data. A similar pair of publications is available for a baseline lake survey program conducted in Labrador in 1982 (Earle et al. 1986; Scruton et al. 1987). This report is intended as a reference document for limnologists working in Newfoundland and Labrador and, as such, the detailed phycological data can be made available to interested researchers, upon request.

METHODS

FIELD SAMPLING

One hundred and nine small headwater lakes on the island of Newfoundland were surveyed by float plane or helicopter from August 16 to October 18, 1981. Lakes were sampled for morphometry, water chemistry, zoo- and phyto-plankton, sediments, benthos, and fish. Details with respect to lake selection criteria and sampling methodologies employed in the field are contained in Scruton (1983). Lake morphometric data were collected on site (bathymetry for some lakes, maximum depth) or calculated from maps and/or air photos.

Water samples were collected from a sampling station established near the lake midpoint. In shallow lakes (3 m or less), a water sample was collected by dipping the sampling bottle 0.5 m below the surface. In all other lakes, water was collected with a tube sampler (tygon tubing) in accordance with procedures outlined in the Ontario Ministry of National Resources Manual (1980). A surface dip was used to obtain the sample for trace metals analyses.

Phytoplankton samples were collected near the lake midpoint by dipping a 500 ml wide-mouth glass bottle 30 cm below the water surface. Samples were fixed immediately (on site) with Lugol's iodine solution.

WATER ANALYSIS

Water samples were analyzed for four parameters in the field (pH, gran alkalinity, dissolved oxygen, and carbon dioxide) and 22 parameters (pH, alkalinity, conductivity, hardness, turbidity, major cations and anions, nutrients, metals, colour, and dissolved organic carbon) by a contracted analytical laboratory. An additional 10 parameters, including non-marine ("excess") ion concentrations (after Watt et al. 1979), were calculated. All analytical methods followed those outlined in Environment Canada (1979) and the

American Public Health Association et al. (1975). Analytical procedures and detection limits are summarized in Table 1. Gran alkalinities were determined by acidimetric titration of the sample to pH 3.5 (after Ontario Ministry of Natural Resources 1980a) and calculation of the inflection point by modified computer routine (after Kramer 1978). Dissolved oxygen was determined by Winkler titration (Strikland and Parsons 1972).

PHYTOPLANKTON IDENTIFICATION AND ENUMERATION

The phytoplankton were identified and enumerated using the Utermöhl method from the Lugol's iodine fixed whole water samples (Ostrofsky and Duthie 1980). A Nikon Diaphot inverted microscope at magnifications of 100X, 300X, and 600X, was used. A combined minimum of 500 cells, filaments, and colonies were counted per sample. Algal counts were expressed as the number of cells of each species per liter of lake water. Identifications were made chiefly from the works of Huber-Pestalozzi (1938-50); Skuja (1948, 1956, 1964); Willen (1963); and Hilliard (1966). Cell biomass, reported as mg m^{-3}, was estimated by assigning geometric shapes to cells and assuming unit specific gravity (Janus and Duthie 1979). The detailed phycological data (species lists, counts, biomass, cell size distribution, Shannon Diversity Index, etc.) for each lake is housed on computer tape at the Northwest Atlantic Fisheries Centre, St. John's, Newfoundland, and at the University of Waterloo (Department of Biology), Waterloo, Ontario, and can be made available upon request.

DATA ANALYSIS AND STATISTICAL TREATMENT

The statistical approach used to describe and interpret the data involved a series of correlation, cluster and factor analyses.

Initially, relationships between the morphometric, physical, and chemical variables were explored by simple linear correlation analyses of the $\log_{10}$ transformed data (SAS Institute 1979) (see the correlation matrix in Appendix 1). The original matrix of 47 variables was then reduced to 23 selected parameters for multivariate analysis. Redundant variables such as laboratory measured alkalinity when field alkalinity was measured, summed variables and minor or trace elements were deleted. Bicarbonate was eliminated because the alkalinity in these lakes is completely HCO_3^-. Non-marine or "excess" concentrations of the major cations and sulphate were also deleted from the analyses. Among the available morphometric variables only lake surface area and drainage area were measured routinely. As a result, lakes could not be classified on the basis of complete morphometric characterization. This limited the investigation of morphometry as a regulator of phytoplankton distributions. Factor analysis was subsequently employed to simplify the variance structure of these highly correlated and interdependent variables.

The morphometric, physical and chemical data were then transformed ($X'=\ln(X+1)$, all data except pH) to normalize the data and then standardized to give each variable an equal weighting in the analyses. Tests performed after transformation and standardization showed that all the variables had been reasonably normalized (Kolmogorov-Smirnov-Lilliefors test; $\alpha=0.10$). More importantly, Log-Anova tests indicated that the parameter variances had been made homogeneous (α=0.05). For the purpose of the multivariate analyses only, the original data set from 109 lakes was reduced to 97, on the basis of incomplete morphometric information.

A first approach involved correlation analysis of pH and algal group abundances and biomass. Spearman's non-parametric procedure was used since the biological data had not been transformed. The phycological data matrix, consisting of 261 phytoplankton taxa, was then reduced to a smaller subset of 77 taxa based on Orlóci's (1978) sum of squares variance procedure. This algorithm calculates the individual proportions of the total variance accounted for by each species. In order to reduce the number of species, those that failed to explain any independent share of the total variance were eliminated. This criterion was adopted because such species can provide no new information about the structure of the phytoplankton communities. The data set was then transformed ($X'=X^{.20}$) in an effort to normalize the distributions of each species and to reduce homoscedasticity. A Box-Cox-Bartlett's analysis was used to determine the best transformation to accomplish both objectives. Subsequently, a Kolmogorov-Smirnov-Lilliefors test indicated over 70% of the species were reasonably normalized (α=0.10).

The phytoplankton data matrix from the 97 lakes was partitioned into groups of co-occurring species on the basis of a complete-linkage cluster analysis of a Canberra distance matrix (Legendre and Legendre 1983). Complete-linkage clustering was chosen since this algorithm should result in clusters representing as functionally distinct groups of species as possible. The criterion for selecting the cluster-group level to represent the phytoplankton associations was made a priori to any analysis being performed. The decision was made to choose the last cluster level in which at least 90% of the species demonstrated significant differences in abundance between the groups. Tests of significance were therefore based on an analysis of variance (α=0.10). Iterative relocation was subsequently performed to optimize the classification of each species into cluster groups. The resulting groups can be considered to represent different associations of species that occur in Newfoundland.

An attempt was then made to correlate the taxa in each association with the physical, chemical, and morphometric variables which regulate their distribution. The orthogonally rotated (VARIMAX) factor scores obtained from the factor analysis were correlated with the species abundances. Spearman correlation coefficients were used to describe the relationship between each species and the various environmental factors identified as potentially influencing their distributions in lakes.

RESULTS

LAKE CHARACTERIZATION

One hundred and nine lakes were sampled for lake morphometry, chemistry, and biological parameters over a two-month period (August 16 to October 18) in

1981. Lakes were generally distributed across the island with the exception of the Burin and Avalon peninsulas. The Avalon Peninsula was not intensively surveyed owing to the comprehensive limnological and fisheries data base which exists for that region. Lakes designated for survey on the Burin Peninsula were not sampled due to prolonged periods of poor weather preventing aircraft access. The resulting distribution of study lakes, by geographical region, is as follows (Fig. 1):

Northern (Peninsula) - 23
Central - 20
Eastern - 22
Southern - 24
Western - 7
Avalon (Peninsula) - 3

Nine major widespread geological types were delineated for the island and lakes were sampled from seven of these geotypes (Scruton 1983). The distribution of lakes, by geological type, is as follows:

Conglomerate, sandstone, etc. - 1
Limestone, dolomite, sandstone - 8
Gneiss, schist, etc. - 17
Siltstone, quartsite, etc. - 7
Granites - 45
Gabbro, diorite, etc. - 1
Acid to mafic volcanics, etc. - 17
Unclassified - 13

Sixty-two lakes (57%) were located in geotypes designated highly sensitive to acidic deposition (silicous bedrock types, not readily weathered and low in available carbonates), while 26 lakes (24%) were located in high to moderately sensitive bedrock types (largely metamorphic or sedimentary rocks, more readily weathered but low in available carbonates), and eight lakes (7%) were in low to non-sensitive geological areas (rocks of sedimentary origin, readily weathered, high in calcium/magnesium carbonates). Thirteen lakes were not classified due to the occurrence of two or more geological types of different sensitivities within their watersheds.

Study lakes ranged in size from 21 to 2519 hectares (mean of 153 ha). No lakes were smaller than 10 ha, while 65 lakes (60%) were in the 10 to 100 ha size class, 41 lakes (38%) in the 100 to 1000 ha size class, and 2 lakes (2%) were greater than 1000 ha (Fig. 2). The Department of Fisheries and Oceans has digitized a comprehensive data base (consisting of lake area, watershed area, drainage order, elevation, etc.) for all lakes of 1 ha or greater in size, from large geographical areas in Newfoundland and Labrador, in order to establish the natural distribution of these lake parameters. Lake area distributions from this study are compared with natural distributions in Fig. 3. It is apparent that the distribution of lake areas from the survey is not representative of natural distributions, and the sample was particularly under represented in the 0 to 10 ha size class (representing 89% of natural lake distributions). Inaccessibility by fixed wing aircraft and possible poor fish production potential were reasons why this lake size class was not surveyed.

Lakes designated for study were predominantly headwater (first order) systems (98 lakes, 90%) while 8 lakes (7%) were second order and two lakes were of higher order (3° and 5°) (Ontario Ministry of Natural Resources 1980b). The distribution of study lakes by drainage order is also compared to natural distributions in Fig. 4, and again it is apparent the lakes sampled in the survey poorly represent natural lake orders. Drainage order was a consideration in lake selection and the survey was directed (biased) to smaller lakes in the headwaters of their respective drainage systems, owing to the acknowledged sensitivity of these water bodies to anthropogenic acid deposition (Harvey et al. 1981).

Watershed area to lake area ratios for the lakes were relatively low, ranging from 2.5 to 36.2 (mean of 8.4) (Fig. 2). Eighty-one lakes (75%) had ratios of less than 10:1. Lake elevations ranged from 24 to 709 m above sea level (mean of 248 m) with 16 lakes (15%) less than 100 m, 84 lakes (78%) in the 100 to 500 m range, and the remaining 8 lakes (7%) greater than 500 m (Fig. 2). Watershed to lake area ratio and elevation are important features governing relative exposure to acid deposition, and the availability and interaction of depositional and buffering elements. Lakes were located varying distances from salt water (from 3.0 to 87.5 km, mean of 24.5), however all study lakes were within 100 km.

Maximum depth, mean depth, and lake volume were determined for 10 preselected lakes, for which bathymetric surveys were conducted. The absence of detailed lake morphometry for all lakes proved to be a major shortcoming in the assessment of factors regulating phytoplankton distributions (to follow); however, the cost of conducting bathymetric surveys on 109 remote lakes was prohibitive. Maximum depth determined for each lake was in effect the depth measured over the sampling station (which was established over the expected deepest portion of each lake) and must be considered an estimate only. "Estimated" maximum depth ranged from 1 to 29 m and fourty-one lakes (38%) had maximum depths of less than 3 m.

Surface water temperatures varied from 5.6°C to 21.8°C and temperature/depth profiles (at 1 m intervals) were obtained from all lakes. Most lakes demonstrated little evidence of thermal stratification and only 4 of 108 lakes had a clear thermal gradient and true thermocline. These lakes were classified as second class with respect to thermal stratification (stratified but with bottom temperatures greater than 4°C) (Hutchinson 1957). The shallow nature of the lakes, the low solar input, and frequent high winds contribute to water recirculation and the lack of stratification.

Secchi disc depth, as a measure of light penetration, was determined at all lakes and ranged from 0.3 to 9.5 m (mean of 2.7) (Fig. 2). In 34 lakes (31%) the disc was still visible on the lake bottom, and in these lakes the entire water body would be considered in the euphotic zone (Hutchinson 1957). In the other 75 lakes, secchi disc depth varied from 0.3 to 7.5 m (mean of 2.95) and was strongly correlated with water colour ($r = -0.66$) and turbidity ($r = -0.62$) (Scruton 1983).

A characteristic feature of insular Newfoundland's lakes is the high colour content of the water reflecting a natural organic contribution to chemistry and acidity. Colour values ranged from 5 to 225 T.C.U. (mean of 48.5) and 17 lakes (16%) were classified as having clearwater (0 to 15 T.C.U.), 57 lakes (52%) as brown water systems (15 to 50 T.C.U.), and 35 lakes (32%) as being highly coloured systems (greater than 50 T.C.U.) (Fig. 2). Lake turbidities ranged from 0.22 to 3.10 J.T.U. (mean of 0.65) and values in excess of 1.0 were common. Kerekes (1978) has suggested that high turbidities in Newfoundland lakes is a consequence of wind driven recirculation of particulate matter from littoral areas and lake sediments. The high colour content and relatively high turbidities likely restricts the trophogenic zone in some lakes and consequently limits potential primary productivity.

The sum of constituents (or salinity) of the lake water varied from 4.4 to 96.7 mg L^{-1} (mean of 12.8). This value is extremely low by global standards (world average is 112 mg L^{-1}, Livingstone 1963) and, considering the contribution of lakes underlain by limestone/dolomite deposits and the considerable input of marine aerosols (Scruton 1983), reflects the extremely dilute nature of insular Newfoundland's freshwaters.

The dominant cations in the lakes were calcium or sodium, while magnesium was also important and potassium, hydrogen ion (H^+), iron, and aluminum were generally of lesser importance. Lakes underlain by limestones, gabbros, diorites, and volcanies were typically calcium dominated ($Ca>Na>Mg>K/H^+/Fe/Al$) while lakes underlain by granites, gneisses, siltstones, and the conglomerate/sandstone geotype were more frequently sodium dominated ($Na>Ca>Mg>K/H^+/Fe/Al$). Calcium and magnesium were predominantly of terrestrial (geological) origin while sodium and potassium had both terrestrial and marine contributions. Chloride was the dominant anion in lakes underlain by granites, gneisses, siltstones, and conglomerate/sandstones (in order of $Cl>HCO_3>SO_4$, except predominantly $Cl>SO_4>HCO_3$ in the gneitic geotype), while bicarbonate ion ($HCO_3>Cl>SO_4$) was dominant in the limestone, gabbro, and volcanic geotypes. Bicarbonate ion is principally of terrestrial origin while chloride ion is considered to be exclusively of marine origin. Sulphate can originate from marine aerosols, anthropogenic sources (acid rain), geological deposits (pyrite, gypsum) and from terrestrial sources (bogs and/or organic soils with bacterial oxidation). Strong correlations between sodium ($r = -0.60$), chloride ($r = -0.60$), and sulphate ($r = -0.34$) with the distance from salt water confirmed the importance of marine aerosols as sources for these constituents (Scruton 1983). The cationic/anionic profiles for lakes from each geological type are shown in Fig. 5 while frequency distributions for the dominant cation (calcium) and anion (chloride) are shown in Fig. 2.

It is important to note that sulphate was determined by the methlythymol blue (MTB) method which is prone to colourimetric interference in humic waters (Kerekes 1983). Due to the preponderance of highly coloured waters in this survey, considerable colourimetric interference is suspected leading to overestimation of sulphate. In addition, only a qualitative consideration of organic constituents was made in this study (Scruton 1983). In recent years, considerable attention has been paid to characterizing and quantifying the organic content in surface waters, particularly in Atlantic Canada. Oliver et al. (1983) developed a method to estimate organic anion concentration ($COOH^-$) from organic carbon measurements (D.O.C., T.O.C.) and pH. This has allowed a quantitative consideration of organics as an important anion, and as a weak acid contributing to natural water acidification. Quantification of organics is now a routine procedure and organic anions are frequently a dominant ionic constituent in dilute waters with average marine aerosol contribution in Atlantic Canada (Scruton and Taylor 1987; Scruton 1985; Howell 1986).

Lake pH (field measured values) ranged from 4.90 to 8.39 (mean of 6.40) with 2 lakes (2%) demonstrating a pH of less than 5.0, 8 lakes (7%) in the 5.0 to 5.5 range, 24 lakes (22%) in the 5.5 to 6.0 range, while the remaining 74 lakes (69%) had values exceeding 6.0 (Fig. 2). The pH distribution was unimodal and was spatially correlated with bedrock geology (Scruton 1983). Hydrogen ion contribution from weak organic acids and strong acids in precipitation is also suspected to contribute to the observed lake acidity.

Lake alkalinities (gran measured values) varied from -6.4 to 1740 μeq L^{-1} (mean of 95.3). Three lakes had negative alkalinities (defined as acidified), while 56 lakes (52%) had values from 0 to 40 μeq L^{-1} (extremely sensitive to acidification), and 37 lakes (34%) from 40 to 200 μeq L^{-1} (moderately sensitive to acidification). Four lakes (4%) had alkalinities from 200 to 500 μeq L^{-1} (considered low in sensitivity to acidification) while 4 lakes (4%) had values in excess of 500 μeq L^{-1} (considered non-sensitivite) (Fig. 2). Spatial correlation of bicarbonate alkalinity and bedrock geology (reflecting the availability of weatherable carbonates) was good (Scruton 1983). Most lakes demonstrated a deficit in alkalinity (calcium and magnesium minus bicarbonate) in the range of 25 to 50 μeq L^{-1}, which is considered to demonstrate a response to acid loading, likely both from natural and anthopogenic sources.

Conductivity values ranged from 11.4 to 119.0 μScm^{-1} (mean of 28.9). Fifty lakes (46%) had conductivities of less than 20 μScm^{-1} while 43 lakes (40%) had values of between 20 and 30 μScm^{-1}, emphasizing the dilute nature of the majority of Newfoundland lakes (Fig. 2). Lakes with a conductivity less than 30 μScm^{-1}, classified as critically sensitive to acid precipitation (Harvey et al. 1981), includes 86% of the study systems.

The foregoing presents a brief synoposis of the morphometric, physical, and chemical characteristics of the study lakes, as they pertain to an evaluation of phytoplankton associations in the systems. A more detailed evaluation of the lake properties, with particular attention paid to sensitivity to and effects from acid rain, is available in Kendaris (1982), Scruton (1983, 1985), and Kelso et al. (1986). Physical, chemical, and morphometric data for each lake is listed in Tables 2 and 3, while a statistical summary is provided in Table 4.

FACTOR ANALYSIS

A matrix of correlation coefficients for linear regressions of all lake parameters ($\log_{10}$ transformed except for pH) measured in this study is contained in Appendix 1. This matrix was used to select the 23 key morphometric, physical, and chemical variables for use in the subsequent statistical analyses. Parameters that were excluded from the multivariate analyses included laboratory measured pH and alkalinity, excess or non-marine ion concentrations, cation sum, anion sum, sum of constituents, bicarbonate, hardness, cadmium, and lead. Other parameters that were not available for all study lakes (mean depth, lake volume, shoreline development index, copper, nickel and zinc) were also excluded as well as data not pertinent to this study (sediment/water interface pH for eg.).

Table 5 shows the individual loadings of the 23 morphometric, physical, and chemical variables on seven hypothetical factors produced in the factor analysis. Factor 1, which is highly correlated with colour, iron, aluminum, carbon dioxide, turbidity, manganese, secchi depth, and pH, can be considered a dystrophy factor. Factor 2, highly correlated with alkalinity, calcium, pH, magnesium, and total dissolved solids, is considered to represent a hardness factor. Factor 3, which is correlated with sodium and chloride, represents salinity. Factor 4, correlated with drainage area and lake surface area appears to be a lake size (or morphometric) factor. Factor 5, which is correlated with water temperature, and dissolved oxygen appears to represent temporal (seasonal) differences in water conditions owing to sampling over a two month period. This does not appear to represent true between lake differences as all other factors do. Factor 6 is correlated with the drainage area to lake surface area ratio and represents the amount of watershed influence on the allocthonous input to the study lakes. This factor may also be related to lake flushing rate. Factor 7 is correlated with dissolved orthophosphate and may be regarded as representing phosphorus enrichment.

PHYTOPLANKTON ASSOCIATIONS

The 262 species and varieties of phytoplankton found in the Newfoundland lakes are listed in Appendix 2 and the 77 taxa used in the statistical analyses are listed in Table 6. The phytoplankton enumerations (number of taxa and biomass) for each lake are summarized in Table 7. An average of 46 taxa were found per lake, ranging between 20 and 69. The total biomass averaged 179 mg m^{-3} and ranged between 32 and 952 mg m^{-3}. Algal density varied between 157,300 and 2,312,000 cells per litre. The distribution of taxa, by algal group, is as follows:

Cyanophyceae	6 genera	15 taxa
Chlorophyceae	20 genera	49 taxa
Chrysophyceae	14 genera	36 taxa
Bacillariophyceae	9 genera	18 taxa
Cryptophyceae	1 genera	6 taxa
Dinophyceae	2 genera	1 taxa
Rhodophyceae	1 genera	1 taxa

In terms of species diversity, the chrysophytes were dominant in 91 lakes (85%), the chlorophytes dominant in 9 lakes (9%) while the two groups were equally represented in 5 lakes (5%). In terms of biomass, the chrysophytes dominated in 71 lakes (68%), diatoms in 18 lakes (17%), the dinoflagellates in 7 lakes (7%), the cyanophytes and the cryptophytes in 3 lakes each (3%), the chlorophytes in 2 lakes (2%) while the chrysophytes and diatoms contributed equally to the biomass in one lake.

The dendrogram from the complete-linkage cluster analysis of the 77 selected taxa (Fig. 6) indicates that the phytoplankton can be categorized into 12 different species associations. The similarity coefficient at which the taxa fuse into clusters is indicated along the oridinate. Clusters of species, numbered 1 through 77, represent groups of co-occurring taxa. The twelve group level, after relocation to optimize the clusters, appears to best describe the natural phytoplankton associations occurring in the lakes. The species comprising these associations are shown in Fig. 6.

