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RESEARCH ARTICLE

Phytoplankton composition in the coastal Magnetic Island lagoon, Western Pacific Ocean (Australia)

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Abstract

1 - Coastal lagoons have traditionally been considered as transitional systems between continental and marine domains. The phytoplankton plays a key role in these aquatic environments, forming the base of the food web and having a substantial function in nutrient dynamics and in the carbon biogeochemical cycle.

2 - Due to their short life cycle, planktonic algae respond quickly to environmental changes and they are thus a valuable indicator of water quality. It is essential to investigate the development of phytoplankton populations to understand the biological functioning and to detect changes in aquatic systems.

3 - Phytoplankton studies in the Australian estuaries and lagoons are relatively scarce. This study has provided a broad perspective and preliminary information on taxonomic structure of phytoplankton guilds for the Magnetic Island Lagoon (Queensland, Australia). This work may provide valuable information of interest to later ecological studies.

4 - In the whole sampling a total of 143 taxa were identified. In terms of species richness, diatoms (Bacillariophyceae, Coscinodiscophyceae, Fragilariophyceae) and dinoflagellates (Dinophyceae) were the most important groups. In taxonomic terms, diatoms were the major contributor to the phytoplankton composition (~ 70%) whereas Dinophyceae were moderately abundant (~23%). Diatoms are a very important component in estuarine and shallow coastal wetlands and they are increasingly being utilized as indicators of environmental change.

Keywords: phytoplankton; diatoms; dinoflagellates; taxonomic structure; Magnetic Island; Western Pacific Ocean; Australia.

Introduction

Coastal lagoons have traditionally been considered as transitional systems between continental and marine domains, a consideration that has gained in importance in the context of the Water Framework Directive (WFD) of the European Union (Bianchi, 1988; Pérez-Ruzafa *et al.*, 2008). They are characterized by particular features, such as shallowness, relative isolation from the open sea, usually as a result of coastal barriers that maintain some communication channels or inlets, and the presence of boundaries with strong physical and ecological gradients (UNESCO, 1981). Bottoms are usually well irradiated, because of their shallowness, while currents and hydrodynamics are closely conditioned by bottom topography and wind affects the entire water column, promoting the resuspension of materials and nutrients from the sediment surface layer. Emergent properties of lagoon ecosystems have recently been reviewed in comparison with other types of transitional waters (Basset *et al.*, 2013).

Due to the fact of being areas with restricted exchange with the adjacent ocean and thus may accumulate nutrients supplied by the surrounding watershed, coastal lagoons are commonly characterised by high productivity (Taylor *et al.*, 1999).

Phytoplankton drives the bulk of primary production in most aquatic ecosystems and contribute 50 per cent to the global assimilation of organic carbon (Falkowski *et al.*, 1998). These photosynthetic organisms plays a key role in aquatic environments, forming the base of the food web and having a substantial function in nutrient dynamics and in the carbon biogeochemical cycle (Graham and Wilcox, 2000; Sarmiento and Gruber, 2006; Almandoz *et al.,*2011).

Due to their short life cycle, planktonic algae respond quickly to environmental changes and are thus a valuable indicator of water quality. To this extent, phytoplankton cell size and shape represent morpho-functional traits of overwhelming importance (Stanca *et al.*, 2013a); phytoplankton size spectra and size classes have been shown to have a high information content to detect environmental condition change in transitional and coastal waters (Sabetta *et al.*, 2008; Lugoli *et al.*, 2012; Vadrucci *et al.*, 2013). Then it is essential to investigate the development of phytoplankton populations to understand the biological functioning of aquatic systems and detect changes in them (Hötzel and Croome, 1999).

Much work is still needed to unrevel phytoplankton patterns and composition in many remote areas that remain largely unexplored. Magnetic Island lagoon, in Queensland (Australia) is one of these.

