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STUDIES ON THE PHYTOPLANKTON AND THE WATER QUALITY OF MALPEQUE BAY, PRINCE EDWARD ISLAND, CANADA

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The phytoplankton populations of Malpeque Bay, Prince Edward Island, Canada were studied to determine the role, if any, of the water quality in realtion to the biomass, distribution and size of taxonomic groups. The phytoplankton population density was in the range 10^3 - 10^6 cells L^{-1} and 153 species were identified. Summer blooms of *Thalassiosira gravida, T. nordenskioldii, Biddulphia pulchella, B. rhombus, Chaetoceros constrictum, Dinophysis caudata* and *D. norvegica* were observed. The salinity, pH and dissolved oxygen analyses showed that the Malpeque Bay waters were of good quality. Regression analysis of the biomass data and the physico-chemical characteristics of the water indicated a positive correlation between the phytoplankton population density and the dissolved oxygen concentration, the temperature of the water, its salinity and its chlorophyll content.

Les populations phytoplanctoniques de la Baie de Malpeque, Ile-du-Prince-Edouard furent étudiées afin de déterminer le rôle, s'il y a, de la qualité de l'eau en relation avec la biomasse, la distribution et la taille des groupes taxonomiques. La densité des populations phytoplanctoniques se situait entre 10^3 - 10^6 cellules L^{-1} et 153 espèces furent identifiées. Des blooms estivales de *Thalassiosira gravida, T. nordenskioldii, Biddulphia pulchella, B. rhombus, Chaetoceros constrictum, Dinophysis caudata* et *D. norvegica* furent observées. La salinité, le pH et les analyses d'oxygène dissout démontrent que les eaux de la Baie sont de bonne qualité. Les analyses de régression des données de la biomasse et des caractéristiques physico-chimiques de l'eau indiquent qu'il y a une corrélation positive entre la densité de la population phytoplanctonique et la concentration d'oxygène dissout, la température de l'eau, la salinité ainsi que le contenu chlorophyllien.

Introduction

Malpeque Bay, Prince Edward Island is known for its shell fishery. Work on oysters (Needler, 1931, Medcof, 1961) and other invertebrates (Sullivan, 1943) has been reported from this area. The Canadian Committee of the International Biological Programme (1969-1972) conducted studies in the Gulf of St. Lawrence, and Malpeque Bay was included in this work (Steven, 1974). The annual production cycle of Malpeque Bay, and especially its primary productivity and chlorophyll variation with respect to changes in levels of nitrate and phosphate were investigated by McIver (1972). Bailey (1910, 1912, 1913a & b) reported identifications of some phytoplankton and benthic diatoms found in the coastal waters of Prince Edward Island. Benthic diatom communities colonizing plastic collectors in the Bideford River estuary of Malpeque Bay have been studied (Bacon, 1972, Bacon & Taylor, 1976). Full details of chemical analyses, taxonomy of collected organisms and seasonal changes in the main groups of phytoplankton are given in the Ph.D. thesis (Sita Devi, 1980) which has been deposited in the Library, University of Salford, Salford, Lancashire, U.K. and a copy of the same is available at the Library, Bedford Institute of Oceanography, Dartmouth, N.S., Canada.

Materials and Methods

Water samples (204, each 4 L) were collected from 22 locations (Fig 1); those near the Ellerslie Biological Station were named N1 to N6 to denote their estuarine character and to separate them from the stations in the body of Malpeque Bay which were designated M1 to M16. Samples were collected from the sites labelled N in 1973 (13) and in 1974 (N1, 10; N3, 10; and N6, 11). Samples (3) were collected in June, July and August 1973 from the M stations.

Physico-chemical analyses. Transparency was determined with a Secchi disc (20 cm diameter) and acidity with a pH meter. Salinity was measured hydrometrically and by means of a salinometer (Beckmann) against a standard sea-water sample. Analyses for dissolved oxygen, ammonia, nitrate, nitrite, Kjeldahl nitrogen, phosphate and silicate were done by standard methods. Trace metals - Cd, Hg, Cu, Fe, Mn, Zn (direct aspiration), Ni and Pb (extraction) were estimated using an atomic absorption spectrophotometer (Jarrell Ash, Model 810). Chlorophyll and phaeophytin were determined fluorimetrically (Menzel, 1963; Holm-Hansen et al., 1965) using a Turner fluorimeter.

