Nanoplankton Distribution and Abundance in the Vietnamese Waters of the South China Sea

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ABSTRACT

A collaborative sea cruise in the Vietnam waters of the South China Sea was conducted in the postmonsoon (21 April to 5 June, 1999) period on board MV SEAFDEC. The nanoplankton from 21 sampling stations consisted of 134 taxa comprising predominantly of centric nanodiatom (29 species), pennata nanodiatom (40 species) and dinoflagellate (65 species). Among the minute plankton collected, three species of nanodiatom (*Minidiscus comicus, M. chilensis, M. trioculatus*) and numerous dinoflagellate species were present. The pennate nanodiatom comprised of the species of *Asterionella, Psammodiscus* and *Amphipleura* ranging from 5.25×10^2 to 1.67×10^4 cell/L; all which were <20μm in size. The dominant centric nanodiatom comprised of species of *Thalassiosira, Minidiscus, Chaetoceros* and *Cyclotella*, ranging from 1.36×10^2 to 4.61×10^4 cell/L. The genera of *Chaetoceros, Minidiscus, Cyclotella, Coscinodiscus, Navicula, Fragilaria* and *Thalassiosira* contained a wide range of species; however, majority of these species were new records and have not been taxonomically identified. The Prymnesiophyta (mostly small flagellate cells and *Prasinophyta* species) were rarely present; while those of dinoflagellate consisted of a wide range of species of genera *Amphidoma, Centrodinium, Palaephalacroma, Peridinum, Planodinium, Gyrodinium, Gonyaulax, Scrippsiella, Protoperidinium* and *Protocentrum*. The genera of *Protoperidinium, Peridinium, Gonyaulax* and *Prorocentrum* had a wide range of species. The class Heptophyceae comprising of Prymnesiaceae, Coccolithaceae and Gephyrocapsaceae were rarely present. The total nanoplankton population (ranging from 0.24×10^4 to 5.47×10^4 L^{-1}) was dense in nearshore regions (especially in waters between Da Nang and Nha Trang) and tend to spread out in concentric semicircle into the open sea. The presence of the dinoflagellate species of *Amphidoma, Centradinium* and *Planadinium* were detected in considerable amounts at midshore Vietnam waters of the South China Sea. Blooms of *Gyrodonium* sp. and *Amphidoma* sp. (to a limited extend) occurred during the study period.

Key words: algae, dinoflagellate, nanoplankton, Vietnam, South China Sea

Introduction

For the past many years, the nanoplankton study has not been emphasised or given priority due its minute size (<20 μm) and difficulty in identifying; however, this should not lead to its reglect since in many waters it is responsible for more than 50% biomass carbon fixation and production in the ocean than the more immediate microplankton whose size is much bigger (20 to 200 μm) Only a few studies of plankton (especially the minute nanoplankton) and other related parameters were carried out on the Malaysian waters in the South China Sea. Chua and Chong (1973) showed that the distribution and abundance of pelagic species especially the small tuna (*Euthynus affinis*), chub mackerel (*Rastrelliger* sp.) and anchovies (*Stolephorus* sp.) were related to the density of phytoplankton.

Qualitative studies of microplankton (20-200 μm in size) in the Malaysian coastal waters, especially the Malacca Straits have been conducted by Sewell (1933), Wickstead (1961) and Pathansali (1968). Primary productivity in the same location had been carried out by Doty *et al.* (1963); however, a detailed study of the nanoplankton community structure, distribution and abundance in such waters had been lacking. Studies by Shamsudin *et al.* (1987) in the South China Sea around coasts of Johore, Terengganu and Kelantan found that majority of the phytoplankton found were diatoms which comprised of numerous species of *Bacteriastrum, Chaetoceros, Rhizosolenia* and *Pleurosigma*. The blue green, *Trichodesmium erythraeum* was found in abundance in such tropical waters (Chua & Chong, 1973). Studied on plankton (Shamsudin, 1987; Shamsudin & Baker, 1987; Shamsudin *et al.*, 1987; Semina, 1967; Markina, 1972) had raised questions about the qualitative and quantitative seasonal availability of these organisms as sources of food for those organisms higher up in the food chain and the relative production of these organisms in various study sectors of the South China Sea.

In the present study, the nanoplankton community structure has been analysed during the postmonsoon study period (April/June 1999) in the Vietnam waters of the South China Sea. The species community structure patterns, distribution, composition and species abundance at various study sectors of the South China Sea had been highlighted and emphasized in this study.

Materials and Methods

Study Area

The study area (Fig. 1) covers an area which extends from the northern tip of Vietnam (21° 0' N; 107° 55' E) to the south west covering the Mekong Delta (9° 0.1' N; 104° 30.5' E) of the South China Sea. The estimated study area is ca 6000 nautical square miles (ca 2000 sq. km) covering the economic exclusive zone (EEZ) of the Vietnam waters of the South China Sea. The sea cruise track followed a zig-zag manner starting from the northern coastal Vietnam waters and ended up at the southern end of the Vietnam waters (facing the Mekong Data) covering a total of 21 sampling stations. The Gulf of Tongking and the Hainan Dao island are situated in the north of the Vietnam waters while the Paracel island and Spratly island to the south of Hainan Dao island. The Mekong river delta is at the southern tip of Vietnam, while the Song Pa river with its river tributaries passing through Hai Phong.

Sampling Method & Preparation

The research survey was carried out during the cruise survey in April/June 1999 covering twenty one stations. Water sampler (twin 10 L sampler) was used to collect water sample from the depth of the maximum chlorophyll layer (MCL). The water sampel was first filtered through the 40 μm mesh-size filtering net; it was again subsequently filtered through a membrane filter paper (0.8 μm mesh-size) with square grid marks on its surface. The samples which had been fixed and preserved in absolute alcohol, were then mounted on (SEM) stubs with double-sided cellotape. The stubs with adhering samples were then coated with an alloy (gold with pelladium) before being observed under the scanning electron microscope (Barber & Haworth, 1981). For each stub, only 5 square grids (one grid having 20 fields of observation; one field measures 32.5 x 25 μm area) were considered whereby the organisms found on the grid were countered. The subsamples or subportions of original sample were preserved in 10% formalin and subsequently examined for species composition and abundance using an inverted microscope (Vollenweider *et al.*, 1974; Tippett, 1970; Shamsudin, 1987, 1993, 1994, 1995; Shamsudin & Shazili, 1991; Shamsudin & Sleigh, 1993, 1995; Shamsudin *et al.*, 1987, 1997). Algal were identified with reference to Okada and McIntyre (1977), Gaardnar and Heindel (1978) and Heimdal and Gaarder (1980, 1981).

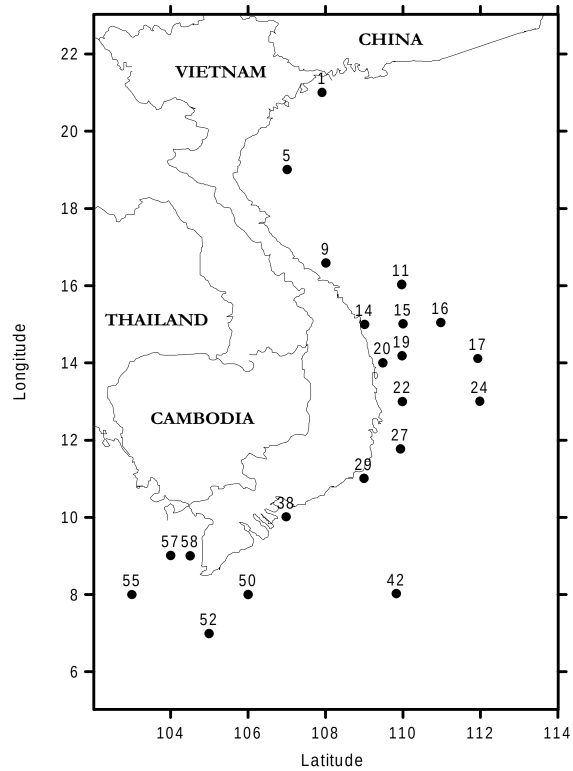

Fig. 1. The map showing the sampling stations in the Vietnam waters of the South China Sea (cruise April-June 1999).

Statistical Analysis

An index of the composition of the plankton community in the aquatic habitat is given by calculating the diversity index (H) and evenness (J) of the community structure using the Shannon-Weiner index (1949). The formula for calculating Shannon-Weiner (diversity) index (H) is:

$$H = P_i \log_2 P_i, \quad \text{Where } P_i = n_i/N$$

n_i = The number of individuals of the i th species
N = The total number of individuals

The diversity index can measure species richness (H) and species evenness (J)

$$J = H/\log_2 S \text{ - (ii)}, \quad S \text{ is the number of species}$$

One way analysis of variance can be implyed when comparisons are made between a number of independent random samples, one sample from each population. All counts must be classified in the same manner, but the number of counts in the various samples can be different (Elliott, 1977). Analysis of variance can be used to assess the relative importance of different sources of variation, e.g. between sites, between dates, etc., but it may be necessary to transform the data before analysis of variance tests are applied.

Coefficients of similarity are simple measures of the extent to which two habitats have species (or individuals) in common (Southwood, 1978). Essentially, such coefficient can be of two types, as given below, and both types reflect the similarity in individuals between the habitats.

(i) Jaccard $Cj = j / (a + b-j)$

(ii) Sorensen $Cs = 2j / (a+b)$

where a, b are the total individuals sampled in habitat a and b respectively, and j is the sum of the lesser values for the species common to both habitats (Southwood, 1978). In habitats where one or few species have high dominance the coefficients under-estimate the contributions of the moderately common species which may be more stable indicators of the characteristic fauna of an area while the rare species have little impacts (Southwood, 1978). It is apparent that Cs is greater than Cj and the inequality reduces as j approaches the magnitude of 1/2 (a+b).

The microplankton can be classified into species assemblages or associations in cluster analysis on species sampled from the nearshore and offshore stations according to their preference on environmental conditions using the Unweighted Pair Group Average (UPGA) Pearson Correlation Iindex (Pielou, 1984; Ludwig & Reyholds, 1988).

Multivariate statistical analyses, performed by the computer program PC – ORD version 2.0 (ter Braak 1988, 1990), were used to identify relationship between the measured environmental variable and the species assemblages. Our calibration model included a total of 50 diatom taxa, using a cut-off criterion of $\geq$1% relative abundance. Because of space constraints and the limitations of inferring ecological preferences for rare taxa, we present here information for only the 40 most abundant diatom taxa (i.e. taxa with a relative abundance $\geq$2%).

Canonical Correspondence Analysis (CCA), using forward selection and Monte Carlo permutation tests, was then used to identify variables which were significant in explaining the variation in the diatom assemblages (ter Braak & Verdonschot 1995). Species data were square root transformed and rare taxa were down-weighted in order to maximize the signal:noise ratio within the data set.

Results

The nanoplankton from 21 sampling stations comprising of 134 taxa consisting predominantly of centric nanodiatom (29 species), pennate (40 species) and dinoflagellate (65 species) was collected from the Vietnam waters of the South China Sea (Appendix). Among the minute plankton collected were three species of centric nanodiatom (*Minidiscus comicus, M. chilensis, M. trioculatus*) and numerous other pennate species (Tables 1.1, 1.2 & 1.3).

The nanodiatom population in the Vietnam waters of the South China Sea toward the south was sparse (1.3×10^3 to 2.4×10^3 L^{-1}) while the Vietnam waters toward the central and south wastern parts were high (5.7×10^3 to 3.9×10^3 L^{-1}) (Fig. 2a). The dominant centric nanodiatom, ranging from 2.4×10^3 to 4.6×10^3 L^{-1} comprised of species of *Thalassiosira, Minidiscus, Chaetoceros, Cyclotella* and *Stephanodiscus*; while the dominant pennate nanodiatom (ranging from 8.9×10^3 to $16.7 \times 10^3 L^1$) comprised of species of *Asterionella*, *Psammodiscus*, *Amphipleura*, *Navicula*, *Deadesmis*, *Fragilaria* and *Nitzschia* (Fig. 2b).

The Diversity H and Evenness J indices were especially high in central Vietnam waters with values ranging from 1.5 – 3.1 and 0.70 to 0.87 respectively (Fig. 2c & d). The *Thalassiosira* species were dominant (ranging from 6.3×10^3 to 10.8×10^3 L^{-1}) in the northern, central and southern Vietnamese waters; while the *Minidiscus* species (ranging from 5.8×10^3 – 8.14×10^3 L^{-1}) were predominant to the north of central Vietnam waters (Fig. 2.1).

The *Chaetoceros* and *Cyclotella* species were less abundant ranging from 1.12×10^3 to 7.2 x

10^3 L^{-1} toward the southern and south eastern portion of the Vietnamese waters. The pennate species of *Asterionella* and *Psammodiscus* were also present in the south of the central Vietnamese waters with values ranging from 4.8 x 10^3 to 7.19 x 10^3 L^{-1}) (Fig. 2.2). Patches of pennate species belonging to genera *Amphipleura, Navicula, Diadesmis* and *Fragilaria* with values ranging from 1.57 x 10^3 to 4.76 x 10^3 L^{-1} were also present (Fig. 2.3). The distribution of the pennate nanodiatom genera of *Nitzschia* (north and south west tips of the Vietnamese waters), *Thalassionema* (central and around Mekong Delta of the Vietnamese waters) and *Fallacia* (south west tip of the Vietnamese waters) had moderate values ranging from 1.02 x 10^3 to 2.84 x 10^3 L^{-1} (Fig. 2.4). The toxic dinoflagellate species of *Pseudo nitzschia* was less predominant (1.02 x 10^3 to 1.42 x 10^3 L^{-1}) in the south of central Vietnamese waters.