The Australian continent is surrounded by three oceans and its marine waters, extending over 16 million km^2, are amongst the largest in the world (Newton and Boshier, 2001). The coastal and shelf waters of Australia are very diverse in their water temperature, sun light exposure and nutrient concentrations, the three key drivers of phytoplankton blooms. The large size and variability of the Australian coastal and continental shelf waters make the different monitoring methods of phytoplankton, traditional oceanographic sampling and alternative method using satellite ocean color remote sensing (Blondeau-Patissier *et al.*, 2011).

Algae studies in Australia begun in 1730, when William Dampier published the first record of Australian algae. Since then, a number of phytoplankton studies covering the oceanic waters, lakes and lagoons have been carried out in different regions of Australia (Dakin and Colefax, 1993; Wood, 1954; Humphrey, 1963; Hallegraeff, 1981; Royle, 1985; Hallegraeff and Jeffrey, 1984; King *et al.*, 1997; Trott and Alongi, 1999; O'Donohue *et al.*, 2000; Chan and Hamilton, 2001; Ajani *et al.*, 2001, 2002). But compared with the off-shore research, phytoplankton studies in the Australian estuaries and lagoons are relatively scarce. Many Australian governments have established water quality objectives for major estuaries and are developing the sustainable management procedures under the various water reform initiatives (Liu, 2008). Guidelines for all aspects of phytoplankton monitoring in Australian freshwaters has been developed at a time when lakes and rivers have become the focus of many water resource issues in Australia, in particular the need to ensure ecosystem sustainability (Hötzel and Croome, 1999).

Most of the studies were carried out in the Australian coastal waters, estuaries and coastal lagoon but there is no detailed information on phytoplankton and their ecological features in Magnetic Island Lagoon. Therefore, the present study aimed to examine the taxonomic structure of phytoplankton to provide preliminary information on the Magnetic Island Lagoon, as a model ecosystem of leaky lagoons characterized by meso-tidal regimes ensuring high openness and low water turnover times at high tides.

Material and methods

Study site

Magnetic Island is an inshore continental island (52 km^2) of the GBR located about 8 km offshore from Townsville, in NE Queensland, Australia (Fig. 1) (Lewis *et al.*, 2012).

It is located within the dry tropics region of north Queensland and the Great Barrier Reef World Heritage Area (GBRWHA) and is part of the Townsville City local government area. The island is about 5184 ha in size, contains around 40 km of coastline and is the seventh largest and the fourth highest of the 600 continental islands in the GBRWHA. About half of the island (2533 ha) and much of the elevated country is protected (under the Queensland *Nature Conservation Act 1992*) as the Magnetic Island National Park and there are also two small areas designated as Conservation Parks. There are five matters of national environmental significance relevant to Magnetic Island. Specifically, the island is: home or habitat to listed threatened species and a threatened ecological community; habitat to listed migratory species; part of the Great Barrier Reef World Heritage Area; part of the Great Barrier Reef National Heritage place, and surrounded by the Great Barrier Reef Marine Park. A variety of marine environments occur around the island, including mangrove forests, salt marshes, fringing coral reefs and seagrass communities; these provide important habitat for marine flora and fauna. Many listed species live in the waters around the island including sea snakes, turtles,