Collection, identification and estimations of population densities of phytoplankton. Phytoplankton were collected by passing the water sample (4 L) through nets of porosity 20 μ and 40 μ. The number of phytoplankton per liter were estimated by fixing the organisms in Lugol's iodine and counting them by using an Inverted Microscope, Wild Model - 40 (Utermohl, 1958; Lund et al., 1958).

Identification of diatoms was done on permanent slides which were prepared by clearing and digesting chloroplasts using acid and hydrogen peroxide. The diatoms were mounted either in Hyrax, Pleurax or Euparol medium. The classification of Hendey (1964) for diatoms and the checklist of British Marine Algae (Parke and Dixon, 1976) for the taxonomic description of the remaining phytoplankton were used.

Species of phytoplankton were divided into three groups based on their population densities: one group, considered to be dominant consisted of species present in more than one water sample at a density greater than 10^4 cells L^{-1} and comprising more than 1% of the total population. A second group, considered to be subdominant had population densities in the range 10-5000 cells L^{-1} and comprised $<1\%$ and $>0.5\%$ of the population. The third group was the remaining species. The data were sufficiently comprehensive to allow calculations of species densities (d) and equitability (e) using the methods of Lloyd et al (1964, 1968). The effects of season and water depth on these phytoplankton groups were studied by separating the collection stations as follows: stations M1-M16 (summer, surface waters); stations N1, N3, & N6 (all seasons, surface waters); stations N2, N4, N5 (summer and autumn, surface waters); and stations N1, N3, & N6 (all seasons, bottom waters). Correlation coefficients were then calculated for comparisons of the phytoplankton populations and the physico-chemical analyses obtained on the water samples collected in these grouped locations, using the Statistical Package for the Social Sciences (SPSS) on a UNIVAC - 1100 computer - Model-60, at the Marine Environment Data Service, Department of Fisheries & Oceans, Ottawa.

Results

The physico-chemical characteristics of the water at the sampling stations are briefly summarized in Table I. The values given in Table I are the mean values obtained, with an indication of the range observation in each case. The summer surface water temperatures of the M stations (Fig 1) lay in the range 19°C to 25°C and the highest temperatures were recorded in June. The bottom water temperatures were usually $\pm 1°$ of the surface temperature. Although the range of dissolved oxygen

