Microplankton (Including Dinoflagellate And Foraminifera) in the South China Sea, Area I : Gulf of Thailand and Peninsular Malaysia

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ABSTRACT

Joint collaborative research surveys in the Gulf of Thailand and the South China Sea around the east coast of Peninsular Malaysia during the pre northeast monsoon (4 September - 4 October, 1995) and the post northeast monsoon (24 April - 17 May, 1996) periods were carried out on board the MV SEAFDEC. The microplankton from the sampling stations consisted of more than 205 taxa consisting predominantly of blue green algae (2 species), diatoms (> 120 species), dinoflagellates (> 80 species) and microzooplankton (> 30 groups). The dominant diatom species comprised of *Chaetoceros lorenzianum,C. coastatum, Thalassionema frauenfeldii, Skeletonema costatum, Pleurosigma elongatum, Bacteriastrum comosun, Bacillaria paxillifera, Coscinodiscus jonesianus* and *Rhizosolenia calcar-avis*. The genera *Chaetoceros, Rhizosolenia, Coscinodiscus, Bacteriastrum* and *Ceratium* were found to contain a wide range of species. *Skeletonema* bloom (1.12 x $10^6/m^3$; 47% of the total cell count) occurred around the Johore waters of the South China Sea. Dinoflagellate was also present during the premonsoon period, especially in offshore waters of the Gulf of Thailand and Terengganu nearshore waters of the South China Sea. The microzooplankton consisted of more than 30 species dominated by copepod nauplii while the foraminifera consisted mainly of the *Globigerina* species. The diversity index (H) and evenness index (J) values were usually high at stations near to the coast.

Key words: Plankton, Tropic, Northeast Monsoon, Dinoflagellate, Algae, South China Sea.

Introduction

This study is complementary to the other related oceanographic data and fishery resource studies being conducted on joint collaborative research surveys in the Gulf of Thailand and the South China Sea adjoining the east coast of peninsular Malaysia in 1995/96. The aim of this survey is to compare the distribution, composition, species abundance and their contribution to production processes at various study sectors of the South China Sea during the pre and post northeast monsoon seasons. Studies on microplankton (Shamsudin 1987, Shamsudin & Baker 1987, Shamsudin *et al.* 1987, Chua & Chong 1973) 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.

Published works on microplankton, especially diatoms, blue greens, dinoflagellates and other related organisms of the Gulf of Thailand and Malaysian waters in the South China Sea are scanty. Qualitative studies of plankton in 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 species composition, distribution and abundance of microplankton in such waters had been lacking. Studies by Shamsudin *et al.* (1984) in the South China Sea around coasts of Johore, Terengganu and Kelantan found the majority of the phytoplankton found were diatoms which comprised of *Bacteriastrum, Chaetoceros, Rhizosolenia* and *Pleurosigma*. Studies by Chua and Chong (1973) in the Malacca Straits showed that the distribution and abundance of pelagic species especially the small tuna (*Euthynnus affinis*), chub makerel (*Rastrelliger* sp.) and anchovies (*Stolephorus* sp.) were related to the density of phytoplankton.

In the present study the composition of the microplankton community has been analysed during the pre and postmonsoon periods in 1995/96 in the Gulf of Thailand and the South China Sea around the east coast of peninsular Malaysia. The distribution, composition and species abundance at various study sectors of the South China Sea during the two seasons were determined.

Methods

Study Area

The study area covered an area which extends from the Gulf of Thailand in the North east (Lat. 12° 31.4 E; Long. 100° 10.5'N) to the southern tip of peninsular Malaysia covering the Johore waters (1° 37.4'E; 105° 12'2 N) of the South China Sea (Fig. 1). The estimated study area is ca 15910 nautical square miles (ca 51600 sq. km) covering the economic exclusive zone (EEZ) of Thailand and Malaysia seas of the South China Sea. The cruise track followed a zig-zag manner starting from the northern tip of the Gulf of Thailand and ended up at the southern tip of Johore waters covering a total of 80 sampling stations.

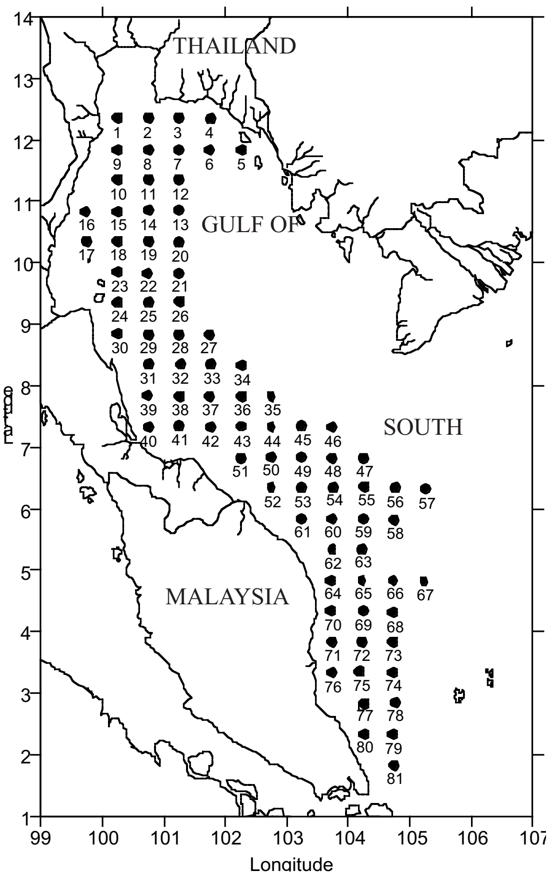

Fig. 1. Map showing various sampling stations in the Gulf of Thailand and the South China around the east coast of Peninsular Malaysia.

Sampling Method & Preparation

The research survey were carried out at eighty stations in October 1996 and June 1997 during the surveys. A vertical plankton net (mesh size 56 ?m, dia. 45 cm, length 92 cm) was hauled at a speed of 1 m/s from 40 m (twice the depth of the 1% surface illumination) to the surface. Samples at various depths using Van Dorn water sampler (20 litres) were also taken to quantify the microplankton population which also include some of the microzooplankton. This was to compensate the error which might arise from plankton escaping the net. The samples were preserved in 10% formalin. The microplankton fractions of the samples were examined for species composition and abundance.

The microplankton cells were routinely examined with a Nikon microscope using a x 10 eyepiece and a x 40 bright field objective. Difficult specimens were examined under a x 100 oil immersion objective. Where it was necessary for detailed identification, samples were treated by boiling and washing in 10% HCI (Tippett, 1970) to clean diatom frustules in order to show up their ultra fine structure for identification purposes, employing the scanning electron microscope (SEM) technique. 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). Microplankton were identified with reference to Palmer & Keely (1900), Cleve (1901, 1904), Gran (1912), Pascher (1914, 1915 & 1925), Hustedt (1930), Sewell (1933), Handey (1933, 1964), Fritsch (1935), Cummins & Mulryan (1937), Cupp (1943), Cleve-Euler (1944), Crossby & Wood (1959), Winstead (1961), Banse (1964), Patrick & Reimer (1968), Shirota (1966), Newell & Newell (1973), Taylor (1976), Taylor & Seliger (1979) and Barber & Haworth (1981).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 (1949) index. The formula for calculating Shannon-Wiener (diversity) index (H) is :

$$\mathbf{H = P_i \log_2 P_i},$$

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

Statistical Analysis

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. One way analysis of variance can be employed 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).