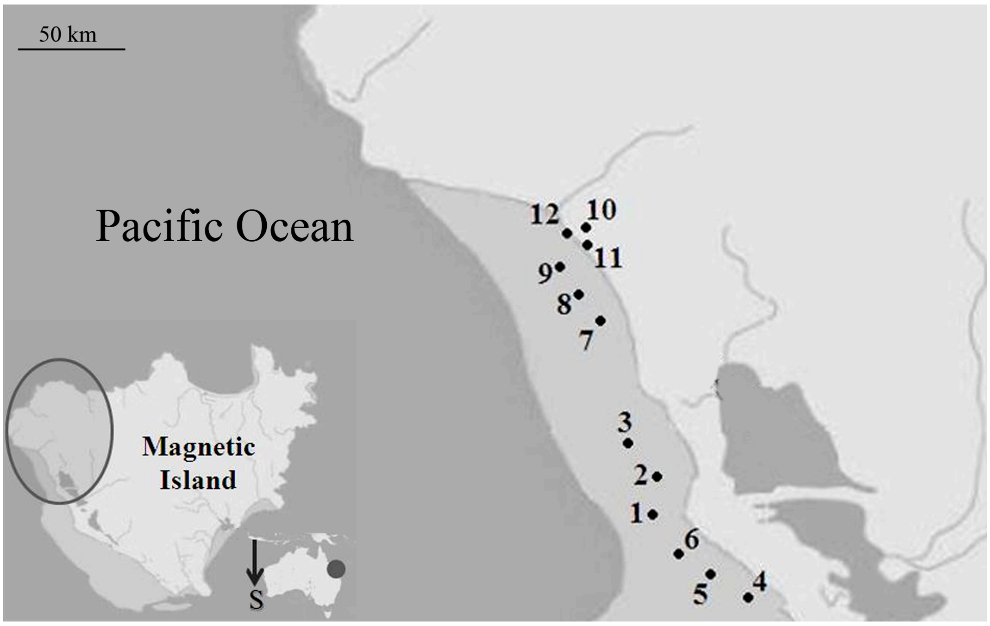

Figure 1. Study site.

dugongs and dolphins (Commonwealth of Australia, 2010).

Field procedures and Phytoplankton analysis
A hierarchical sampling design was followed, according to the criteria adopted for a large scale survey, which is currently in progress in various worldwide eco-regions (POR Strategic Project) (see, Durante *et al.*, 2013; Roselli *et al.*, 2013; Souza *et al.*, 2013; Stanca *et al.*, 2013b for other world eco-regions) (for further information see the web site: http://phytobioimaging.unisalento.it/en-us/studysites/samplingdesign.aspx.).
A total of 4 ecologically distinct habitat typology exist within the Magnetic Island lagoon, which differ considerably in relation to their type identified on the basis of the granulometry of the sediments and the presence and type of vegetation, according to Roff and Taylor (2000).
At each habitat typology, 3 station are selected and for each station, 3 replicates were collected for a total of 36 water samples Phytoplankton sampling was made in March 2011. Water samples were collected with horizontal tows from the subsurface (0.5 m) with a 6 µm plankton net. Water samples were fixed with Lugol's solution.
General phytoplankton composition was determined using the Utermohl method (Utermohl, 1958).
Phytoplankton cells were identified and counted at 400x magnification with a Nikon Eclipse T*i*-S inverted microscope, connected to a video interactive image analysis system (L.U.C.I.A, Version 4.8, Laboratory Imaging Ltd., Prague) after sedimentation of 5 to 10 mL samples. For each sample 400 cells were identified and counted. For more detailed identification was used an inverted microscope Nikon Eclipse T*i*-E coupled with an image analysis system (NIS–Elements AR Nikon Instruments software, version 3.06).
The texts and journal articles used most frequently to aid in taxonomic identification were: Smith and Tuffen, 1853; Van Heurck, 1880-1885; Boyer, 1926; Cupp, 1943; Crosby and Wood, 1958, 1959; Wood *et al.,* 1959; Subrahmanyan, 1971; Rampi and Bernhard, 1978, 1980; Dodge, 1982; Ricard, 1987; Sournia, 1986, 1987; Chrétiennot-Dinet, 1990; Round *et al.,* 1990; Hasle, 1995; Tomas, 1997; Bérard-Therriault *et al.,* 1999; Faust and Gulledge, 2002; Wehr and Sheath, 2003; Pavel Škaloud and Řezáčová, 2004; Sar *et al.*, 2007; Iwataki, 2008; Sunesen and Hernàndez- Becerril, 2008; Al-Kandari *et al.,* 2009; Tabassum and Saifullah, 2010; Yun *et al.*, 2011. The "cf." qualifier was used to indicate specimens that were similar to (or many actually be) the nominate species. Taxa which contain "undet."(undetermined) identifier were likely to be algal entities, but could not be identified as any identified genus. In some cases, species were broken out into separate taxa based on size (e.g., Dinophyceae undet. > 20 micron).
During phytoplankton identification, sometimes is not possible to identify the organism to the species level, though recognizing common characteristics within a group of cells belonging to the same genus. In this case, to identify that organism in the phytoplankton list is reported the name of the genus followed by numbered "sp." (e.g. *Chaetoceros* sp.1, *Chaetoceros* sp.2, *Chaetoceros* sp.3, etc). The complete list, including all numbered species, is available on the website www.phytobioimaging.unisalento.it.