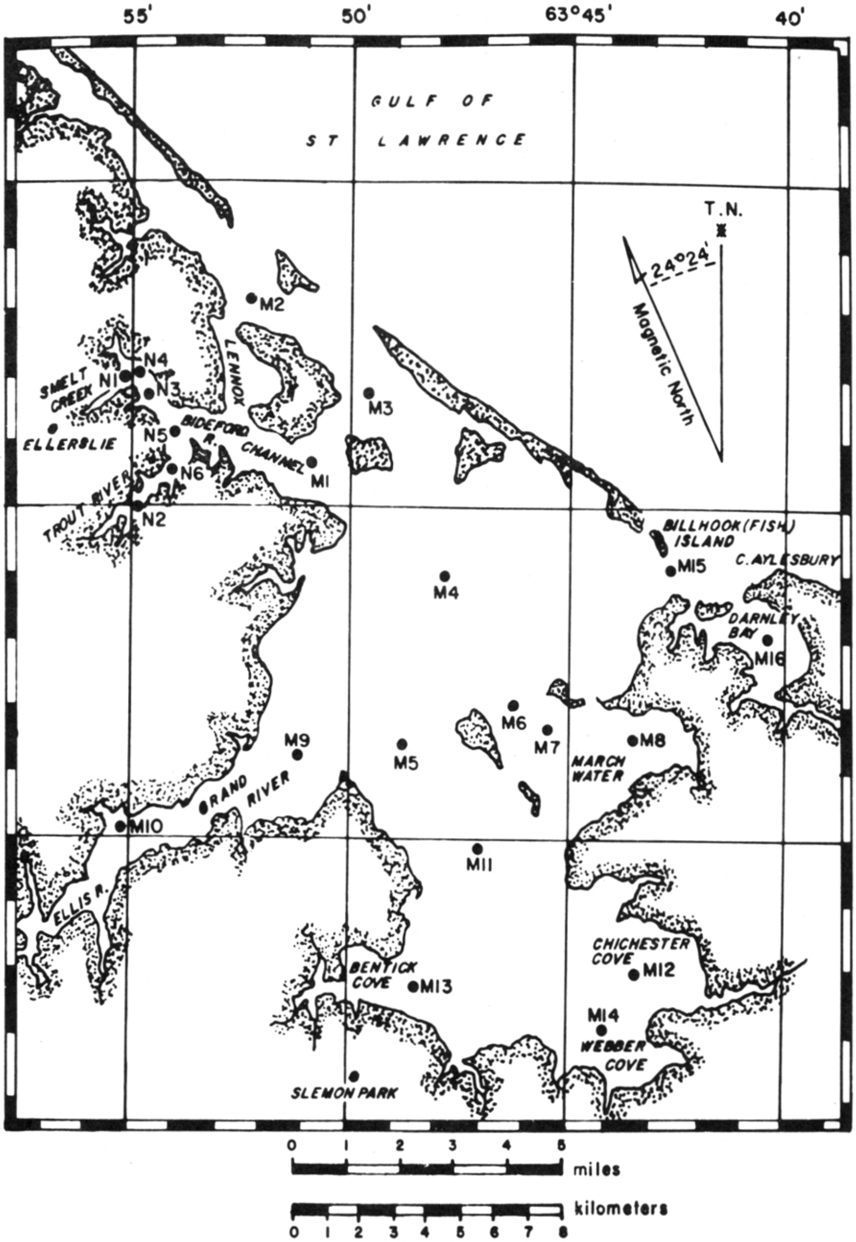

Fig 1 Map of Malpeque Bay, Prince Edward Island, showing the location of the collecting sites.

Table I Water quality characteristics of Malpeque Bay, Prince Edward Island

Characteristic	Units	Mean Value (S.D.)	Range	No. of Analysis
Stations N1-N6				
temperature	deg. C	13.3	-1.4-26	176
pH	-	8.1	7-8.9	176
salinity	0/00	24.6	0.1-27.9	176
dissolved oxygen	$\mu g\ mL^{-1}$	6	10.6-0.7	176
nitrogen (Kjeldahl)	$\mu g\ mL^{-1}$	.43 (.16)	0.14-0.79	176
phosphate	$\mu g\ mL^{-1}$	.04 (.02)	.009-.084	176
silicate	$\mu g\ mL^{-1}$	0.11	.01-.38	176
chlorophyll	$\mu g\ mL^{-1}$	2.9	0.1-10.7	176
Stations M1-M16				
temperature	deg. C	21.9	19.4-24.8	48
transparency	M	2.1	1.1-3.7	48
phosphate	$\mu g\ mL^{-1}$	.01 (.002)	.003-.013	48
silicate	$\mu g\ mL^{-1}$	0.014	.008-.034	48
chlorophyll	$\mu g\ L^{-1}$	2.01	.6-6.4	48

concentrations at the N stations varied, the variation was largely due to the lower values obtained in winter, presumably due to low photosynthetic activity. Apart from Kjeldahl nitrogen determinations, values for ammonia (2-90 ng mL^{-1}) nitrate (2-510 ng mL^{-1}) and nitrite (1-41 ng mL^{-1}) were obtained. In general the highest values for these entities were found at the N stations. A number of analyses for trace metals in the water at the N stations were obtained. The values (in ng mL^{-1}) obtained were: Ni & Zn, 10-60; Cu, Fe, Pb & Mn, 10-40; Cd, 1-6; and Hg, 1-3. These values were comparable to those reported by other workers. From all these analyses it may be concluded that the water in Malpeque Bay in 1973 and 1974 was of high quality. The low numbers of coliform bacteria found in the water samples lends support to this conclusion.