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 index (Pielou, 1984; Ludwig & Reyholds, 1988).

Results

The microplankton from the sampling stations during the pre and post monsoon survey cruises consisted of more than 205 taxa consisting predominantly of blue green algae (2 species), diatom (> 120 species) and dinoflagellates (> 80 species) (Tables 1 & 2). One species of blue green (*Trichodesmium erythraeum*) and 12 species of diatom were dominant. The dominant diatom species comprised of *Chaetoceros lorenzianum, C. compressum, C. coastatum, C. pseudocurvisetum, C. didynum, Thalassionema* (*Thalassiothrix* ?) *frauenfeldii, Skeletonema costatum, Pleurosigma elongatum, Bacteriastrum comosun, Bacallaria paxillifera, Coscinodiscus jonesianus* and *Rhizosolenia calcar-avis*; while those of dinoflagellates consisted of *Ceratium fusus, C. pentagonum, C. arietinum, Protoperidinium* sp., *Protoceratium* sp., *Ceratocorys* sp. and *Alexandrium* sp.(Table 3 and 4). The genera *Chaetoceros, Rhizosolenia, Coscinodiscus, Bacteriastrum* and *Ceratium* were found to contain a wide range of species. The total microplankton densities ranged from 11.2 to 85.7 x 10^6 cells/m^3 and from 0.24 to 1.76 x 10^6 cells/m^3 during the premonsoon (more stable water column) and postmonsoon periods (less stable mixing water column) respectively (Fig. 1.1). There was an increase of ca 50 times in magnitude in the total cell population during the premonsoon as compared to the post monsoon season. The diversity index H values ranged from 1.7 to 4.8 with usually high values in the coastal stations during both seasons (Fig. 2.). The J evenness index values were usually directly proportional to the H values.

The results from Figs. 3.1 and 3.2 show the distribution of dominant species at various stations during the pre and postmonsoon seasons in the South China Sea. During the premonsoon period, various species of *Chaetoceros, Bacteriastrum, Rhizosolenia, Trichodesmium, Coscinodiscus, Thalassionema, Ceratium, Hemiaulus,* Copepod nauplii, *Tintinnopsis* and *Protoperidinium* in the order of dominance were encountered. The first six dominant species ranged in cell density from 6.3 to 19.9 x 10^4/m^3 while the *Protoperidinium* ranged from 5.3 to 39.8 x 10^3/m^3. However, during the postmonsoon, the dominant species arranged in the order of importance were *Trichodesmium, Bacteriastrum, Chaeroceros, Coscinodiscus, Rhizosolenia, Thalassionema, Ceratium, Hemiaulus,* Copepod nauplii, *Tintinnopsis* and *Protoperidinium*. The first four dominant species ranged in cell density from 3 to 13.1 x 10^4/m^3 while *Protoperidinium* ranged from 2.1 to 11.4 x 10^3/m^3.

Microplankton population at various sectors

The sampling stations during the study period can be categorised into at least 6 sectors with respect to their similarities in species composition using cluster analyses on 80 stations by mean of the unweighted pair group average (UPGA) Pearson index analyses (Fig. 4). The identified sectors in the South China Sea comprised of a) Chao Phraya bay, b) Pattany bay, c) Terengganu nearshore waters, d) Johore waters, e) Thailand offshore waters and f) Malaysian offshore waters. The mean cell densities of various stations of the 6 sectors (data from various stations from each sector were pooled) were high during the premonsoon with values of 1.79 x 10^7, 2.16 x 10^7, 2.39 x 10^7, 1.28 x 10^7, 4.25 x 10^6 and 6.54 x 10^6 cells/m^3 respectively.

The major microplankton species at the Chao Phraya bay sector during pre monsoon comprised of *Rhizosolenia calcar-avis, Chaetoceros lorenzianus, Coscinodiscus jonesianus, Trichodesmium*

Table 1. Taxonomic list of microplankton identified from the Gulf of Thailand and the South China Sea of the east coast of Peninsular Malaysia (* dominant)

1. **Class, Cyanophyceae; Order Hormogoneae; Family Osciliatoriaceae;**
* Trichodesmium erytheraeum Ehrenberg
T. thiebautii Gom.
2. **Pylum Bacillariphyceae (Diatom)**
Actinophychus undulatus Ralfs
Actinocyclus Ehrenberg
Asterolampra marylandica Ehrenberg
Asteromphalus elegans Greville
A. heptactis Ralfs
A. flabellatus Greville
Bacillaria paxillifera (O.F. Muller)
Bacteriastrum comossum Pavillard
* B. delicatulum Cleve
B. elegans Pavillard
B. elongatum Cleve
* B. hyalinum Lauder
B. mediaterraneum
B. minus
* B. varians Lauder
Biddulphia dubai
B. longicrucia
* B. mobilensis
B. regia
B. sinensis
Campylodiscus biangulatus Hantsch
C. daemelianus Grun
C. echeneis Ehrenberg
C. orratus Grun
C. undulatus sp.
Cerataulina Bergonii
C. Compacta
C. pelagica (Cleve) Hendey
C. coarctatum Lauder
Chaetoceros affinis Lauder
C. brevis Schutt
C. compressum Lauder
C. constrictum Gran
C. costatus Pavillard
* C. curvisetum Cleve
C. dadayi Pavillard
C. debile Cleve
* C. decipiens Cleve

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C. messanensis Castracane
C. paradoxum Cleve
C. pendulus Karsten
* C. peruvianum Brightwell
* C. pseudocurvisetum Mangin
C. setaceum Jorg
C. siamense Ostenfeld
C. sumatranum Karsten
C. tetrastichon Cleve
C. tripos Nitsch
C. weissflogii Schutt
Climacodium biconcavum Cleve
C. frauenfeldianum Grunow
Corethron hystrix Henden
C. pelagicum Brun
Coscinodiscus asteromphalus Ehrenberg
* C. concinus W. Smith
* centralis
* C. curvatulus Grunow
* debilis
* C. gigas Ehrenberg
C. granii Gough
C. janischii Schmidt
* C. jonesianus (Greville) Ostenfeld
C. lineatus Ehrenberg
C. marginatus Ehrenberg
C. nitidus Gregory
C. nobilis Grunow
C. nodulifer Schmidt
C. occulus rividis Ehrenberg
C. perforatus Ehrenberg
C. radiatus Ehrenberg
C. Rothii Grunow
C. stellaris Roper
C. subtilis Ehrenberg
C. weilesii Gran & Angst
Cylindrotheca closterium Ehrenberg
Dactyliosolen blavyanus H. Peragallo
D. fragilissinum (Bergon) Hasle
Detonula pumila (Castracane) Gran
Ditylum brightwelii (West) Grunow
D. sol Grunow
Eucampia cornuta (Cleve) Grunow

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H. membranacea Cleve
H. sinensis Greville
* **Hemidiscus cuneiformis Wallich (Indicator sp.)**
H. hardmanianus
Lauderia annulata Gran
L. borealis
Leptocylindrus danicus Cleve
L. mediterraneus (H. Peragallo) Hasle
Lithodesmium undulatum **Ehrenberg**
Navicula sp.
* **Nitzschia closterium W. Smith**
N. closterium W. Smith
N. hungarica Grun
N. lanceolata W. Smith
N. longissima Gran
N. longissima var. reversa
N. paradoxa Gmelin
N. pacifica Cupp
N. plana W. Smith
N. pungens Cleve
N. seriata Cleve
N. sigma W. Smith
N. sigma var intercedens
N. spectavilis Ralfs
N. vitrea Norman
N. bicapitata Cleve
Odentella mobiliensis (Bailey) Grunow
O. sinensis (Greville) Grunow
Planktoniella blanda A. Schmidt
P. sol (Wallich) Schutt
Pleurosigma affine Gran
P. angulatum W. Smith
P. coompactum Grew
* P. elongatum W. Smith
P. fasciola W. Smith
P. intermedium W. Smith
P. nicobaricum Gran
P. Normanii Ralfs
P. pelagicum Perag
P. rectum Donkim
P. rigidum Brun
P. salinarum Gran

Table 1. (cont.)