Results and discussion

Phytoplankton composition
Overall, 14400 phytoplankton organisms were identified, measured and counted. A total of 143 taxa were identified: 100 diatoms (Bacillariophyceae, Coscinodiscophyceae, Fragilariophyceae), 33 Dinophyceae, 1 Chlorodendrophyceae, 1 Chlorophyceae, 1 Cryptophyceae, 1 Crysophyceae, 1

Cyanophyceae, 1 Euglenophyceae, 1 Prymnesiophyceae, 1 Xanthophyceae, and 2 undetermined taxa. Among these taxa, at least 67 to the species level, 64 to the genus level and 12 to the class level were identified. Appendix 1 lists the species found in the present study.

In taxonomical terms, diatoms (Bacillariophyceae, Coscinodiscophyceae, Fragilariophyceae) comprised the largest number of species representing ~ 70% of the total, followed by dinoflagellates (Dinophyceae) with 23% of the total. The other remaining 10 classes(Chlorodendrophyceae, Chlorophyceae, Cryptophyceae, Crysophyceae, Cyanophyceae, Euglenophyceae, Prymnesiophyceae, Xanthophyceae, and 2 undetermined taxa) reaching ~7% of the total taxa.

In terms of species richness, diatoms and dinoflagellates were the most important groups.

Nevertheless, in this study we describe more in details taxonomic composition of diatoms.

Diatoms composition

During the study period, a total of 100 diatom taxa (71 Coscinodiscophyceae, 20 Bacillariophyceae, 9 Fragilariophyceae), belonging to 31 genera were identified, which of 55 to species level, 43 to the genus level, and 2 to the class level. The identification at species level for some diatoms made more difficult, at least in part, because of the methodology based on light microscopy. Identification to species level for these diatoms often requires examination under electron microscopy.

High species richness was observed for genera *Chaetoceros* Ehrenberg (29 taxa), *Bacteriastrum* Shadbolt (9 taxa), *Pseudo-nitzschia* H.Peragallo (6 taxa), *Thalassionema* (Grunow) Mereschkowsky (5 taxa). The following observed genera present 3 taxa: *Cerataulina* H.Peragallo ex Schütt, *Dactyliosolen* Castracane, *Eucampia* Ehrenberg, *Guinardia* H. Peragallo, *Hemiaulus* Heiberg, *Rhizosolenia* Brightwell. 2 taxa are present in *Attheya* West, *Coscinodiscus* Ehrenberg, *Leptocylindrus* Cleve, *Licmophora* Agardh, *Navicula* Bory de Saint-Vincent, *Odontella* Agardh, *Thalassiosira* Cleve. 17 genera were the most species-poor, with only one taxon recorded in each (Appendix 1).

Almost 50% of globally sampled phytoplankton cells, in term of numerical abundance, were represented by only 5 taxa: 3 of which were *Chaetoceros laevis*, *Chaetoceros* spp., *Skeletonema costatum*, belonging to Coscinodiscophyceae; *Pseudo-nitzschia* spp. belonging to Bacillariophyceae, and *Thalassionema nitzschioides* belonging to Fragilariophyceae (Fig. 2).