Composition and seasonal variation of the phytoplankton collected. The five orders of phytoplankton found are given in Table II together with the number of genera detected and the number of species identified in each order. The dominant species in each order are also given in Table II where in addition an indication of their seasonal variation may be found. Blooms of single species were observed in Malpeque Bay; some of these are indicated in Table II, but other species outside the dominant and subdominant classes e.g. *Biddulphia rhombus* and *Chaetoceros constrictum* were also observed to bloom in the summer. A full list of all species identified is given in Appendix I. Sixty species of benthic algae were identified; the dominant species are marked with an asterisk in Table II.

An attempt was made to calculate a species diversity index (Parsons & Takahashi, 1973) and values of 2.2-2.7 were obtained from the 1973 data from the N stations and 3-3.7 from the M stations. The greater values obtained from the M stations indicates greater biological stability (Odum, 1951).

Detailed statistical analyses of the chemical and biological data were undertaken. In particular, multiple regression analyses were carried out on the parameters of phytoplankton numbers (total numbers, reciprocal & logarithmic transforms of these numbers) and porphyrin analyses, air and water temperatures, salinity, acidity and concentrations of oxygen, phosphate, nitrogen, silicate and the trace metals Cu, Cd and Hg. The positive correlations are summarized in Table III and these results indicate, as expected, that the population density of the phytoplankton is correlated

Table II Dominant species of phytoplankton found in the waters of Malpeque Bay, Prince Edward Island and seasonal changes in their populations.

Order	No. of genera	No. of species	Dominant Species	Seasons
Baccillariophyceae	55	123	*Hyalodiscus scotius**	all
			Skeletonema costatum	all
			Biddulphia aurita	all
			*Bacillaria paxillifer**	not winter
			*Paralia sulcata**	not winter
			Chaetoceros concavicorne	not winter
			C. decipiens	not winter
			Thalassiothrix longissima	spr. & sum.
			Thalassiosira gravida	spr. & sum.
			T. nordenskioldii	spr. & sum.
			Biddulpia pulchella	spr. & sum.
			Thallassionema nitzschioides	summer
			Asterionella sp.	summer
			Coscinodiscuns marginatus	autumn
			Asterionella japonica	not autumn
Dinophyceae	8	21	*Dinophysis acuta*	all
			Gymnodinium lunula	not winter
			Peridinium ovatum	not winter
			Gonyaulax tamarensis	not winter
			Ceratinum macroceros	not winter
			Ceratinum tripos	not winter
			Dinophysis caudata	spr. & aut.
			Dinophysis norvegica	spr. & sum.
Cyanophyceae	4	4	*Arthospira sp.*	all
			Agmenellum sp.	all
			Oscillatoria sp.	not winter
			Anabaena sp.	sum. & fall
Chrysophyceae	3	3	*Dinobryon balticum*	all
			Distephanus speculum	not winter
			Chrysosphaerella sp.	not winter
Chlorophyceae	2	2	*Scenedesmus acuminatus*	all
			Actinastrum sp.	not winter

Table III Correlation coefficients between chlorophyll, salinity, dissolved oxygen, phosphate, water temperature and phytoplankton numbers in Malpeque Bay, Prince Edward Island.

	Chlorophyll	Plankton Numbers
Chlorophyll	-	.78
Dissolved oxygen	.65	.83
Phosphate	0	0
Salinity	.56	.78
Temperature	.59	.84
Phytoplankton numbers	.78	-

Table IV Seasonal changes in chlorophyll and pheophytin concentrations (μg L^{-1}) in the Bideford estuary, Malpeque Bay, Prince Edward Island.