PLANKTONIC ASSEMBLAGES IN RELATION TO ACIDITY

Scatter-plots of pH versus species number and biomass for the seven major algal groups, with the accompanying statistical parameters from the Spearman correlation analysis, are shown in Fig. 7 to 10. The correlation coefficients (r) between pH and the number of taxa per sample were found to be significant ($0.10 > p > 0.001$) with the exception of the Chrysophyceae and the Diatomaceae. Generally, numbers of taxa were low in the more acidic lakes rising to a broad maximum in the pH range of 6.0 to 7.0 before declining slightly in the lakes of higher pH.

The mean number of total species and species by algal class, for lakes grouped by pH interval, is shown in Fig. 11 and listed in Table 8. A trend to decreasing species diversity as pH interval declines is apparent and appears to occur most rapidly over the pH interval 5.0 to 6.0 (mean species number declines from 48.2 at 6.0 to 6.5 to 31.4 at pH interval 4.5 to 5.0). However, lakes in the highly acidic pH interval (4.5 to 5.0) still contain approximately 60% as many species as the circumneutral and alkaline lakes.

Mean algal biomass (both total and by algal class) for lakes grouped by pH interval is shown in Fig. 12 and listed in Table 8. There is no apparent trend to declining biomass in the lower pH classes, although lakes in the pH class 4.5 to 5.0 had low mean biomass (72.2 mg m^{-3}, range of 52 to 98 mg m^{-3}, $n = 5$) relative to the other pH classes. The Chrysophyceae were the dominant algal group (as % biomass) in all pH classes and became increasingly more important in the highly acidic lakes (pH 4.5 to 5.0). Conversely, the Dinophyceae assumed an increasing proportion of the total biomass as pH increased to reach a maximum of 18.2% in the alkaline pH group (7.5 to 8.0). Significant correlations between pH and algal group biomass were far less evident. Although relationships with pH were detected for Cyanophyceae, Chlorophyceae and Chrysophyceae, these were weak. An inspection of the scatter-plots (Figs. 9 and 10) shows only very tenuous correlations and furthermore, there was no correlation between pH and total sample biomass (Fig. 10).

The failure of the univariate analyses to reveal any clear relationships between lakewater pH and either algal biomass or species numbers suggests that phytoplankton distributions are regulated by several highly interdependent environmental variables. For this reason, a multivariate approach was used to elucidate the effects of many highly correlated variables which by themselves reveal little about the factors controlling the occurrence and distribution of algal species.

RELATIONSHIPS BETWEEN PHYSICAL-CHEMICAL FACTORS AND PHYTOPLANKTON ASSOCIATIONS

The seven derived factors describing the morphometric, physical, and chemical characteristics of the 97 lakes (Table 5) were correlated with the transformed abundances of the 77 phytoplankton species (Table 6). Spearman rank correlation analysis was used to describe these relationships since several species distributions remained skewed despite having optimally transformed the data. For ease of interpretation, the species were arranged into their respective cluster groups, (i.e. associations) so as to describe the apparent environmental requirements of the groups as a whole. A comparison of the patterns in each group provided evidence of similar environmental requirements. Species showing no significant correlation with any of the seven derived factors were excluded from Table 6.

A large number of species were positively correlated with Factor 1 (dystrophy) (Table 6). The most highly correlated included *Salpingoeca frequentissima* (Group 2), *Ankistrodesmus falcatus* (Group 6), *Dinobryon borgei* (Group 6), *Ankistrodesmus spiralis* (Group 8), *Euastrum binale* (Group 10), *Chromulina glacialis* (Group 12), *Chromulina minuta* (Group 12), and *Desmarella moniliformis* (Group 12). Dystrophic species occurred predominantly in Groups 2, 6, 8, 10, and 12. Indeed in Group 12, all members were positively dystrophic. Many species were negatively correlated with Factor 1, but the strongest relationships were observed for *Chroococcus turgidus* (Group 3), *Sphaerocystis schroeteri* (Group 3), *Oocystis lacustris* (Group 5), and *Gomphosphaeria lacustris* (Group 6). Groups 1, 3, 4 and 5 contained most of the 15 species exhibiting this characteristic. Among them, only Group 1 contained a positively correlated taxon, *Crucigenia quadrata*.

Nearly 50% of the taxa, particularly in cluster groups 1 and 2, proved to be positively correlated with Factor 2 (hardness). Several of these demonstrated very strong relationships including *Rhodomonas minuta* (Group 1), *Gomphosphaeria lacustris* (Group 6), *Arthrodesmus incus* (Group 6), *Ankistrodesmus falcatus* (Group 8), and *Katablepharis ovalis* (Group 8). By comparison, only 5 species were negatively correlated with hardness. Three of these species occurred in Group 12, including *Chromulina glacialis*, *Mallomonas elongata*, and *Mallomonas akrokomos*.

Many phytoplankers were positively correlated with Factor 3 (salinity). Among the most highly correlated were *Cyclotella michiganiana* (Group 1), *Selenastrum minutum* (Group 5), *Rhizosolenia eriensis* (Group 6), *Euastrum elegans* var. *ornatum* (Group 9), *Dinobryon sociale* (Group 9), and *Desmarella moniliformis* (Group 12). Several groups demonstrated a positive affinity for lakes with a strong marine influence, including Groups 1, 2, 5, and 12. All of the species in Group 12 were positively correlated with salinity. A negative affinity for lakes with high marine aerosol influence was observed for most of the species in Groups 6, 8, and 10. In Groups 8 and 10 all of the species were either negatively associated or showed no correlation with salinity. However, two of the species clustered in Group 6 exhibited a positive correlation with this factor.

Factor 4, lake size, showed significant correlations with many species, including the diatoms, *Asterionella formosa* (Group 2), *Tabellaria fenestrata*

(Group 2), and Rhizosolenia eriensis (Group 6). These three species had the highest correlations for this factor. By contrast, few species were negatively correlated with lake size and none of the cluster groups had more than a single inversely associated member.

Several species were correlated with Factor 5, which had a strong positive loading on dissolved oxygen (r = 0.82) and a negative loading on water temperature (r = -0.71) suggesting the influence of seasonality. There were approximately an equal number of positively and negatively associated taxa. Groups 1, 2, 4, and 5 were comprised of only negatively correlated taxa while Groups 7, 8, and 10 strictly contained positively correlated species. The remaining groups demonstrated both types of relationships. Mallomonas akrokomonas (Group 12) was the species most highly correlated (negatively) with this factor.

Factor 6, which had a highly significant loading on the ratio of drainage area to lake surface area, exhibited twice as many negative associations as positive associations. Relationships with this factor were observed in only two groups, 7 and 11, and although all the species were negatively associated, few were significantly correlated ($\alpha = 0.10$). A small number of species including Tabellaria fenestrata (Group 2), Navicula radians (Group 11), and Gymnodinium varians (Group 7) were highly correlated with Factor 6.

Many phytoplankton taxa (~25%) were positively correlated with Factor 7, which had a relatively small but significant positive loading on orthophosphate concentration and a negative loading on potassium concentration. Many of the positively correlated taxa were also highly correlated with Factor 2 (hardness). Arthrodesmus incus (Group 6), Elakatothrix gelatinosa (Group 8), Katablepharis ovalis (Group 8), Pseudokephyrion anctonicum (Group 8), Pseudokephyrion minutissima (Group 9), and Rhabdoderma lineare (Group 4) were among the most highly correlated taxa. By contrast, only 5 species were negatively associated with Factor 7, and 4 of these relationships were non significant ($\alpha = 0.10$).

DISCUSSION

This NIS lake survey program has provided the basis for an island wide description of phytoplankton assemblages and the environmental factors that influence these association. Some 261 different algal taxa were identified from headwater lakes ranging from dystrophic to alkaline in character. Comparatively, a recent (May 1984) survey of whole water phytoplankton assemblages in 34 headwater lakes in insular Newfoundland (from Environment Canada's LRTAP monitoring lakes), sampled over a two day period during spring homothermal conditions, identified a total of 142 taxa (72 genera) (Lakshminarayana et al. 1985). Phytoplankton numbers varied from 440 to 5750 cells per litre in the Environment Canada study lakes, but no biomass data are available for comparison. In these lakes the chlorophytes were dominant numerically (percent composition) in 12 lakes (35%), the diatoms in 9 lakes (26%) and the chrysophytes and cyanophytes in each of 3 lakes (9% each). In contrast to the biomass measurements in the Environment Canada survey, the importance of the chlorophytes and diatoms appears to be overestimated and the chrysophytes underestimated by algal cell numbers.

Phytoplankton assemblages from 351 lakes in Eastern Canada, including the insular Newfoundland study lakes discussed in this report, were compared and discussed in Kelso et al. (1986). With all regional data combined, the chrysophytes (yellow-green algae) and the chlorophytes (green algae) were the dominant groups followed by the diatoms, cryptophytes, cyanophytes, and dinoflagellates. The community composition was considered typical of non-acidic oligotrophic lakes in North America (Schinder and Holmgren 1971; Ostrosfky and Duthie 1975; Hendrey 1982). With all regional data combined, species diversity in the cyanophytes and chlorophytes were consistently lower at the more acidic pHs, with the greatest change in diversity apparent in the pH interval 5.0 to 6.0.

The results of the Spearman correlation analyses of lake water pH versus algal group abundances (species number and biomass, Figs. 7 to 10)) demonstrated that, in the lower pH ranges, there is a decline in total numbers of phytoplankton species but not in total biomass. This can be interpreted as a simplification of the community structure in response to increasing acidity without a corresponding decline in the total algal standing crop. This is consistent with much of the literature on acidification effects on phytoplankton and primary productivity. A number of synoptic surveys in Canada (Kwiatowski and Roff 1976; Yan and Stokes 1976; Kelso et al. 1986), the U.S. (Crisman et al. 1980; Hendry 1981; Brezonik et al. 1984), and in Scaninavian (Dickson 1975; Lievstad et al. 1976; Almer et al. 1978; Raddum et al. 1980) have reported reduced species diversity in lakes of lower pH, irregardless of whether the lake pH is naturally acidic or a consequence of acidic deposition. For example, Yan and Stokes (1976) found an acidic lake (pH 4.4) in the La Cloche Mountains to have a greatly reduced community complexity (9 species) relative to circumneutral lakes (pH's 6.0 to 7.0, 50+ species) in the same region. Almer et al. (1978) reported similar results from a synoptic survey of Swedish lakes (30 to 80 species in lakes in the pH range 6.0 to 8.0, while acidic lakes, pH of 5.0 and less, contained 12 or fewer species). The decrease in species diversity appears to occur most rapidly over the pH range 5.0 to 6.0 (Kwiatowski and Roff 1976; Environmental Protection Agency 1983), particularly at about pH 5.5.

Lake acidity has also been demonstrated to influence the species composition within algal classes, with the trend to decreased species diversity with decreasing pH apparent in most major groups (Harvey et al. 1981; Environmental Protection Agency 1983). In this study, the Cyanophyceae, Chlorophyceae, and Cryptophyceae showed statistically significant declines (however weak) in species numbers with decreasing pH, while the same trend was not apparent in the chrysophytes and diatoms, and the dinoflagellates were too few to demonstrate any definite trends (Fig. 7 and 8). The ability of some diatoms and chrysophytes to tolerate relatively acidic conditions may be responsible for their importance in lakes of lower pH. Yan (1979) found proportionally smaller declines in diatoms and desmids in low pH lakes in the La Cloche Mountains in Ontario and attributed this observed response to acidity to be related to the occurrence of acid tolerant species within these two groups.

The phytoplankton communities of Canadian lakes are typically dominated by the chrysophytes (Schindler and Holmgen 1971) and in Canadian Shield lakes by the diatoms (Ostofsky and Duthie 1975; Yan et al. 1977). Acidic lakes are more typically dominated by the dinoflagellates. In acidic Swedish lakes (pH 4.5 to 5.5) the dinoflagellates comprise 85 percent of the biomass (Almer et al. 1974; Dickson 1975). In Ontario, this group comprised 30 to 70% of the biomass in low pH lakes (pH 4.4 to 4.8) and from 2 to 30% of the biomass in more circumneutral lakes (pH 5.8 to 6.8) (Yan 1979). This same trend was apparent in the Adirondack region of the Northeastern United States (Hendrey 1981). In Florida, the chlorophytes were most important in low pH lakes (pH 4.5 to 5.0), while this group is considered particularly susceptible to pH declines in Scandinavian lakes (Crisman et al. 1980; Overein et al. 1980). It is apparent that the response of the major algal groups to low pH is not consistent between global regions. This range in response is certainly related to the differing species compositions (and associated acid tolerances) of the major groups between regions as well as the varying physical-chemical characteristics of each regions' water bodies.

Raddum et al. (1980) have also found that acidic clearwater lakes in Norway have a lower species diversity than humic lakes with similar pH levels. The authors concluded that the higher species diversity in humic lakes suggests long-term functional adaptation to naturally acidic conditions while the clearwater plankton assemblages were demonstrating response to anthropogenic acidification (a recent phenomenon). A measure of the response could be related to complexation of potentially toxic metals in humic lakes while clearwater lakes do not complex and therefore do not detoxify metals liberated from catchments by acidic deposition. Raddum et al. (1980) have also reported planktonic seasonal succession to occur at a higher rate in humic Norwegian lakes than in less acidic clearwater lakes. The total number of species over the season is greater in humic lakes while at any one part of the season the total species number may be less. The high acidity related to humics affects species composition through the pH tolerance of individual species, while the dynamics of species succession and interactions also appears to be influenced by organic components. This puts into perspective the shortcomings of synoptic survey programs. Consequently a univariate approach to ecological interpretation, focusing on pH, can also be misleading.

Primary productivity and phytoplankton biomass demonstrated no clear relationships with lake acidity. Several synoptic studies have demonstrated reduced (Kwiatowski and Roff 1976; Crisman et al. 1980; Hendrey 1980), unchanged (Almer et al. 1978; Raddum et al. 1980), or increased (Yan and Stokes 1980; Schindler and Turner 1982) phytoplankton biomass in acidic lakes relative to circumneutral lakes. In some instances interpretation is difficult owing to the common association of low pH with low nutrient and inorganic carbon levels, and therefore no clear cause-effect relationship with acidity can be established. Almer et al. (1978) suggest that, for acidification to affect total productivity, phosphorus availability would need to decrease. Increased availability of organics or heavy metals in response to acidification could immobilize phosphorus through complexation. Grahn et al. (1974) have suggested that acidic deposition induced oligotrophication of sensitive lakes could act to reduce algal biomass by inhibiting the recycling of nutrients within acid-stressed systems. At present, survey information and experimental studies (as reviewed in Bangay and Riordan 1983; Environmental Protection Agency 1983) have not conclusively determined the effect of lake acidification on primary production.

There are problems in drawing too many conclusions from univariate relationships such as pH and algal numbers, diversity, or biomass. Samples included in this study were single collections made over a two month study period. While it has been suggested (Airphoto-Beak 1976) that algal biomass in Newfoundland lakes may be at a maximum in August-September, the well established periodicity of phytoplankton renders interpretation of presence/absence of taxa, dominance of certain taxa or algal groups, etc. less meaningful without an understanding of the seasonal dynamics in the lake physical-chemical properties and the phytoplankton associations. Palmer (1965) and Davis (1972, 1973) have investigated the seasonal dynamics of phytoplankton in Newfoundland lakes and have documented wide seasonal variation in phytoplankton production and composition. Many species (particularly some crysophytes of the genus Dinobryon) are apparent for only very short time intervals and constribute a large proportion to the total algal biomass when they occur (Davis 1973). The comparison of phytoplankton diversity and abundance with only one factor pH, may be too simplistic, considering the relationships between pH and other factors that may be more influential in controlling phytoplankton associations (nutrients for example). Given the synoptic nature of the survey program and the resulting data set, it is not realistic to consider seasonal effects. However, the use of multivariate statistics is a realistic approach to evaluating a complex data set and in interpreting what parameters, either singly or in a synergistic fashion, control the observed phytoplankton associations.

LAKE CHARACTERISTICS AND PHYTOPLANKTON ECOLOGY

The nature of headwater lakes in Newfoundland has been characterized by up to six derived environmental factors: dystrophy, hardness, salinity, lake size, watershed influence, and orthophosphate concentration (enrichment). These factors were demonstrated to influence the distribution of phytoplankton in the lakes. A seventh factor, seasonality, characterizes the temporal variations in dissolved oxygen and temperature that occur within lakes as a consequence of seasonal differences in the amount of solar radiation. This factor does not influence phytoplankton distributions but rather indicates the time of season when certain taxa may predominate.

A large proportion of the Newfoundland phytoplankton correlated highly with one or more of the derived environmental factors. The relative importance of the various environmental factors in controlling the distribution of the phytoplankton may be evaluated by the number of species correlating with each factor. For example, 18 species were significantly correlated ($P < 0.05$) with salinity, 17 species with hardness, 14 species with phosphorus enrichment, 13 species with seasonality, and 12 species with dystrophy. By contrast, very few species were correlated at any level with lake size or watershed influence, implying that morphometric characteristics contribute very little to the distribution of phytoplankton species in Newfoundland. However, other morphometric characteristics such as mean depth and/or shoreline development, not included in this assessment, may be more influential in regulating the distribution of phytoplankton species.

The results of the cluster and relocation analyses indicate that the phytoplankton can be partitioned into recurrent groups of co-inhabiting species. These groups of species describe the structure of the phytoplankton communities in the different types of lakes occurring throughout Newfoundland. However, the choice of cluster level to describe the structure is at least partially subjective. In choosing a level the investigator must always consider the structure of the abiotic environment from which the samples come. With this in mind, twelve cluster groups appear to adequately describe the situation in Newfoundland based on the degree of interpretation appropriate to the study. Consideration was given to the limits of fractioning of the physical and chemical environments as indicated by the factor analysis. It was found that the variance attributed to seasonal differences, imposed by the two month sampling period, effectively limited the level of interpretation possible by masking less conspicuous relationships.

For the purpose of this study, an association is defined as any recurrent group of species found occurring in similar habitats. The twelve groups of species identified in the cluster analysis can therefore be considered 'species associations' characterized by distinct patterns of distribution. Presumably the species co-occur because they have similar reactions to the environment. If this is so, then the ability to relate an association to a particular niche may be useful in interpreting causal relationships between biotic and abiotic variables. Spearman correlations between individual taxa and the seven derived factors indicate the nature of individual algal responses to the abiotic environment. The results indicate that within each association the members do indeed react in a similar manner to a number of different environmental properties.

Group 1, for example, is an association of hardwater, summer taxa which are generally intolerant of polyhumic conditions. Group 2 is an association of dystrophic, saline-tolerant species, most of which reach their peak abundance during the summer. Group 3 is a small association of two dystrophic species including *Chroococcus turgidus*, a late-summer form, and *Sphaerocystis schroeteri*, an autumn form. The few species belonging to Group 4 are all summer algae that appear to be stimulated by increased phosphate concentrations. Owing to phosphorus depletion during the summer, these species probably occur in lakes typically having relatively higher phosphate concentrations. With the exception of *Uroglena americana*, Group 5 appears to be adapted to large, deep-lake conditions. Most of the members of this association are probably halophilous because they appear to be stimulated by higher ionic concentrations.

Group 6 is primarily an association of hardwater taxa. Two of the species, *Rhizosolenia eriensis* and *Crucigenia tetrapedia*, are probably halophilous, while most of the taxa appear to be inhibited by small to moderate amounts of salt and consequently should be considered halophobous. Cluster Group 7 may represent an association of autumn species. The strong correlation with orthophosphate suggests that they may predominate when nutrients become more available. However, the lack of evidence of thermal stratification in many lakes does not suggest nutrient partioning due to thermocline development. Group 8 appears to be an association of hardwater species that are intolerant of higher salt concentrations. Many of the species are autumn forms of algae that seem to prefer the larger, deeper lakes and high phosphate concentrations. The abundance of Group 7 and 8 species in the autumn may represent a temporary positive imbalance between growth and loss rates at that time.

The five taxa that comprise Group 9 appear to have few common environmental requirements. There is some indication that this group of species may be relatively intolerant of extremely low ionic concentrations. This halophobic characteristic is most prevelant in *Euastrum elegans* var. *ornatum* and *Dinobryon sociale*. Group 10 is an autumn association that appears to prefer humic waters and low sodium chloride levels. Despite an obvious preference for hardwater lakes, Group 11 is composed of species exhibiting several different habitat characteristics. Several taxa are negatively correlated with watershed influence (factor 6) suggesting that they may prefer lakes with a higher allochthonous-organic component. The last group, 12, is an association of humic halophilous taxa. Consequently, it is probably characteristic of these taxa to inhabit dystrophic lakes situated close enough to the coast to have strong marine influence.

Many species, such as *Chromulina glacialis*, *Chromulina minuta*, and *Desmarella moniliformis*, appear to prefer dystrophic (polyhumic) waters. A smaller number of taxa, including *Chroococcus turgidus* and *Sphaerocystis schroeteri*, appear to prefer clear, oligohumic waters. Airphoto/Beak (1976) also found the genera *Chromulina* and the algal group Cryptophyceae to be dominant in lakes demonstrating dystrophic characteristics in the Cat Arm drainage. Species exhibiting no correlation with factor 1 are apparently not influenced by humic content and consequently probably occur over a wide range of organic conditions, and perhaps are influenced by one or more other factors. The large number of dystrophic taxa is perhaps a reflection of the extended period that phytoplankton have had to adapt to humic conditions in Newfoundland. It also suggests that such lakes are not necessarily deficient in phytoplankton species which is also supported by a number of other studies (Raddum et al. 1980, Kelso et al. 1986, for e.g.).

Although few algae have been shown to be capable of heterotrophic carbon assimilation (Hellebrust and Lewin 1977; Vincent and Goldman 1980), heterotrophy may explain why some species appear to prefer dystrophic lakes. The high concentrations of dissolved and particulate organic substances may serve to supplement autotrophic nutrition under the low-light conditions characteristic of these highly coloured waters. Under such conditions, facultative heterotrophs may have a distinct competitive advantage over obligate autotrophs. A number of studies have demonstrated good agreement between the heterotrophic capabilities of algae and their occurrence in environments containing an abundant supply of organics (Lee et al. 1975; Helleburst and Lewin 1977). Stokes (1980) found the blue-green algae to be the dominant group in naturally acidic dystrophic lakes in Ontario suggesting that humic materials are conducive to developing populations of this algal group. Consequently, species exhibiting an affinity for polyhumic waters may serve to suggest phytoplankton taxa which should perhaps be investigated for heterotrophic capabilities.