Diatoms are increasingly being utilized as indicators of environmental change because they are abundant in all aquatic environments and are highly sensitive to water quality changes (Gasse *et al.*, 1987; Battarbee, 1988; Round, 1991; Battarbee *et al.*, 1997; Kelly *et al.*, 1998). In particular, diatoms are becoming increasingly used to reconstruct past changes in salinity (Hecky and Kilham, 1973; Fritz *et al.*, 1991; Gasse *et al.*, 1987; Gell, 1997). Diatoms have well defined ecological optima and tolerances enabling reconstruction of water quality changes over long periods of time (Battarbee, 1986; Birks, 1994; Moser *et al.*, 1996).

Conclusions

Our study represents the first attempt to address the phytoplankton assemblages of Magnetic Island. Since it has been done with detailed spatial replication but at a single date, consistent quantitative and qualitative data are still needed to better determine the seasonal and spatial changes of the phytoplankton assemblages in Magnetic Island Lagoon.

Therefore, collection and comprehensive

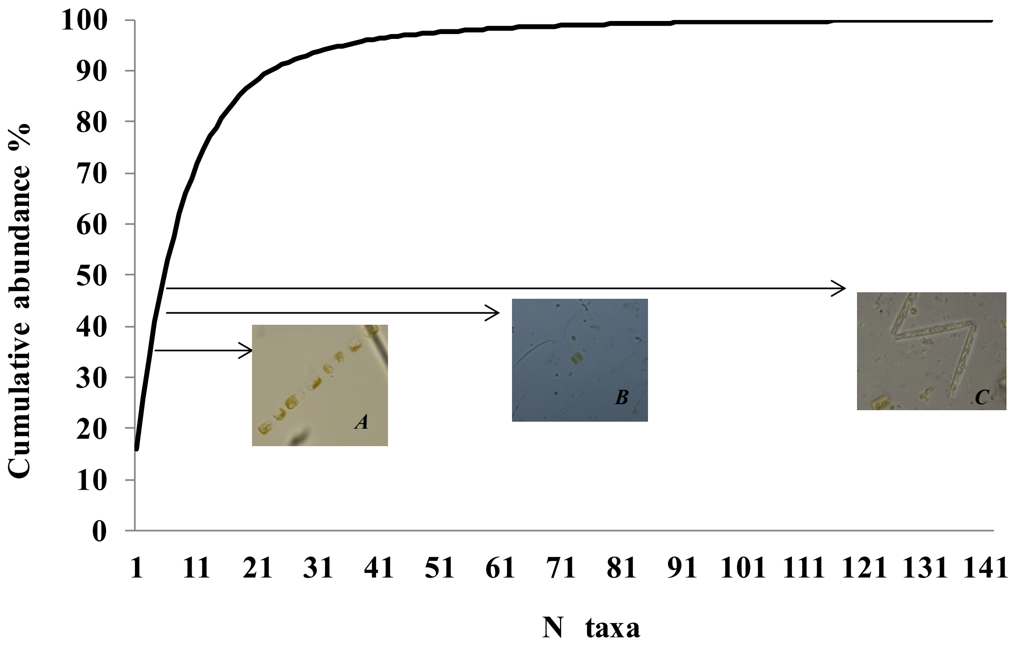

Figure 2. Abundance cumulative percentage of globally sampled phytoplankton cells, in term of numerical abundance. 3 of 5 taxa that are identified at species level, and covering 50% of total cumulative abundance, are shown: A)*Thalassionema nitzschioides*, B)*Chaetoceros laevis*, C)*Skeletonema costatum*.

assessment of taxonomic information makes it possible to expand our current knowledge on phytoplankton structures and their specific ecological characteristics. Besides, comparative analysis using quantitative data allows revealing the changes in species structures that are subject to natural and anthropogenic influences.

We believe that this work may provide valuable information of interest to later ecological studies. Definitive identification of the principal phytoplankton species assumes greater importance also at the light of the potentially serious and harmful effects associated with bloom events.