Date	Station N1	N3	N6
Spring 1973	5	6	3
Summer 1973	6	7	3
Autumn 1973	3	4	3
Winter (Feb.) 1974	3	2	1
Spring 1974	2	1	3
Summer 1974	4	5	5

with the porphyrin levels, and with the water temperature, salinity and dissolved oxygen concentration. There was also some indication that in winter and spring higher levels of the trace metals iron and cadmium were associated with a decrease in phytoplankton numbers.

The high correlation coefficients (Table III) found between phytoplankton numbers and porphyrin levels permits the latter to be used in estimates of population densities. In Table IV changing levels of chlorophyll concentrations with season are given. The results illustrate the validity of this type of estimate of phytoplankton population density, for in all cases a decline in value from summer to winter is observed, followed by a growth in values during the following summer. This conclusion is substantiated by the numbers of cells counted in the water samples collected at stations N1, N3 and N6 over the entire experimental period (Fig 2).

Further analyses of the data were done to evaluate correlation between phytoplankton numbers and the physico-chemical characteristics of the water with respect to season. For the stations in the Bideford estuary in spring the density of the phytoplankton was proved to be realted to the salinity and temperature of the surface water, and its phosphate, silicate and iron content. Similar results were obtained with samples of bottom water taken at the same stations during the summer and winter. It therefore seems probable that nutrient depletion by the phytoplankton population occured during the study period in the N1-N6 stations. The data from the stations largely situated in the open Bay (M1-M16) though less complete suggests that in this environment nutrient depletion is less marked.

Discussion

The experimental data reported in this paper, details of which have been hitherto available only in theses (Sita Devi, 1980), extend the results previously reported by McIver (1972) and by Taylor and his co-workers (1976).

The changing phytoplankton populations of Malpeque Bay illustrate the suggestions of Ryther (1963) that single summer maxima of high production occur in shallow waters. Values found for the chlorophyll levels in water samples during the summer permit a crude estimate of the carbon fixed by the population at this time (Strickland, 1960) to be in the range 5-120 g m^{-2} y^{-1}. However, the present study does not permit an evaluation of the principal species responsible for this activity. The porphyrin estimations represent the total photosynthetic pigments present in the samples. It is now known (Fogg, 1987) that large numbers of small photosynthetic cyanobacteria are present in marine environments. These organisms would not be retained in our 20 μ collection nets.