Continue >>

R. delicatula Cleve
R. imbricata Brightwell
R. hesetata Gran
R. robusta Norman
R. delicatula Cleve
R. setigara Brightwell
R. styliformis Brightwell
*** *Skeletonema costatum* (Greville) Cleve**
***Stephanopyxis palmeriana* Greville**
Striatella sp.
Surirella sp.
*** *Thalassionema frauenfeldii* Grunow**
T. nitzschioides (Grunow)
***Thalassiosira bingensis* Takano**
T. dipporocyclus Hasle
T. eccentrica (Ehrenberg) Hasle
T. oestrupii (Ostenfeld) Hasle
* *T. subtilis* (Ostenfeld) Gran
***Triceratium favus* Ehrenberg**

3. Phylum Dinophyceae (Dinoflagellate)

Family : Peridiniidae

***Alexandrium fraterculus* (Balech)**
A. tamiyavanichi Balech
***Amphidoma steini* Schill**
***Amphisolenia bidentata* Schroder**
A. thrinax Schutt
A. globifera Stein
A. scnauinsianaii Lemmermann
***Ceratium axiale* Kofoid**
C. arietinum Cleve
* *C. breve* Schroder
C. biceps Gourret
C. belone Cleve
* *C. chrenbergii*
C. condillans Jorgensen
C. candelabrium Ehrenberg Stein
C. contortum Gourret
C. carriense Gourret
C. declinatum (Karsten) Jorgensen
* *C. deflexum* (Kofoid) Jorgensen
C. dens Ostenfeld & Schmidt
C. falcatum (Kofoid) Jorgensen
C. longissinum

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* *C. massiliense* (Gourret) Karsten
* *C. platycorne* Daday
* *C. pentagonum* Gourret
C. pulchellum Schroder
C. symmetricum Paviilard
* *C. teres* Kofoid
C. trichoceros (Ehrenberg) Kofoid
C. tripos (O.F. Muller) Nitzsen
C. vulture Cleve
Ceratocorys norrida Stein
C. horrida Stein
C. gourreti Paulsen
Corythodinium resseratum Stein Loebiich Jr. & Loebiien
Dinophysis homunculus Stein
D. caudata Sabille - Kent
D. farus
D. hastata Stein
D. infundibula Schiller
D. miles Cleve
D. ovum Schutt
D. schuettii Murray & Whitting
D. tripos
Diplopsalis lenticulata Berg
Goniodoma polyedricum Pouchet
G. spaericum
Gonyaulax digitale (Pouchet) Kofoid
G. gluptorhynchus Murray & Whitting
G. polygramma Stein
G. spinifera Clapareda & Lachmann
Gynmodinium sp.
Gyrodinium sp.
Kofoidinium sp.
Noctiluca scintillans Macartney
Ornithocercus magnificus Stein
O. thumii A. Schmidt
Pxytoxum scolopax Stein
O. milneri
O. tesselatum
Phalacroma acutoides Balech
P. doryphorum Stein
P. favus Kofoid & Micherner
P. mitra Schutt
P. spinifera Okamura

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*** *Protoceratium spinulosum***
Protoperidinium conicum (Gran)
* *P. brochii*
P. crassipes (Kofoid) Balech
P. depressum (Bsiley) Balech
P. diabolus (Cleve) Balech
P. divergents (Ehrenberg) Balech
P. elegans (Cleve) Balech
P. globulum (Stein) Balech
* *P. grande* (Kofoid) Balech
P. hirobis (Abe') Balech
P. latispinum (Mangin) Balech
P. leonis (Pavillard) Balech
P. murrayi (Kofoid) Balech
* *P. oceanicum* (Vanhoff) Balech
P. okamurai (Abe') Balech
P. ovum (Schiller) Balech
P. pallidum (Ostenfeld) Balech
P. paulseni (Pavillard) Balech
P. Pellucidum Bergn
P. puanerense (Schreaser) Balech
P. spinuiosum (Schiller) Balech
P. stenii (Jorgensen)
P. thorianum (Paulsen) Balech
Pyrophacus horologium Stein
P. stein (J. Schiller) Wall & Dale
Scripsiella trochoidea (Stein) Balech

4. Family : *Dictyochaceae* (Phulum Protozoa)

Class : Mastogophora, Order : Chrysomonadina

Dictyocha fibula Ehrenberg
D. fibula var stapedia Heack
D. fibula var major Rampi

Family : Procentridae

Procentrum micans Ehrenberg

Family : Phytodinidae

* *Pyrocystis elegans* Murray **(Indicator sp.)**
P. fusiformis Murray
P. hamulus var imacqualis Schrober
P. noctulica Murray

Table 2. Taxonomic list of microzooplankton identified from the Gulf of Thailand and the South Sea of the east coast of peninsular Malaysia (*dominant)

Family : Globigerinidae	**Microzooplankton Larvae Abundance (* percentage total count)**	
Order : Foraminifera		
Class : Sarcodina		
Globigerina bulloides d'orb. **(Indicator sp.)**	**Copepoda nauplii (Calanoid, cyclopoid, harpacticoid)**	***48%**
Family : Acanthoplegmidae	**Ostracoda**	**4**
***Acanthocolla cruciata* Haeck** (*)	**Siphonophora**	**2**
Amoebophrya acanthometrae Koeppen	**Gastropod**	**2**
Family : Acanthometridae	**Lucifer**	**2**
***Acanthometron pellucidum* Mull**	**Laevacean**	**2**
A. elongata	**Shrimp**	**2**
Family : Amphilithidae	**Pteropod**	**2**
***Amphibelone hydrotomica* Haeck**	**Bivalve**	**2**
***Amphilithium clavarium* Haeck**	Modusae	
Family : Gigartaconidae	Ctenophora	
***Amphiacon denticulatus* Haeck**	Nemertinea	
Family : Corticellidae	Cyphonautes	
Order : Peritriches	Actinotroch	
***Stichonlonche zanclea* Hertw**	Polychacta	
Family : Codonellidae	Cladocera	
***Codonella aspera* Ion**	Amphipoda	
*** *Tintinnopsis lobiancoi* Daday**	Isopoda	
T. butschlii Daday	Mysidacea	
T. mucula Fol	Cumacea	
T. radix Imhof	Euphausiacea	
Family : Ptychocylidae	Phyllosoma	
***Favella adriatrica* Imhof**	Anomura	
Family : Tintinnidae	Brachyura	
***Tintinnus inquilinus* Muller**	Stomatopod	
	Hetcropoda	
	Pteropoda	
	Cephalopoda	
	Gastropoda	
	Echinodermata	
	Thaliaceae	
	Brichiopoda	
	Crustacea	
	Fish eggs/larvae	

erythraceum, Ceratium fusus and copepod nauplii with mean values of 5.0 x 10^6, 3.9 x 10^6 and 2.5 x 10^6, 1.7 x 10^6, 0.5 x 10^6 and 0.47 x 10^6/m^3 respectively (Fig. 5). Microplankton species during the premonsoon were present in higher concentrations than those during the postmonsoon.