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Appendix 1. List of phytoplankton taxa identified in Magnetic Island Lagoon.

Bacillariophyta
Bacillariophyceae
Bacillaria paxillifera (O.F.Müller) T.Marsson 1901
cf. *Achnanthes* sp.
cf. *Luticola* sp.
cf. *Membraneis challengeri*
Entomoneis alata (Ehrenberg) Ehrenberg 1845
Gyrosigma spp.
Luticola spp.
Navicula transitans Cleve 1883
Navicula spp.
Nitzschia spp.
Pleurosigma sp. 1
Pseudo-nitzschia pseudodelicatissima (Hasle) Hasle 1993
Pseudo-nitzschia pungens cf. *multiseries*
Pseudo-nitzschia sp. 2
Pseudo-nitzschia sp. 3
Pseudo-nitzschia sp. 4
Pseudo-nitzschia spp.
Surirella sp. 1
Bacillariophyceae centrales undet.
Bacillariophyceae pennales undet.
Coscinodiscophyceae
Asteromphalus flabellatus (Brébisson) Greville 1859
Attheya longicornis R.M.Crawford & C.Gardner in Crawford et al. 1994
Attheya spp.
Bacteriastrum cf. *elongatum*
Bacteriastrum comosum J.Pavillard 1916
Bacteriastrum delicatulum Cleve 1897
Bacteriastrum elongatum Cleve 1897
Bacteriastrum furcatum Shadbolt 1854
Bacteriastrum hyalinum Lauder 1864
Bacteriastrum sp. 1
Bacteriastrum sp. 2
Bacteriastrum spp.
Cerataulina pelagica (Cleve) Hendey 1937
Cerataulina sp. 1
Cerataulina spp.
Chaetoceros affinis Lauder 1864
Chaetoceros cf. *compressus*
Chaetoceros cf. *furcellatus*
Chaetoceros cf. *holsaticus*
Chaetoceros cf. *laciniosus*
Chaetoceros coarctatus Lauder 1864
Chaetoceros compressus Lauder 1864

Appendix 1. Continued.

Bacillariophyta
Coscinodiscophyceae
Chaetoceros constrictus Gran 1897
Chaetoceros costatus Pavillard 1911
Chaetoceros curvisetus Cleve 1889
Chaetoceros decipiens Cleve 1873
Chaetoceros didymus Ehrenberg 1845
Chaetoceros didymus var. anglicus (Grunow) Gran 1908
Chaetoceros laciniosus F.Schütt 1895
Chaetoceros laevis G.Leuduger-Fortmorel 1892
Chaetoceros lorenzianus Grunow 1863
Chaetoceros pelagicus cf. *laciniosus*
Chaetoceros peruvianus Brightwell 1856
Chaetoceros pseudocurvisetus Mangin 1910
Chaetoceros tenuissimus Meunier 1913
Chaetoceros throndsenii (Marino, Montresor, & Zingone) Marino, Montresor & Zingone 1991
Chaetoceros wighamii Brightwell 1856
Chaetoceros sp.1
Chaetoceros sp.2
Chaetoceros sp.3
Chaetoceros sp.4
Chaetoceros sp.5
Chaetoceros sp.6
Chaetoceros spp
Coscinodiscus argus Ehrenberg 1839
Coscinodiscus perforatus var. *cellulosus* Grunow
Cyclotella spp.
Dactyliosolen blavyanus (H.Peragallo) Hasle 1975
Dactyliosolen fragilissimus (Bergon) Hasle in Hasle & Syvertsen 1996
Dactyliosolen spp.
Eucampia cf. *cornuta*
Eucampia sp.1
Eucampia spp.
Guinardia delicatula (Cleve) Hasle in Hasle & Syvertsen 1997
Guinardia flaccida (Castracane) H.Peragallo 1892
Guinardia striata (Stolterfoth) Hasle in Hasle & Syvertsen 1996
Hemiaulus hauckii Grunow ex Van Heurck 1882
Hemiaulus sinensis Greville 1865
Hemiaulus spp.
Leptocylindrus danicus Cleve 1889
Leptocylindrus minimus Gran 1915
Odontella mobiliensis (J.W.Bailey) Grunow 1884
Odontella sinensis (Greville) Grunow 1884

Appendix 1. Continued.