A great many species appear to prefer hardwater lakes probably because of their generally higher nutrient content. However, Moss (1973) concluded that the concentration of free carbon dioxide in water is likely the major factor influencing the distribution of such species. Species correlations with hardness perhaps occur because the availability of free carbon dioxide decreases with increasing hardness. Moss (1973) proposed that hardwater taxa are capable of substituting bicarbonate ion as a carbon source when free carbon dioxide is limiting. In this study, those species strongly correlated with hardness, such as *Rhodomonas minuta*, *Gomphosphaeria lacustris*, and *Katablepharis ovalis*, are likely to occur predominantly in lakes situated on the limestone deposits of the Northern Peninsula and western region of Newfoundland. Conversely, *Rhodomonas minuta v. nannoplanctica* was found to be the dominant phytoplanker (numerically) in dystrophic Cat Arm lakes (Airphoto/Beak 1976) over granitic and gneitic bedrock. *Rhodomonus minuta* was also a dominant species in Victoria Reservoir, a large dystrophic water body in central Newfoundland, characterized by low phytoplankton biomass and diversity. Several of the species from this hardwater group are quite common in the relatively hard waters of the lower Laurentian Great Lakes (Munawar and Munawar 1981). Likewise, Earle et al. (1986) found *R. minuta* and *G. lacustris* to be very significantly correlated with hardwater lakes in Labrador. *Ceratium hirundinella*, which also belongs to this group, has seldom been observed in Newfoundland except in the western region (C. C. Davis, pers. comm.).

Generally, these hardwater taxa occur infrequently in humic lakes, which characteristically have very low alkalinities (Scruton 1983). However, a few species, such as *Crucigenia quadrata*, *Ankistridesmus falcatus*, and *Pediastrum tetras*, appear to occur abundantly under both hardwater and dystrophic conditions. This suggests that these species may not require the higher nutrient content associated with hardwater. Alternatively, such species may be as equally efficient users of free carbon dioxide as the low-pH, dystrophic species, while also demonstrating a competitive advantage in hardwaters where they can utilize bicarbonate ion as a carbon source.

Although the phytoplankton from this study are all freshwater, oligohalobous forms, several species appear to be stimulated by higher ion concentrations. These halophilous species, such as *Cyclotella michiganiana* and *Selenastrum minutum*, occur more abudantly in lakes situated within relatively close proximity to the coast where marine aerosols influence the ionic composition of lakes. Other species, such as *Rhabdoderma lineare*, *Gymnodinium varians*, and *Eustrum binale*, should probably be considered halophobous according to Lowe's (1974) modified halobion spectrum, because of their apparent inhibition by small amounts of salts. Species that showed no significant correlation with salinity may be regarded as saline indifferent. Most of the phytoplankton appear to belong to this category with consists of species exhibiting a tolerance for high salt concentrations. Such species probably possess well developed methods of osmoregulation capable of dealing with a wide range of ionic conditions.

Many planktonic algae that lack an obvious morphological adaptation for regulating their buoyancy appear to occur more abundantly in large, deep lakes, possibly as a consequence of wind-driven circulation although the same may also occur in shallower lakes as well. This was most apparent for 'heavy' algae, such as the diatoms, *Asterionella formosa*, *Tabellaria fenestrata*, and *Rhizosolenia eriensis*, which were very strongly correlated with lake size. A similar relationship was noted for lakes in Labrador (Earle et al. 1986). Numerically, *Asterionella formosa* was an important component of the algal community in the dystrophic waters of Cat Arm. It was also found to be of very small size relative to specimens identified from continental samples, suggesting possibly a new unreported variety (Airphoto/Beak 1976). In Newfoundland, the few algae that appeared to prefer small, shallow lakes were either flagellated forms capable of maintaining themselves in the euphotic zone or benthic diatoms adapted to a littoral existence. Most taxa, however, appeared to have no preference for lakes of any specific size. Generally, these species had one or more recognized means of reducing their sinking rates. Presumably these mechanisms prevent such species from sinking out of the euphotic zone in small, well sheltered lakes where mixing is usually inadequate to maintain most cells.

About 75% of the phytoplankton in this study exhibit evidence of seasonal periodicity. Many species, such as *Frustulia vulgaris* and *Chrysolykos skujai*, were positively correlated with factor 5 and are probably late-summer forms possibly adapted to relatively higher temperature conditions. However, the correlation with temperature and dissolved oxygen does not indicate that these properties necessarily influence phytoplankton distributions, as many variables undergo marked seasonal fluctuations (Scruton 1986). It is unwise to draw too many conclusions with respect to seasonal periodicity owing to the synoptic nature of this survey and the two month length of the sampling program.

Factor 6, the ratio of drainage area to lake area, appears to reflect the relative importance of allochthonous sources of organic matter to the lakes. Consequently, species that were positively correlated with this factor may prefer waters that receive a relatively larger amount of terrestrial organic material. It follows that the negatively correlated taxa perhaps occur more abundantly in lakes with a higher autochthonous organic component.

It is also probable that Factor 6 is a reflection of varying lake flushing rates. Drainage area determines the amount of runoff available to each lake and the lake volume determines the renewal time and hence the flushing rate. Lake volume was not measured in this study, however, lake surface area was demonstrated to be strong correlated with volume ($r = 0.74$) in a similar survey in Labrador in which lake bathymetric surveys were conducted (Scruton 1986). Many lakes in the size range sampled have extremely high flushing rates (Ryan and Wakeham 1984, O'Connell and Andrews 1987). O'Connell and Andrews (1987) have shown that water renewal rates can profoundly influence species composition and population densities. Lakes with high flushing rates are characterized by phytoplankton forms (particularly phytoflagellates) which possess reproductive rates sufficient to offset their removal by flushing and consequently significant populations can be maintained. The reverse applies to the larger, slower reproducing net plankton forms (e.g. *Asterionella formosa*, *Tabellaria fenestrata*, *Anabaena flos-aquae*). Further, O'Connell and Andrews (1987) found species diversity and population sizes in an Avalon peninsula lake to be greatest in the summer, the period of greatest water retention. Consequently, the two morphometry based factors (lake size, Factor 4; watershed influence, Factor 6) and the seasonality factor (Factor 5) may also be a reflection of spatial and temporal differences in water renewal.

Orthophosphate concentrations showed little variation throughout the lakes (Kendaris 1982), however, several species occurred in significantly higher numbers in relatively enriched waters. Few species appeared to be inhibited by the availability of orthophosphate in these lakes, which are characteristically extremely low in total phosphorous (Scruton 1983). Taxa that do, such as Bicoeca cylindrica, may be more tolerant of low nutrient levels and hence better capable of successfully competing with other algae under conditions of extremely low phosphate concentrations. There was no correlation with cell size which might have suggested that smaller algae are more efficient at phosphate uptake than larger algae.

ASSESSMENT OF ACIDIFICATION EFFECTS

The data exhibit little evidence to suggest that acidic precipitation has substantially affected the water chemistry of headwater lakes in Newfoundland. An investigator using factor analysis should be able to discern between natural and anthropogenic acidification. One would expect to find a factor with a significant loading on pH as well as on other variables (sulphate) which indicate susceptible i.e. poorly buffered, impacted lakes. The results show no evidence of a negative loading on pH other than in association with naturally acidic dystrophic conditions. Additionally, algal species diversity, while showing a trend toward decreasing diversity with declining pH, did not exhibit severely impoverished algal communities in the very acidic lakes. Insular Newfoundland lakes in the pH range 4.5 to 5.0 had a mean species number of 31.6 and no lake contained fewer than 20 species. Comparatively, Lumsden Lake, an acidic lake (pH 4.4) in Ontario, was found to contain only 9 species (Yan 1979) while lakes in the pH range of 4.5 to 5.0 in Sweden contained 12 or fewer species (Almer et al. 1978). The lower species diversity in regions such as Sweden and Ontario, severely affected by acidic precipitation, suggests phytoplankton assemblages in acidic Newfoundland lakes are functionally adapted to naturally acidic, often dystrophic conditions.

These results largely supports conclusions drawn from other aquatic and biological studies in Newfoundland. While the sensitivity of the region's freshwaters to potential acidification has been well established (Scruton 1983, 1985; Howell 1986; Howell and Brooksbank 1987) widespread lake acidification and resulting perturbation of biological communities have not been documented. To date observable acidification effects have been limited to deficits in alkalinity (erosion of available buffer capacity), possible slight pH declines, and episodic pH declines of a seasonal nature (mostly in lotic systems) (Scruton 1983, 1985, 1986; Howell 1986; Scruton et al. 1987; Howell and Brooksbank 1987). The combination of aquatic sensitivity and declining buffering capacity with current and projected acidic deposition levels (Martin and Brydges 1986) suggests the island of Newfoundland could be on the edge of a potential acidification problem. With this in mind, the physical/chemical data and phytoplankton assemblages information, with the analysis contained in this report, represents baseline data against which changes in response to anthropogenic pollution and other environmental perturbations can be evaluated.

Although this study reveals no evidence of lake acidification from the long range transport of atmospheric pollutants, factor analysis may be a useful means of periodically assessing future problems in Newfoundland. The ability to adequately interpret large numbers of highly correlated variables makes this a superior method over univariate approaches. The latter fail to take into account the complexity of variables such as pH, whose values may reflect several environmental interactions. Thompson (1983) has explored the use of factor analyses in the interpretation of lake and river water chemistry data and precipitation data from Eastern Canada, and found the technique to be useful in identifying a 'LRTAP' factor and the variables contributing to this factor. A LRTAP factor (negative loadings on pH and alkalinity, positive loading to sulphate) was identified for the data for Northeast Pond River on the Avalon Peninsula in Newfoundland, but was considered relatively unimportant (19% of the variance). Her analysis also identified dystrophy, hardness, and salinity as key factors accounting for much of the variance in water chemistry in Eastern Canada.

COMPARISON OF NEWFOUNDLAND AND LABRADOR PHYTOPLANKTON AND ENVIRONMENTAL INFLUENCES

Phycological and environmental data collected from selected lakes in insular Newfoundland (this study and Earle et al. 1987) and Labrador (Earle et al. 1986; Scruton et al. 1987) were subjected to common analyses to facilitate comparisons between the two regions. Factor analysis indicated that Newfoundland and Labrador have similar environmental properties characterizing their lakes. Dystrophy, hardness, lake size, and salinity were identified as the most important factors in both regions. However, there appears to be some obvious differences in the relative importance of the four factors in the these regions. In Newfoundland, dystrophy and salinity account for more of the variability in physical and chemical properties between lakes than in Labrador. The most prominent difference, in the salinity of lakes in Newfoundland, is a reflection of its longer coast line, prevailing wind patterns, and insular nature (Scruton 1983). Newfoundland also has a greater proportion of humic lakes than Labrador and the organic content is generally higher. This can be related to higher annual rainfall, low evapotranspiration rates, and generally poorly developed drainage patterns in Newfoundland leading to development of bogs, fens, and organic soils (MacPherson and MacPherson 1981). By contrast, hardness and lake size explained a greater proportion of the variability between lakes in Labrador than it did in Newfoundland. The Labrador lake sample however demonstrated a wider range in size and represented lakes from all drainage orders, not predominantly headwater systems as in Newfoundland (Scruton 1984).

A seasonality factor, reflecting temporal variability in dissolved oxygen content and water temperature, was also observed in the data from both regions. In Labrador, an oligotrophic factor was distinguished on the basis of maximum depth and secchi depth. The Newfoundland data, however, did not include measurement of lake depth or volume, hence a comparable factor did not emerge.

Instead, lake status may have been represented by factor 7, orthophosphate concentration. In the Newfoundland data only, there was evidence of a factor discriminating lakes on the basis of the amount of influence the watershed has on allochthonous input to the lakes (factor 6).

A large proportion of the Newfoundland and Labrador flora correlated highly with one or more of the derived environmental factors. The relative importance of the various environmental factors influencing the distribution of the phytoplankton can be judged qualitatively by the number of species correlating with each factor. In Newfoundland, for example, 26 species were significantly ($\alpha = 0.10$) correlated with salinity; 23 species with seasonality; 22 species with hardness and dystrophy; and 18 species with orthophosphate enrichment. In contrast, much fewer species were significantly correlated with lake size or watershed influence. In Labrador, the factors with the largest number of significantly correlated species were dystrophy (24), hardness (21), and lake size (19). The others factors, including salinity, had considerably fewer significantly correlated species.

These results suggest that there are differences in the importance of various environmental factors controlling phytoplankton distributions in these two regions. In Newfoundland, salinity appears to be a more influential factor than in Labrador. The longer coast line and proximity of study lakes to salt water in Newfoundland may provide for a larger number of suitable niches for saline indifferent and halophilous species. In Labrador, differences in lake size appear to influence the distribution and abundance of more species than in Newfoundland (which may also be an artifact of lake selection criteria). There were no obvious differences in the importance of either dystrophy or hardness in regulating species distributions.

In order to be confident of any ecological interpretations based on studies of phytoplankton distribution, it becomes necessary to demonstrate similar conclusions from other regions. In this study, the interpretations of the autecology of Newfoundland phytoplankton correspond well with the interpretations reached for the Labrador phytoplankton (Earle et al. 1986). Although the comparison is partially hampered by differences in species composition between the two regions, there were very few contradictions. One notable exception was the ecological interpretation for *Kephyrion obliquum* which was negatively correlated with hardness and dystrophy in Labrador but apparently indifferent to these factors in Newfoundland. The phytoplankton associations of Newfoundland and Labrador correspond reasonably well with the environmental structure described by the factor analysis. Hardwater, saline, and dystrophic associations are easily discerned in both regions. The species comprising these associations often differ, primarily due to basic differences in regional species composition.

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Table 1. Water quality parameters measured, analytical methods employed, and limits of detection for 20 physical and chemical water properties determined for the study lakes (from Scruton 1983).

Parameter	Analytical Procedure	Required Vol. (ml)	Limit of Detection (mg/L)
Conductivity	Radiometer Conductivity Meter	20	0.5 (μScm^{-1})
Colour	Visual Comparison using Platinum Colour Plasma	10	5 (TCU)
pH	Combination Glass & Reference Electrode Radiometer pH Meter	8	0.01 (pH units)
Turbidity	Nephelometric Method	10	- (JTU)
Sodium	Atomic Absorption	2	0.1
Potassium	Atomic Absorption	2	0.02
Calcium	Atomic Absorption	2	0.01
Magnesium	Atomic Absorption	2	0.02
Alkalinity	Auto Analyzer Colormetric Bromophenol Blue	8	0.1
Sulfate	Auto Analyzer Colormetric Methylthymol Blue	8	0.3
Chloride	Auto Analyzer Colormetric Mercuric Thiocyanate	8	0.1
Phosphate total as P	Auto Analyzer Colormetric-U.V. Digestion & Molybate Ascorbic Acid	8	0.001
Nitrogen total as N	Auto Analyzer Colormetric-U.V. Digestion & Diazotization	8	0.02
Aluminum	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.010
Zinc	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.002
Nickel	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.001
Copper	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.0015
Lead	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.001
Cadmium	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.0006
Iron	Atomic Absorption - ICP (Inductively Coupled Plasma)	50	0.007
Manganese	Atomic Absorption - ICP (Inductively Coupled Plasma)	50	0.003

Table 2. Morphometric and physical data.

LAKE	LSA	DRAINAGE AREA	DA:LSA	WATER TEMP	SECCHI DEPTH	TDS	TURBIDITY	COLOR
1	147.0	706.0	4.8	12.4	2.5	150.3	0.44	5
2	23.0	205.0	8.9	13.9	4.2	110.7	0.52	5
3	47.0	597.0	12.7	13.7	1.5	64.2	0.74	50
4	99.0	591.0	6.0	14.0	6.5	22.1	0.48	5
5	29.0	574.0	19.8	14.5	1.5	23.5	0.80	125
6	361.0	1634.0	4.5	13.2	6.0	17.6	0.35	10
7	77.0	572.0	7.4	12.9	4.5	19.2	0.62	25
8	104.0	617.0	5.9	12.7	3.0	17.2	0.76	30
9	130.0	438.0	3.4	9.0	2.5	17.6	0.55	30
10	117.0	342.0	2.9	9.0	4.3	18.1	0.25	10
11	232.0	660.0	2.8	11.7	5.0	106.3	0.54	10
12	25.0	167.0	6.7	8.6	1.0	21.4	0.93	90
13	941.0	3964.0	4.2	8.1	2.2	19.2	1.00	35
14	50.0	643.0	12.9	9.3	1.5	20.7	1.20	125
15	60.0	719.0	12.0	11.5	0.8	21.4	1.20	125
16	64.0	396.0	12.9	10.6	3.5	19.9	0.68	5
18	35.0	311.0	8.9	10.5	3.0	18.3	0.56	45
19	32.0	199.0	6.2	10.1	7.5	19.2	0.76	10
20	83.0	529.0	6.4	11.8	2.5	17.6	0.95	45
21	33.0	404.0	12.2	13.5	1.7	86.9	0.58	65
22	33.0	150.0	4.5	11.6	1.0	23.9	0.48	35
23	78.0	368.0	4.7	10.6	5.0	17.0	0.45	15
52	82.0	889.0	10.8	9.9	2.0	22.8	0.96	75
53	406.0	3194.0	7.9	16.1	3.8	17.5	0.40	25
54	103.0	495.0	4.8	15.8	2.0	17.6	0.43	60
55	104.0	910.0	8.8	20.4	3.0	30.9	0.37	45
56	42.0	285.0	6.8	11.4	3.2	30.7	0.40	30
57	82.0	542.0	6.6	19.5	3.0	17.8	0.40	40
58	179.0	2007.0	11.2	21.8	1.0	22.7	0.36	80
59	165.0	659.0	14.0	16.7	2.6	23.8	0.37	10
60	37.0	185.0	5.0	9.5	2.0	15.8	0.65	25
61	123.0	1089.0	8.9	17.1	1.0	24.2	0.50	25
62	31.0	516.0	16.6	6.4	1.5	15.2	0.30	5
63	96.0	714.0	7.4	6.7	1.3	24.5	1.70	45
64	98.0	957.0	9.8	19.7	2.2	18.0	0.55	45
66	72.0	355.0	4.9	15.0	6.0	15.8	0.30	15
67	324.0	1304.0	4.0	16.2	4.5	18.9	0.53	15
68	65.0	358.0	5.5	16.5	5.5	15.9	0.77	30
69	75.0	450.0	6.0	5.6	1.5	15.4	1.30	60
70	164.0	825.0	5.0	20.4	2.1	22.7	0.53	25
71	32.0	791.0	24.7	10.4	2.0	22.1	0.43	65
72	33.0	731.0	22.2	6.0	0.5	21.4	1.10	200
73	125.0	730.0	5.8	15.9	1.2	21.4	0.41	20
75	65.0	350.0	5.4	6.2	2.0	17.8	1.60	55
76	40.0	151.0	3.8	6.5	1.8	18.1	0.77	55
77	24.0	103.0	4.3	6.9	2.0	17.1	0.64	50
78	100.0	462.0	4.6	19.5	2.5	20.4	0.50	20
79	140.0	584.0	4.2	14.8	3.5	24.2	0.40	40
81	141.0	807.0	5.7	16.5	3.0	38.3	0.31	30
82	132.0	717.0	5.4	19.2	2.8	18.9	0.56	30
83	87.0	3150.0	36.2	20.8	1.7	18.6	0.67	60
102	46.0	368.0	8.0	7.5	0.3	49.7	1.70	225
103	46.0	654.0	14.2	7.7	0.8	36.0	1.90	150
104	48.0	129.0	2.7	11.6	5.5	26.4	0.30	25
105	39.0	308.0	7.9	6.8	0.8	36.7	1.30	125

Table 2 (Cont'd.)