Distribution of the nanodinoflagellate genera of *Amphidoma* and *Centrodinium* were widespread, stretching right from the central Vietnamese waters via the south to the south west of the Vietnamese waters with values ranging from 0.81 x 10^3 to 2.38 x 10^3 L^{-1} (Fig. 2.5). Species of *Gonyaulax* and *Paleophalacroma* were also present (0.8 x 10^2 to 9.5 x 10^2 L^{-1}) in offshore Vietnam waters (Fig. 2.5c & d). The other 3 nanodinoflagellate species of *Protoperidinium, Planodinium* and *Scrippsiella* were present in lesser amounts (3.42 x 10^2 to 14.3 x 10^2 L^{-1}) in the central and south western Vietnamese waters; while *Prorocentrum* species were found in considerable amounts (3.42 x 10^2 to 4.78 x 10^2 L^{-1}) in the northern coastal and southwest offshore regions of the Vietnamese waters.

Species Distribution and Density in Vietnamese Waters

The three nanodiatom species of *Minidiscus* (*M. comiscus, M chilensis, M. trioculus*) were centric diatom whose density ranging from 4.08 x 10^3 to 7.34x 10^3 L^{-1}; while the pennate forms consisted of the genera *Navicula, Fragilaria, Diploneis, Pseudo-nitzschia* and *Amphiplaura* including those belonging to the minute species whose size range was between 5-50µm (Tables 1.1 & 1.2). Some of the known *Navicula* species consisted of *Navicula grevileana, N. schonkenii, N. fucicola* and *N. pseudanglica* var. signata (mean density 18.6 x 10^3 L^{-1}); while the *Thalassiosira* species comprised of Thal*assiosira tenera, T. climatosphaera, T. oestrupii* var. *ventrickae* and *T. pacifica* (ranging 4.49 x 10^3 to 9.39 x 10^3 L^{-1}). Among the nanodiatom, 5 genera were new records in the Vietnam waters during the study period.

Asterionella from nearshore had 4 species (2 of them are dominant) with a high total cell count (16749 L^{-1}); while the toxic *Pseudo-nitzschia* species (total cell count of 2859 L^{-1}) had 5 dominant species namely *P. seriata, P. lineata, P. fraudulenta, P. tugula* and *Sabpacifica* with values ranging from 4.08 x 10^2 to 12.2 x 10^2 L^{-1}. The genera of *Thalassiosira, Minidiscus, Chaetoceros, Stephanophyxis, Coscinodiscus* and *Navicula* had numerous species (6 to 17 species) while the others (*Amphipleura, Berkeleya, Raphoneis, Cosmioneis, Luticola, Cymbella*) had only 1 to 2 species.

The mean nanodiatom cell density from nearshore stations was significantly ($p<0.01$) higher than those away from the coast (Figs. 3.1, 3.2 & 3.3, Table 2.1). The cell density of the nearshore, middle shore and offshore zones ranged from 9.3 x 10^3 to 30.2 x 10^3 L^{-1}, 6.9 x 10^3 to 15.9 x 10^3 L^{-1} and 2.04 x 10^3 to 11.0 x 10^3 L^{-1} respectively. The pie chart diagram in percentage abundant of nanodiatom with depth shows that the percentage abundance is highest for the chlorophyll maximum layer (40.6%), followed by subsurface layer (32.6%), sub chlorophyll maximum layer (24%) and finally the thermocline layer (2.7%) (Fig. 3.4). The nanodiatom tend to aggregate at the chlorophyll maximum layer rather than at the other 3 levels namely subsurface, thermocline or sub chlorophyll maximum layer (Fig. 3.5, Table 2.2). The *Thalassiosira* and *Minidiscus* species were well distributed in the 4 depth zones while the other 4 dominant species of *Fragilaria, Cocconeis, Pseudo-nitzschia* and *Navicula* were found commonly in the chlorophyll maximum layer (Table 2.3).

Nanodinoflagellate Abundance

The dinoflagellate consisted of a wide range of species of *Amphidoma, Centrodinium, Gonyaulax, Scrippsiella, Protoperidinium, Palaeophalacroma, Oxytoxum* and *Prorocentrum* ; many of which were in the cyst forms found especially in the cental Vietnam waters (Table 3.1). The Vietnam waters of the South China Sea contained significantly ($p>0.01$) high cell density of *Gonyaulax* sp., *Gymnodinium* sp. and *Amphidoma* ; these species have the potential to form blooms. The presence of the dinoflagellate species of *Protoperidinium* sp. and *Prorocentrum* were detected in considerable amounts in the middle shore of Vietnam waters of the South China Sea. Related genera belonging to Haptophyceae comprising of Prymnesiaceae and Coccolithceae were rarely present in the Vietnam waters during the study period.

The nanodinoflagellate commonly found in the three zones of the Vietnam waters of the South China Sea comprised of 11 genera; among the genera, *Amphidoma*, *Centrodinium* and *Gonyaulax* were frequently sampled (Table 3.1). The offshore Vietnam waters had significantly ($p<0.01$) high nanodinoflagellate cell count when compared to those of the coastal or middle zones. The nanodinoflagellate distribution of the Vietnam waters showed that the highest cell density was at the subchlorophyll maximum layer; while the subsurface layer at the middle zone of the Vietnam waters had the highest cell count (Table 3.2). The nanodinoflagellate genera of *Prorocentrum* and *Gonyaulax* had a wide range of species (8 – 9 species) with cell density values ranging from 800 to 1225 L^{-1} especially at stations 55F and 52F (both offshore) respectively (Table 3.3). *Prorocentrum* comprised of 4 dominant species (*P. gracile, P. micans, P. minimun* and *P. sigmoides*) while *Gonyaulax* had also 4 main species (*G. diagenis, G. polygramme, G. scrippsae, G. polyedro*).

Species Association and Assemblage

The species assemblage in the Vietnam waters of the South China Sea consisted of at least 8 groups comprising of the combined pennate and centric nanodiatom (group A, B, D, E and F) as well as the groups consisting of the only centric nanodiatom member (group C, G and H) (Fig. 4.1, Table 4.1). The all centric nanodiatom member species assemblage comprised of group C (*Mastogloia, Luticola, Cosmioneis*), group G (*Psammodiscus, Nitzschia, Raphoneis, Fragilaria, Amphipleura*) and H (*Navicula, Thalassionema*).

The dendrogram from Fig. 4.2 shows the similarity in species community composition between stations in at least 5 groups (A, B, C, D and E) during the 1999 cruise survey in the Vietnam waters of the South China Sea. The 3 groups comprising of A, B and C were actually coastal zone stations while the other two were mixed stations (coastal and offshore). The species association or assemblage of nanodinoflagellate in the Vietnam waters comprises of 4 groups; namely group A (*Gyrodinium, Centrodinium*), group B (*Palaeophalacroma, Amphidoma*), group C (*Scrippsiella, Gonyaulax*) and group D (*Planodinium, Goniodium*) (Fig. 4.3, Table 4.2).

Canonical Correspondence Analysis

The environmental parameters for the water masses from different zone and depth layer are given in Table 5. The salinity and temperature profile values showed the existence of the thermocline stratified layer in the Vietnam waters of the South China Sea. The PC-ORD statistical program using the Canonical Correspondence Analysis (CCA) is used to show the relationship between the nanoplankton with the environmental physical factors of the water masses. The copper concentration in the Vietnam waters of the South China Sea (especially around the vicinity of the Mekong Delta) ranged from 3.2 to 9.7 nM in the water column (Hungspreugs *et al.*, 1998).

The Canonical Correspondence Analysis (CCA) of algal species assemblage in the Vietnam waters during the April/June 1999 cruise showed that the majority of the species were dependent on specific environmental parameters such as salinity, electrolyte metal concentration (especially Cu), depth and pH (Fig. 3.1, Table 5). The depth and salinity parameters were the strongest variable influencing algal assemblage composition within our sample set of species communities from different water masses. High salinity and depth were characterized by a higher abundance of stenohaline species of *Cymbella, Cosmioneis, Asterionella, Amphora, Psammodiscus* and *Mastogloia*. Lower salinity values favoured species such as *Nitzschia* and *Diploneis*.

The pH value also showed significant ($p>0.05$) influence on certain species association and assemblage. Low pH values favoured association of species of *Diadesmis, Pseudo-nitzschia* and *Fragilaria*; while at higher pH favoured species of *Thalassiosira* and *Minidiscus*. The CCA analysis on the relationship between algal cells in the water masses from different water depth showed that the species such as *Amphora, Psammodictyon* and *Berkeleya* were sensitive to depth and salinity while *Cyclotella* and *Navicula* were sensitive to temperature. *Thalassiosira* and *Minidiscus* species were highly influenced by dissolved oxygen; whereas high pH value favoured the presence of *Minidiscus*.

The CCA analysis on the relationship between nanodinoflagellate in water masses from different depth showed that most species were dependent on two specific parameters namely, salinity and depth (Fig. 3.3). These two parameters were the strongest variable influencing nanodinoflagellate preference, especially species of *Prorocentrum, Peridinium, Scrippsiella, Centrodinium* and *Goniodema*. Other species of *Gonyaulax, Amphidoma* and *Oxytoxum* were dependent on temperature as environmental preference. Dissolved oxygen did not show any strong influence on the presence of dinoflagellate species; however, the influence of pH was even less.

Discussion

Prior to this present survey, a collaborative cruise in the waters of the South China Sea of the Western Philippines was conducted in the postmonsoon (April and May, 1998) periods on board MV SEAFDEC (Shamsudin & Kartini, 1999). Surprising, the most abundant nanoplanktonic Coccolithophorid species comprised of *Emilinia huxleyi, Oolithotus fragilis* and *Gephyrocapsa oceanica* (collectively up to 10^5 L^{-1}) which occurred in sharp subsurface maximum chlorophyll layer down to 40 m depth; however, these species never occur in the Vietnam waters during the study period. The cosmopolitan Coccolithophorid species in the Philippines waters originated from the ocean gyre of the central Pacific ocean; whereas the Vietnam waters are completely block from this gyre by long streaches of islands (eg. Spratly island to the south east and Paracel island in the centre of Vietnam waters) including the Philippines.

The other explanation is probably due to the seasonality occurrence of the *Coccolithophorid* in the seawater (Hallegraeff, 1984). The 4 physical factors influencing the dynamic motion in the sea comprise of the pressure gradient, *Coriolis force*, gravity and friction. The calculated dynamic height of the sea surface can be obtained (usually <1m) when the slope of the sea surface in the ocean gyre circulation is formed due to the geostrophic surface current which has the tendency to balance the pressure gradient. The surface gyre sea water circulation plays an important role in transporting nanoplankton from a given region to the other in the ocean. The sea surface height anomaly from the Topex/Ers-2 analysis (satellite data) can also be used to explain this phemomenon (Snidvongs – personal communication).

The nanoplankton (including the smaller microplanktonic species) from 31 sampling stations during the 1998 cruise consisted of more than 200 taxa comprising predominantly of nanodiatom (>150 species), Dinoflagellata (>30 species) and Prasinophyta (>18 species). However, the present study in the Vietnam waters showed that the nanoplankton comprised of centric and pennate diatoms as well as the nanodinoflagellate. The coccolithophorids in the Australian waters of the South China Sea showed a dominant change from *Emiliania huxleyi* to *Gephyrocapsa oceanica* and a southward transport of many tropical species (eg. *Scyphosphaera apsteinii* and *S. pulichra* (Hallegraeff, 1984).

Among the minute plankton collected during the 1998 cruise of the Philippines waters of the South China Sea, three species of the nanodiatom (*Minidiscus comicus, M. chilensis, M. trioculatus*) and numerous flagellate species were present. The dominant pennate diatom comprised of *Synedra parasitica*, *Fragilaria brevistriate*, *Diploneis crabro* and *Neodenticula* sp., all of which were <20 µm in size. However, the present study in the Vietnam waters shows high density of centric nanodiatom especially *Thalassiosira* and *Minidiscus* species. The central diatom comprised of *Cyclotella striata, C. meneghiniana* and *Stephenopyxis palmeriana* were also encountered.

In both study areas, the genera of *Synedra, Navicula, Fragilaria* and *Thalassiosira* contained a wide range of species; while those of dinoflagellate consisted of a wide range of species of genera *Gyrodinium, Pyrodinium, Gonyaulax, Scrippsiella, Protoperidinium, Protoceratium, Ceratocorys* and *Alexandrium*. The genera of *Protoperidinium, Minidiscus* and *Thalassiossira* had a wide range of species. The total nanoplankton population in the Philippines waters was dense in nearshore regions (especially around Subic and Manila bays) and tend to spread out in concentric semicircle into the open sea. The presence of the dinoflagellate species of *Protoperidinium* and *Alexandrium* were detected in considerable amounts at nearshore and midshore Philippines waters of the South China Sea. However, high density of the nanodinoflagellate species of *Amphidoma* and *Centrodinium* were present in the Vietnam waters.