The mean total cell densities in the Terengganu nearshore waters were 7.9 x 10^7 and 6.31 x 10^5/m^3 during both monsoon seasons respectively (Fig. 6). During the premonsoon the blue green alga, *Trichodesmium erythraeum* reached its peak bloom at concentration of 7.15 x 10^7/m^3 (> 90% of its total cell density); however, this species was not detected during the postmonsoon. *Rhizosolenium alata, Bacteriastrum cosmosum, Chaetoceros compressum, Thalassionema frauenfeldii* were dominant diatoms present during the premonsoon with values ranging from 2.51 x 10^5 to 15.8 x 10^5/m^3. *Pleurosigma elongatum* were present only during the premonsoon. The dinoflagellate, *Ceratium fusus* and *Protoperidinium* sp. were also present with values ranging from 0.12 x 10^5 to 2.51 x 10^5/m^3. *Tintinnopsis* sp. and Copepod nauplii were high during the premonsoon.

Table 3. The number of species in the genera of the microplankton polulation in the Gulf of Thailand and the South China Sea of the east coast of peninsular Malaysia (* Dominant)

Genus	Number of Species
1. Bacillariophyceae	
(Diatom)	
Asteromphalus	2
*** *Bacillaria***	**1**
Compylodiscus	4
Cerataulina	3
Climacodium	2
Corethron	1
Dactyliosolen	2
Ditylum	2
* *Eucampia*	2
* *Fragilaria*	1
* *Guinardia*	3
* *Gyrosigma*	4
* *Hemiaulus*	3
* *Hemidiscus*	2
* *Lauderia*	2
Leptocylindrus	2
* *Nitzschia*	8
Odentella	2
* *Planktoniella*	2
Pseudoguinardia	2
*** *Skeletonema***	**1**
* *Thalassiosira*	5
Triceratium	1
2. *Dinophyceae*	
Alexandrium	2
Amphisolenia	4
*** *Ceratium***	**28**
*** *Ceratocorys***	**2**
**Dinophysis*	5
Goniodoma	2
* *Gonyaulax*	4
* *Noctiluca*	1
*** *Ornithocercus***	**5**
Palacroma	5
****Podolampas***	**4**
Prorocentrum	3
*** *Protoperidinium***	**5**
Pyrophalus	2
3. *Cyanophyceae*	
Trichodesmium	**2**
4. *Dictyochaceae*	
Dictyocha	4
Procentrum	1
Pyrocystis	**3**
5. *Microzooplankton*	
Globigerina	1
Codonella	1
Tintinnopsis	**2**
Favella	**1**
Tintinnus	1
6 *Larvae/* nauplii	
Chaetognatha	-
Ostracoda	-
Siphonophora	-
Gastropod	-

Table 4. Dominant microplankton species in the Gulf of Thailand and the South China Sea of the east coast of peninsular Malaysia during the study period.

Genus	Species
1. Cyanophyceae	
(Blue greens)	
Trichodesmium	***T. erythraeum*** Ehrenberg
2. Bacillariophyceae	
(Diatoms)	
Bacillaria	***B. paxillifera*** O.F. Muller
Bacteriastrum	***Bac. comosum*** Pavillard
Chaetoceros	***C. coarctatum*** Lauder
	C. compressum Lauder
	C. curvisetum Cleve
	C. didynum Ehrenberg
	C. lorenzianum Grun
	C. lauderi Reefs
	C. messanensis Castracane
	C. siamense Ostenfeld
	C. tripos Nitsch
Coscinodiscus	*Cos. concinnus* W. Smith
	Cos. gigas Ehrenberg
	Cos. jonesianus Greville
	Cos. radiatus Ehrenberg
Ditylum	*D. sol* Grun
Eucampia	*E. cornuta* Cleve
Fragilaria	*F. intermedia* Grun
Guinardia	*G. cylindrus* Cleve
Hemiaulus	*H. hauckii* Grun
	H. indicus Karsten
Lauderia	*L. anmulata* Grun
Nitzschia	*N. closterium* W. Smith
	N. longissima Gran
Pleurosigma	***P. elongatum*** W. Smith
	P. fasciola W. Smith
Rhizosolenia	*R. alata* Brightwell
Skeletonema	***S. costatum***
	(Greville) Cleve
Thalassionema	***T. frauenfeldii*** Grun
	T. nitzschioides Grun
3. Dinophyceae	
(Dinoflagellate)	
Alexandrium	*Alexandrium* sp.
Ceratium	*C. arietinum* Cleve
	C. furca Ehrenberg
	C. fusus Ehrenberg
	C. pentagonum Gourret
Noctiluca	*N. scintillans* Macartney
Ornithocercus	*O. magnificus* Stein
Podolampas	*P. bipes* Stein
Protoperidinium	*P. brochii* Gran
	P. grande Kofoid
	P. oceanicum Vanhoff
4. Phytodinidae	
Pyrocystis	*P. elegans* Murray