LAKE	LSA	DRAINAGE AREA	DA:LSA	WATER TEMP	SECCHI DEPTH	TDS	TURBIDITY	COLOR
107	114.0	731.0	6.4	6.7	1.0	26.8	1.60	90
108	257.0	1036.0	4.0	14.9	4.5	26.4	0.35	30
109	341.0	1056.0	3.1	18.0	4.5	33.5	0.49	10
110	197.0	1570.0	8.0	18.3	3.0	23.8	0.33	40
111	169.0	2047.0	12.1	16.8	4.0	21.2	0.40	35
112	97.0	773.0	8.0	17.8	0.8	19.7	0.85	45
113	95.0	1197.0	12.6	18.0	2.0	23.1	0.80	70
114	57.0	1272.0	22.3	17.7	2.5	23.1	0.60	35
116	24.0	475.0	19.8	8.5	1.5	21.7	0.73	90
117	251.9	1370.6	5.4	16.4	2.0	19.4	0.30	35
118	100.0	648.0	6.5	17.7	4.0	.	.	
119	127.0	720.0	5.7	14.7	0.8	17.3	0.54	50
120	37.0	323.0	8.7	8.4	1.2	23.4	0.77	45
121	79.0	422.0	5.4	15.5	2.0	20.8	0.54	70
122	226.0	2354.0	10.4	17.6	2.0	21.9	0.47	60
123	353.0	869.0	2.5	16.6	4.0	19.7	0.42	30
124	250.0	1533.0	6.1	16.3	2.0	19.7	0.58	50
125	359.0	1031.0	2.9	15.7	5.5	17.8	0.36	10
152	250.0	5110.0	20.4	17.9	2.0	28.7	0.46	75
153	96.0	404.0	4.2	16.4	3.0	26.4	0.39	30
154	48.0	396.0	8.2	16.8	2.5	24.2	0.36	35
201	98.0	700.0	7.1	11.8	3.3	31.8	0.33	55
203	24.0	127.0	5.3	9.5	3.5	19.9	0.41	25
204	23.0	257.0	11.2	8.5	2.0	21.4	0.69	65
205	80.0	566.0	7.1	16.2	3.5	21.4	1.10	35
206	120.0	874.0	7.3	15.5	2.8	17.3	0.35	35
207	195.0	1057.0	5.4	16.2	4.0	20.4	0.43	25
208	173.0	1030.0	6.0	14.9	2.0	18.2	0.60	55
209	88.0	591.0	6.7	15.5	2.2	23.8	0.48	25
211	95.0	1209.0	12.7	14.4	2.5	19.4	0.66	40
213	209.0	1726.0	8.3	15.4	2.0	18.2	0.60	60
215	87.0	508.0	5.8	15.7	3.8	24.5	0.40	35
217	244.0	1010.0	4.1	16.6	4.2	19.4	0.42	25
219	1177.0	1027.0	5.8	16.7	2.5	21.9	0.63	40
220	385.0	2180.0	5.7	16.7	4.8	20.4	0.39	25
221	558.0	4577.0	8.2	16.6	3.0	23.1	0.62	35
222	36.0	193.0	5.4	8.5	2.8	19.2	0.52	15
224	28.0	148.0	5.3	8.9	0.5	19.2	0.84	55
225	166.0	577.0	3.5	16.3	9.5	20.1	0.22	5
226	176.0	1163.0	6.6	15.4	0.8	20.1	0.58	15
228	71.0	475.0	6.7	9.7	2.2	22.1	0.55	35
229	93.0	813.0	8.7	8.5	1.0	21.1	1.20	80
230	65.0	617.0	9.5	9.7	1.5	22.1	0.64	80
232	82.0	903.0	11.0	16.7	4.0	20.4	0.35	35
251	33.0	415.0	12.6	10.6	0.8	38.3	0.59	40
252	101.0	585.0	5.8	18.8	4.0	19.7	0.42	35
253	37.0	231.0	6.2	11.5	3.5	103.5	0.25	25
254	45.0	254.0	5.6	16.4	2.8	21.4	0.45	40
255	141.0	169.3	12.0	16.2	2.9	25.7	0.40	60
256	21.0	465.0	22.1	9.6	1.0	45.9	1.10	175

LSA = LAKE SURFACE AREA   DA = DRAINAGE AREA   DA:LSA = DRAINAGE AREA:LAKE SURFACE AREA

Table 3. Physical and chemical data.

LAKE	DO	CD	SD	PH	ALK	CA	MG	NA	K	CL	SO4	PO4	NO3	AL	MN	FE
1	11.6	0.0	2.5	8.39	.	1400	410	139	3	163.0	50.0	0.064	0.714	4.6	0.4	2.2
2	10.9	0.4	4.2	8.17	1160.6	1100	224	117	5	140.8	52.0	0.064	0.714	2.8	0.8	3.1
3	11.2	1.0	1.5	7.68	478.2	335	287	165	4	205.0	64.0	0.064	0.714	8.1	0.8	4.9
4	9.8	1.9	6.5	6.13	19.5	29	32	73	6	84.0	52.0	0.258	0.714	4.1	0.2	1.9
5	8.9	2.5	1.5	6.54	49.0	65	39	73	3	81.0	62.0	0.064	0.714	28.9	0.4	8.7
6	9.7	2.1	6.0	5.65	10.5	17	16	56	1	61.0	29.0	0.258	2.857	5.3	0.3	1.8
7	9.8	1.9	4.5	6.37	23.0	24	29	60	3	67.0	33.0	0.064	1.428	6.9	0.1	2.2
8	9.9	2.6	3.0	5.37	2.9	17	17	47	1	59.0	14.0	0.129	0.714	10.0	0.4	.
9	11.1	1.8	2.5	5.97	1.4	21	19	56	1	61.0	27.0	0.129	0.714	3.9	0.5	6.0
10	10.7	1.3	4.3	6.48	10.0	19	23	60	1	64.0	29.0	0.129	5.000	5.2	0.1	0.9
11	11.3	0.3	5.0	8.05	1044.9	800	368	178	6	208.0	72.0	0.064	0.714	3.7	0.2	1.5
12	10.5	4.9	1.0	4.90	0.0	27	25	56	3	67.6	54.0	0.064	1.428	23.3	1.4	11.6
13	11.7	2.9	2.2	5.50	10.6	16	19	56	2	70.0	22.0	0.064	1.428	5.2	0.6	6.9
14	9.9	4.9	1.5	5.10	4.6	24	30	56	2	64.0	47.0	0.064	0.714	30.0	0.6	17.8
15	10.1	4.0	0.8	5.00	3.4	21	30	65	3	74.0	56.0	0.064	0.714	27.8	0.8	18.8
16	10.0	1.2	3.5	6.16	8.9	19	23	78	1	95.0	29.0	0.064	5.000	4.1	0.2	2.2
18	10.5	1.4	3.0	6.79	37.8	44	26	47	2	56.0	31.0	0.129	1.428	9.4	0.7	3.4
19	10.3	1.7	7.5	5.51	4.1	15	20	69	1	90.0	62.5	0.258	3.571	4.9	0.4	1.2
20	10.0	2.2	2.5	6.22	39.7	52	16	43	2	53.0	33.0	0.064	2.857	14.4	0.2	2.8
21	10.2	0.4	1.7	7.46	820.3	550	345	191	8	200.0	89.0	0.064	2.143	21.0	0.4	6.3
22	9.1	1.6	1.0	6.63	71.6	79	45	60	5	67.6	45.0	0.194	0.714	10.0	0.2	5.7
23	10.6	1.4	5.0	5.54	5.5	13	16	52	2	61.0	27.0	0.129	0.714	5.6	0.4	5.2
52	10.1	3.5	2.0	6.44	64.2	103	29	60	6	61.0	60.0	0.064	0.714	7.7	0.6	0.1
53	9.2	1.7	3.8	6.03	32.1	30	23	47	3	47.0	37.0	0.064	0.714	0.0	0.2	2.7
54	8.8	2.0	2.0	6.30	46.6	26	48	43	2	39.0	41.0	0.064	0.714	0.0	0.2	5.8
55	9.3	1.3	3.0	7.38	209.3	195	46	69	4	53.0	39.0	0.129	0.714	9.8	0.1	4.4
56	10.7	1.6	3.2	7.28	188.3	185	45	65	1	61.0	45.0	0.194	0.714	7.6	0.2	2.7
57	9.1	1.6	3.0	6.99	61.1	34	23	52	3	39.0	29.0	0.129	1.430	10.6	0.8	5.5
58	9.2	2.2	1.0	7.04	101.6	120	35	56	1	42.0	47.0	0.064	0.714	13.9	0.1	8.0
59	9.6	1.0	2.6	7.60	115.7	85	40	60	4	50.0	29.0	0.064	0.714	3.9	0.1	1.9
60	10.7	1.3	2.0	6.82	33.1	22	19	40	2	25.0	37.0	0.194	1.428	10.0	0.1	3.0
61	9.3	1.5	1.0	7.29	96.8	85	44	60	6	47.0	37.0	0.064	0.714	8.9	0.4	2.2
62	11.4	1.2	1.5	6.52	28.4	16	12	43	2	28.0	29.0	0.194	0.714	3.1	0.0	1.0
63	11.6	1.7	1.3	7.11	116.3	115	45	56	5	56.0	50.0	0.064	0.714	14.3	0.8	7.4
64	10.0	1.4	2.2	6.70	65.6	70	21	38	1	28.0	31.0	0.129	0.714	10.7	0.2	6.6
66	10.1	1.3	6.0	6.68	27.0	25	15	37	2	30.0	35.0	0.064	2.143	8.2	0.2	0.9
67	9.4	1.5	4.5	7.48	71.8	54	19	43	3	39.0	29.0	0.064	0.714	2.8	0.2	0.9
68	9.8	3.4	5.5	5.77	12.1	23	16	39	2	36.0	41.0	0.064	2.143	14.3	0.2	1.5
69	11.8	2.3	1.5	6.47	18.6	36	15	33	1	33.0	39.0	0.129	0.714	9.0	0.4	12.5
70	8.5	1.3	2.1	6.91	95.6	100	39	47	3	47.0	39.0	0.129	0.714	6.6	0.2	3.1
71	10.7	2.6	2.0	6.46	45.0	59	31	65	3	73.0	56.0	0.064	2.143	19.2	0.4	8.5
72	10.8	6.4	0.5	5.18	6.4	50	31	47	2	56.0	97.0	0.064	0.714	15.5	1.2	29.0
73	10.1	4.5	1.2	7.01	64.2	79	23	47	3	45.1	50.0	0.064	0.714	4.4	0.2	3.1
75	11.5	2.9	2.0	5.86	22.2	36	18	47	2	53.0	45.0	0.064	3.571	31.1	0.3	9.8
76	11.5	3.3	1.8	5.66	5.8	31	15	52	2	50.0	45.0	0.064	0.714	24.4	1.1	5.8
77	11.2	2.6	2.0	6.02	23.3	31	23	42	2	47.0	45.0	0.064	0.714	10.6	0.2	7.2
78	9.3	1.3	2.5	6.67	65.6	65	38	47	1	50.0	31.0	0.064	0.714	5.4	0.2	2.3
79	9.4	3.7	3.5	5.59	13.4	35	29	91	3	107.0	52.0	0.064	2.857	9.1	0.3	0.5
81	9.8	1.1	3.0	7.54	246.8	234	51	91	7	87.0	58.0	0.129	0.714	9.1	0.1	2.9
82	9.3	1.7	2.8	6.48	42.1	54	27	52	3	53.0	35.0	0.064	0.714	10.3	0.2	5.8
83	8.7	2.4	1.7	6.36	38.2	60	21	56	1	47.0	39.0	0.064	0.714	13.1	0.5	9.8
102	10.7	6.2	0.3	5.59	47.5	92	110	278	8	394.0	114.0	0.064	0.714	42.2	1.8	44.3
103	10.9	5.2	0.8	5.80	25.9	48	70	182	5	233.0	77.0	0.064	0.714	47.8	1.7	44.6
104	10.3	1.6	5.5	7.04	84.8	62	48	78	5	92.0	47.0	0.194	1.428	7.1	0.2	2.0
105	11.2	4.7	0.8	5.42	13.3	37	62	195	4	261.0	66.0	0.194	0.714	38.9	0.7	46.9

Table 3 (Cont'd.)

LAKE	DO	CD	SD	PH	ALK	CA	MG	NA	K	CL	SO4	PO4	NO3	AL	MN	FE
107	11.4	4.6	1.0	5.78	12.2	27	53	113	3	143.0	62.0	0.323	0.714	30.0	1.1	20.1
108	9.4	1.4	4.5	6.08	27.2	25	43	134	3	149.0	41.0	0.064	6.430	14.4	0.2	1.2
109	9.7	1.0	4.5	6.95	173.6	130	80	104	3	104.0	31.3	0.129	2.140	2.6	0.4	1.1
110	9.6	1.5	3.0	6.60	56.6	60	46	91	3	95.0	25.0	0.129	0.428	8.0	0.2	2.1
111	9.8	2.3	4.0	6.07	27.7	35	35	73	6	78.0	33.0	0.064	5.710	12.2	1.4	5.3
112	9.9	1.4	0.8	6.88	62.3	43	27	69	5	56.0	27.0	0.064	0.714	7.8	0.3	14.6
113	9.6	2.1	2.0	6.58	67.3	54	35	86	6	70.0	37.0	0.064	0.714	21.8	0.9	19.6
114	9.8	1.5	2.5	6.70	79.5	75	39	69	8	64.0	33.0	0.064	0.714	8.7	0.2	4.0
116	10.7	4.3	1.5	5.88	31.8	37	27	82	8	84.0	45.0	0.129	0.714	26.7	1.3	30.4
117	9.7	1.5	2.0	6.32	38.6	39	32	56	3	59.2	35.0	0.064	5.710	9.0	0.2	4.4
118	9.0	2.5	4.0	5.85	11.8	19	52	169	10	.	.	.	.	22.2	0.4	2.9
119	9.7	1.6	0.8	5.90	13.6	31	30	43	2	47.0	35.0	0.129	3.571	8.4	0.2	4.1
120	11.0	2.8	1.2	6.72	83.0	90	31	69	3	90.0	54.0	0.258	0.714	8.4	0.4	10.7
121	9.2	1.9	2.0	6.50	39.4	33	50	69	5	73.0	45.0	0.194	0.714	13.7	0.6	5.8
122	8.5	2.4	2.0	6.36	51.7	60	30	78	3	73.0	39.0	0.064	0.714	12.9	0.6	7.1
123	9.2	1.2	4.0	6.67	42.4	54	22	60	3	78.0	33.0	0.129	0.714	8.0	0.2	3.6
124	9.4	1.5	2.0	6.84	36.8	54	30	60	3	67.0	39.0	0.064	1.428	4.6	0.1	1.6
125	9.7	0.9	5.5	7.44	34.0	30	17	60	2	56.0	29.0	0.129	0.714	9.1	0.4	7.9
152	8.4	2.4	2.0	6.67	65.3	54	48	143	3	135.2	27.1	0.323	0.714	18.2	0.9	7.7
153	9.2	1.4	3.0	6.72	58.9	41	39	126	2	140.8	47.9	0.129	0.714	8.1	0.2	3.2
154	8.8	1.8	2.5	6.25	19.4	32	30	121	2	112.7	22.9	0.258	1.428	14.7	0.3	4.5
201	9.4	2.3	3.3	5.58	43.4	66	50	139	5	166.0	68.0	0.064	4.285	10.6	0.4	5.2
203	10.4	2.2	3.5	5.79	0.0	19	16	69	1	81.0	47.0	0.064	3.571	10.3	0.3	1.8
204	10.3	4.1	2.0	5.14	0.0	27	20	65	1	73.0	70.0	0.064	1.428	18.9	0.7	6.7
205	9.2	2.2	3.5	5.89	16.5	33	20	73	2	78.0	54.0	0.129	7.143	14.4	0.3	2.1
206	9.3	1.7	2.8	6.18	21.0	27	16	52	2	47.0	41.0	0.064	1.428	8.6	0.5	4.3
207	9.8	2.4	4.0	5.14	1.1	15	18	65	1	73.0	47.0	0.064	3.571	11.1	0.8	2.9
208	9.8	2.2	2.0	5.78	27.6	28	16	69	1	81.0	39.0	0.129	0.714	12.9	0.2	3.9
209	9.4	1.1	2.2	6.94	85.8	100	26	73	1	73.0	35.0	0.258	2.857	3.2	0.3	3.0
211	10.1	1.8	2.5	5.97	22.6	33	19	69	4	64.0	33.0	0.064	5.714	8.2	0.1	4.7
213	8.8	2.2	2.0	6.02	20.7	28	25	69	1	64.0	39.0	0.064	18.571	16.1	0.2	4.7
215	10.2	2.1	3.8	5.76	13.9	25	30	113	3	123.0	52.1	0.064	6.428	17.3	0.3	0.1
217	9.4	2.0	4.2	6.00	24.7	28	22	73	1	78.0	35.0	0.194	0.714	6.2	1.5	2.6
219	10.2	1.9	2.5	6.18	18.7	38	29	91	5	92.0	41.0	0.258	0.714	11.4	0.6	4.3
220	9.4	1.6	4.8	5.98	16.7	26	21	82	3	87.0	33.0	0.194	1.428	9.0	0.1	1.2
221	10.2	1.5	3.0	6.48	42.3	28	30	91	4	98.6	35.0	0.194	0.714	8.3	0.4	6.1
222	11.3	2.3	2.8	5.74	5.3	16	16	73	3	73.2	35.0	0.064	0.714	6.9	0.3	3.7
224	11.3	3.7	0.5	5.55	5.6	26	19	65	2	70.0	35.0	0.064	0.714	10.6	0.5	11.6
225	10.5	1.4	9.5	6.42	6.0	25	17	78	2	76.0	33.0	0.194	4.285	6.1	0.0	1.5
226	10.6	1.1	0.8	6.85	36.4	33	19	78	3	78.0	45.8	0.064	0.714	3.2	0.1	5.6
228	10.7	2.9	2.2	5.69	7.6	20	23	95	2	98.0	52.0	0.064	0.714	18.9	0.5	2.9
229	11.0	3.4	1.0	6.22	52.5	50	28	73	3	76.0	50.0	0.064	0.714	15.6	0.6	17.0
230	10.4	4.3	1.5	5.30	12.9	36	26	82	2	90.0	62.0	0.064	2.857	23.3	1.9	9.4
232	9.1	2.1	4.0	6.08	14.4	28	23	78	2	81.0	39.0	0.064	1.428	11.3	0.4	3.1
251	10.1	1.6	0.8	7.22	317.7	275	77	69	3	56.0	50.0	0.064	0.714	6.2	0.4	0.1
252	9.1	1.8	4.0	6.84	40.6	48	25	56	3	53.0	47.0	0.064	2.143	18.2	0.5	4.6
253	10.3	1.0	3.5	7.81	1221.4	700	406	91	3	101.0	62.0	0.194	0.714	5.3	0.1	1.9
254	10.0	2.0	2.8	6.22	23.4	51	23	65	2	64.8	87.0	0.258	0.714	14.4	0.4	4.4
255	10.2	1.7	2.9	6.83	104.7	150	35	65	2	59.0	58.0	0.194	1.428	13.3	0.4	8.5
256	9.3	2.3	1.0	7.12	174.3	190	25	221	9	211.3	116.0	0.129	1.243	41.1	1.0	

DO = DISSOLVED OXYGEN
CD = CARBON DIOXIDE
MG = MAGNESIUM
NA = SODIUM
SUL = SULPHATE
AL = ALUMINIUM
CA = CALCIUM
CL = CHLORIDE
ALK = ALKALINITY
K = POTASSIUM
MN = MANGANESE
FE = IRON

Table 4. Statistical summary of lake morphometric characteristics, physical and chemical properties, and trace metal levels.

Parameter	n	Minimum	Maximun	Mean	Standard error
Morphometric characteristics					
Lake area (ha)	109	21.0	2519.0	153.5	280.0
Watershed area (ha)	109	98.0	13706.0	950.3	1496.0
Watershed area to lake area ratio	109	2.50	36.20	8.35	5.41
Elevation (m)	109	24.4	708.7	248.2	141.7
Distance from the coast (km)	109	3.0	87.5	24.5	19.3
Physical Properties					
Colour (TCU)	108	5.0	225.0	48.5	41.3
Turbidity (JTU)	108	0.22	3.10	0.65	0.42
Secchi disc depth (m)	109	0.30	9.50	2.72	1.63
Hardness (μeq L^{-1})	109	44.6	2591.6	231.2	395.5
Conductivity (μScm^{-1})	108	11.4	199.0	28.9	29.6
Total dissolved solids (mg L^{-1})	108	15.2	150.3	27.8	21.2
Water Chemistry					
pH	109	4.90	8.39	6.40	0.73
Alkalinity (μeq L^{-1})	109	-6.4	1221.4	95.3	209.5
Calcium (μeq L^{-1})	109	13.0	1400.0	102.5	202.1
Magnesium (μeq L^{-1})	109	12.0	410.0	50.1	75.1
Sodium (μeq L^{-1})	109	33.0	278.0	82.3	46.2
Potassium (μeq L^{-1})	109	1.0	17.0	3.3	2.4
Bicarbonate (μeq L^{-1})	108	0.0	1740.0	99.5	230.7
Chloride (μeq L^{-1})	108	25.0	394.0	87.8	58.4
Sulphate (μeq L^{-1})	108	14.0	127.0	46.8	19.6
Orthophosphate (μeq L^{-1})	108	0.064	0.323	0.114	0.070
Nitrate (μeq L^{-1})	108	0.428	18.571	1.841	2.290
Anion sum (μeq L^{-1})	108	85.3	1953.4	244.4	289.6
Cation sum (μeq L^{-1})	108	75.3	1952.7	241.8	294.0
Excess calcium (μeq L^{-1})	108	11.7	1396.5	101.4	202.4
Excess magnesium (μeq L^{-1})	108	10.1	399.2	44.2	73.6
Excess sodium (μeq L^{-1})	108	13.5	103.5	32.7	15.7
Excess potassium (μeq L^{-1})	108	0.0	11.8	1.5	1.8
Excess sulphate (μeq L^{-1})	108	5.7	91.4	34.5	15.4
Trace Metals					
Lead (μeq L^{-1})	109	0.000	0.200	0.002	0.019
Aluminium (μeq L^{-1})	109	0.00	47.80	12.4	9.00
Mangenese (μeq L^{-1})	109	0.00	1.90	0.46	0.39
Cadmium (μeq L^{-1})	109	0.018	0.044	0.019	0.003
Iron (μeq L^{-1})	108	0.10	53.60	7.37	9.97
Copper (μeq L^{-1})	18	0.062	0.103	0.065	0.010
Nickel (μeq L^{-1})	18	0.034	0.034	0.034	0.000
Zinc (μeq L^{-1})	18	0.062	0.074	0.063	0.003

Table 5. Factor analysis of 23 physical, chemical and morphometric variables. Correlation coefficients are between the seven derived factors and the original variables. Non-significant coefficients ($r<0.25$, $P>0.10$) have been replaced by 0.