Semina and Tarkhova (1972) recorded 1000 species of phytoplankton, mainly of diatoms and dinoflagellates in the Pacific Ocean. They also reported that the only other conspicuous marine microplanktonic forms are the spherical green cells belonging to Prasinophyta (*Halosphaera*, *Pterosperma*) and the bundles of filaments of the Cyanophyte genus, *Trichodesmium* (*Oscillatoria*): both of these groups tend to float to the surface, the former buoyed up by oil globules and the latter by gas vacuoles in the cells. The nanoplankton is almost entirely composed of small flagellate cells belonging to the Prymnesiophyta. They possess two flagella with a haptonema. This group now contains the genera of the *Prymnesiales* (= Coccolithophoridaceae) since many of these have been shown to possess a haptonema. Some are delicate and are assually damage beyond recognition or are destroyed by preservatives (formalin, is not an ideal preservative for phytoplankton) and their numerical abundance is rarely determined.

Prymnesiophyta bearing calcareous plates (coccoliths) are more easily damage than the delicate forms bearing organic scales (*Chrysochromulina*), but the latter can make up a considerable amount of the biomass in some seas. It is also interesting to note that the present study did not show that Prasinophyta and Phrymnesiophyta were present in the Vietnam waters of the South China Sea. An increase in the diversity value of the nanoplankton population could be due to an increased number of species or even distribution of individuals per species as described by Gray (1981). In reality, such community organisation is constantly acted on by biological and physical factors in many different ways to produce, perhaps a different organisation in the future as a response to such environmental changes. When a bloom occurs, only a few plankton species will predominate and thus effect or influence the number of species or the even distribution of individual species.

Nanoplankton species tend to occur in groups throughout natural communities and it ought to be possible to distinguish associations of species in the plankton. Observations from some detailed surveys and from the continuous plankton recorded certainly suggest that there are discrete associations. These associations appear to be linked with geographical zones (currents, water masses) rather than with subtle differences in water chemistry. The present cruise survey shows that the bulk of the nanoplankton comprised of nanodiatom, dinoflagellate and flagellate; all of these organisms reach a value close to 150 taxa, many of which are yet to be carefully identified.

The fact that the nanoplankton is small should not lead to its neglect since in many waters it is responsible for more carbon fixation than the more immediately obvious microplankton. On an annual basis 70-80%(total carbon 82-78 meq m-2) was attributable to the nanoplankton. McCarthy, Rowland Taylor & Loftus (1974) found that over a two year study in Chesapeake Bay the nanoplankton (in this case species passing through a 35 mm mesh net) was responsible for 89.6% of the carbon fixation.

In the open ocean, especially in oligotrophic regions, the nanoplankton are often the most abundant organisms (Hulbert, Ryther & Guillard, 1960). Pomeroy (1974) gives a table which shows that over 90% of total fixation is by forms smaller than 60 µm in diameter. It is necessary to measure cells and to calculate cell volumes if more detailed information of the biomass of individual species species is required. The nanoplankton together with the Coccolithophoridaceae were present in significant quantities and many of these organisms are minute having the size range between 5 to 50 µm; these organisms have been shown to contribute >50% in total biomass and productivity in the sea.

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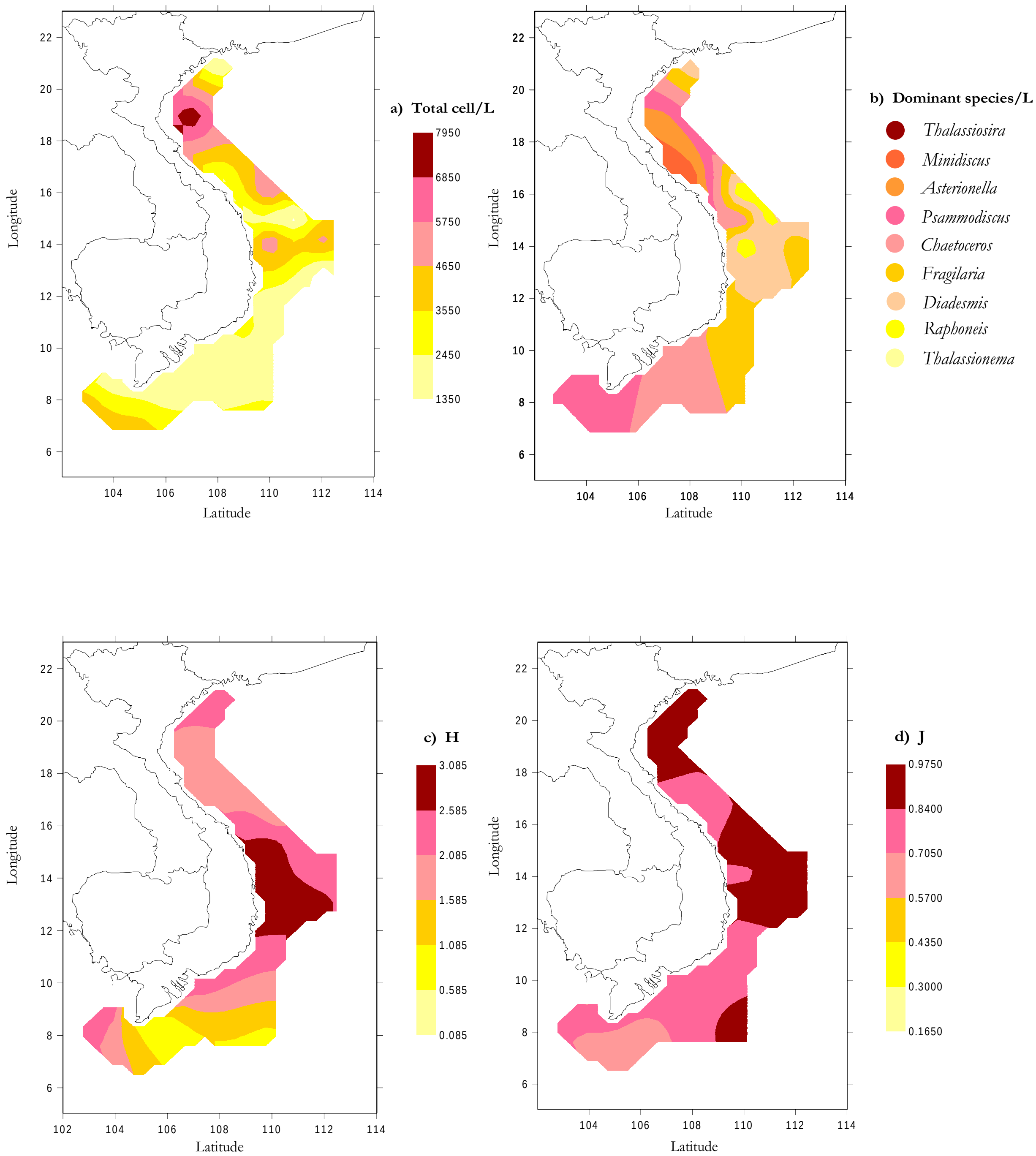

Fig. 2. a) Total cell/L density, b) Dominant nanoplankton species, c) Diversity H index and d) Evenness J index in the Vietnamese waters of the South China Sea (April-June 1999 cruise survey).

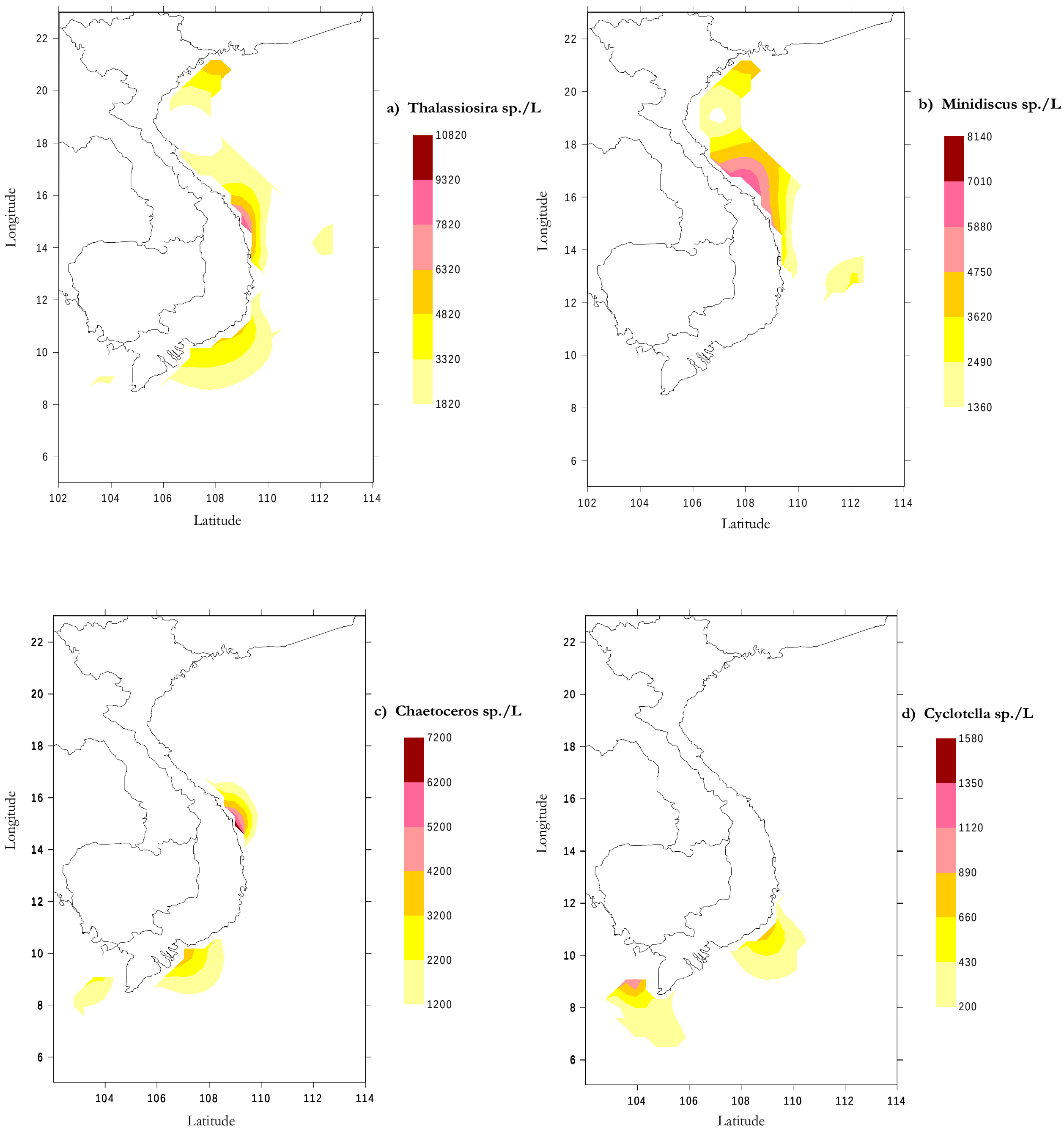

Fig. 2.1. Distribution of the centric nanodiatom genera (a) *Thalassiosira*, (b) *Minidiscus*, (c) *Chaetoceros*and (d) *Cyclotella* in the Vietnamese waters of the South China Sea (April-June 1999 cruise survey).

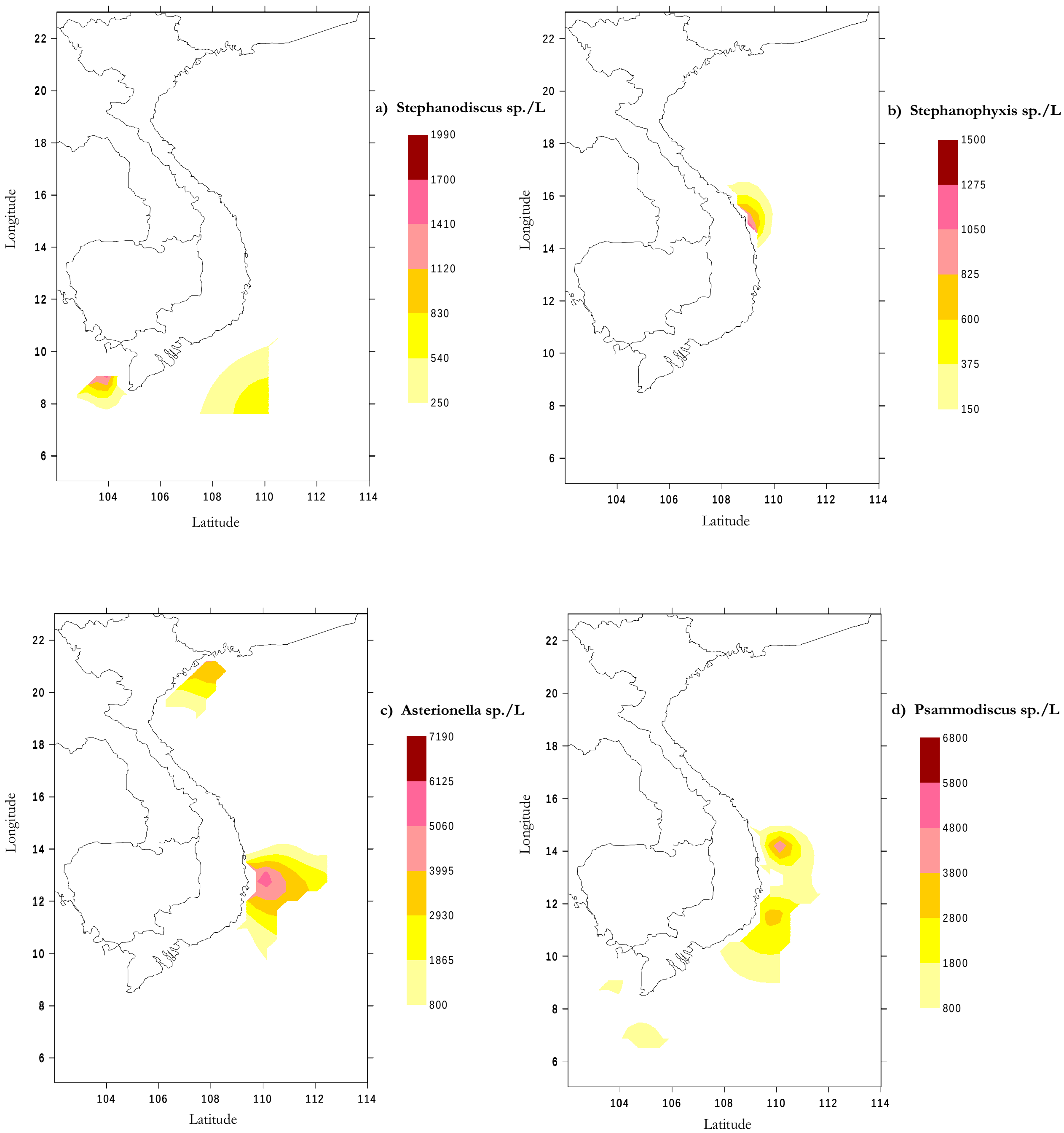

Fig. 2.2. Distribution of the centric nanodiatom genera (a) *Stephanodiscus*, (b) *Stephanophyxis* ; the pennate genera (c) *Asterionella* and (d) *Psammodiscus* in the Vietnamese waters of the South China Sea (April-June 1999 cruise survey).