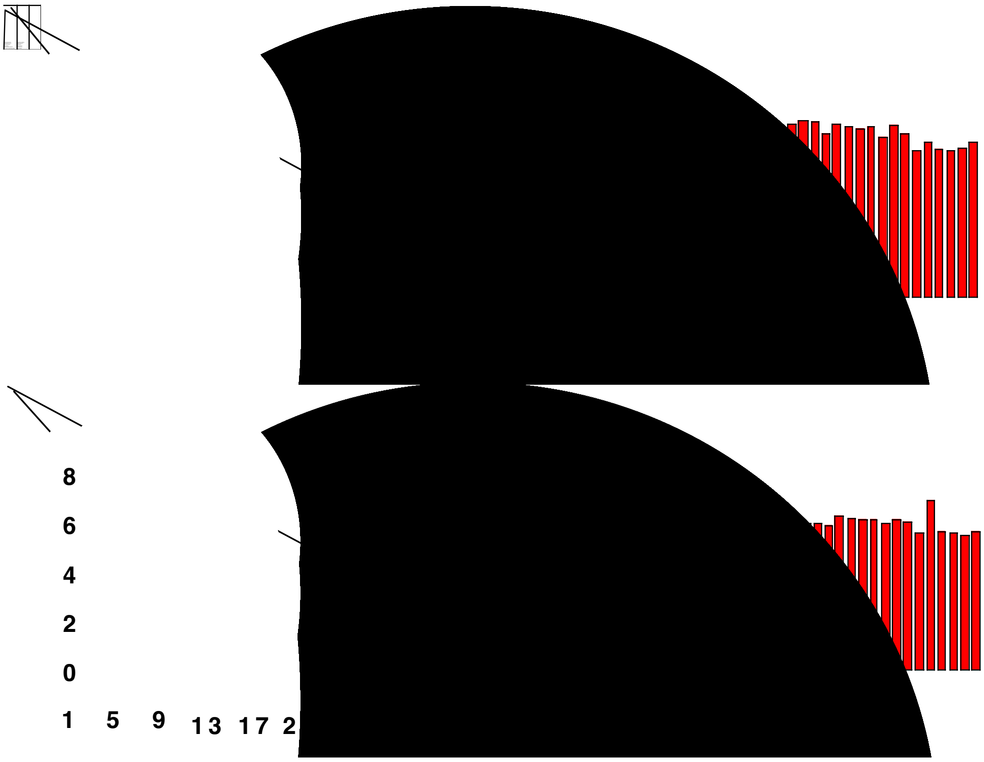


Fig. 1b. Total cell densities (log nos./m^3) at different stations during the pre and post - monsoon period (Oct. 1996 / June 1997 respectively) of the cruise surveys in the Gulf of Thailand and the South China Sea of the east coast of Peninsular Malaysia

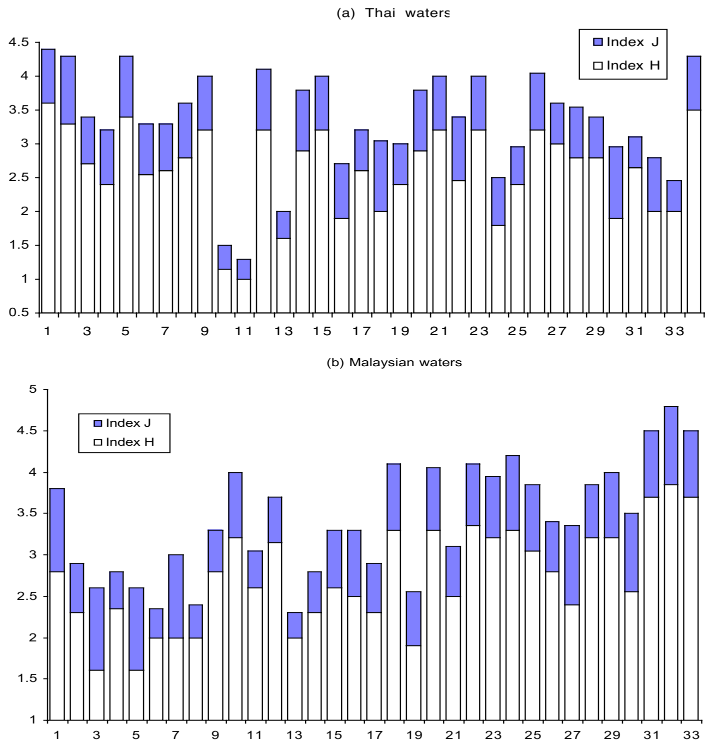


Fig. 2. The diversity (H) and evenness (J) indices of various stations in (a) the Gulf of Thailand and (b) waters of Peninsular Malaysia of the South China Sea during the post monsoon cruise (Apr.-May 1996).

Rhizosolenia sp. (mean density of 1.25 x 10^6/m^3) and *Trichodesmium erythraeum* (mean density 7.94 x 10^5/m^3) were dominant species in the Terengganu offshore waters, however both the species were present in lower concentrations during the postmonsoon(Fig. 7). *Bacillaria paxillifera, Planktonella sol, Pleurosigma elongatum* and *Thalassionema frauenfeldii* were present during the premonsoon; however *Chaetoceros compressum, Hemiaulus hauckii*., *Ceratium fusus* and copepod nauplii were found during both seasons. *Protoperidinium* sp. was present in considerable concentration during the post monsoon. The mean total cell densities in this sector were 5.01 x 10^6 and 2.51 x 10^5/m^3 during the two seasons respectively.

Trichodesmium erythraeum bloom occurred in offshore waters of the Gulf of Thailand with its peak density value of 2.24 x 10^6/m^3 (93.4% of total cell density)(Fig. 8). *Rhizosolenia alata, Pleurosigma elongatum, Lauderia annulata, Bacillaria paxillifera, Chaetoceros lorenzianum* and *Thalassionema frauenfeldii* were diatoms present during the premonsoon with values ranging from 6.31 x 10^4 to 7.76 x 10^5/m^3. During the post monsoon, species of *Rhizosolenia, Thalassionema, Chaetoceros* and *Protoperidinium* were present in low concentrations ranging from 2.51 to 2.78 x 10^3/m^3. The mean total cell density of the post monsoon was ca 63% that of the premonsoon.

The fifth sector was identified for those stations around the Pattany bay. During the premonsoon, the dinoflagellate *Ceratium* sp. (especially *C. fusus*); the diatoms (*Rhizosolenia calcar avis, Chaetoceros lorenzianum, Bacillaria paxillifera*) and the blue greens (*Trichodesmium erythraeum*) were dominant with values ranging from 1.14 x 10^3 to 6.3 x 10^3/m^3 (Fig. 9). Many of these dominant species were either absent or negligible during the postmonsoon and being replaced by species of *Ceratium* and *Coscinodiscus*. Copepod nauplii were present during both seasons with values ranging from 150 to 1150/m^3. The mean total cell densities were 2.45 x 10^6 and 4.07 x 10^5/m^3 during the two seasons respectively.

Another interesting sector situated at the southern tip of peninsular Malaysia was identified as the Johore waters of the South China Sea. The striking phenomenon occurred in this sector was the occurrence of *Skeletonema costatum* bloom during the postmonsoon with a value of 6.5 x 10^5/m^3 (54.2% of total cell density) (Fig. 10). The dominant diatom *Chaetoceros lorenzianum* (1.55 x 10^3/m^3) was present in high concentration during the premonsoon. During the *Skeletonema* bloom, *Bacteriastrum comosum* and *Chaetoceros lorenzianum* were found to be associated with the bloom. Other species association that occurred during the bloom included those species of *Ceratium, Coscinodiscus* and *Hemiaulus*. The microzooplankton species of *Tintinnopsis* and copepod nauplii also present in small amount (> 0.1% of total density).