	Derived Factors						
Variable	1 Dystrophy	2 Hardness	3 Salinity	4 Lake Size	5 Seasonality	6 Watershed Influence	7 Enrichment
Colour	.906	0	0	0	0	0	0
Iron	.818	0	0	0	0	0	0
Aluminum	.808	0	0	0	0	0	0
CO_2	.684	-.544	0	0	0	0	0
Turbidity	.648	0	0	0	.373	0	0
Manganese	.634	0	.303	0	0	0	0
Secchi Depth	-.724	0	0	0	-.264	0	0
Alkalinity	0	.923	0	0	0	0	0
Calcium	0	.923	.270	0	0	0	0
pH	-.360	.850	0	0	0	0	0
Magnesium	0	.742	.546	0	0	0	0
TDS	0	.708	.640	0	0	0	0
Potassium	.266	.491	.370	0	0	0	0
Nitrate	-.279	-.337	0	0	0	0	-.301
Chloride	0	0	.935	0	0	0	0
Sodium	0	.269	.908	0	0	0	0
Sulphate	.401	0	.484	-.420	0	0	0
Drainage Area	0	0	0	.884	0	0	0
LSA	0	0	0	.850	0	-.320	0
Dissolved Oxygen	0	0	0	0	.824	0	0
Water Temperature	-.311	0	0	.380	-.710	0	0
DA:LSA Ratio	.391	0	0	0	0	.765	0
Orthophosphate	0	0	0	0	0	0	.415
% Variance Explained by Factor	27.5%	25.4%	17.8%	11.1%	10.0%	5.1%	3.1%

TDS = Total Dissolved Solids
LSA = Lake Surface Area

Table 6. Spearman correlation coefficients between seven derived factors and the abundance of selected photoplankton. Taxa are grouped according to their cluster association. Significant correlations (r > 0.168; P < 0.10) are in italics and values less than 0.10 have been replaced by a period (after Earle et al. 1987).

	FACTOR						
SPECIES	1 Dystrophy	2 Hardness	3 Salinity	4 Lake-Size	5 Season	6 Watershed	7 Phosphate
Group 1							
Anabaena flos-aquae	.	*.30*	.	.	*-.19*	.	.
Rhodomonas minuta	*-.19*	*.63*	.	.	*-.30*	.14	.10
Ceratium hirundinella	*-.17*	*.30*	.	.11	.	-.11	.
Cyclotella michiganiana	*-.17*	*.21*	*.35*	.10	-.14	-.15	.
Crucigenia quadrata	*.18*	*.21*	*.20*	.	.	.14	.15
Microcystis aeruginosa	.	.	.16	.12	*-.28*	.16	.
Group 2							
Asterionella formosa	.	.	*.19*	*.28*	.	.	.
Tabellaria fenestrata	*.19*	.	.	*.28*	.	*-.26*	*.26*
Dinobryon utriculus	.	.	.15	.	*-.19*	.	.14
Cryptomonas erosa	.11	.13	.10	.	-.12	.	.
Salpingoeca frequentissima	*.26*	.11	.16	.	-.10	.	.
Group 3							
Chroococcus turgidus	*-.29*	.	-.15	.	*.22*	.13	-.14
Sphaerocystis schroeteri	*-.26*	.	.	.16	*-.25*	.	.
Group 4							
Chroococcus limneticus	*-.19*	.	.	.	*-.37*	-.11	.16
Cryptomonas marssonii	.	.	.	.	*-.28*	*.17*	.
Euastrum abruptum	.	.	-.13	*.18*	*-.19*	-.15	*.19*
Rhabdoderma lineare	-.12	.	*-.29*	.13	*-.27*	*-.17*	*.27*
Group 5							
Uroglena americana	-.14	.	.	-.15	.	.	.14
Gleocystis planctonica	.	.	.10	.15	-.12	-.10	.16
Selenastrum minutum	*-.18*	.	*.42*	.16	.	*-.22*	.
Rhodomonas lens	.	-.15	.11	*.19*	-.12	.	.
Staurastrum anatinum	.	.	.	*.20*	-.11	.	.
Melosira distans	.	.	*.19*	.10	-.12	.	.
Oocystis lacustris	*-.21*	.	*.17*	.	.	.11	.
Group 6							
Ankistrodesmus falcatus	*.28*	*.31*	.	.14	.14	.	*.23*
Rhizosolenia eriensis	.	*.18*	*.29*	*.31*	.	.	*.19*
Crucigenia tetrapedia	.15	*.31*	.16	*.18*	.	.	*.20*
Gomphosphaeria lacustris	*-.25*	*.47*	*-.23*	*.18*	.	.	.
Pediastrum tetras	*.21*	*.22*	-.12	.	.	.	.
Arthrodesmus incus	.11	*.40*	*-.27*	.	.	.	*.27*
Dinobryon borgei	*.28*	.12	*-.26*	.	.	.	.
Gymnodinium uberrimum	.	.12	*-.24*	.11	.	*-.18*	.
Frustulia vulgaris	.	.	-.12	.	*.30*	*.20*	*.18*
Mallomonas pumillio v *canadensis*	.	.	*-.26*	.	.15	*-.17*	.15
Tabellaria flocculosa	.	.	.	.13	-.13	.	*.17*
Planctococcus alsium	.	*.23*	*-.18*	.	*-.18*	.	.13

Table 6 (Cont'd.)

	FACTOR						
SPECIES	1 Dystrophy	2 Hardness	3 Salinity	4 Lake-Size	5 Season	6 Watershed	7 Phosphate
Group 7							
Chrysochromulina parva	.	.	.	.	.	.	*.23*
Chrysolykos skujai	.	.	.	.	*.35*	.	*.19*
Kephyrion boreale	.15	.	.	.	.16	.	.14
Gymnodinium ordinatum	.	.	.12	.	*.18*	-.14	*.24*
Gymnodinium varians	.11	*.18*	*-.29*	.	*.22*	*-.21*	.
Group 8							
Ankistrodesmus spiralis	*.28*	.	.	.10	.10	.11	.
Kephyrion obliquum	.	.	.	.15	.10	.	.
Gomphonema angustatum	.	.	*-.22*	.	.	.	-.10
Chrysosphaerella longispina	.10	*.19*	*-.27*	.13	.	.	.
Merismopedia elegans	.	.11	-.11	.	.	.	*.21*
Dinobryon bavaricum	.	.16	*-.17*	.13	*.17*	.	*.24*
Elakatothrix gelatinosa	.	*.26*	*-.26*	.15	.	.	*.27*
Katablepharis ovalis	.	*.48*	.	*.22*	.	.	*.29*
Heliochrysis eradians	.11	*.21*	-.14	.11	.	.	.
Kephyrion littorale	.	.10	.	.	.16	-.10	.
Paramastix minuta	*.17*	.	-.12	.	.	.10	.16
Pseudokephyrion planctonicum	.	.	-.12	.	*.23*	.	.16
Group 9							
Dinobryon crenulatum	-.11	-.13	.10	.	*.20*	.	.
Euastrum elegans v *ornatum*	.	.10	*.27*	.	.	-.11	.
Dinobryon sociale	.	.	*.25*	.	*.18*	.	.
Pseudokephyrion minutissimum	.10	.12	.10	.10	.	.	*.27*
Oocystis submarina	.	.	.	.	-.13	.	.12
Group 10							
Bicoeca cylindrica	.15	.	-.10	.	*.17*	.	-.16
Euastrum binale	*.27*	.	*-.29*	.	*.17*	.	.
Eunotia pectinalis	*.22*	.	.	-.11	*.37*	.16	-.12
Frustulia rhomboides	*.20*	.	*-.25*	.	.32	.	.
Dinobryon divergens	*-.20*	*.27*	*-.20*	.	.14	-.10	.
Melosira islandica	*.21*	.	*.22*	.16	*.26*	.	.
Group 11							
Botryococcus braunii	.	.	.	*.21*	*-.18*	.	.
Crucigenia rectangularis	.	.	.	.10	*-.26*	.	.14
Navicula radians	.	*.17*	.	-.13	.	*-.28*	*.19*
Spondylosium planum	.13	*.19*	.	.	.	-.11	*.25*
Cyclotella comta	-.16	*.30*	.10	.	.	.	-.11
Staurastrum cuspidatum	.	.	.	.	-.14	.	.
Fragilaria crotonensis	-.11	*.18*	.	.	.	-.14	.15
Ochromonas globosa	.15	*.29*	-.12	.	.13	-.10	.15
Group 12							
Chromulina glacialis	*.37*	*-.33*	*.21*	.	.12	.	.
Chromulina minuta	*.30*	.	*.23*	.	-.11	.	*.28*
Desmarella moniliformis	*.30*	.	*.31*	.	.11	.	.10
Mallomonas elongata	.10	*-.27*	.10	.	.	*-.19*	.
Mallomonas akrokomos	.15	*-.18*	.13	-.35	-.10	.	.

Table 7. Number of phytoplankton taxa and proportional biomass, by algal class, for 105 insular Newfoundland lakes.

		NO. TAXA							BIOMASS (%)						
LAKE	pH	CY	CHL	CH	DI	CR	PY	TOT	CY	CHL	CH	DI	CR	PY	TOT
1	7.96	4	14	26	8	4	3	59	12	20	23	1	6	37	280
2	7.80	7	8	23	10	4	5	57	12	5	20	21	12	30	189
3	7.27	6	17	25	13	3	5	69	2	4	22	33	11	28	224
4	5.91	6	10	13	6	2	2	39	7	6	72	7	3	5	46
5	5.94	.	3	14	4	3	4	28	.	.	45	1	34	20	218
6	5.49	4	5	13	10	3	1	36	14	9	35	34	7	1	32
7	5.90	4	13	15	4	4	2	42	9	20	30	9	23	1	114
8	5.32	2	3	18	5	6	2	36	1	4	70	5	10	10	153
9	5.41	2	11	19	9	2	3	46	.	3	46	43	3	3	412
10	5.82	2	5	20	3	2	1	33	3	27	46	3	5	17	36
11	7.77	3	11	16	13	4	4	51	3	4	19	54	5	15	185
12	4.84	3	4	17	6	5	1	36	14	3	57	7	17	1	91
13	5.25	4	7	17	7	3	2	40	1	2	30	49	4	15	139
14	4.95	.	5	9	3	2	1	20	.	2	43	12	38	6	61
15	4.96	1	4	15	10	3	.	33	2	5	34	43	17	.	98
16	5.79	4	7	14	4	5	.	34	4	60	17	16	3	.	228
18	6.08	4	12	20	6	5	2	49	15	11	46	5	10	13	139
19	5.66	3	10	17	7	3	3	43	3	10	54	7	9	17	54
20	6.08	3	14	13	4	5	2	41	6	30	31	1	15	17	70
21	7.56	2	10	20	5	4	1	42	9	16	37	2	34	.	94
22	6.47	6	18	14	4	4	2	48	28	16	34	4	16	2	134
23	5.53	2	2	14	4	5	3	30	23	2	40	9	9	17	231
52	6.19	4	9	22	8	4	2	49	2	2	54	17	17	7	96
53	6.12	5	7	21	5	4	3	45	8	4	40	2	41	6	136
54	6.22	5	13	13	4	4	3	42	27	13	25	13	10	12	120
55	7.02	5	11	15	2	4	1	38	14	7	55	4	19	1	69
56	7.05	7	14	14	4	4	2	45	18	10	42	6	13	10	111
57	6.54	4	10	21	9	3	1	48	12	22	55	5	5	2	125
58	6.61	3	15	21	.	4	2	45	9	7	55	.	12	17	140
59	6.85	5	13	26	3	2	3	52	24	12	45	8	6	5	181
60	6.27	4	11	21	8	5	2	51	7	9	48	11	23	3	187
61	6.78	5	13	20	9	3	1	51	4	7	67	16	2	3	173
62	6.33	4	9	10	9	3	1	36	18	11	63	4	2	1	108
63	6.60	2	19	22	17	3	6	69	2	8	34	9	7	39	336
64	6.55	5	8	12	3	3	1	32	20	9	16	20	33	1	69
66	6.14	5	11	12	12	4	3	47	8	16	14	31	11	20	86
67	6.58	4	13	12	5	4	5	43	2	5	16	21	2	53	393
68	5.72	4	12	15	12	3	4	50	9	19	23	24	4	21	60
69	5.66	3	17	19	17	4	1	61	.	10	57	17	4	11	188
70	6.63	6	16	18	10	3	3	56	19	19	22	9	6	26	180
71	6.11	3	9	11	7	3	1	34	9	12	25	19	16	18	42
72	4.93	.	5	17	15	1	1	39	.	1	56	31	5	3	52
73	6.42	6	13	19	8	4	2	52	29	76	22	13	23	5	72
75	5.55	3	14	22	20	3	4	66	1	18	30	20	7	25	395
76	5.41	4	10	23	9	2	4	52	3	2	50	11	2	31	212
77	5.72	3	9	19	10	4	.	45	2	21	51	7	19	.	69
78	6.59	6	15	17	6	3	5	52	9	9	27	43	3	48	189
79	5.43	3	9	23	6	3	4	48	2	5	29	24	21	19	107
81	7.01	5	14	16	4	4	.	43	14	18	26	6	36	.	63
82	6.36	5	6	15	5	3	2	36	4	8	63	7	12	5	82
83	6.06	6	16	17	1	3	1	44	12	7	61	1	17	3	43
102	5.48	2	15	19	15	2	3	56	1	16	24	25	15	19	235
103	5.41	.	7	16	14	3	1	41	.	11	27	58	4	1	536
104	6.62	5	10	15	3	4	.	37	15	16	51	3	15	.	91

Table 7 (Cont'd.)

LAKE	pH	NO. TAXA							BIOMASS (%)						
		CY	CHL	CH	DI	CR	PY	TOT	CY	CHL	CH	DI	CR	PY	TOT
105	5.31	1	12	23	10	2	4	52	.	3	52	28	4	13	178
107	5.13	1	13	24	12	2	1	53	.	3	79	13	3	2	178
108	5.94	3	12	18	5	4	2	44	8	9	63	8	11	1	84
109	6.96	4	19	19	9	5	5	61	2	6	19	52	3	17	347
110	6.38	4	9	11	7	4	1	36	1	1	8	78	2	9	489
111	5.88	2	16	17	6	5	3	49	1	10	11	58	10	11	228
112	6.36	9	21	23	8	3	5	69	7	12	44	4	4	3	387
113	6.25	6	16	20	3	4	3	52	4	6	51	21	10	7	122
114	6.50	6	15	24	10	5	7	67	15	6	28	36	23	13	352
116	5.81	2	12	20	4	5	2	45	.	71	21	1	5	2	259
117	6.22	4	15	16	6	4	1	46	6	15	29	33	14	3	70
118	.	3	7	20	3	5	3	41	3	1	12	79	3	2	500
119	5.70	7	23	18	4	4	3	59	11	33	34	3	7	12	143
120	6.44	6	16	25	7	4	5	63	3	7	59	5	10	16	161
121	5.96	7	16	19	9	4	2	57	21	4	32	36	5	2	268
122	6.10	8	19	19	11	4	2	63	13	9	55	16	5	2	132
123	6.20	7	14	22	8	5	6	62	5	3	37	37	6	12	311
124	6.16	6	18	16	7	4	1	52	32	10	35	5	14	3	138
125	6.27	5	19	18	8	4	3	57	31	10	29	8	12	8	82
152	6.14	3	26	16	8	5	2	60	4	18	32	28	15	3	146
153	6.17	6	18	21	11	5	.	61	7	12	42	33	6	.	303
154	5.72	5	15	18	6	4	4	52	10	27	39	4	12	7	142
201	6.13	3	9	14	3	4	1	33	2	17	63	3	14	1	41
203	5.29	2	4	17	5	3	.	31	8	1	34	52	4	.	139
204	4.99	2	3	14	5	3	2	29	3	1	73	2	6	15	59
205	5.70	4	10	14	8	4	2	42	5	10	47	5	19	13	103
206	5.88	5	7	15	7	4	2	40	8	6	37	29	18	2	89
207	5.10	.	5	8	5	5	1	24	.	5	24	6	17	47	133
208	5.65	4	15	23	7	3	5	57	5	9	67	4	3	10	189
209	6.61	7	11	20	4	4	2	48	37	2	52	3	6	1	432
211	6.10	6	10	22	4	4	3	49	12	5	68	1	9	5	193
213	5.81	6	14	21	5	3	1	50	25	12	53	4	5	1	135
215	5.68	5	8	19	6	5	2	45	5	2	33	48	1	12	238
217	5.74	5	13	12	7	4	2	43	4	5	49	26	11	4	253
219	5.68	6	16	20	10	4	5	61	2	35	6	47	1	8	952
220	5.91	5	15	20	9	3	1	53	2	2	86	6	2	3	419
221	6.26	8	9	19	5	4	2	47	4	1	13	61	4	16	546
222	5.96	4	9	16	5	3	4	41	6	2	64	3	11	13	70
224	5.51	3	10	27	5	3	5	53	.	1	71	7	4	15	154
225	5.98	4	4	12	4	6	3	33	36	1	42	2	13	6	104
226	6.26	7	14	20	7	4	2	54	10	7	68	2	9	3	130
228	5.53	4	11	20	5	5	1	46	6	7	77	1	8	1	89
229	6.09	4	17	24	10	3	2	60	1	5	69	16	7	3	232
230	5.45	2	4	18	5	2	.	31	1	4	73	8	14	.	76
232	5.75	3	6	17	5	5	.	36	12	2	56	1	28	.	76
251	7.00	8	13	22	8	4	1	56	13	8	58	7	14	1	143
252	6.18	4	14	18	5	4	2	47	4	7	53	27	7	2	120
253	7.77	3	11	14	6	5	4	43	1	8	37	9	20	23	103
254	5.99	2	8	17	3	5	1	36	2	10	50	19	10	9	78
255	6.52	2	5	17	2	6	2	34	1	1	38	21	29	10	108
256	6.72	2	11	11	4	4	2	34	10	17	30	4	9	31	146

CY = CYANOPHYCEAE CHL =CHLOROPHYCEAE CH = CHRYSOPHYCEAE TOT = TOTAL
CR = CRYPTOPHYCEAE PY = PYRROPHYCEAE DI = DIATOMACEAE TOTAL BIOMASS IN MG.M-3

Table 8. Mean number of taxa and mean proportional biomass (%) of phytoplankton (both total and by algal class) for the study lakes grouped by pH class.

pH interval	No. of lakes	Cyanophyceae		Chlorophyceae		Chrysophyceae		Diatomaceae		Cryptophyceae		Dinophyceae		Totals	
		No. Taxa	Biom. (%)	No. Taxa	Biom. (%)	No. Taxa	Biom. (%)	No. Taxa	Biom. (%)	No. Taxa	Biom. (%)	No. Taxa	Biom. (%)	No. Taxa	Total Biom.
4.50-4.99	5	1.2	3.8	4.2	2.4	14.4	52.6	7.8	19.0	2.8	16.6	1.0	5.0	31.4	72.2
5.00-5.49	13	2.1	2.4	8.1	8.0	18.3	44.1	8.6	27.4	2.9	8.3	2.0	12.4	42.0	194.6
5.50-5.99	31	3.9	7.4	11.4	14.5	17.6	45.3	6.8	13.9	3.9	9.8	2.4	8.6	45.6	182.3
6.00-6.49	30	5.2	10.6	14.1	9.3	17.7	42.7	6.6	16.9	4.0	12.0	2.3	6.9	48.2	163.9
6.50-6.99	15	4.4	12.1	13.9	9.7	18.3	37.0	6.3	16.7	3.7	10.6	3.0	15.1	48.6	217.5
7.00-7.49	5	6.2	12.2	13.8	9.4	18.4	40.6	6.2	11.2	3.8	18.6	1.8	8.0	50.2	122.0
7.50-7.99	5	3.8	7.6	10.8	11.0	19.8	29.8	8.4	19.4	4.2	13.4	3.4	18.2	50.4	165.2

Total Biomass in mg • m^{-3}
No. Taxa = Number of taxa
Biom. (%) = Proportion of Total Biomass as %.

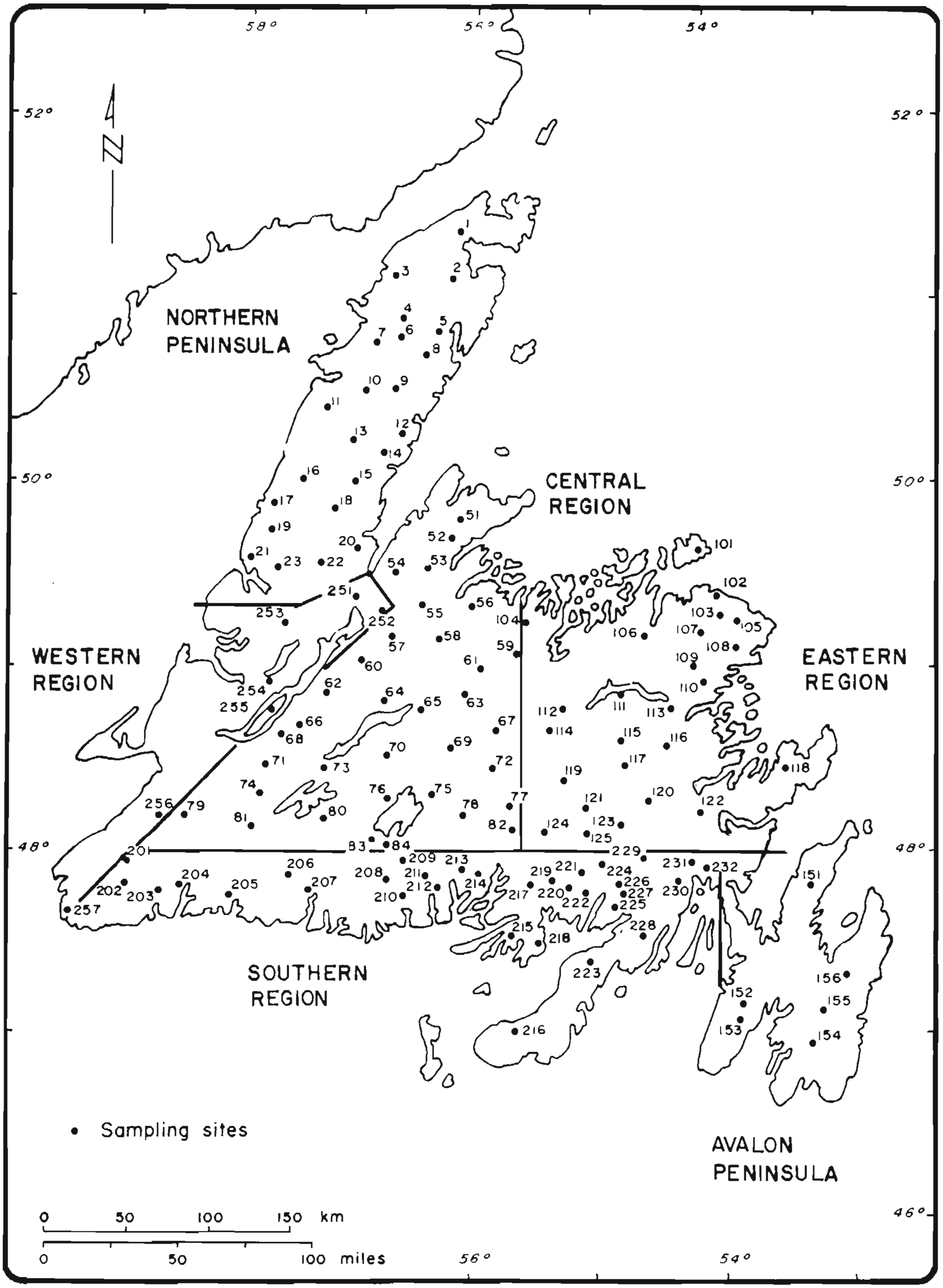


Fig. 1. Map of insular Newfoundland showing location of study lakes and geographic regions (from Scruton 1983).