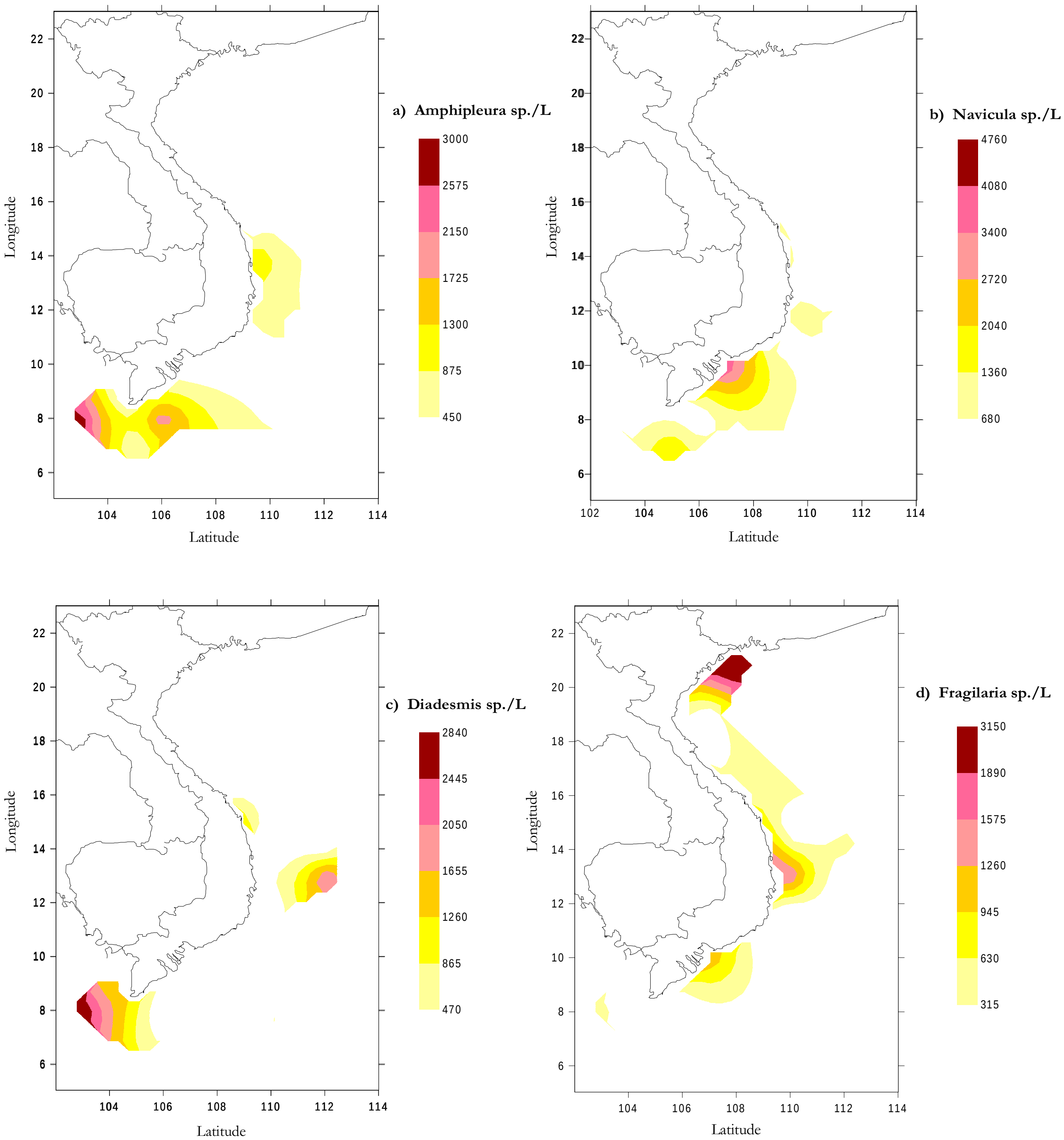

Fig. 2.3. Distribution of the pennate nanodiatom genera (a) *Amphipleura*, (b) *Navicula*, (c) *Diadesmis* and (d) *Fragilaria* in the Vietnamese waters of the South China Sea (April-June 1999 cruise survey).

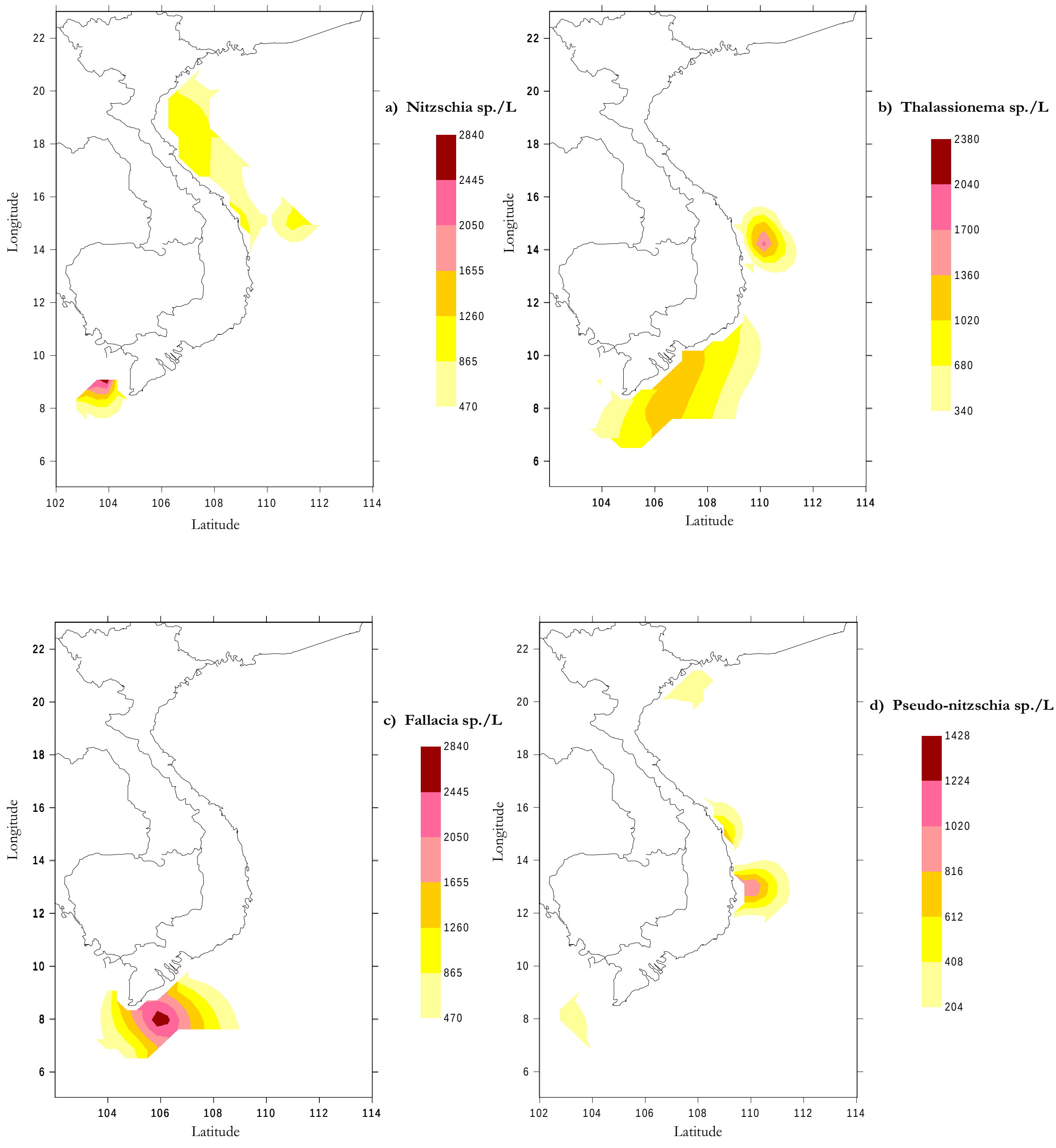

Fig. 2.4. Distribution of the pennate nanodiatom genera (a) *Nitzschia*, (b) *Thalassionema*, (c) *Fallacia* and (d) *Pseudo-nitzschia* in the Vietnam waters of the South China Sea (April /June 1999 cruise survey).

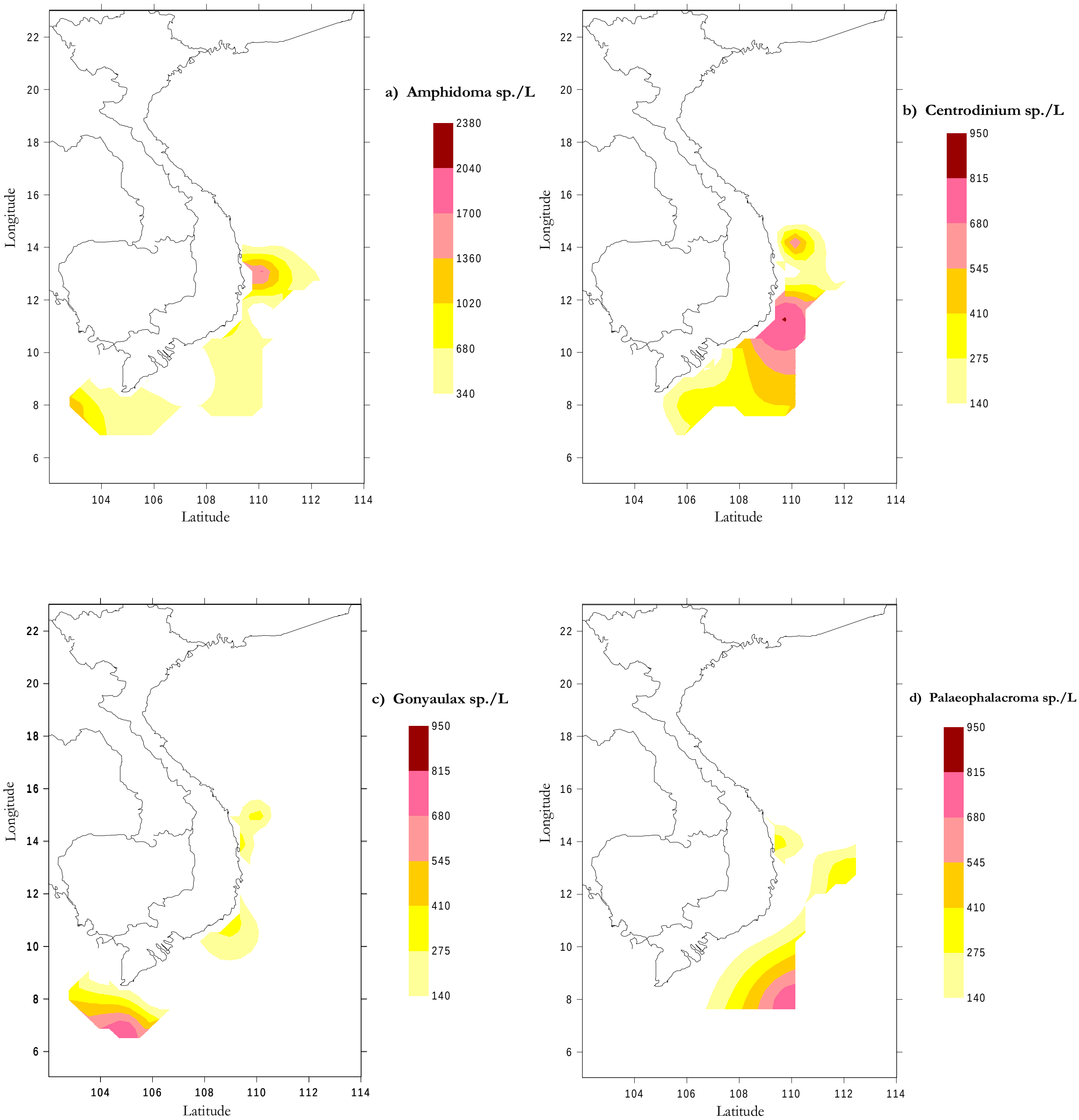

Fig. 2.5. Distribution of the nanodinoflagellate genera (a) *Amphidoma*, (b) *Centrodinium*, (c) *Gonyaulax* and (d) *Palaeophalacroma* in the Vietnamese waters of the South China Sea (April- June 1999 cruise survey).