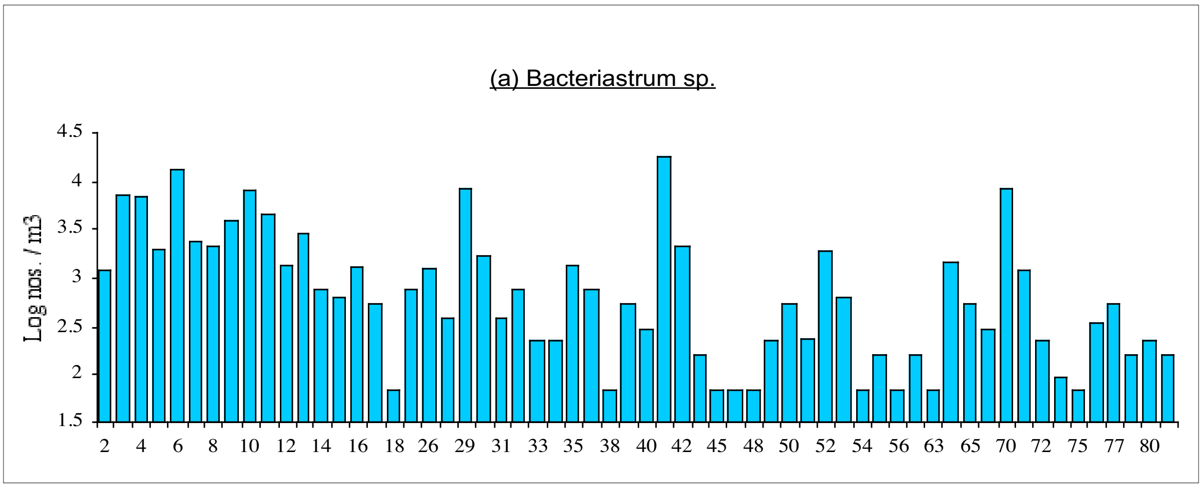
Diversity and evenness indices

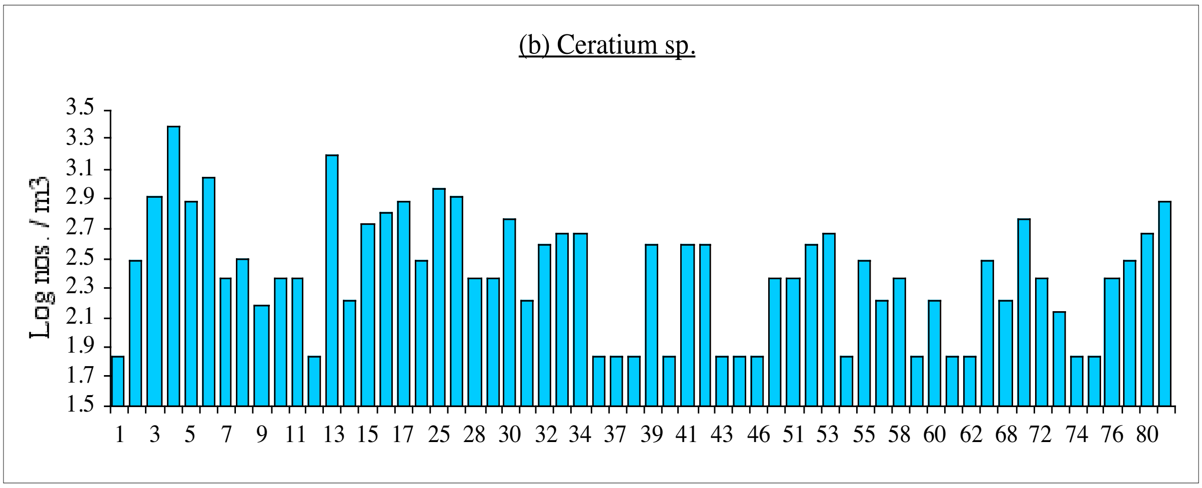
The results from Fig. 11 show the diversity H index for the six sectors of stations studied. This index was effectively altered due to the occurrence of specific blooms, especially the offshore *Trichodesmium* bloom and the nearshore diatom as well as dinoflagellate blooms. The H diversity values were usually higher at nearshore sectors (ranging from 2.9 to 4.4) than those of offshore waters (ranging from 1.95 to 3.4).

Percentage microplankton abundance

The percentage abundance (expressed as the percentage of total cell density) of diatom, dinoflagellate, blue green and microzooplankton at the six identified sectors is as shown in Figs 12 a-d. Chao Phraya bay had high percentage of diatom during the two season with values ranging from 63 to 91%; however the value for Terengganu nearshore waters was high during the post monsoon. Thailand offshore sector had low percentage values (6 to 22%). High dinoflagellate percentage values were observed in certain sectors , especially Terengganu offshore waters (33%).

Pattaya bay (31%), Johore nearshore (24%) and Terengganu nearshore (23%) had high per-