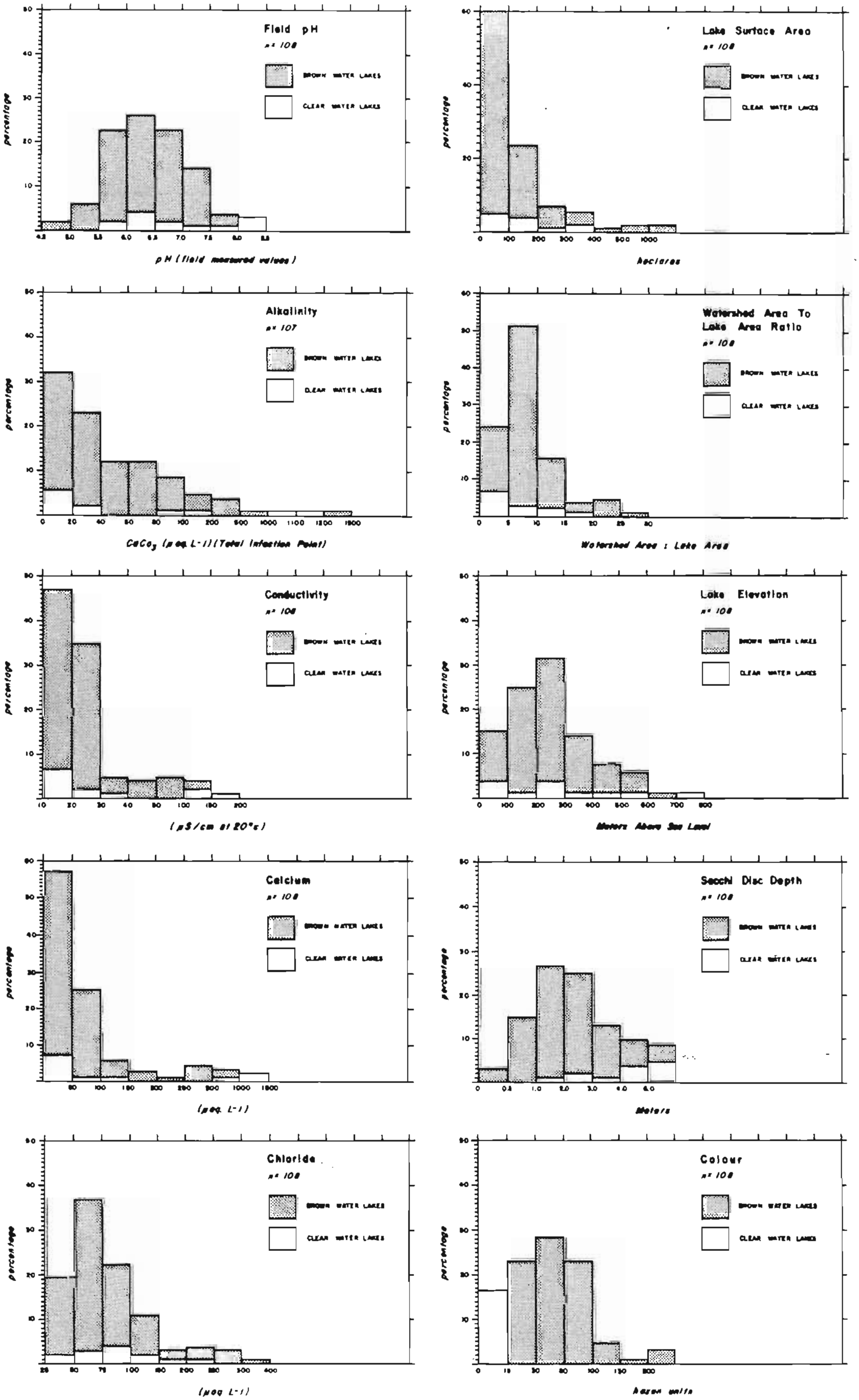


Fig. 2. Distribution of key morphometric, physical, and chemical parameters for the study lakes.

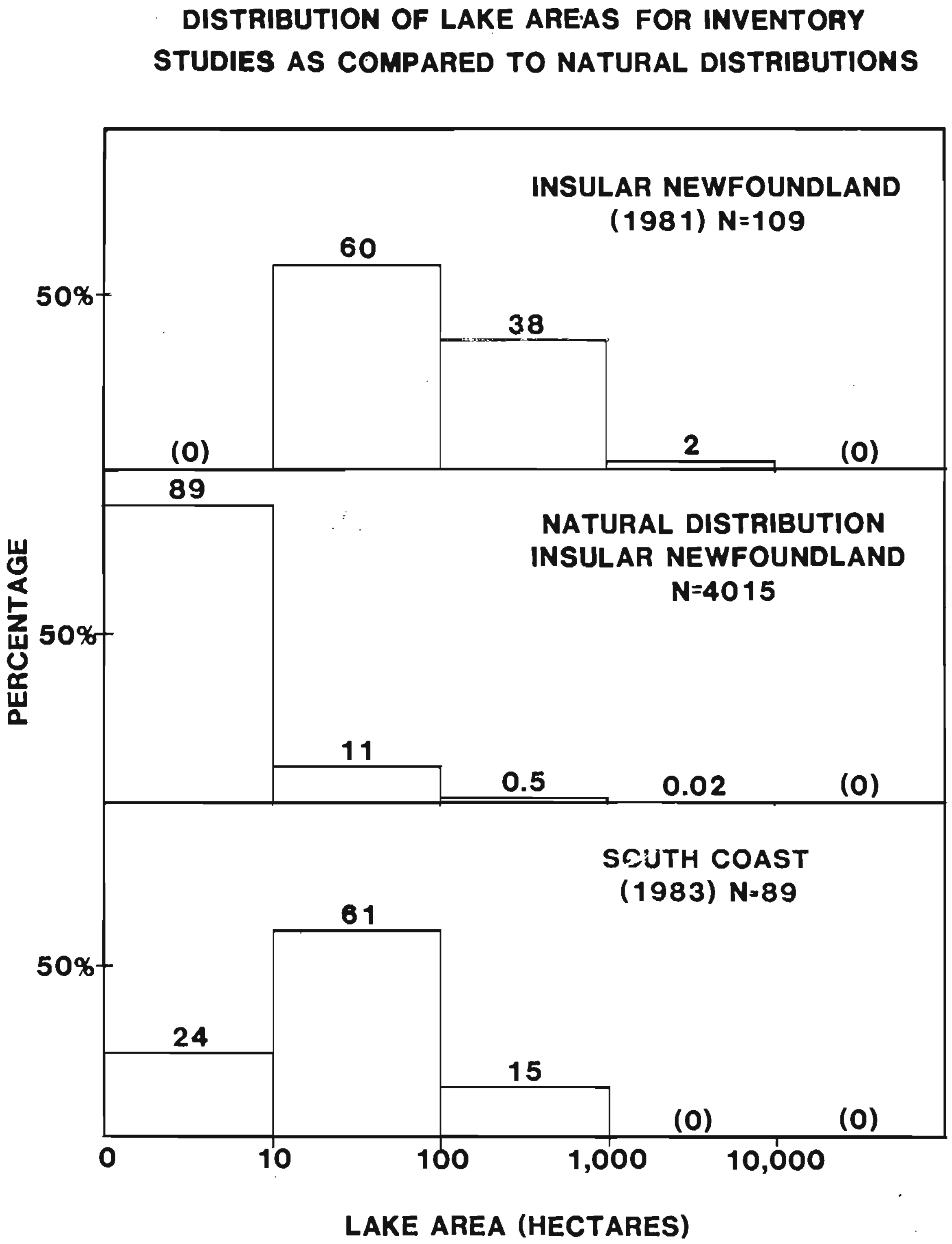
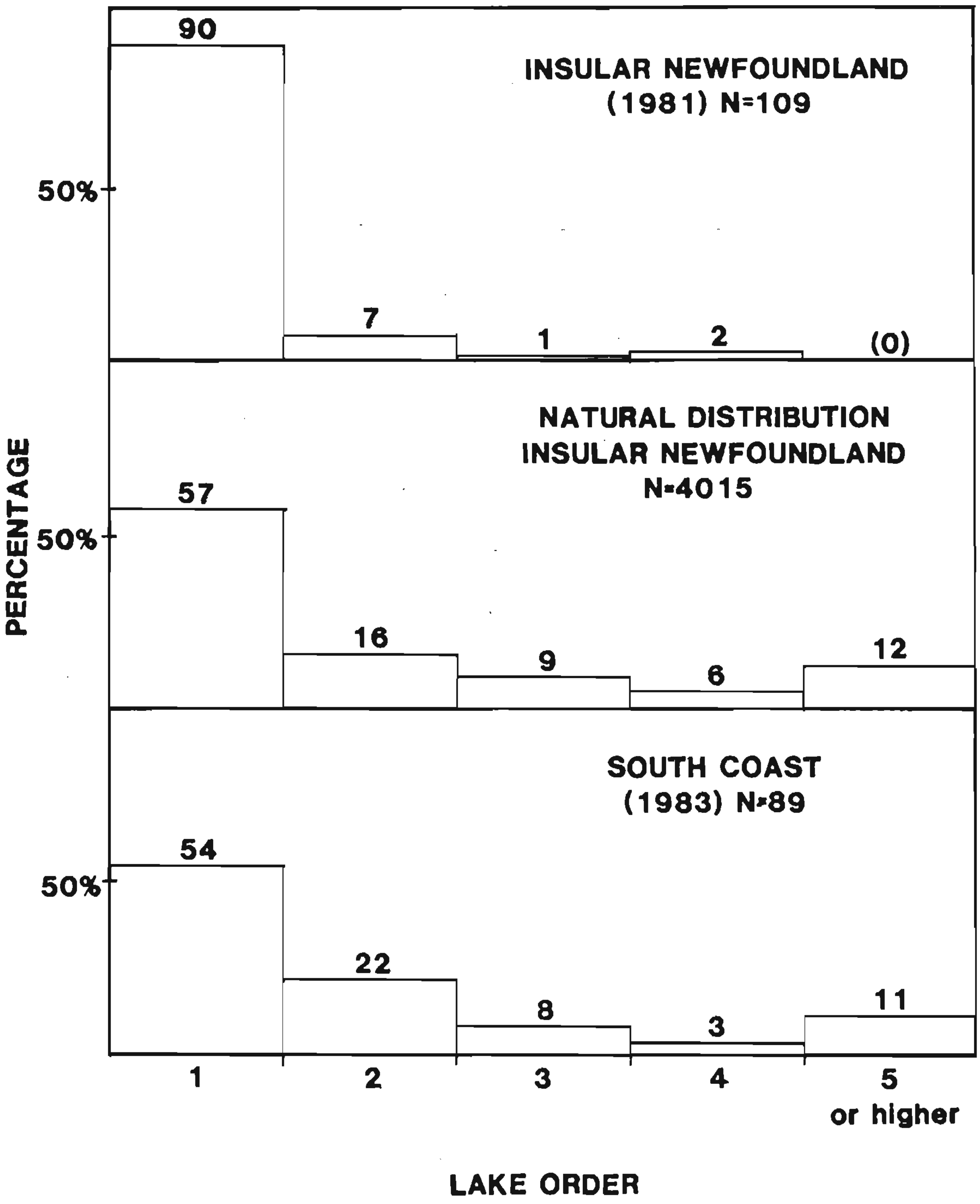


Fig. 3. Distribution of areal classes for lakes included in this survey versus natural lake distributions.



DISTRIBUTION OF LAKES BY ORDER FOR INVENTORY SURVEYS AS COMPARED TO NATURAL DISTRIBUTIONS

Fig. 4. Distribution of lake drainage orders for lakes included in this survey versus natural lake distributions.

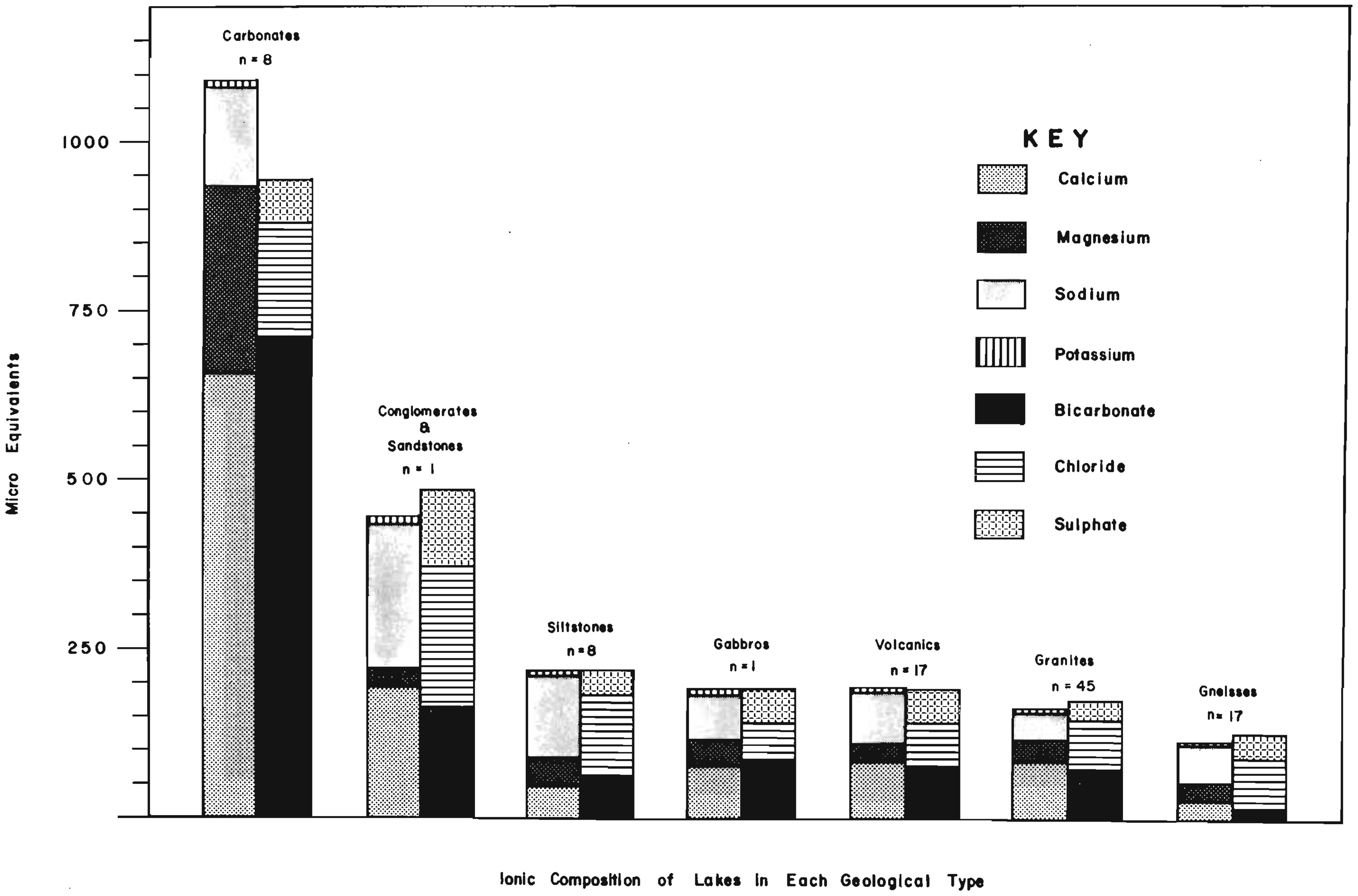


Fig. 5. Mean cationic and anionic profiles for the study lakes grouped by geological type.

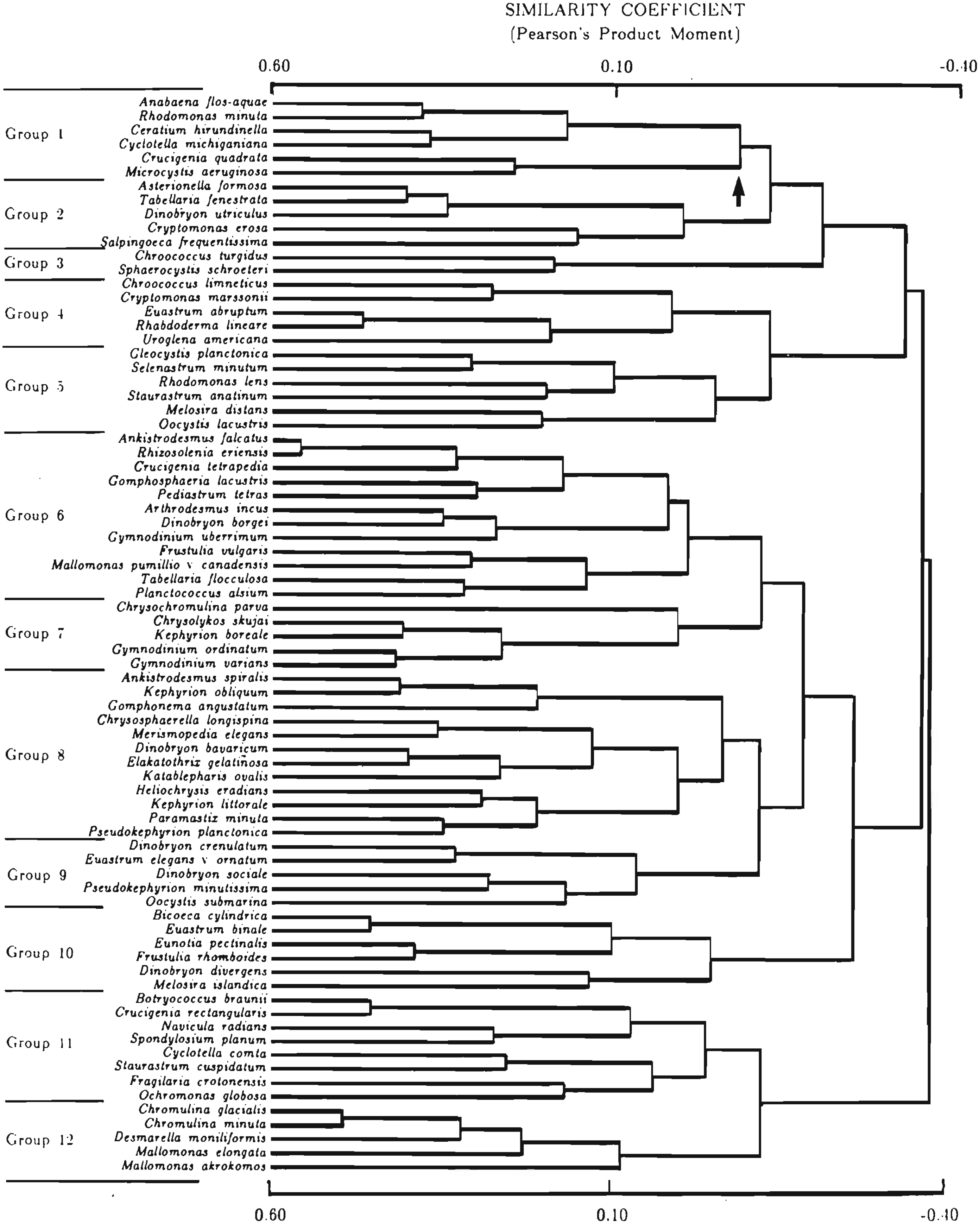


Fig. 6. Results of a complete linkage cluster analysis of 77 selected phytoplankton taxa based on their abundances in 97 insular Newfoundland lakes. Arrow indicates the 12 cluster group level (after Earle et al. 1977).