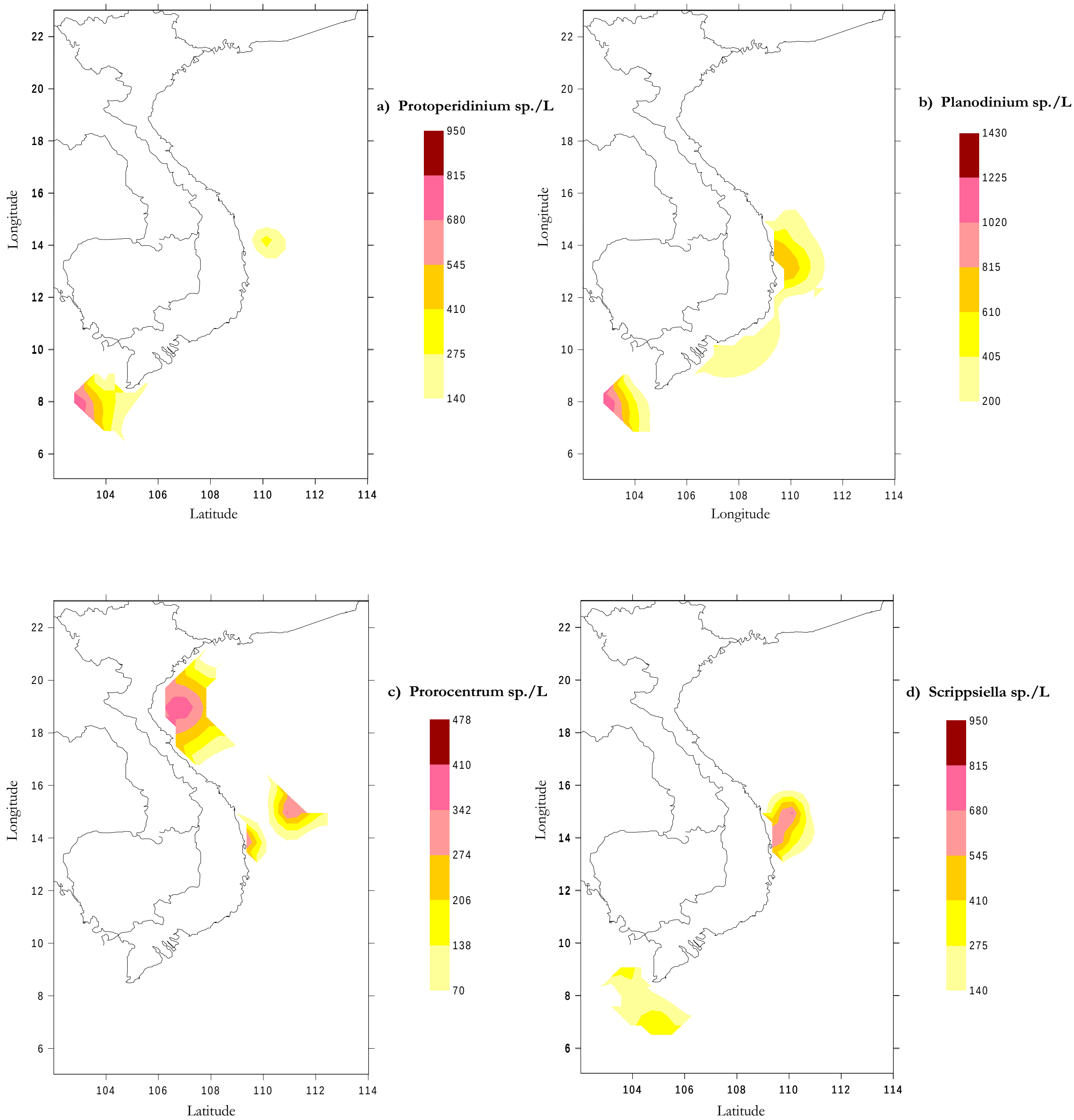

Fig. 2.6. Distribution of the nanodinoflagellate genera (a) *Protoperidinium*, (b) *Planodinium*, (c) *Prorocentrum* and (d) *Scrippsiella* in the Vietnamese waters of the South China Sea (April - June 1999 cruise survey).

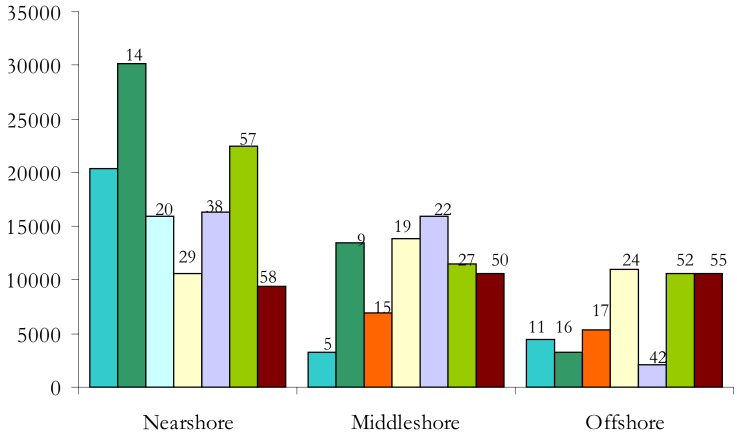

Fig. 3.1. Distribution and abundance of nanodiatom from chlorophyll maximum layer at 3 different zones in the Vietnamese waters (cruise April-June 1999).

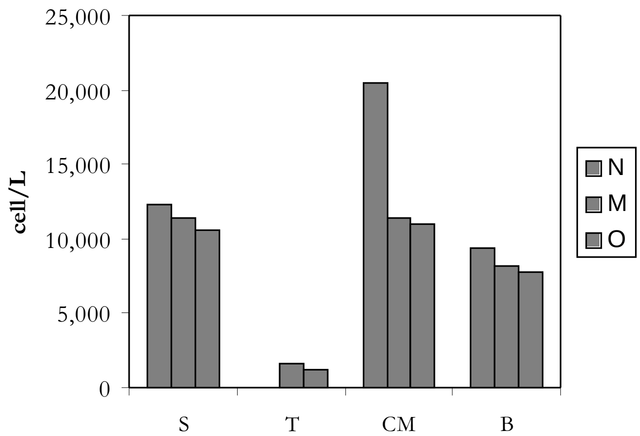

Fig. 3.2. Nanodiatom abundance (L^{-1}) of selected stations from different zones (coastal, middle and offshore) during the April-June 1999 cruise in the Vietnam waters (S – subsurface, T - thermocline, CM – chlorophylla maximum, B – sub chlorophyll maximum layer).

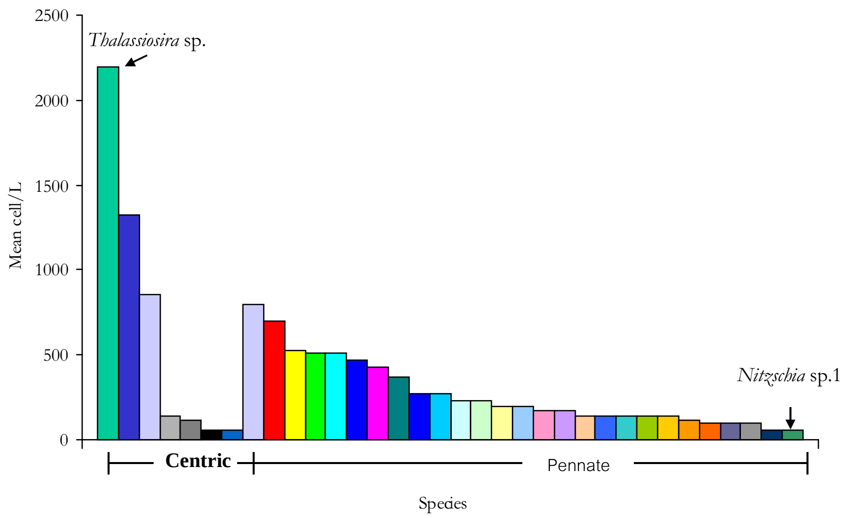

Fig. 3.3. Distribution and abundance of nanodiatom species (centric, pennate) in the Vietnamese waters (cruise April-June 1999).

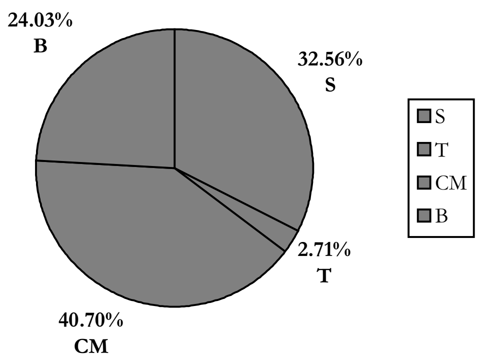

Fig. 3.4. Pie-chart graph in percentage abundance of nanodiatom with depth from selected stations during the April-June 1999 cruise in the Vietnamese waters (S – subsurface, T – thermocline, CM – chlorophylla maximum, B – sub chlorophyll maximum layer).

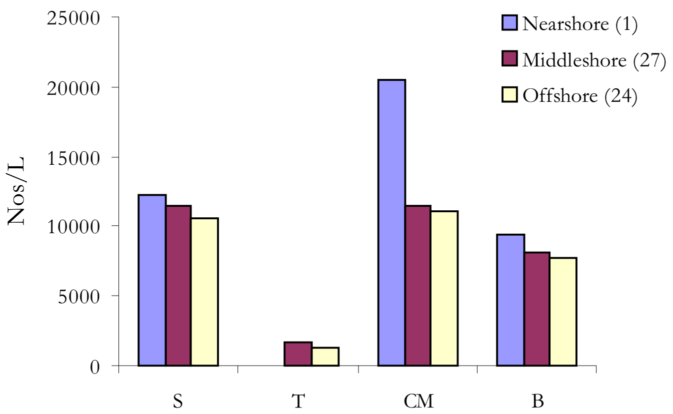

Fig. 3.5. Distribution and abundance of nanodiatom from different depth level (S – sub surface, T – thermocline, CM – chlorophyll maximum layer, B – sub chlorophyll maximum layer) from selected stations (1, 24, 27) in the Vietnamese waters (cruise April-June 1999).

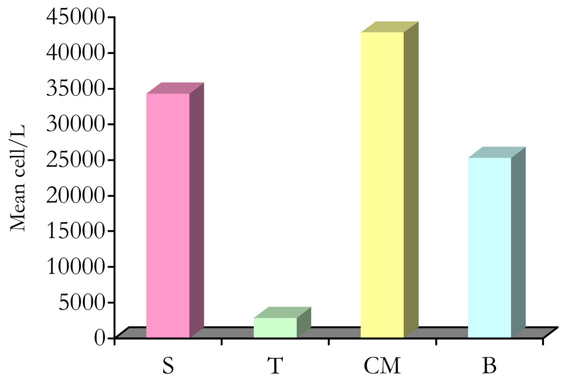

Fig. 3.6. Distribution and abundance of nanodiatom cell from different depth (S – sub surface, T – thermocline, CM – chlorophyll maximum layer, B – sub chlorophyll maximum layer) from selected stations (1, 24, 27) in the Vietnamese waters (cruise April-June 1999).

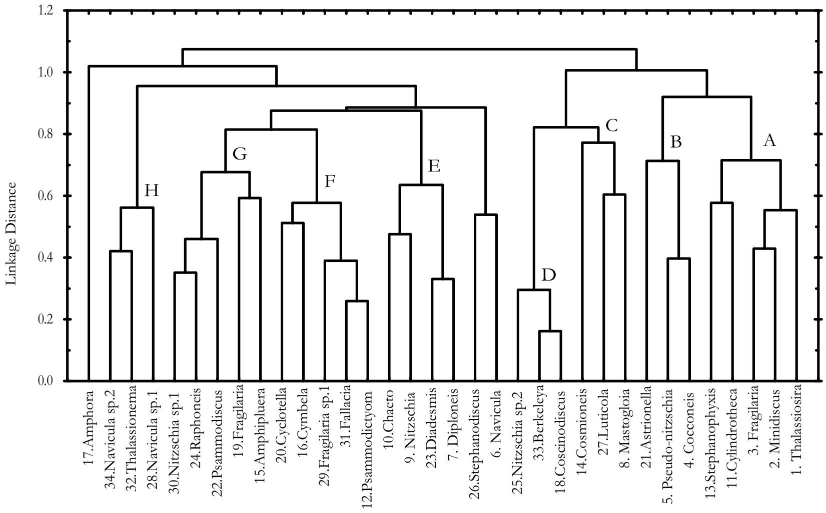

Fig. 4.1. Dendrogram showing nanodiatom species association during the 1999 cruise survey in the Vietnamese waters (cruise April-June 1999).

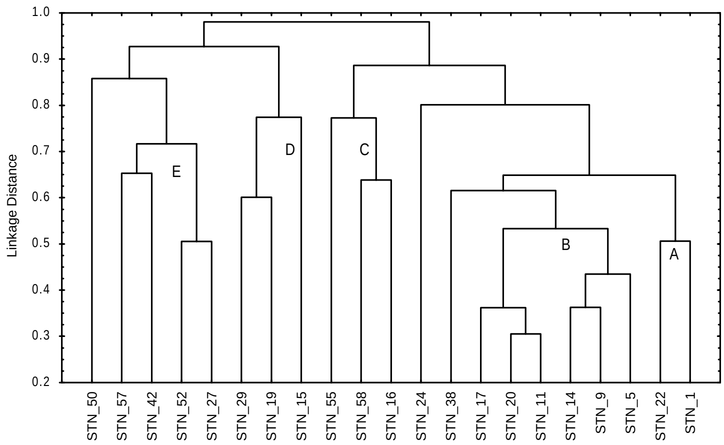

Fig. 4.2. Dendrogram showing similarity between stations in the Vietnamese waters (cruise April - June1999).