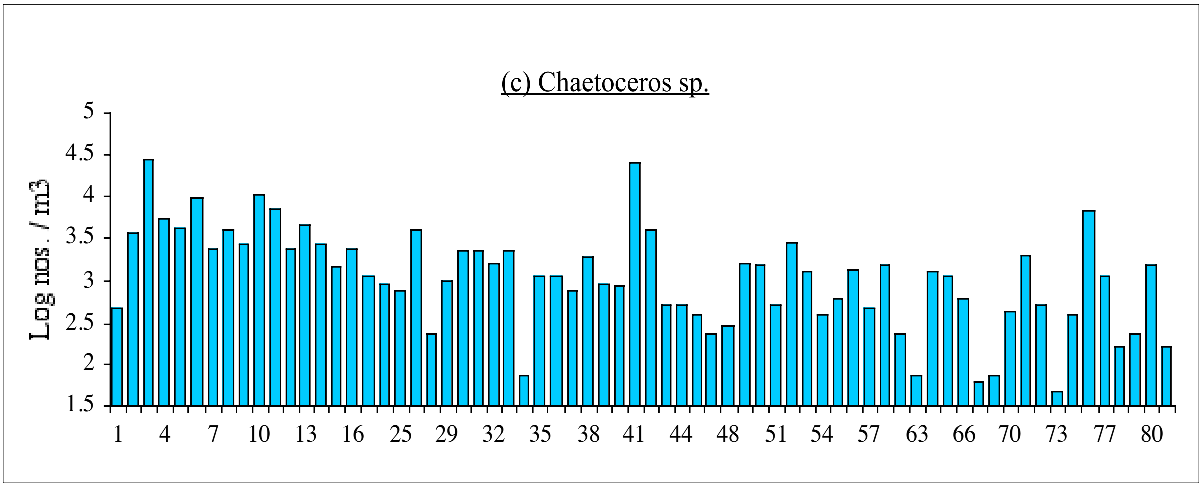
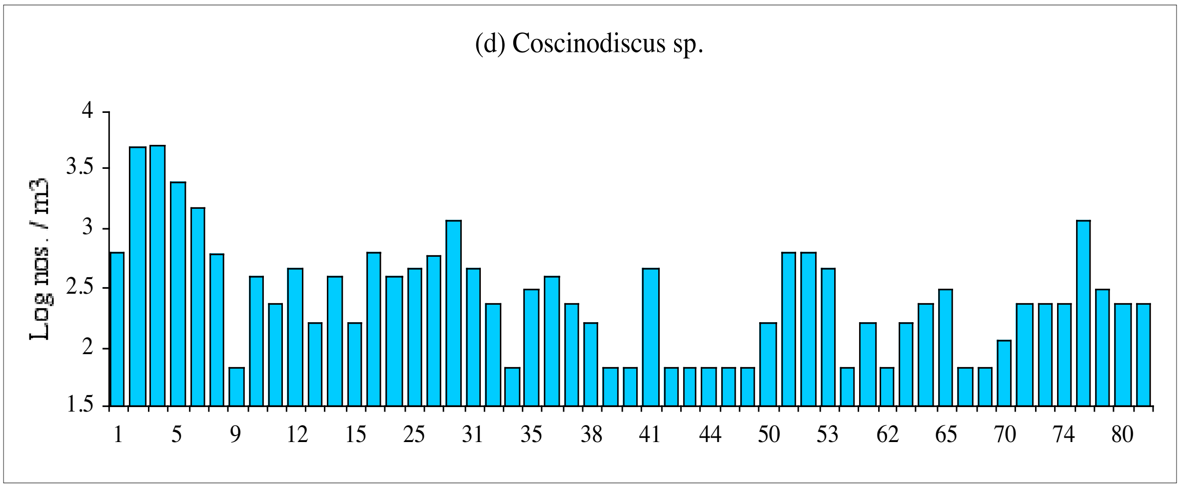
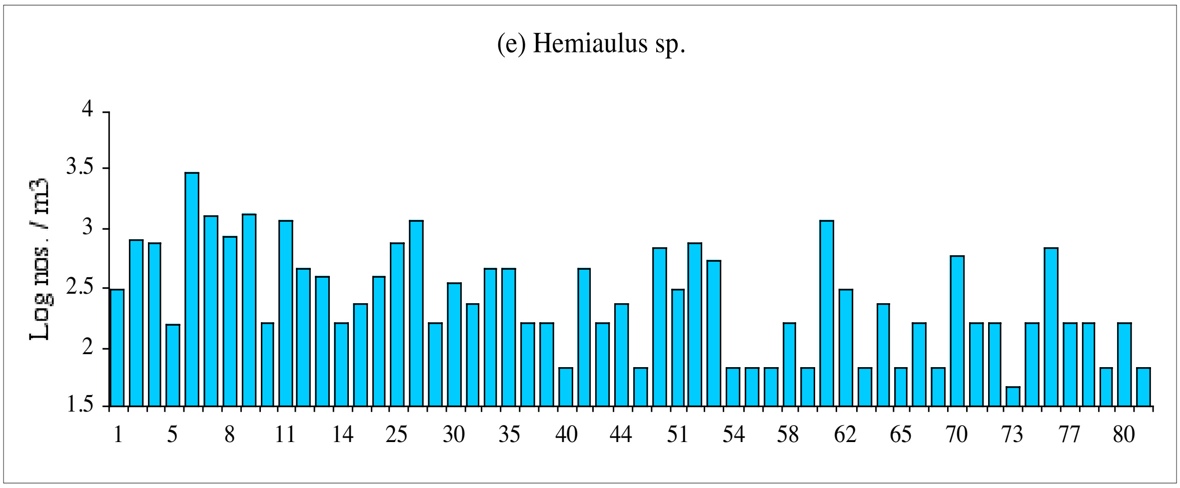
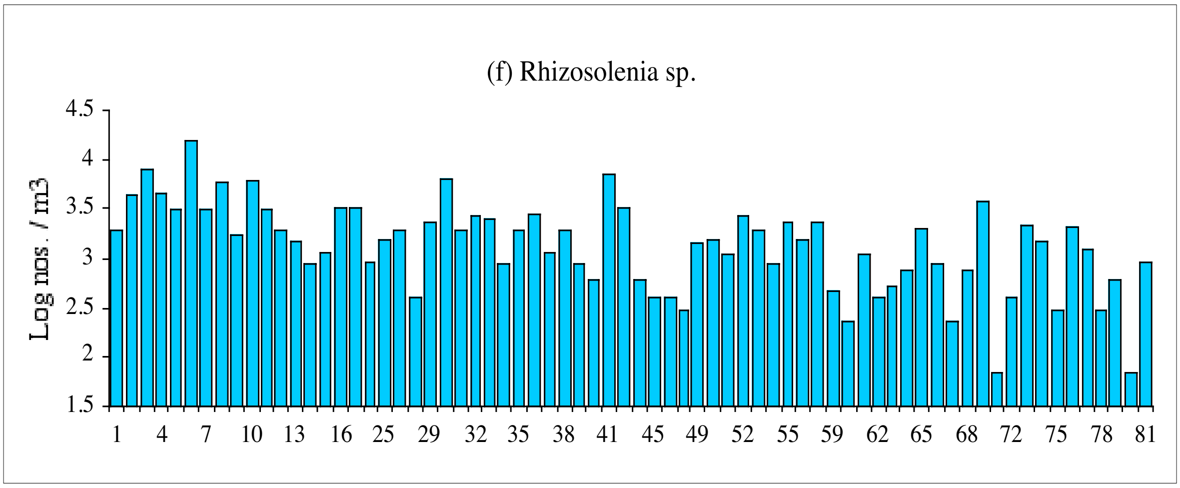


Fig. 3.1 Microplanktonic distribution of various dominant species at different stations during the premonsoon cruise (Sept/Oct 1995) in the Gulf of Thailand and waters of peninsular Malaysia of the South China Sea. (a) Bacteriastrum sp., (b) Ceratium sp., (c) Chaetoceros sp., (d) Coscinodiscus sp., (e) Hemiaulus sp., (f) Rhizosolenia sp., (g) Thalassionema sp., (h) Protoperidinium sp., (i) Trichodesmium sp., (j) Tintinnopsis sp. and (k) Copepod nauplii.







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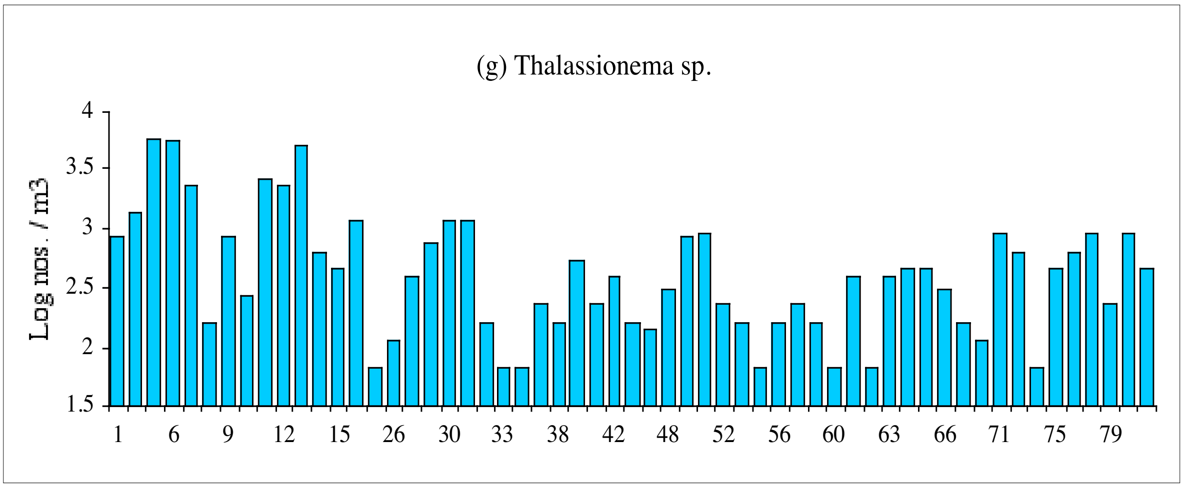