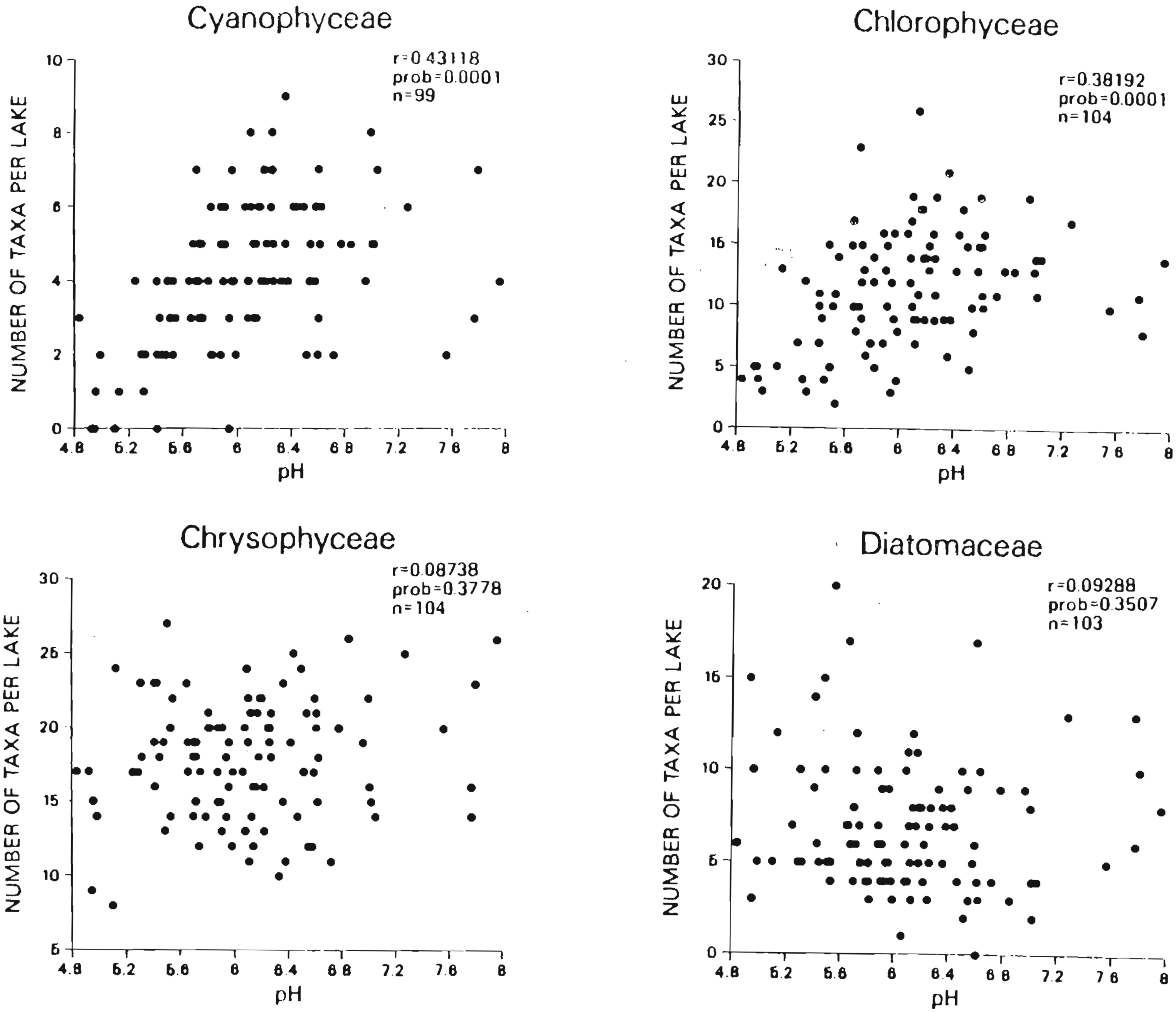


Fig. 7. Scatter-plots of lake water pH vs. the number of taxa per lake for the Cyanophyceae, Chlorophyceae, Chrysophyceae and Diatomaceae. Spearman correlation statistics and samples sizes are provided.

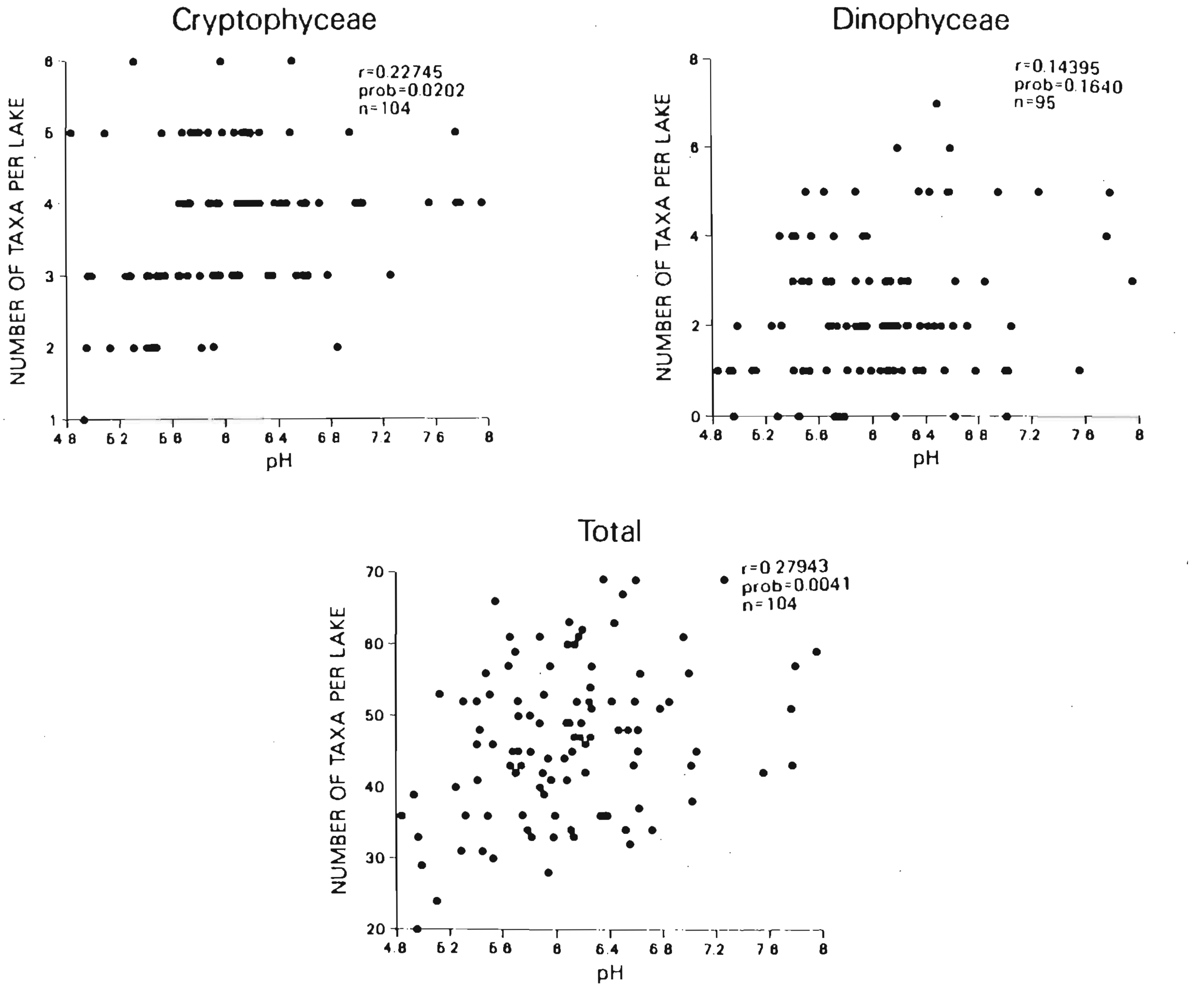


Fig. 8. Scatter plots of lake water pH vs. the number of taxa per lake for the total phytoplankton, Cryptophyceae and Dinophyceae. Spearman correlation statistics and samples sizes are provided.

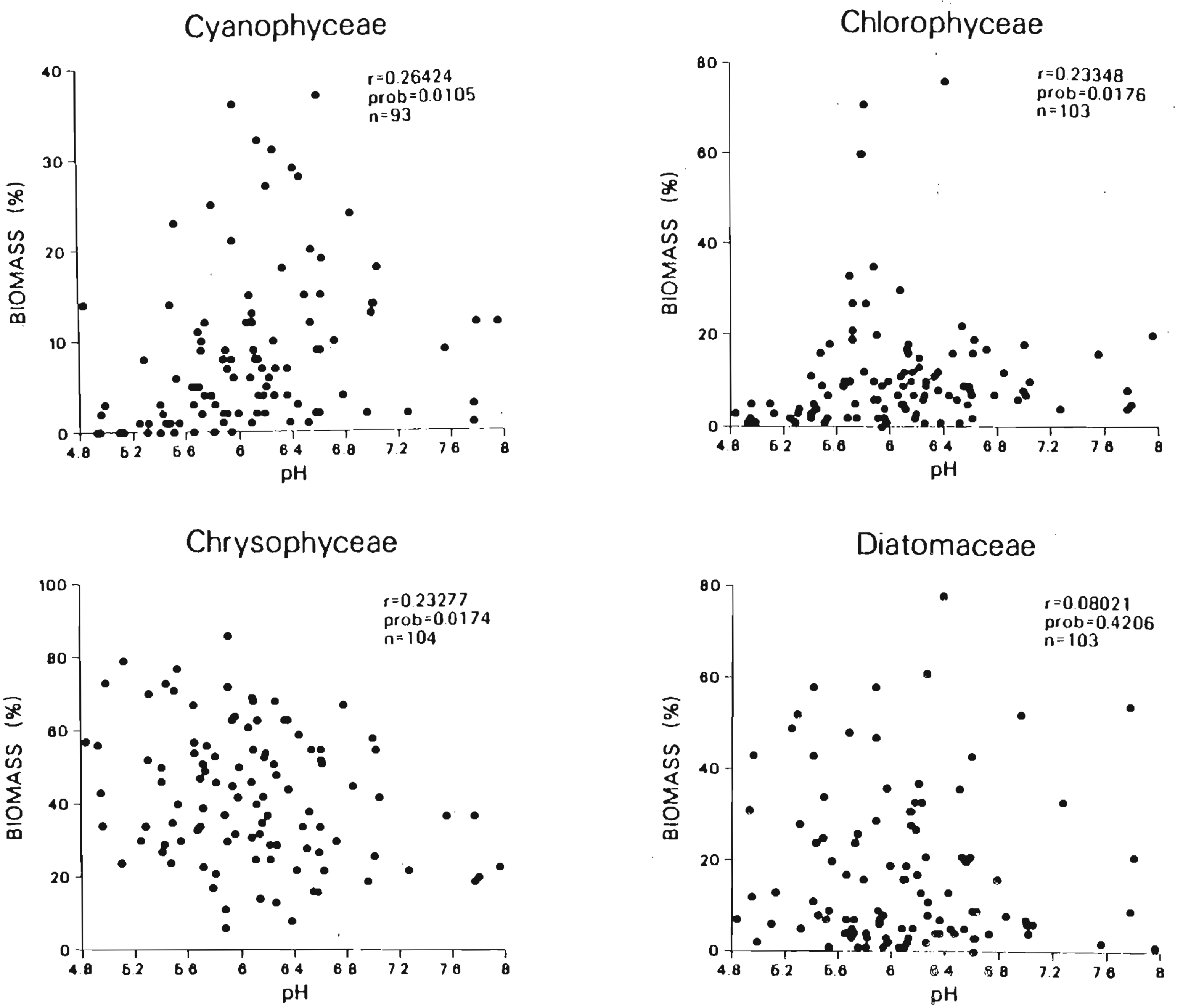


Fig. 9. Scatter plots of lake water pH vs. the percent biomass of Cyanophyceae, Chlorophyceae, Chrysophyceae and Diatomaceae. Spearman correlation statistics and samples sizes are provided.

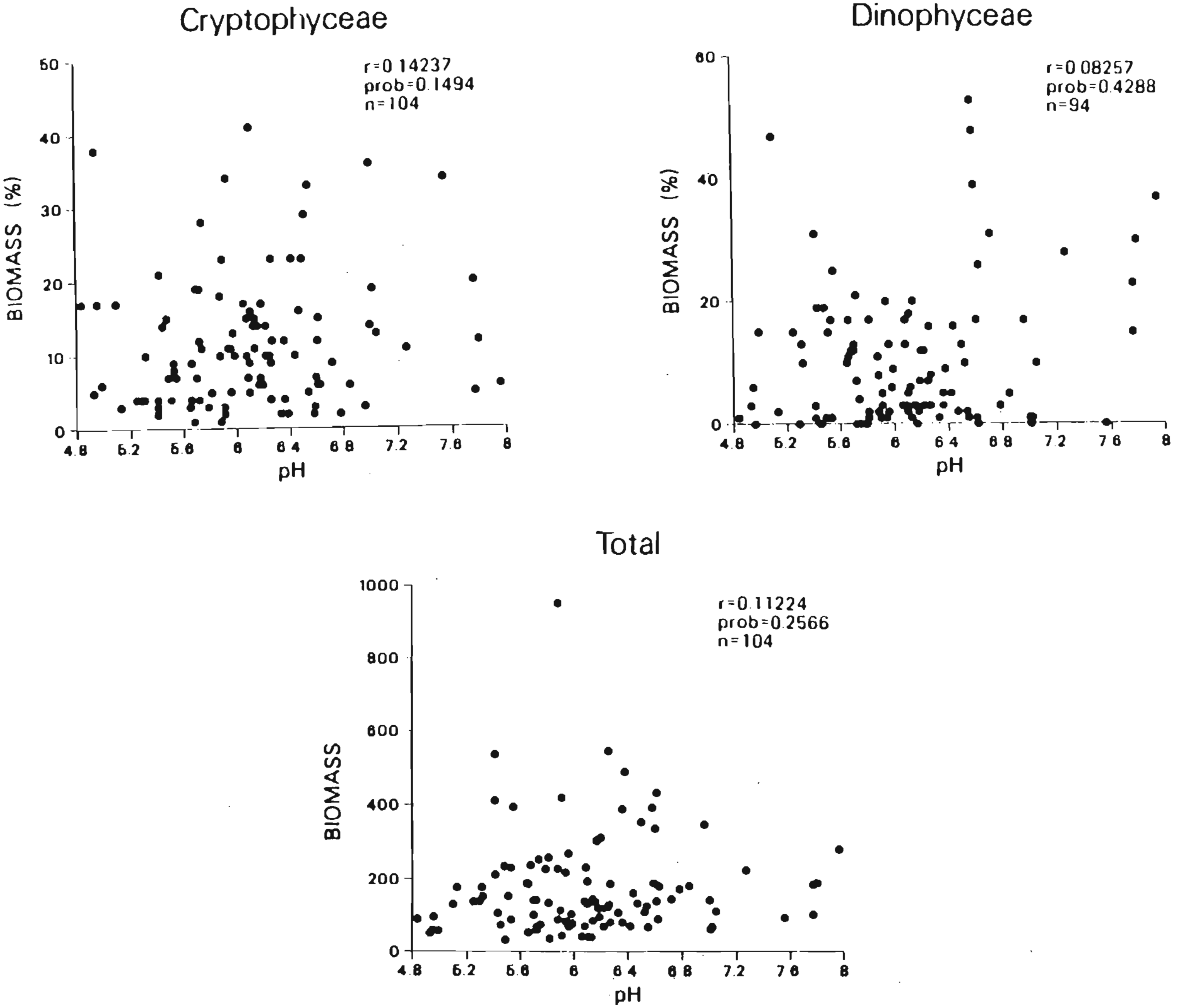


Fig. 10. Scatter plots of lake water pH vs. the percent biomass for the total phytoplankton, Cryptophyceae and Dinophyceae. Spearman correlation statistics and samples sizes are provided.

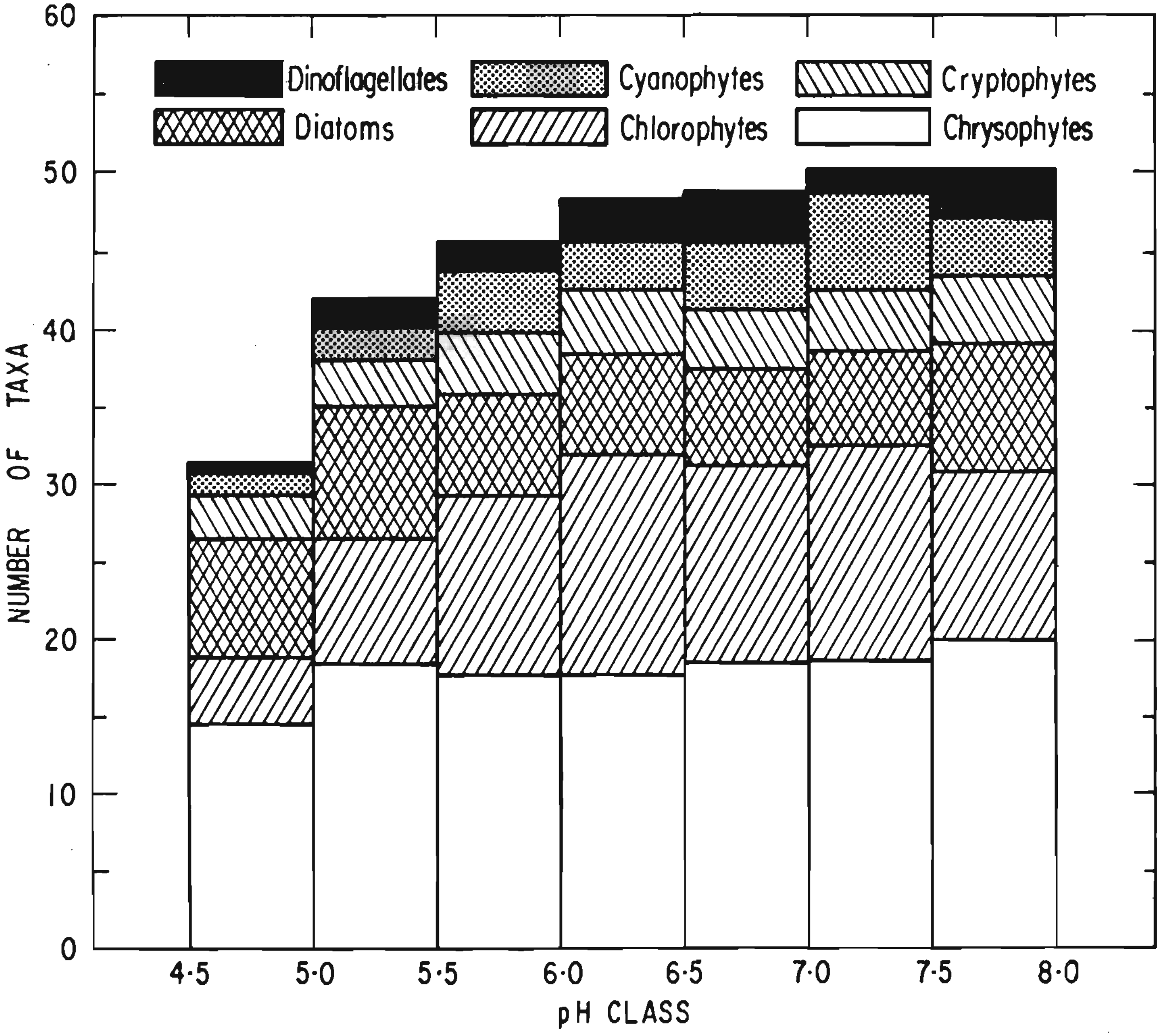


Fig. 11. Mean number of species (both total and by algal groups) for the study lakes grouped by pH intervals.

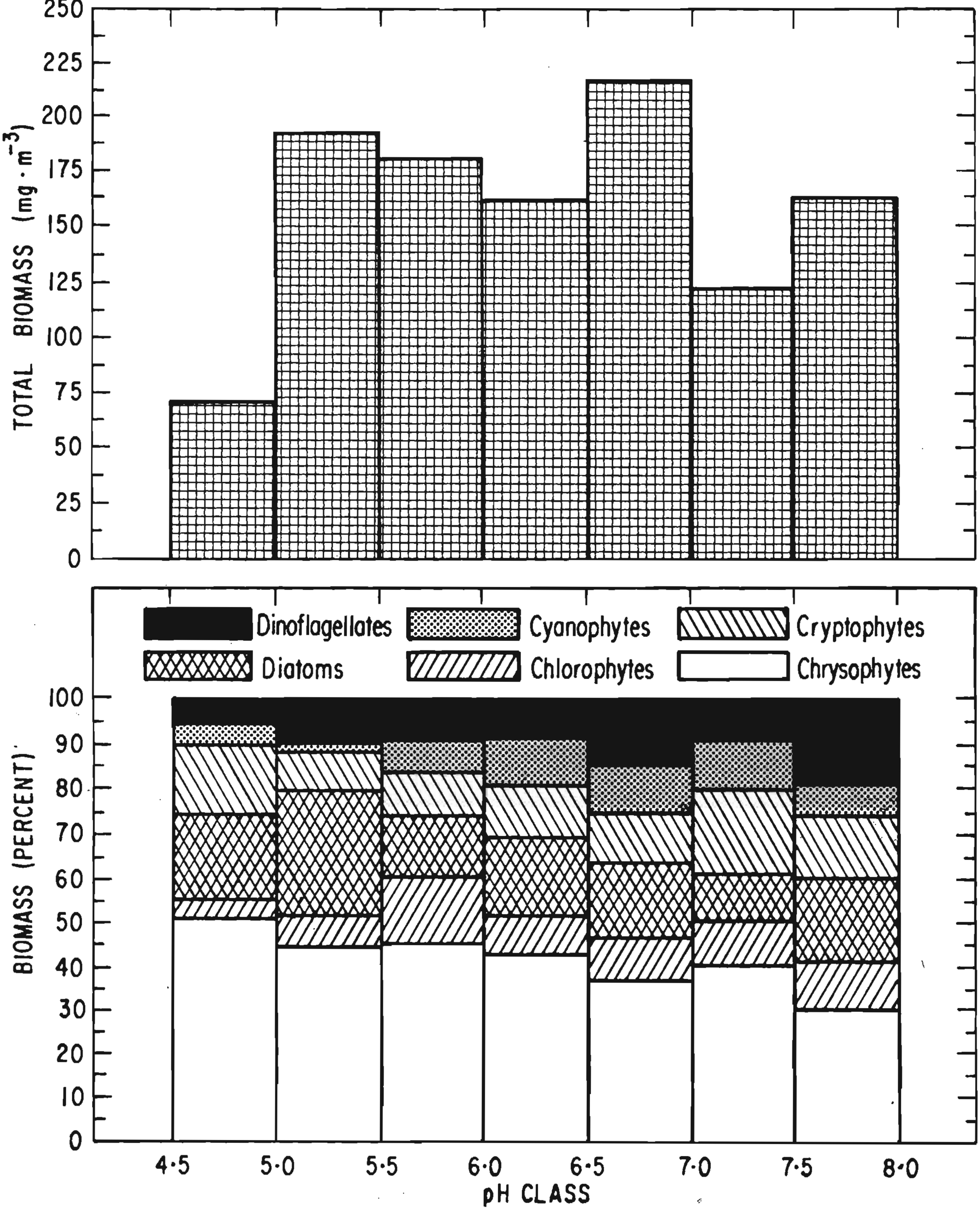


Fig. 12. Total algal biomass and proportional (%) distribution of algal groups for the study lakes grouped by pH intervals.