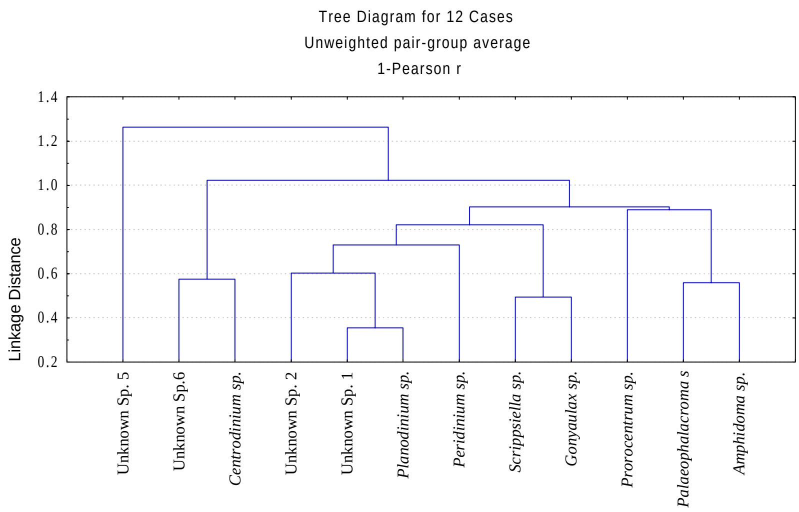

Fig. 4.3. Dendrogram showing nanodinoflagellate species association in Vietnamese waters (cruise April - June 1999).

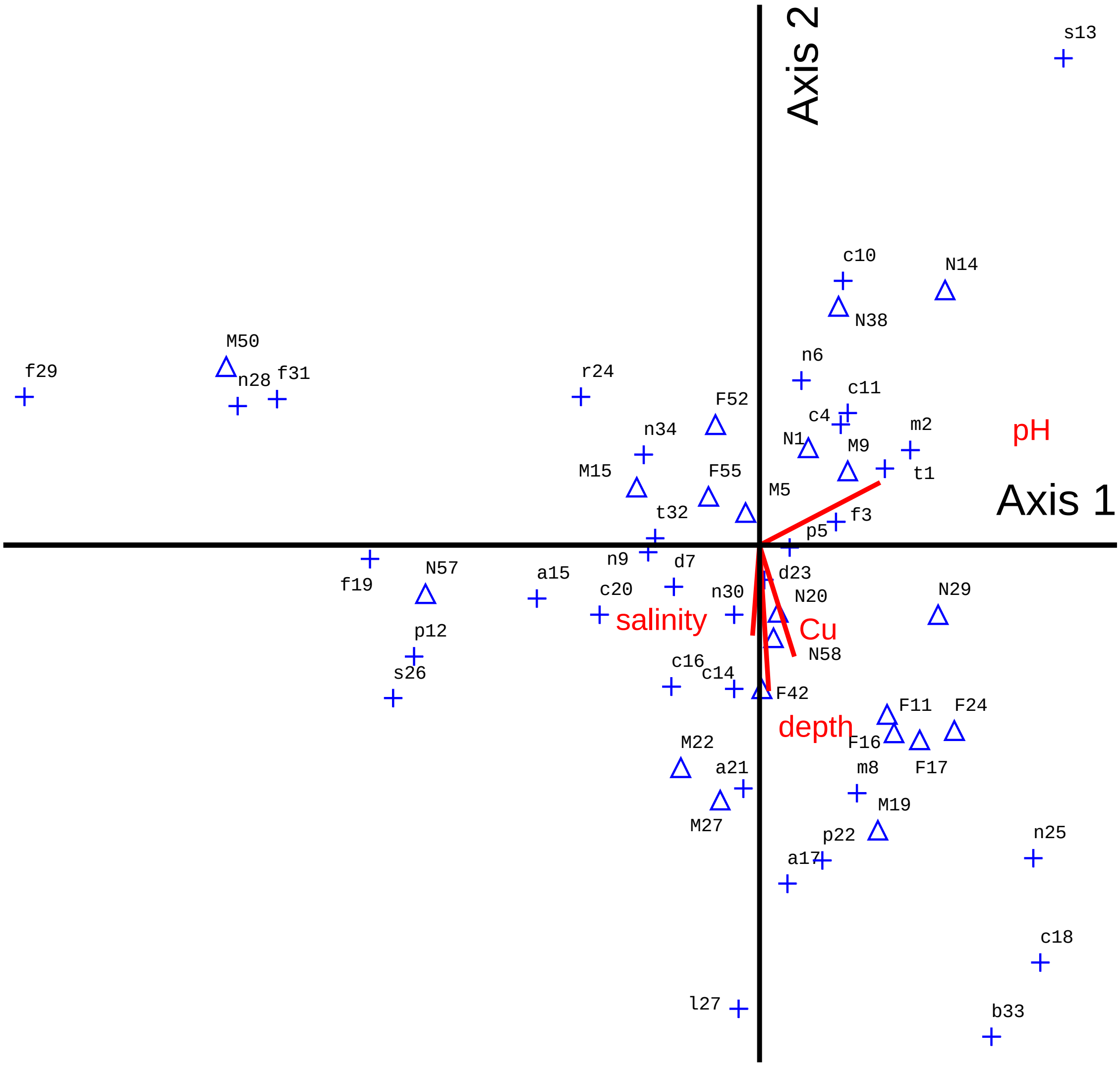

Fig. 5.1. CCA analysis on the relationship between algal cells in water masses from different stations during April/June 1999 cruise in Vietnamese waters (t1 – *Thalassiosira* sp., m2 – *Minidiscus* sp., f3 – *Fragilaria* sp., c4 – *Cocconeis* sp., p5 – *Pseudo-nitzschia* sp., n6 – *Navicula* sp., d7 – *Diploneis* sp., m8 – *Mastogloia* sp., n9 – *Nitzschia* sp., c10 – *Chaetoceros* sp., c11 – *Cylindrotheca* sp., p12 – *Psammodictyon* sp., s13 – *Stephanophyxa* sp., c14 – *Cosmioneis* sp., a15 – *Amphipluera* sp., c16 – *Cymbella* sp., a17 – *Amphora* sp., c18 – *Coscinodiscus* sp., f19 – *Fragilariopsis* sp., c20 – *Cyclotella* sp., a21 – *Asterionella* sp., p22 – *Psammodiscus* sp., d23 – *Diademis* sp., r24 – *Raphoneis* sp., n25 – *Nitzschia* sp. 2, s26 – *Stephanodiscus* sp., l27 – *Luticola* sp., n28 – *Navicula* sp. 1, f29 – *Fragilaria* sp., n30 – *Nitzschia* sp. 1, f31 – *Fallacia* sp., t32 – *Thalassionema* sp., b33 – *Berkeleya* sp., n34 – *Navicula* sp. 2, D – Station, N – Nearshore, M – Middle Shore, F – Offshore/Farshore, Cu – Copper mg/L).

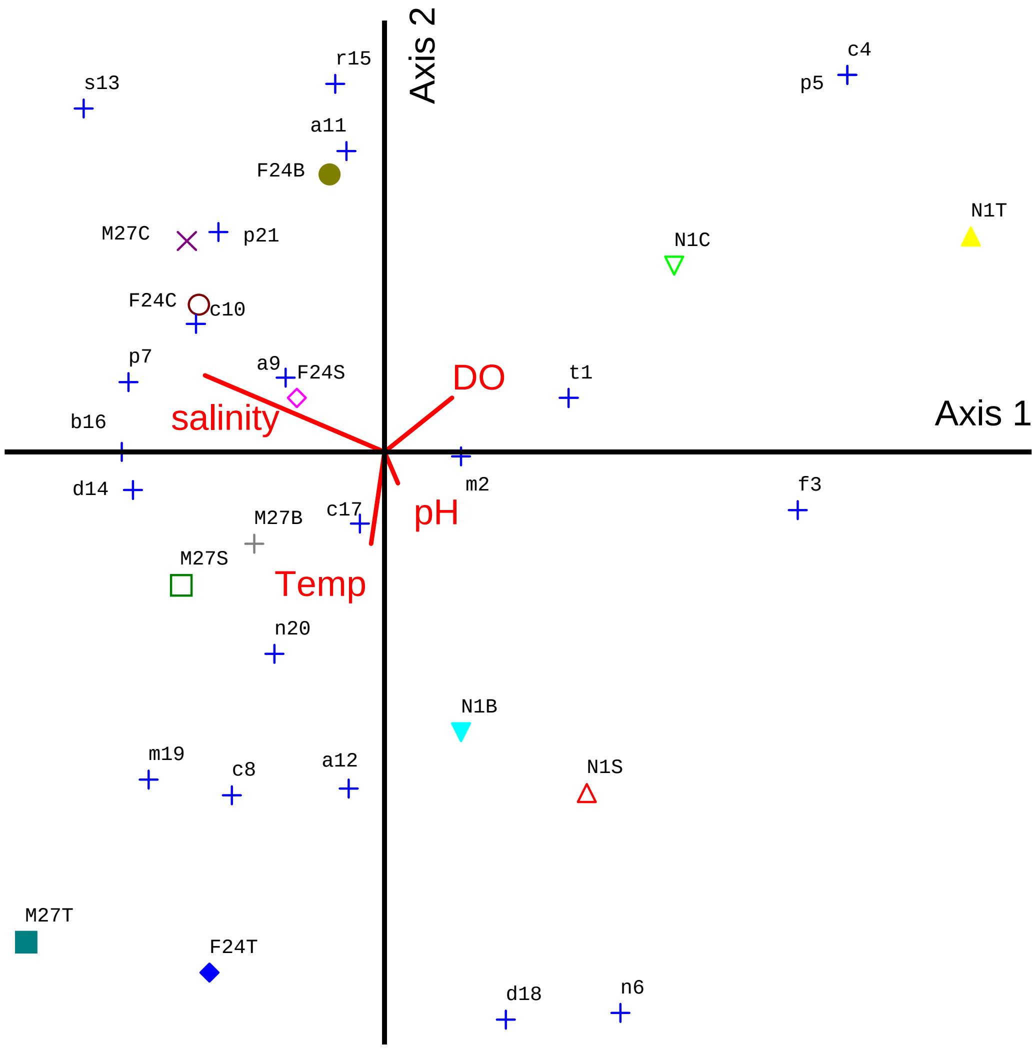

Fig. 5.2. CCA analysis on the relationship between nanodinoflagellate cells in water masses from different depth at selected stations during April/June 1999 cruise in Vietnam waters (N – Nearshore, M – Middle shore, F – Farshore, S – Subsurface, T – Thermocline, CM – Chlorophyll Maximum layer, B – Sub Chlorophyll Maximum layer; D.O – Dissolved Oxygen, t1 – *Thalassiosira* sp., m2 – *Minidiscus* sp., f3 – *Fragilaria* sp. 3, c4 – *Cocconeis* sp., p5 – *Pseudo-nitzschia* sp., n6 – *Navicula* sp., p7 – *Psammodictyon* sp., c8 – *Cosmioneis* sp., a9 – *Amphora* sp., c10 – *Coscinodiscus* sp., a11 – *Asterionella* sp., a12 – *Amphipluera* sp., s13 – *Stephanophyxa* sp., d14 – *Diademis*, r15 – *Raphoneis*, b16 – *Berkeleya*, c17 – *Chaetoceros*, d18 – *Diploneis*, m19 – *Mastogloia*, n20 – *Nitzschia*, p21 - *Psammodiscus*).

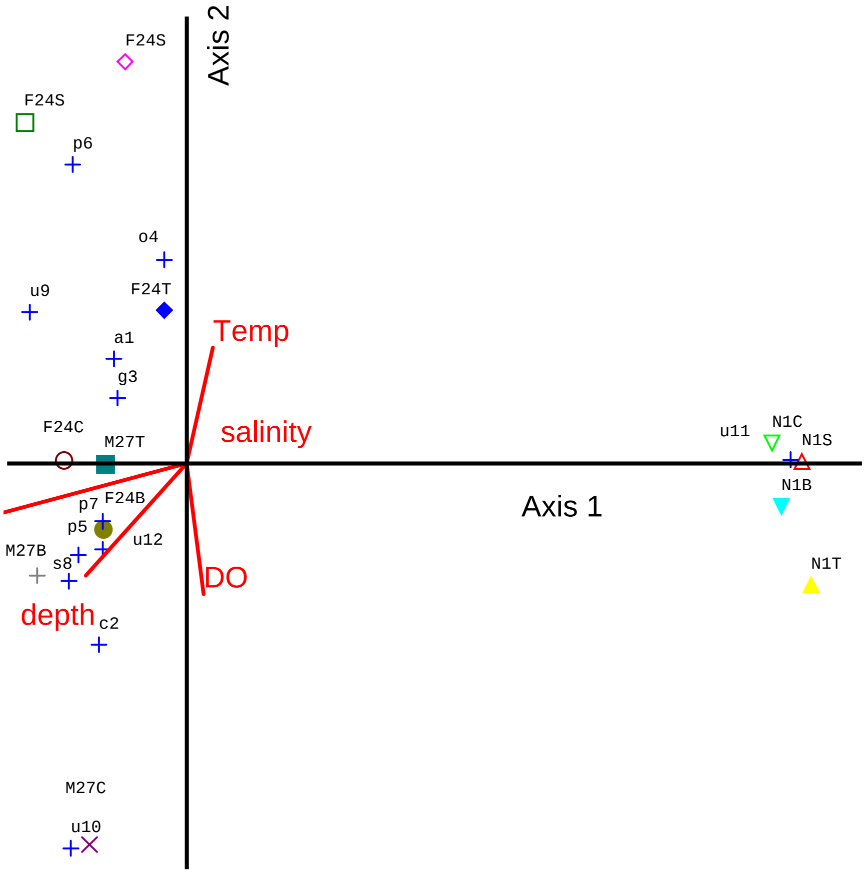

Fig. 5.3. CCA analysis on the relationship between algae cells in water masses from different depths at selected stations during April-June 1999 cruise in Vietnamese waters (a1 – *Amphidoma* sp., c2 – *Centrodinium* sp., g3 – *Gonyaulax* sp., p4 – *Palaeophalacroma* sp., p5 – *Protoperidinium* sp., p6 – *Planodinium* sp., p7 – *Prorocentrum* sp., u1 – *Goniodoma* sp., u2 – *Gyrodinium* sp., u3 – *Gymnodinium* sp., u4 – *Protoceratium* sp., u5 – *Heterodinium* sp., N – Nearshore, M – Middleshore, F – Offshore, D.O – Dissolved Oxygen mg/L).