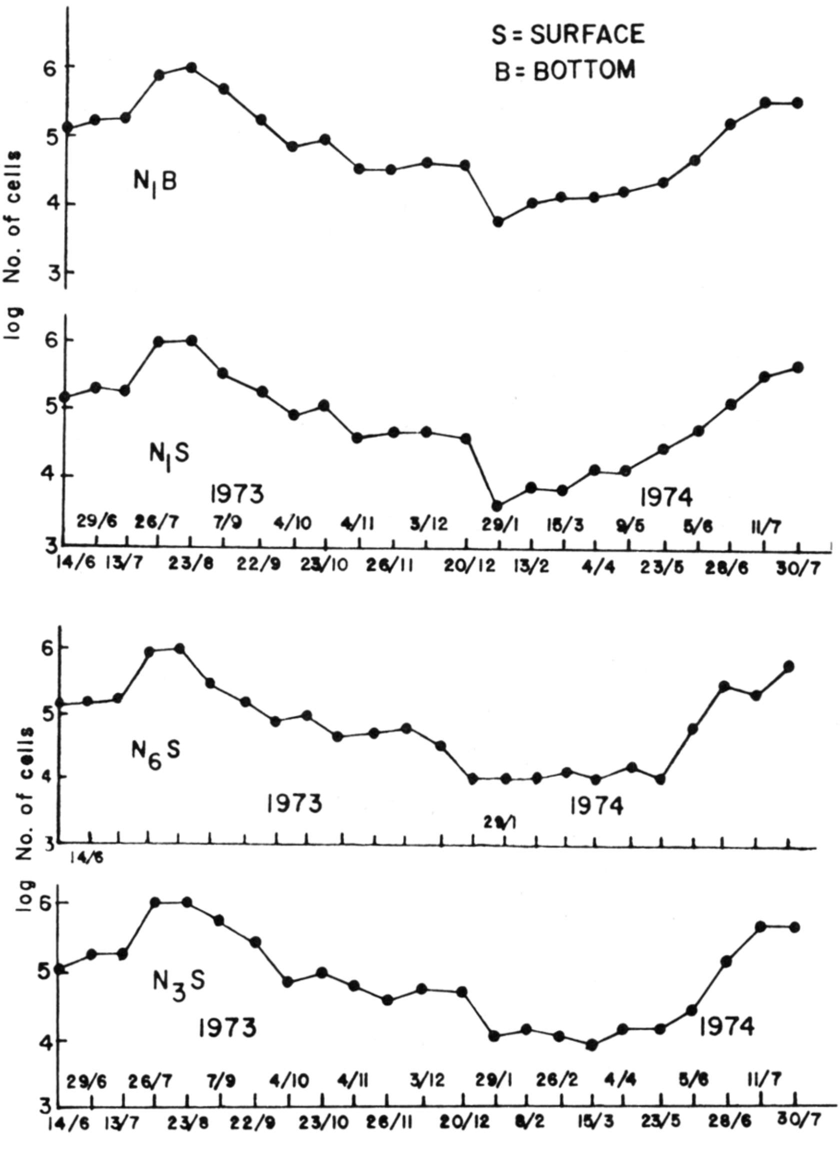

Fig 2 Numbers of phytoplankton collected at sites: N1 (surface (S) and bottom (B) waters; N3 (surface water) and N6 (surface water).

The higher population densities in the esturine stations (N1-N6) than in the more open Bay stations (M1-M16) cannot be solely attributed to higher nutrient levels in the estuary. The equilibrium between supply and removal of nutrients depends on the efficiency of mixing and it may be surmised that the conditions at the M stations were more akin to the steady state thought to be present in the open ocean (Spencer, 1975).

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APPENDIX I List of Phytoplankton Recorded from Malpeque Bay, Prince Edward Island, Canada.

BACILLARIOPHYCEAE	
Order:	BACILLARIALES
Sub-Order:	COSCINODISCINEAE
Family:	COSCINODISCACEAE
	Melosira Agardh
	M. nummuloides (Dillw.) Agardh
	M. juergensii Agardh
	Paralia Heiberg
	P. sulcata (Ehrenb.) Cleve
	Cyclotella (Kützing) de Brébisson
	C. striata (Kütz.) Grun.
	C. meneghiniana Kütz.
	Coscinodiscus Ehrenberg
	C. radiatus Ehrenb.
	C. concinnus Wm. Sm.
	C. centralis Ehrenb.
	C. lineatus Ehrenb.
	C. marginatus Ehrenb.
	C. eccentricus Ehrenb.
	Actinocyclus Ehrenberg
	A. octanarius Ehrenb.
	Thalassiosira Cleve
	T. gravida Cleve
	T. condensata Cleve
	T. decipiens (Grun.) Jörg.
	T. nordenskioldii Cleve
	Coscinosira Gran
	C. polychorda (Gran) Gran
	Hyalodiscus Ehrenberg
	H. scoticus (Kütz.) Grun.
	Skeletonema Greville
	S. costatum (Grevi.) Cleve
Family:	ACTINODISCACEAE
	Actinoptychus Ehrenberg
	A. senarius (Ehrenb.) Ehrenb.
Sub-order:	AULISCINEAE
Family:	AULISCACEAE
	Auliscus Ehrenberg
	A. sculptus (Wm. Sm.) Ralfs ex Pritch.
	A. incertus A.S.
Sub-order:	BIDDULPHINEAE
Family:	BIDDULPHIAEAE
	Biddulphia Gray
	B. pulchella Gray
	B. aurita (Lyngb.) de Bréb.
	B. rhombus (Ehrenb.)
	B. mobiliensis (Bail.) ex Van Heurck
	B. laevis Ehrenb.
	Eucampia Ehrenberg.
	E. zodiacus Ehrenb.
	Triceratium Ehrenb.
	T. alternans Bail.
	Isthmia Agardh
	I. nervosa Kütz.
Family:	CHAETOCERACEAE
	Chaetoceros Ehrenberg
	C. boreale Bail.
	C. atlanticum Cleve
	C. convolutum Castr.
	C. concavicorne Mangin
	C. constrictum Gran
	C. didymum Ehrenb.
	C. affine Laud.