Bacillariophyta
Coscinodiscophyceae
Paralia sulcata (Ehrenberg) Cleve 1873
Pseudosolenia calcar-avis (Schultze) B.G.Sundström 1986
Rhizosolenia bergonii H.Peragallo 1892
Rhizosolenia imbricata Brightwell 1858
Rhizosolenia setigera Brightwell 1858
Skeletonema costatum (Greville) Cleve 1873
Thalassiosira eccentrica (Ehrenberg) Cleve 1904
Thalassiosira spp.
Fragilariophyceae
Asterionellopsis glacialis (Castracane) Round in Round, R.M.Crawford & D.G.Mann1990
Ceratoneis closterium Ehrenberg 1839
Licmophora flabellata (Grev.)C.Agardh 1831
Licmophora sp.2
Thalassionema cf. *synedriforme*
Thalassionema frauenfeldii (Grunow) Hallegraeff 1986
Thalassionema nitzschioides (Grunow) Mereschkowsky 1902
Thalassionema pseudonitzschioides (G.Schuette & H.Schrader) G.R.Hasle
Thalassionema spp.
Chlorophyta
Chlorodendrophyceae
Tetraselmis spp.
Chlorophyceae
Chlorophyceae undet.
Cryptophyta
Cryptophyceae
Cryptophyceae undet.
Cyanobacteria
Cyanophyceae
Oscillatoria spp.
Dinophyta
Dinophyceae
Akashiwo sanguinea (K.Hirasaka) G.Hansen & Ø.Moestrup 2000
Biceratium furca (Ehrenberg) Vanhoeffen 1897
cf. *Glenodinium* sp.
cf. *Gonyaulax* sp.
Dinophysis caudata Saville-Kent 1881
Gonyaulax spp.
Gymnodinium spp.
Heterocapsa pygmaea cf. *psammophila*
Heterocapsa spp.
Oxytoxum crassum Schiller 1937

Appendix 1. Continued.

Dinophyta
Dinophyceae
Oxytoxum variabile Schiller 1937
Peridinium quinquecorne Abé 1927
Phalacroma cf. *rotundatum*
Prorocentrum cf. *maximum*
Prorocentrum compressum (J.W.Bailey) Abé ex Dodge 1975
Prorocentrum cordatum (Ostenfeld) Dodge 1975
Prorocentrum micans Ehrenberg 1834
Prorocentrum sp.1
Prorocentrum spp.
Protoperidinium cf. *breve*
Protoperidinium cf. *crassipes*
Protoperidinium ovum cf. *sfericum*
Protoperidinium sp. 1
Protoperidinium sp. 2
Protoperidinium sp. 4
Protoperidinium spp.
Protoperidinium steinii (Jorgensen) Balech 1974
Scrippsiella trochoidea (Stein) Balech ex Loeblich III 1965
Scrippsiella sp.1
Dinophyceae athecate undet. 2 (<20µm)
Dinophyceae athecate undet.1 (>20µm)
Dinophyceae thecate undet. 2 (<20µm)
Dinophyceae thecate undet.1 (>20µm)
Euglenophyta
Euglenophyceae
cf. *Euglena* spp.
Haptophyta
Prymnesiophyceae
Prymnesiophyceae undet. 5
Ochrophyta
Chrysophyceae
Chrysophyceae undet. 2
Xanthophyceae
Meringosphaera spp.
Other Phytoplankton
Phytoflagellates undet.
Phytoplankton undet. 12