Table 1.1. Mean and total nanodiatom cell number L^{-1} of the centric and pennate type from Cruise April-June 1999 in Vietnamese waters.

	Centric			Pennate		
	Species	Total (L^{-1})	Mean (L^{-1})	Species	Total (L^{-1})	Mean (L^{-1})
1	*Thalassiosira* sp.	46164	2198	*Asterionella* sp.	16749	797
2	*Minidiscus* sp.	27781	1322	*Psammodiscus* sp.	14707	700
3	*Chaetoceros* sp.	17975	855	*Fragilaria* sp.	9804	466
4	*Cyclotella* sp.	2859	136	*Fragilaria* sp.1	3676	175
5	*Stephanodiscus* sp.	2451	116	*Nitzschia* sp.2	2859	136
6	*Stephanophyxis*	1225	58	*Berkeleya* sp.	2859	136
7	*Coscinodiscus* sp.	1225	58	*Pseudo-nitzschia* sp.	2859	136
8				*Fragilariopsis* sp.	2042	58
9				*Nitzschia* sp.1	1225	58

Table 1.2. Abundance and distribution of centric nanodiatom in the Vietnamese waters of the South China Sea during April - June cruise 1999 (N-nearshore, M-middleshore, F-offshore, H-diversity index, J-evenness index).

Centric Genus	No. of species	Main species	Total cell/ L	Stations	Nos/L	% Abundance	H	J
1. *Thalassiosira*	16	*T. binata* (Fryxell)	46,164	14N	9396	20.8	2.8	0.84
		T. conferta (Hasle)		20N	6128	13.3	2.38	0.85
		T. eccentrica (Ehr) Cleve		1N	5719	12.4	2.37	0.71
		T. alenii (Takano)		29N	5310	12.2	2.55	0.76
		T. curviseriata (Takano)		38N	4491	9.7		
		T. oestrupii (Ostenfeld) Hasle						
		T. tenera (Proschkina-Lavrenko)						
		T. punctigera (Castrare) Hasle						
2. *Minidiscus*	3	*M. comicus* (Tanako)	27,781	9M	7354	26.5	2.03	0.72
		M. chilensin (Rivera et Koch)		14N	5310	19.1	0.8	0.84
		M. trioculatus (Taylor) Hasle		1N	4085	14.7	0.38	0.85
3. *Chaetoceros*	9	*C. didymum* (Ehr.)	17,975	14N	7354	40.9	2.8	0.84
		C. daricum (Cleve)		38N	4085	22.7	2.55	0.76
4. *Cyclotella*	3	*C. striata* (Kutz) Grunow	2,895	57N	1225	42.3	2.47	0.69
		C. meneghiniana (Kutz)		38N	817	28.2	2.55	0.76
		C. cryptica (Reimann)						
5. *Stephanodiscus*	2	*Stephanodiscus* sp. (Ehr.)	2451	57N	1634	66.7	2.47	0.69
6. *Stephanophyxis*	6	*S. nipponica* (Gran & Yando)	1225	14N	225	18.3	2.8	0.84
		S. palmeriana (Grunow)						
		S. turris (Greville)						
7. *Coscinodiscus*	8	*C. asteromphalus* (Ehr)	1225	19M	408	33.3	2.72	0.78
		C. curvatulus (Grunow)						

Table 1.3. Abundance and distribution of pennate nanodiatom in the Vietnamese waters of the South China Sea during April-June cruise (N-nearshore, M-middleshore, F-offshore, H-diversity index, J-evenness index).

Pennate Genus	No. of species	Main species	Total cell/ L	Stations	Nos/L	% Abundance	H	J
Pennate								
1. *Asterionella*	4	*A. japonica* (Cleve)	16,749	1N	4085	24.3	2.38	0.85
		A. notata (Grunow)		22M	6128	36.6	3.08	0.97
2. *Navicula*	8	*N. grevileana* (Henley)	18,621	29N	2042	10.9	2.37	0.71
		N. schonkenii (Hustedt)						
		N. fucicola (Taasen)						
		N. pseudonglica var. *signata* (Hustedt)						
3. *Nitzschia*	4	*N. lavidensis* (W. Smith) Van Heurek	8987	5M	1225	13.6	1.91	0.95
		N. pungans (Grunow)		57N	2859	31.8	2.47	0.69
				14N	1225	13.6	2.8	0.84
4. *Fragilaria*	2	*F. brevistria* (Bory)	9804	16F	1225	12.4	2.16	0.93
		F. opephoraides (Takano)						
		F. striatula (Lyngbye)						
5.*Pseudo-nitzschia*	5	*P. seriata* (Cleve)	2859	22M	1225	42.8	3.08	0.97
		P. lineata (Perag.)		55F	408	14.2	2.34	0.74
		P. fraudulenta (Cleve)		1N	408	14.2	2.38	0.85
		P. tugidula (Fryxell)		14N	817	28.4	2.8	0.84
		P. subpacifica (Hasle)		55F	408		2.34	0.74
6.*Psammodiscus*	2	*Psammodiscus* sp. (Round & Menn)	14707	19M	5719	38.8	2.72	0.78

Table 1.3. (Continued).

Pennate Genus	No. of species	Main species	Total cell/ L	Stations	Nos/L	% Abundance	H	J
Pennate								
1. *Asterionella*	4	*A. japonica* (Cleve)	16,749	1N	4085	24.3	2.38	0.85
		A. notata (Grunow)		22M	6128	36.6	3.08	0.97
2. *Navicula*	8	*N. grevileana* (Henley)	18,621	29N	2042	10.9	2.37	0.71
		N. schonkenii (Hustedt)						
		N. fucicola (Taasen)						
		N. pseudonglica var. *signata* (Hustedt)						
3. *Nitzschia*	4	*N. lavidensis* (W. Smith) Van	8987	5M	1225	13.6	1.91	0.95
		Heurek		57N	2859	31.8	2.47	0.69
		N. pungans (Grunow)		14N	1225	13.6	2.8	0.84
4. *Fragilaria*	2	*F. brevistria* (Bory)	9804	16F	1225	12.4	2.16	0.93
		F. opephoraides (Takano)						
		F. striatula (Lyngbye)						
5. *Pseudo-nitzschia*	5	*P. seriata* (Cleve)	2859	22M	1225	42.8	3.08	0.97
		P. lineata (Perag.)		55F	408	14.2	2.34	0.74
		P. fraudulenta (Cleve)		1N	408	14.2	2.38	0.85
		P. tugidula (Fryxell)		14N	817	28.4	2.8	0.84
		P. subpacifica (Hasle)		55F	408		2.34	0.74
6. *Psammodiscus*	2	*Psammodiscus* sp. (Round & Menn)	14707	19M	5719	38.8	2.72	0.78

Table 2.1. Distribution and abundance of nanodiatom from nearshore, middle shore and offshore in the Vietnamese waters (cruise April-June 1999).

Nearshore		Middle shore		Offshore	
Stations	**Cell/L**	**Stations**	**Cell/L**	**Stations**	**Cell/L**
1	20426	5	3268	11	4493
14	30231	9	13482	16	3268
20	15932	15	6945	17	5310
29	10621	19	13890	24	11030
38	16341	22	15933	42	2042
57	22468	27	11438	52	10621
58	9396	50	10621	55	10621
Total	**125420**	**Total**	**75579**	**Total**	**47389**
Mean	**17917**	**Mean**	**10797**	**Mean**	**6769**

Table 2.2. Distribution and abundance of nanodiatom from different depth cruise in the Vietnamese waters (cruise April-June 1999.)

Stations and Zones	Water Mass Layer			
	Sub-surface	**Thermocline**	**Chlorophyll Max.**	**Sub-chlorophyll Max.**
1 (N)	12256	110	20426	9396
24 (F)	10621	1225	11030	7762
27 (M)	11438	1634	11438	8170
Total	34316	2859	14298	25329
Mean	11438	1540	-	8443

Table 2.3. Nanodiatom dominant species distribution with depth at selected stations during the April-June 1999 cruise in the Vietnamese waters (S-sub surface, T-thermocline, CM-chlorophyll maximum, B-sub chlorophyll maximum,N-nearshore,M-middle,F-offshore, + - present).

	Species	1N				24M				27F			
		S	**T**	**CM**	**B**	**S**	**T**	**CM**	**B**	**S**	**T**	**CM**	**B**
1	*Thalassiosira* sp.	+	+	+	+	+	+	+		+		+	+
2	*Minidiscus* sp.	+		+	+	+		+	+		+		+
3	*Fragilaria* sp.	+		+		+							
4	*Cocconeis* sp.			+									
5	*Pseudo-nitzschia* sp.			+									
6	*Navicula* sp.	+			+	+						+	+

Table 3.1. Distribution and abundance of nanodinoflagellate (L^{-1}) at 3 zones (namely nearshore, middle shore, offshore) in the Vietnamese waters (cruise April-June 1999).

Species	Nearshore	Middle shore	Offshore
1. *Amphidoma*	1634	2450	2450
2. *Centrodinium*	817	2042	408
3. *Gonyaulax*	817	408	1230
4. *Oxytoxum*	408	400	1225
5. *Palaeophalacroma*	408	1634	817
6. *Planodinium*	1634	418	1230
7. *Prorocentrum*	408	12230	400
8. *Scrippsiella*	1225	817	410
9. *Goniodema*	2859	2450	1220
10. *Gyrodinium*	2850	408	2042
11. *Gymnodinium*	-	12560	12250
Total	13075	24512	23695

Table 3.2. Distribution and abundance of nanodinoflagellate (L^{-1}) with depth at selected stations (N-nearshore, M-middleshore, F- offshore) in the Vietnamese waters (cruise April-June 1999 (H-diversity index; J-evenness index).

Species	1N				27M				24F			
	S	T	CM	B	S	T	CM	B	S	T	CM	B
1. *Amphidoma*	-	-	-	-	-	-	-	-	200	500	408	150
2. *Centrodinium*	-	-	-	-	-	-	-	-	50	150	100	1200
3. *Gonyaulax*	10	20	40	5	5	800	700	40	50	800	100	50
4. *Oxytoxum*	-	-	-	-	10	450	100	410	10	400	10	10
5. *Palaeophalacroma*	-	-	-	-	-	-	-	-	200	100	500	1600
6. *Planodinium*	10	20	30	10	1600	400	10	5	900	10	20	800
7. *Prorocentrum*	-	-	-	-	5	405	10	5	10	20	10	800
8. *Scrippsiella*	-	-	-	-	5	5	20	390	10	5	10	400
9. *Goniodema*	1000	50	1000	408	350	10	20	420	40	50	100	1200
10. *Gyrodinium*	-	-	-	-	-	-	812	404	-	-	-	-
11. *Gymnodinium*	-	-	-	-	5	10	30	10	-	-	-	-
Total	1120	90	1070	423	1980	1680	1702	1654	1290	2035	1038	6200
H	0.51	0.43	0.62	0.54	0.72	1.92	0.91	1.22	0.52	0.73	0.51	1.02
J	0.31	0.32	0.45	0.27	0.41	0.52	0.48	0.42	0.34	0.21	0.43	0.62

Table 3.3. The abundance and distribution of nanodinoflagellate in the Vietnamese waters (cruise April - June1999). N- nearshore, M- middleshore, F- offshore, H-diversity index, J-evenness index.