C. laciniosum Schütt
C. diadema (Ehrenb.) Gran
C. septentrionale Oestrup
C. decipiens Cleve
C. lorenzianum Grun.
C. danicum Cleve

Sub-Order: RHIZOSOLENINEAE
Family: LEPTOCYLINDRAECEAE
Leptocylindrus Cleve
L. danicus Cleve
L. minimus Gran
Guinardia Peragallo
G. flaccida (Castr.) Perag.

Family: RHIZOSOLENIACEAE
Rhizosolenia Brightwell
R. fragilissima Berg.
R. styliformis Brightw.
R. setigera Brightw.
R. alata Brightw.
R. habetata Bail.

Sub-order: FRAGILARINEAE
Family: FRAGILARIACEAE
Fragilaria Lyngbye
F. crotonensis Kitton
F. pinnata Ehrenb.
F. striatula Lyngb.
F. schulzi Brockm.
Raphoneis Ehrenberg
R. amphiceros (Ehrenb.) Ehrenb.
Dimeregramma Ralfs ex Pritchard
D. marinum (Greg.) Ralfs ex Pritch.
D. minor (Greg.) Ralfs ex Pritch.
Asterionella Hassall
A. japonica Cleve & Möller
S. Sp.
Striatella Agardh
S. unipunctata (Lyngb.) Agardh
Synedra Ehrenberg
S. affinis Kütz.
S. pulchella Kütz.
Thalassiothrix Cleve & Grunow
T. longissima Cleve & Grun.
Thalassionema Grunow ex Hustedt
T. nitzschioides Hust.
Plagiogramma Greville
P. staurophorum (Greg.) Heib.
Licmophora Agardh
L. lyngbyei (Kütz.) Grun. ex Van Heurck
L. paradoxa (Lyngb.) Agardh
L. gracillis (Ehrenb.) Grun.
Grammatophora Ehrenberg
G. marina (Lyngb.) Kütz.
G. angulosa Ehrenb.
G. stricta Ehrenb.
Rhabdonema Kütz.
R. minutum Kütz.

Sub-order: ACHNANTHINEAE
Family: ACNANTHACEAE
Achnanthes Bory
A. brevipes Ag.
A. longipes Ag.
Cocconeis Ehrenberg
C. scutellum Ehrenb.
Rhoicosphenia Grunow
R. curvata (Kütz.) Grun.

Sub-order: NAVICULINEAE
Family: NAVICULACEAE
Navicula Bory
N. cryptocephala Kütz.
N. granulata Bail.
N. digito-radiata (Greg.) Ralfs
N. grevilleana Hendey
N. peregrina (Ehrenb.) Kütz.
Stauroneis Ehrenberg
S. salina Wm. Sm.
S. gracilis Ehrenb.
Diploneis Ehrenberg.
D. smithii (de Bréb.) Cleve var. *Smithii*
D. didyma (Ehrenb.) Cleve
D. littoralis (Donk.) Cleve
D. elliptica (Kütz.) Cleve
Caloneis Cleve
C. brevis (Greg.) Cleve
C. westii (Wm. Sm.) Hendey
Pinnularia Ehrenberg
P. quadratarea (Schm.) Cleve
Trachyneis Cleve
T. aspera (Ehrenb.) Cleve
Mastogloia Thwaites in Wm. Smith
M. pumila (Grun.) Cleve
Amphipleura Kützing
A. rutilans (Trent.) Cleve
Brebissonia Grunow
B. boeckii Wm. Sm.
Pleurosigma Wm. Sm.
P. strigosum Wm. Sm.
P. normanii Ralfs
P. decorum Wm. Sm.
Gyrosigma Hassall
G. balticum (Ehrenb.) Cleve
G. wansbeckii (Donk.) Cleve

G. fasciola (Ehrenb.) Cleve
Amphiprora Ehrenberg
A. alata (Ehrenb.) Kütz.
Tropidoneis Cleve
T. vitrea (Wm. Sm.) Cleve

Family: AURICULACEAE
Auricula Castracane
A. Sp.