APPENDIX 1

Matrix of Correlation Coefficients ($\log:\log_{10}$ regression) for 39 Physical, Chemical, and Morphometric Parameters for 109 Insular Newfoundland Lakes.

Only significant (at $p \leq 0.05$) coefficients listed. Note: a = significant ($p \leq 0.05$), b = highly significant ($p \leq 0.01$), and c = very highly significant ($p \leq 0.001$). Also n = 105 to 109 for most parameters except n = 10 for maximum depth (3), n = 18 for copper (33) and zinc (34), and n = 84 for excess potassium (36).

Key to Parameters

1. Field pH
2. Lake surface area
3. Maximum depth
4. Elevation
5. Distance from the coast
6. Drainage area
7. Ratio drainage area to lake area
8. Carbon dioxide
9. Secchi disc depth
10. Field alkalinity
11. Conductivity
12. Total dissolved solids
13. Hardness
14. Bicarbonate
15. Calcium
16. Magnesium
17. Sodium
18. Potassium
19. Chloride
20. Sulphate
21. Excess Sulphate
22. Orthophosphate
23. Nitrate
24. Cation sum
25. Anion sum
26. Sum of constituents
27. Turbidity
28. Colour
29. Aluminium
30. Manganese
31. Cadmium
32. Iron
33. Copper
34. Zinc
35. Excess sodium
36. Excess potassium
37. Excess calcium
38. Excess magnesium
39. Dissolved organic carbon

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	-																		
2	...	-																	
3	...	...	-																
4	-0.31[b]	...	...	-															
5	...	...	...	0.47[c]	-														
6	...	0.78[c]	...	...	...	-													
7	...	-0.33[c]	...	...	...	0.23[a]	-												
8	-0.74[c]	...	...	...	...	...	0.27[b]	-											
9	...	0.31[b]	...	0.21[a]	...	...	-0.38[c]	-0.40[c]	-										
10	0.87[c]	...	...	-0.39[c]	...	...	...	-0.57[c]	...	-									
11	0.55[c]	-0.21[a]	...	-0.63[a]	-0.41[c]	...	...	-0.38[c]	...	0.71[c]	-								
12	0.56[a]	-0.21[a]	...	-0.62[c]	-0.40[c]	...	...	-0.41[c]	...	0.71[c]	0.99[c]	-							
13	0.71[c]	...	...	-0.59[c]	-0.21[a]	...	...	-0.46[c]	...	0.86[c]	0.94[c]	0.93[c]	-						
14	0.84[c]	...	...	-0.43[c]	...	...	...	-0.57[c]	...	0.92[c]	0.74[c]	0.74[c]	0.88[c]	-					
15	0.79[c]	...	...	-0.48[c]	...	...	...	-0.48[c]	...	0.90[c]	0.86[c]	0.86[c]	0.96[c]	0.90[c]	-				
16	0.56[c]	...	...	-0.65[c]	-0.30[b]	...	...	-0.40[c]	...	0.72[c]	0.93[c]	0.74[c]	0.94[c]	0.78[c]	0.82[c]	-			
17	...	...	...	-0.67[c]	-0.59[c]	...	...	...	...	0.34[c]	0.76[c]	0.75[c]	0.57[c]	0.35[c]	0.44[c]	0.66[c]	-		
18	0.31[b]	...	...	-0.48[c]	...	...	...	...	-0.23[a]	0.47[c]	0.51[c]	0.49[c]	0.50[c]	0.44[c]	0.43[c]	0.52[c]	0.54[c]	-	
19	...	-0.46[a]	....	-0.64[c]	-0.60[c]	...	...	...	...	0.59[a]	0.74[c]	0.71[c]	0.53[c]	0.25[b]	0.40[c]	0.63[c]	0.96[c]	0.46[c]	-
20	...	-0.45[c]	...	-0.27[b]	-0.30[b]	-0.34[c]	0.23[a]	...	-0.38[c]	0.32[c]	0.56[c]	0.54[c]	0.49[c]	0.25[b]	0.46[c]	0.47[c]	0.54[c]	0.42[c]	0.55[c]
21	...	...	...	...	...	-0.34[c]	0.21[a]	0.20[c]	-0.34[b]	0.26[b]	0.31[c]	0.29[c]	0.32[c]	...	0.34[a]	0.25	...	0.29[b]	...
22	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
23	-0.22[a]	...	0.71[c]	...	...	...	...	...	0.33[c]	...	...	...	-0.20[a]	-0.28[b]	-0.21[a]	...	...	...	...
24	0.62[c]	...	...	0.65[c]	0.36[c]	...	...	-0.41[c]	...	0.77[c]	0.99[c]	0.98[c]	0.97[c]	0.80[c]	0.90[c]	0.94[c]	0.74[c]	0.53[c]	0.69[c]
25	0.62[c]	-0.19[a]	...	-0.64[c]	-0.35[c]	...	...	-0.42[c]	...	0.78[c]	0.98[c]	0.98[c]	0.95[c]	0.80[c]	0.90[c]	0.93[c]	0.73	0.51[c]	0.69[c]
26	0.60[c]	-0.21[a]	...	-0.64[c]	-0.33[c]	...	...	-0.39[c]	...	0.73[c]	0.95[c]	0.95[c]	0.93[c]	0.77[c]	0.88[c]	0.91[c]	0.68[c]	0.49[c]	0.65[c]
27	-0.29[b]	-0.28[b]	...	...	...	...	0.19[a]	0.38[c]	-0.62[c]	...	...	...	...	...	...	...	...	...	0.21[a]
28	-0.35[c]	-0.24[a]	...	...	...	...	0.43[c]	0.61[c]	-0.66[c]	...	...	...	...	...	...	...	...	...	...
29	-0.43[c]	-0.31[b]	...	...	-0.22[a]	...	0.36[c]	0.58[c]	-0.45[c]	...	...	...	...	...	...	...	0.29[b]	0.23[a]	0.27[b]
30	-0.33[c]	-0.23[a]	...	-0.26[b]	-0.23[a]	...	0.28[b]	0.43[c]	-0.36[c]	...	...	...	...	...	...	...	0.30[b]	...	0.34[c]
31	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	-0.25[b]	...
32	-0.24[a]	...	...	...	...	...	0.33[c]	0.41[c]	-0.56[c]	...	...	...	...	...	...	...	...	...	...
33	...	...	...	...	...	...	...	...	...	...	0.48[a]	0.50[a]	...	...	...	0.47[a]	...	...	...
34	...	...	...	...	...	...	...	...	...	...	0.55[a]	0.59[a]	0.53[a]	...	0.47[a]	0.57[a]	...	...	...
35	0.37[c]	...	...	-0.61[c]	-0.46[c]	...	0.21[a]	-0.26[b]	...	0.48[c]	0.70[a]	0.68[c]	0.57[c]	0.46[c]	0.51[c]	0.59[c]	0.89[c]	0.55[c]	0.73[a]
36	0.38[a]	...	...	...	...	...	...	-0.33[b]	...	0.39[c]	...	...	0.24[a]	0.31[b]	0.29[b]	...	...	0.67[c]	...
37	0.78[c]	...	...	-0.49[c]	...	...	...	-0.48[c]	...	0.90[c]	0.85[c]	0.85[c]	0.96[c]	0.90[c]	1.00[c]	0.82[c]	0.45[c]	0.46[c]	0.38
38	0.59[c]	...	...	-0.63[c]	-0.24[a]	...	...	-0.42[c]	...	0.74[c]	0.89[c]	0.89[c]	0.94[c]	0.80[c]	0.84[c]	0.99[c]	0.60[c]	0.51[c]	0.55[c]
39	-0.34[c]	-0.28[b]	...	...	...	...	0.46[c]	0.62[c]	-0.69[c]	...	...	...	...	...	...	...	0.24[a]	0.25[b]	0.25[b]

20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
-																			
0.91^{c}	-																		
...	...	-																	
...	...	...	-																
0.54^{c}	0.30^{b}	...	...	-															
0.55^{c}	0.32^{c}	...	..	0.98^{c}	-														
0.57^{c}	0.38^{c}	...	...	0.96^{c}	0.96^{c}	-													
0.33^{c}	0.26^{b}	...	-0.23^{a}	...	...	...	-												
0.44^{c}	0.40^{c}	...	...	...	...	...	0.51^{c}	-											
0.46^{c}	0.37^{c}	...	...	...	...	...	0.51^{c}	0.81^{c}	-										
0.32^{c}	0.19^{a}	...	...	..	...	...	0.49^{c}	0.45^{c}	0.51^{c}	-									
-0.24^{a}	-0.29^{b}	...	...	...	...	...	...	...	...	...	-								
0.26^{b}	0.21^{a}	...	-0.26^{b}	...	...	...	0.48^{c}	0.60^{c}	0.58^{c}	0.44^{c}	...	-							
...	...	...	...	...	...	...	...	...	...	...	...	...	-						
...	...	...	...	0.52^{a}	0.53^{a}	0.51^{a}	...	...	...	-0.48^{a}	...	...	...	-					
0.44^{c}	...	...	...	0.71^{c}	0.68^{a}	0.62^{c}	...	...	0.21^{a}	...	...	...	...	...	-				
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	-			
0.45^{c}	0.34^{c}	...	-0.22^{a}	0.90^{c}	0.89^{c}	0.88^{c}	...	...	...	...	...	...	...	0.47^{a}	0.50^{c}	0.30^{b}	-		
0.43^{c}	0.23^{a}	...	...	0.91^{c}	0.88^{c}	...	...	...	...	...	...	...	...	0.56^{a}	0.53^{c}	...	0.83^{c}	-	
0.51^{c}	0.44^{c}	...	...	...	...	...	0.56^{c}	0.96^{c}	0.81^{c}	0.49^{c}	...	0.66^{a}	...	...	...	...	...	...	-

APPENDIX 2

Species List of the Phytoplankton Taxa Identified in the Insular Newfoundland study lakes.

Appendix 2 (Cont'd.)

Division *CYANOPHYTA*

Class *Cyanophyceae*

Anabaena flos-aquae (Lyngbye) Brébisson in Born. and Flah.

Anabaena limnetica G.M. Smith

Anabaena species A (unidentified)

Aphanothece species A (unidentified)

Calothrix parientana (Naegeli) Thuret

Chroococcus dispersus (Keissler) Lemmermann

Chroococcus dispersus var. *minor* G.M. Smith

Chroococcus limneticus Lemmermann

Chroococcus turgidus (Kuetzing) Naegeli

Chroococous dispersus (Keissler) Lemmermann

Dactylococcopsis acicularis Lemmermann

Dactylococcopsis species A (unidentified)

Gomphosphaeria aponina Kuetzing

Gomphosphaeria aponina var. *cordiformis* Wolle

Gomphosphaeria lacustris Chodat

Haplosiphon hibernicus West and West

Lyngbya limnetica Lemmermann

Merismopedia elegans A. Braun

Merismopedia tenuissima Lemmermann

Microcystis aeruginosa Kuetzing

Oscillatoria minima Gicklhorn

Rhabdoderma irregulare (Naumann) Geitler

Rhabdoderma lineare Schmidle and Lauterborn in Schmidle

Rhabdoderma sigmoidea Carter

Spirulina princeps (West and West) G.S. West

Appendix 2 (Cont'd.)

Spirulina species A (unidentified)

3 unidentified *Cyanophyceae*

Division *CHLOROPHYTA*

Class *Chlorophyceae*

Ankistrodesmus falcatus (Corda) Ralfs

Ankistrodesmus falcatus var. *mirabilis* (West and West) G.S. West

Ankistrodesmus falcatus var. *spiralis* (Turner) Lemmermann

Arthrodesmus convergens Ehrenberg

Arthrodesmus incus Brébisson

Arthrodesmus octocornis Ehrenberg

Arthrodesmus triangularis Lagerheim

Bambusina moniliformis Ehrenberg

Binuclearia tatrana Wittrock

Botryococcus braunii Kuetzing

Botryococcus protuberans var. *minor* G.M. Smith

Botryococcus sudeticus Lemmermann

Carteria cordiformis (Carter) Diesing

Carteria species A (unidentified)

Chlamydomonas frigida Skuja

Chlamydomonas globosa Snow

Chlamydomonas speceis A (unidentified)

Chlamydomonas species B (unidentified)

Chlorella species A (unidentified)

Chlorella species B (unidentified)

Closteriopsis longissimus var. *tropicale* West and West

Closterium ceratium Perty

Appendix 2 (Cont'd.)

Closterium gracile Brébisson in Ralfs

Closterium navicula (Brébisson) Lutkemuller

Closterium parvulum Naegeli

Closterium species A (unidentified)

Coelastrum cambricum Archer

Coelastrum reticulatum (Dangeard) Senn

Cosmarium punctulatum Brébisson

Cosmarium quadrifarium Lund

Cosmarium species A (unidentified)

Cosmarium species B (unidentified)

Crucigenia quadrata Morren

Crucigenia rectangularis (A. Braun) Gay

Crucigenia tetrapedia (Kirchner) West and West

Cylindrocapsa geminella Wolle

Desmidium swatzii (C. Agardh.) Ralfs

Desmidium Grevelii (Kuetzing) De Bary.

Dictyosphaerium pulchellum Wood

Elakatothrix gelatinosa Wille

Euastrum abruptum Nordstedt

Euastrum binale (Turpin) Ralfs

Euastrum divericatum Lundell

Euastrum elegans var. *ornatum* West and West

Euastrum insulare (Wittrock) Roy

Eudorina elegans Ehrenberg

Gleocystis planctonica (West and West) Lemmerman

Gleocystis vesiculosa Naegeli

Gleocystis species A (unidentified)

Appendix 2 (Cont'd.)

Hyalotheca neglecta Raciborski

Kirchneriella species A

Kirchneriella lunaris (Kirchner) Moebious

Kirchneriella obesa (W. West) Schmidle

Mougeotia species A (unidentified)

Mougeotia species B (unidentified)

Mougeotia species C (unidentified)

Nephrocytium agardhianum Naegeli

Nephrocytium limneticum G.M. Smith

Oedogonium species A (unidentified)

Oocystis lacustris Chodat

Oocystis pusilla Hansgirg

Oocystis submarina var. *variabilis* Skuja

Oocystis submarina Lagerheim

Paramastix corifera Skuja

Pediastrum Boryanum (Turpin) Meneghini

Pediastrum obtusum Lucks

Pediastrum tetras (Ehrenberg) Ralfs

Planctococcus alsius Skuja

Planktoshaeria gelatinosa G.M. Smith

Pleurotaenium minutum (Ralfs) Delponte

Quadrigula lacustris (Chodat) G.M. Smith

Scenedesmus abundans (Kirchner) Chodat

Scenedesmus abundans var. *brevicauda* G.M. Smith

Scenedesmus brevicauda G.M. Smith

Scenedesmus denticulatus Lagerheim

Scenedesmus longus Meyen

Appendix 2 (Cont'd.)

Scenedesmus quadricauda (Turpin) Brébisson

Scenedesmus serratus (Corda) Bohlin

Scenedesmus species A (unidentified)

Schroederi setigera (Schroeder) Lemmermann

Scourfieldia complanata G.S. West

Selenastrum minutum (Naegeli) Collins

Sphaerocysptis schroeteri Chodat

Sponidylosium planum (Wolle) West and West

Sponidylosium species A (unidentified)

Staurastrum anatinum Cooke and Wills

Staurastrum ankyroides Wolle

Staurastrum avicula Brébisson

Staurastrum brachiatum Ralfs

Staurastrum chaetoceras (Schroeder) G.M. Smith

Staurastrum cuspidatum Brébisson

Staurastrum furcatum (Ehrenberg) Brébisson

Staurastrum inflexum Brébisson

Staurastrum lacustre G.M. Smith

Staurastrum leptocladum var. *simuatum* Wolle

Staurastrum paradoxum Meyen

Tetraēdron minimum (A. Braun) Hansgirg

Tetraēdron regulare Kuetzing

Tetraēdron trigonum (Naegeli) Hansgirg

Xanthidium antilopoeum (Brébisson) Kuetzing

4 unidentified *Chlorophyceae*

Appendix 2 (Cont'd.)

Division *CHRYSOPHYTA*

Class *Chrysophyceae*

Bicoeca cylindrica (Lackey) Bourrelly

Bicoeca mitra Fott

Bicoeca petiolata (Stein) Bourrelly

Bicoeca species A (unidentified)

Bicoeca species B (unidentified)

Binuclearia tatrana Whittrock

Bitrichia chodati (Reverdin) Hollande

Bitrichia ollula (Fott) Bourrelly

Bodo species A (unidentified)

Chromulina glacialis Skuja

Chromulina minor Pascher

Chromulina minuta Doflein

Chrysidiastrum catenatum Lauterborn

Chrysochromulina parva Lackey

Chrysolykos planctonicus Mach

Chrysolykos skujai (Nauwerck) Bourrelly

Chrysosphaerella longispina Lauterborn

Chrysosphaerella rhodei Skuja

Desmarella irregularis Stokes

Desmarella moniliformis Kent

Desmarella species A (unidentified)

Dinbryon suecicum Lemmermann

Dinobryon bavaricum Imhof

Dinobryon borgei Lemmermann

Dinobryon crenulatum West and West

Appendix 2 (Cont'd.)

Dinobryon cylindricum Imhof

Dinobryon divergens Imhof

Dinobryon pediforme (Lemmermann) Steinecke

Dinobryon sociale Ehrenberg

Dinobryon sociale var. *americanum* (Brunnthaler) Bachmann

Dinobryon utriculas (Ehrenberg) Klebs

Dinobryon species A (unidentified)

Heliochrysis eradians Pascher

Heliochrysis species A (unidentified)

Hyalobryon polymorphum Lund

Kephyrion boreale Skuja

Kephyrion littorale Lund

Kephyrion obliquum Hilliard

Kephyrion petasatum Conrad

Kephyrion sitta Pascher

Mallomonas akrokomos Ruttner in Pascher

Mallomonas elongata Reverdin

Mallomonas pumillo var. *canadensis* Holmgren

Mallomonas tonsurata Teiling

Mallomonas species A (unidentified)

Ochromonas globosa Skuja

Ochromonas species A (unidentified)

Pseudokephyrion alaskanum Hillard

Pseudokephyrion attenuatum Hilliard

Pseudokephyrion minutissimum Conrad

Pseudokephyrion planctonicum Hillard

Pseudokephyrion species A (unidentified)

Rhizochrysis limnetica G.M. Smith

Salpingoeca frequentissima (Zacharias) Lemmermann

Stichogloea doederleinii (Schmidle) Wille

Synura uvella Ehrenberg

Uroglena americana Catkins

5 unidentified *Chrysophyceae*

Class *Diatomaceae*

Achnanthes microcephala (Kuetzing) Grunow

Achnanthes minutissimum Kuetzing

Actinella punctata Lewis

Asterionella formosa Hassall

Asterionella ralfsii W. Smith

Cyclotella comta (Ehrenberg) Kuetzing

Cyclotella glomerata Bachmann

Cyclotella michigiana Skvortzow

Cymbella lunata W. Smith

Cymbella minuta Hilse in Rabenhorst

Eunotia bidentula W. Smith

Eunotia curvata (Kuetzing) Lagerstedt

Eunotia elegans Ostrup

Eunotia meisteri Hustedt

Eunotia pectinalis (Dilwyn) Rabenhorst

Fragilaria crotonensis Kitton

Frustulia rhomboides (Ehrenberg) De Toni

Frustulia vulgaris G.M. Smith

Gomphonema angustatum (Kuetzing) Rabenhorst

Gyrosigma acuminatum (Kuetzing) Rabenhorst

Appendix 2 (Cont'd.)

Melosira distans (Ehrenberg) Kuetzing

Melosira islandica O. Mueller

Melosira islandica sbsp. *helvetica* O. Mueller

Melosira italica var. *subarctica* O. Mueller

Navicula pupula Kuetzing

Navicula radiosa Kuetzing

Navicula radiosa var. *tenella* (Brébisson in Kuetzing) Grunow

Navicula species A (unidentified)

Nitzschia acicularis W. Smith

Nitzschia gracile Hantzsch

Nitzschia linearis W. Smith

Nitzschia palea (Kuetzing) W. Smith

Rhizosolenia eriensis H.L. Smith

Rhizosolenia longiseta Zacharias

Semiorbis hemicyclus (Ehrenberg) Patrick

Stauroneis anceps Ehrenberg

Surirella ovata Kuetzing

Synedra acus Kuetzing

Synedra acus var. *delicatissima* (W. Smith) Grunow

Synedra rumpens Kuetzing

Synedra ulna (Nitzsch) Erhenberg

Tabellaria fenestrata (Lyngbye) Kuetzing

Tabellaria flocculosa (Rothest) Kuetzing

Division *CRYPTOPHYTA*

Class *Cryptophyceae*

Cryptomonas caudatum Schiller

Appendix 2 (Cont'd.)

Cryptomonas erosa Ehrenberg

Cryptomonas erosa var. *reflexa* Marsson

Cryptomonas gracilis Skuja

Cryptomonas marssonii Skuja

Cryptomonas ovata Ehrenberg

Cryptomonas phaseolus Skuja

Cryptomonas pusila Bachmann

Cryptomonas species A (unidentified)

Katablepharis ovalis Skuja

Rhodomonas lens Pascher in Ruttner

Rhodomonas minuta Skuja

Rhodomonas minuta var. *nannoplanktic* Skuja

Division *PYRROPHYTA*

Class *Dinophyceae*

Ceratium hirundinella (O.F. Mueller) Dujardin

Peridinium aciculiferum Lemmermann

Peridinium cinctum (Mueller) Ehrenberg

Peridinium goslaviense Woloszynska

Peridinium inconspicum Lemmermann

Peridinium limbatum (Stokes) Lemmermann

Peridinium pusillum (Penard) Lemmermann

Peridinium species A (unidentified)

Division *RHODOPHYTA*

Class *Rhodophyceae*

Batrachospermum moniliformis Rothest