Genus	No. of species	Main species	Total cell/L	Stations	Nos/L	%	H	J
Amphidoma	1	*A. steini* (Schill)	6495	22M	2042	29.4	1.66	0.63
Centrodinium	1	*C. mimeticum* (Balech) Taylor	3268	27M	817	25.0	1.12	0.41
Gonyaulax	9	*G. diagenis* (Koch) *G. polygramme* (Stein) *G. scrippsae* (Kofoid) *G. polyedra* (Stein)	2450	52F	800	32.6	1.96	0.74
Oxytoxum	3	*O. tesselatum* (Stein) *O. milneri* (Murr & Whitt) *O. scolopax* (Stein)	400	22M	200	50.0	1.66	0.63
Palaeophalacroma	1	*P. unicinctum* (Schiller)	1634	42F	408	24.9	1.92	0.72
Planodinium	1	*P. striatum* (Sounder & Dodge)	4493	57N	1220	27.2	1.58	0.64
Prorocentrum	8	*P. gracile* (Shutt) *P. micans* (Ehr) *P. minimun* (Pavilland) *P. sigmoides* (Bohm)	2500	55F	1225	49.0	2.17	0.63
Scrippsiella	5	*S. crystalline* (Lewis) *S. rotunda* (Lewis) *S. trochoides* (Loeblica)	2859	20N	810	28.3	2.72	0.67
Goniodema	2	*G. polyedricum* (Jorgensen) *G. sphaericum* (Murray & Whitting)	4900	42F	810	16.5	1.92	0.72
Gyrodinium	5	*G. aureolum* (Hulburt) *G. dominans* (Hulburt)	27,300	5M	7300	26.7	0.52	0.30
Gymnodinium	5	*G. brufe* (Davis) *G. fungiforme* (Anissinova)	2040	50M	800	39.2	0.52	0.30

Table 4.1. Species assemblage or association of nanodiatom in the Vietnamese waters (April- June 1999 cruise survey).

Group association	Nanodiatom centric	Pennate
A	*Stephyanophyxis* sp. *Minidiscus* sp. *Thalassiosira* sp.	*Cylindrotheca* sp. *Fragilaria* sp.
B	*Navicula* sp.	*Asterionella* sp. *Pseudo-nitzschia* sp. *Cocconeis* sp.
C		*Cosmioneis* sp. *Luticola* sp. *Mastoglaia* sp.
D	*Coscinodiscus* sp.	*Nitzschia* sp. *Berkeleya*
E	*Chaetoceros* sp.	*Nitzschia* sp. *Diadesmis* sp. *Diploneis* sp.
F	*Chaetoceros* sp.	*Cymbella* sp. *Fragilaria* sp. 1 *Fallacia* sp. *Psammodictyon* sp.
G		*Psammodiscus* sp. *Nitzschia* sp.1 *Raphoneis* sp. *Fragilaria* sp. *Amphipluera* sp.
H		*Navicula* sp. *Thalasionema* sp.

Table 4.2. Species assemblage or association of nanodinoflagellate in the Vietnamese waters (cruise April - June 1999).

Group	Species association
A	*Gyrodinium, Centrodinium*
B	*Palaeophalacroma, Amphidoma*
C	*Scrippsiella, Gonyaulax*
D	*Scrippsiella, Gonyaulax*
E	*Planodinium, Goniodium*

Table 5. The mean values of various environmental parameters of water masses in the Vietnamese waters (cruise April- June 1999) .
S- sub surface, T-thermocline, CM-chlorophyll maximum layer depth(m), B - sub chlorophyll maximum layer, DO-dissolved oxygen mg/L

Parameter	Depth Level (m)	Nearshore	Middleshore	Offshore
pH	S	8.190	8.247	8.265
	T	8.192	8.272	8.270
	CM	8.194	8.233	8.148
	B	8.178	8.100	8.036
D.O. (mg/L)	S	4.415	3.798	3.733
	T	4.420	7.046	3.809
	CM	4.470	4.471	4.457
	B	4.664	4.564	4.850
Temp. (°C)	S	24.03	28.04	29.40
	T	23.76	27.37	29.39
	CM	23.47	22.14	21.29
	B	23.22	20.96	17.22
Salinity ppt.	S	31.64	33.85	33.30
	T	31.66	33.84	33.31
	CM	31.69	34.41	34.44
	B	31.82	34.54	34.62
CM depth (m)	S	3.5	5.5	5.5
	T	10	20	20
	CM	22	75	65
	B	30	125	125
Actual depth (m)		34	1734	3332

Appendix

Division : BACILLARIOPHYTA

Class : COSCINODISCOPHYCEAE

Subclass : THALASSIOSIROPHYCIDAE

Order : THALASSIORALES (Glezer & Makarova, 1986)
Family : Thalassiosiraceae (Lebour, 1930)
Genus : Thalassiosira
Thalassiosira sp. (P.T. Cleve, 1973)
T. alenii (Takano) 8μ
T. binata (Fryxell) 4μ
T. conferta (Hasle) 3.5μ
T. curviseriata (Takano) 7.8μ
T. diporocyclus (Hasle) 12μ
T. eccentrica (Ehr.) Cleve 10μ
T. guillardii (Hasle) 4μ
T. hyalina (Grunow) Gran 15μ
T. laudiana (Fryxell) 13μ
T. mala (Takano) 3μ
T. minima (Gaarder) 3.5μ
T. orstrupii (Ostenfeld) Hasle 5μ
T. punctigera (Castracare) Hasle 10μ
T. tealata (Takano) 6μ
T. tenera (Proschkina-Lavrenko) 10μ
T. weissflagii (Grunow) Fryxell et Hasle 5μ

Genus : Minidiscus
Minidiscus sp. (G.R. Hasle, 1973)
M. chilensis (Riversa et Koch)
M. comicus (Takano)
M. trioculatus (Taylor, Hasle)

Family : Stephanodiscaceae (Glezer & Makarova, 1986)
Genus : Cyclotella
Cyclotella sp. (F.T. Kutzing ex A. de Brebosson)
C. cryptica (Reimann) 5μ
C. meneghiniana (Kutz) 10μ
C. striata (Kutz) Grunow 10μ

Genus : Stephanodiscus
Stephanodiscus sp.
(C.G. Ehrenberg, 1845)

Subclass : COSCINODISLOPHYCIDAE

Order : MELOSIRALES (Crawford, ord. Nov)
Family : Stephynopyxidacea (Nikolaev)
Genus : Stephynopyxis
Stephynopyxis sp.
(C.G. Ehrenberg)

Order : COSCINODISCALES (Round & Crawford ord. Nov.)
Family : Coscinodiscaceae (Kutzing, 1844)
Genus : Coscinodiscus
Coscinodiscus sp.
(C.G. Ehrenberg)

Subclass : CHAETOCEROTOPHYCIDAE

Order : CHAETOCEROTALES (Round & Crawford ord. Nov.)
Family : Chaetocerotaceae (Rafs in Pritchard, 1861)
Genus : Chaetoceros
Chaetocceros sp. (C.G. Ehrenberg)
C. costatum (Pavillard) 12μ
C. danicum (Cleve) 8μ
C. debile (Cleve) 12μ
C. decipiens (Cleve) 10μ
C. didymum (Ehr.) 10μ
C. muelleri (Lemmermann) 5μ
C. pseudocurvisetum (Mangin) 15μ
C. salsugineum (Takano) 2μ
C. sociale (Lauder) 4μ

Family : Nitzschiaceae
Genus : Nitzschia
Species : *N. levidensis* (W. Smith) Van Heurck
N. martiana (Agardh) Van Heurck
N. pungens (Grunow)
N. tenuiarcuata (Takano)

Genus : Pseudo-nitzschia
Species : *P. multistriata*

Genus : *Amphora*
Species : *A. bigibba* (Grunow) 10μ
A. coffeaeformis (Agardh) Kutzing

Genus : *Berkeleya*
Species : *B. fragilis* (Greville) 10µ
B. rutilan (Grunow) 18µ

Genus : *Caloneis*
Species : *C. brevis* (Gregory) Cleve 30µ

Genus : *Fallacia*
Species : *F. pygmaen* (Kutz) Stickce et Mann 20µ

Genus : *Lauderia*
Species : *L. annulata* (Cleve) 26µ

Class : FRAGILARIOPHYCEAE

Subclass : FRAGILARIOPHYCIDAE

Order : FRAGILARIALES (Silva, 1962 sensu emend.)
Family : Fragilariaceae (Greville, 1833)
Genus : Fragilaria
Species : *Fragilaria* sp. (A.H. Lyngbye, 1819)
F. opephoroides (Takano) 2.5µ
F. striatula (Lyngbye) 4µ
Genus : Asterionella
Asterionella sp. (A.H. Lyngbye, 1850)

Order : RHAPHONEIDALES (Round, ord. nov.)
Family : Rhaphoneidaceae (Forti, 1912)
Genus : Raphoneis
Raphoneis sp. (C.G. Ehrenberg, 1844)

Family : Psammodiscaceae (Round & Mann, fam. nov.)
Genus : Psammodiscus
Psammodiscus sp. (F.E. Round & D.G. Menn)

Order : THALASSIONEMATALES (Round, ord. nov)
Family : Thalassionemataceae (Round, fam. nov.)
Genus : Thalassionema
Thalassionema sp. (A. Grunow ex F. Hustedt, 1932)

Subclass : BACILLARIOPHYCIDAE

Order : MASTOGLOIALES (D.G. Mann, ord. nov.)
Family : Mastogloiales (D.G. Mann, ord. nov.)
Genus : Mastogloia
Mastogloia sp. (G.H.K. Thwaites ex W. Smith, 1856)

Family : Cocconeidaceae (Kutzing, 1844)
Genus : Cocconeis
Cocconeis sp. (C.G. Ehrenberg, 1837)
Species : *C. placentula* (Ehr.) var euglypta (Ehr.) Cleve 10µ
C. stauroneiformis (W. Smith) Okuna

Order : NAVICULALES (Bessey, 1907 sensu emend)
Family : Berkeleyaceae
Genus : Berkeleya
Berkeleya sp. (R.K. Greville, 1827)

Genus : Navicula
Species : *N. fucicola* (Taasen) 5µ
N. grevilleana (Hendey) 10µ
N. pseudonglica var *signata* (Hustedt)
N. schonkenii (Hustedt) 10µ

Family : Cymbellaceae (Greville, 1833)
Genus : Cymbellaya
Cymbella sp. (C. Agardh, 1830)

Division : DINOPHYTA

Order : Dinoflagellate
Family : Prorocentridae
Genus : Prorocentrum
Species : *P. micans* (Ehrenberg) 2.0µ

Family : Peridiniidae
Genus : Amphidoma
Species : *A. steini* (Schill)

Genus : Gonyaulax
Species : *G. polyedra* (Stein)
G. polygramma (Stein)

Genus : Goniodoma
Species : *G. polyedricum* (Pouchet) Stein
G. sphaericum (Murr, Whitt) 35µ

Genus : Gymnodinium
Species : *G. maguelonnense* (Biecheler)
G. gracile (Berg)

Genus : Gyrodinium
Species : *G. glaucum* (Labour)

Genus : Oxytoxum
Species : *O. tesselatum* (Stein)
O. milneri (Murr & Whitt)
O. scolopax (Stein)

Genus : Peridinium
Species : *P. breve* (Paulsen)
P. lenticula (Bergh)
P. paulseni (Pavillard)
P. pellucidum (Lebour)
P. steini (Jorg)

Genus : Centrodinium
Species : *C. mimeticum* (Balech) Taylor

Order : Prorocentrales
Family : Prorocentraceae
Genus : Prorocentum
Species : *P. balticum* (Lohmann) Loeblich
P. compressum (Bailey) Abe ex Dodge
P. obtusidens (Schiller)
P. gracile (Schutt)
P. micans (Ehrenberg)
P. minimun (Pavillard) Schiller
P. sigmoides (Bohm)
P. triestinum (Schiller)

Family : Cladopyxidaceae
Genus : Palaeophalacroma
Species : *P. unicinctum* (Schiller)

Family : Gonyaulacaceae
Genus : Gonyaulax
Species : *G. diegenis* (Kofoid)
G. digitale (Pouchet) Kofoid
G. milneri (Murray et Whitting) Kofoid
G. polygramme (Stein)
G. scrippsae (Kofoid)
G. spinifera (Claparede et Lachmann) Diesing)
G. turbynei (Murray et Whitting)
G. verior (Sournia)
G. polyedra (Stein)

Family : Amphidiniopsidaceae
Genus : Planodinium
Species : *P. striatum* (Sounder & Dodge)

Order : Peridiniales
Genus : Scrippsiella
Species : *S. Crystallina* (Lewis)
S. precaria (Moutesor et Zingore)
S. rotunda (Lewis)
S. spinifera (Honsell & Cabrini)
S. trochoidea (Stein) Loeblich

Family : Triadiniaceae
Genus : Goniodoma
Species : *G. polyedricum* (Pouchet) Jorgensen
G. sphaericum (Murray et Whitting)

Order : Gymnodiniales
Family : Gymnodiniaceae

Genus : Gymnodinium
Species : *G. breve* (Davis) 15m
G. fungiforme (Anissinova) 8 m
G. mikimotoi (Miyoke et Kominami ex Oda) 14m
G. sanguineum (Hirasaka) 30m
G. striatissium (Hulburt) 35m

Genus : Gyrodinium
Species : *G. aureolum* (Hulburt) 20m
G. dominans (Hulburt) 10m
G. falcatum (Kofoid et Swezy) 25m
G. instriatum (Freudenthal et Leu) 30m
G. spirale (Bergh) Kofoid et Swezy) 20m

Genus : Protoperidinium
Species : *P. ventricum* (Abe) 30m
P. thulesense (Balech) 30m
P. steinii (Jorgensen) 22m
P. pyriforme (Paulsen) Balech 30m
P. punctulatum (Paulsen) 30m
P. pellucidum (Bergh) 30m
P. ovum (Schiller) Balech 30m
P. mite (Pavillerd) Balech
P. minutum (Kofoid) Loeblich 20m
P. divaricatum (Meunier) Parke et Dodge 30m
P. diabohes (Cleve) Balech 30m
P. bipes (Paulsen) 17m
P. avellana (Meuner) 30m