Family: CYMBELLACEAE
Amphora Ehrenberg
A. robusta Greg.
A. hyalina Kütz.
A. obtusa Greg.

Family: EPITHEMIAECAE
Epithemia de Brébisson
E. turgida (Ehrenb.) Kütz.
E. gibba Kütz.
E. zebra (Ehrenb.) Kütz.
Rhopalodia O. Müller
R. gibberrula var. *producta* (Grun. Müll.

Family: BACILLARIACEAE
Bacillaria Gmelin
B. paxillifer (Müll.) Hendey
Nitzschia Hassall
N. closterium (Ehrenb.) Wm. Sm.
N. angularis Wm. Sm.
N. seriata Cleve
N. spathulata Wm. Sm.
N. obtusa Wm. Sm.
N. apiculata (Greg.) Grun.
N longissima (de Bréb.) Ralfs ex Pritchard
N. socialis Ralfs var. *socialis*

Sub-Order: SURIRELLINEAE

Family: SURIRELLACEAE
Surirella Turpin
S. ovata Kütz.
S. fastuosa (Ehrenb.) Kütz.
Campylodiscus Ehrenb.
C. Sp.

Class: DINOPHYCEAE

Order: DINOPHYSIALES

Family: DINOPHYSIACEAE
Dinophysis Ehrenberg
D. acuta Ehrenb.
D. caudata Savilli-Kent
D. norvegica Clap. et Lachm.
D. Sp.

Order: GYMNODINIALES

Family: GYMNODINIACEAE
Amphidinium Claparédé et Lachmann
A. ovum C. Herdm.
A. Sp.
Gymnodinium Stein
G. lunula Schütt
G. punctatum Pouchet
Gyrodinium Kofoid et Swezy
G. spirale (Bergh.) Kof. et Swezy
G. Sp.

Family: PERIDINIACEAE
Peridinium Ehrenberg
P. ovatum (Pouchet) Schütt
P. Sp.

Family: GONYAULACACEAE
Gonyaulax Diesing
G. tamarensis Lebour
G. catenata (Levender) Kof.

Family: CERATIACEAE
Ceratium Schrank
C. arcticum (Ehrenb.) Cleve
C. furca (Ehrenb.) Clap. et Lachm.
C. fusus (Ehrenb.) Dujard
C. longipes (Bail.) Gran
C. macroceros (Ehrenb.) Vanhöffen
C. tripos (O. F. Müll.) Nitzsch.

Family: OXYTOXACEAE
Oxytoxum Stein
O. Sp.

CHLOROPHYTA

Order: CHLOROCOCCALES

Family: SCENEDESMACCEAE
Scenedesmus Meyen
S. acuminatus (Lagerh.) Chodat
Actinastrum Lagerheim
A. Sp.

CYANOPHYTA

Order: NOSTOCALES

Family: OSCILLATORIACEAE
Oscillatoriaceae Vaucher ex Gomont
O. Sp.
Arthospira Strizenberger ex Gomont
A. Sp.

Family: NOSTOCACEAE
Anabaena Bory
A. Sp.

Order: CHROOCOCCALES

Family: CHROOCOCCACEAE
Agmenellum Bregisson
A. Sp.

CHRYSOPHYTA

Order: OCHROMONADALES

Family: DINOBRYACEAE

Dinobryon Ehrenberg

D. Balticum (Schütt) Lemm.

Family: SYNURACEAE

Chrysosphaerella Lauterborn

C. Sp.

Order: DICTYOCHALES

Family: DICTYOCHACEAE

Distephanus Stöhr

D. speculum (Ehrenb.) Haeckel