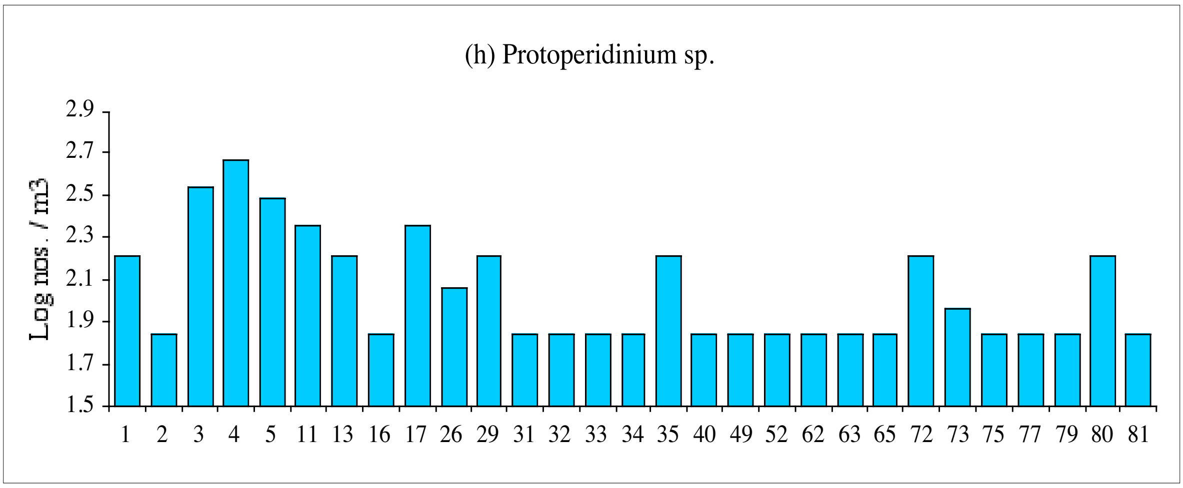

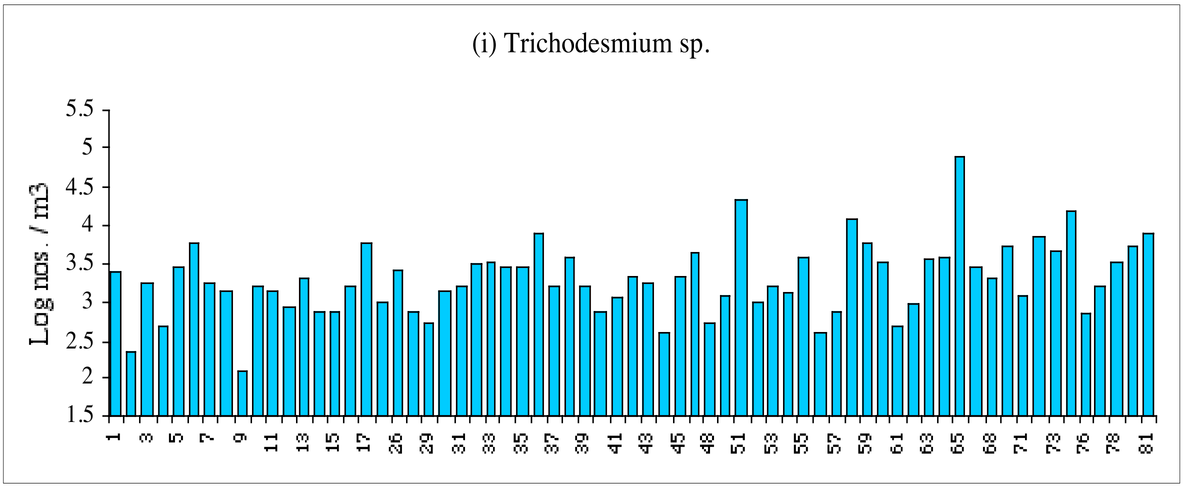

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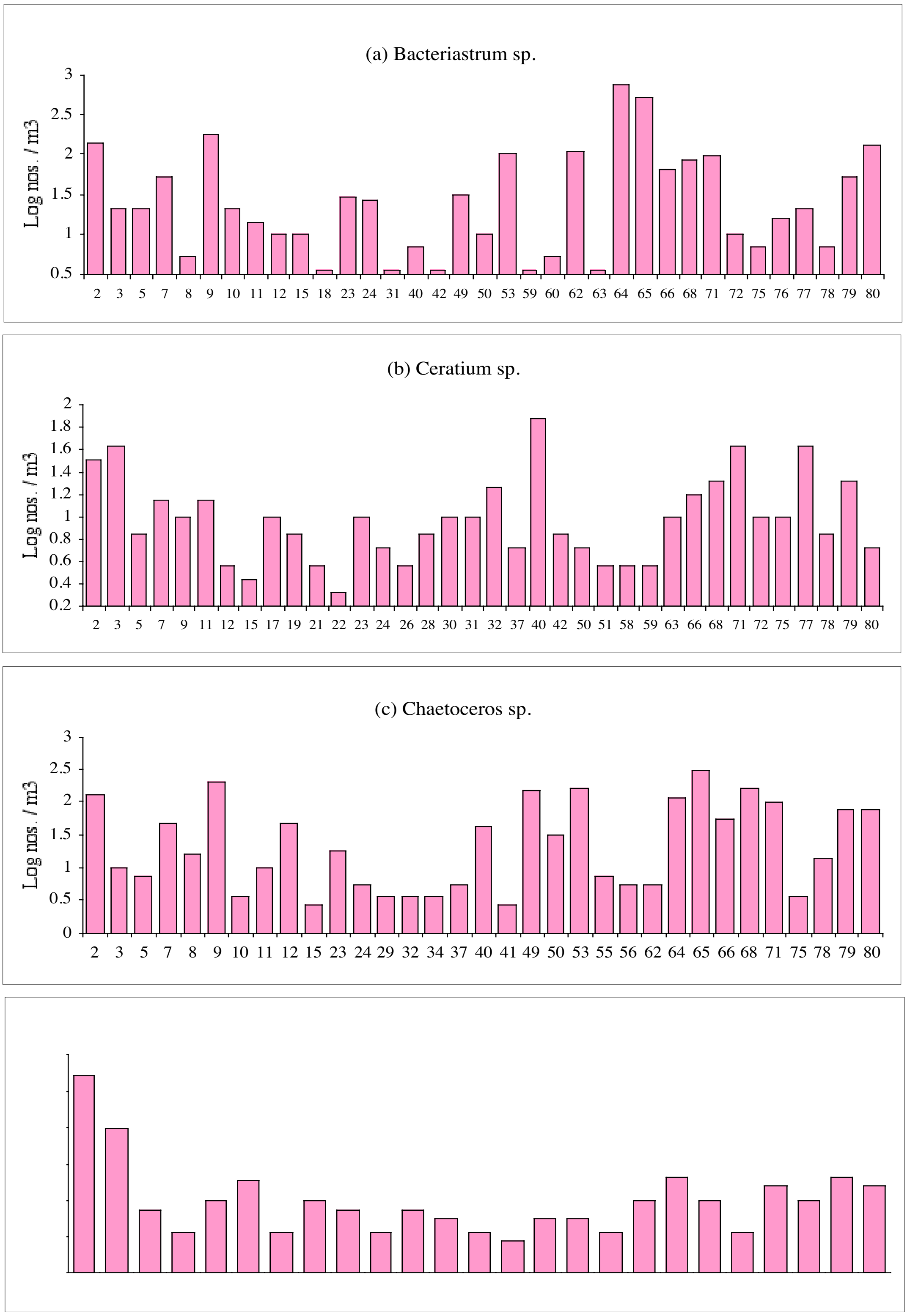
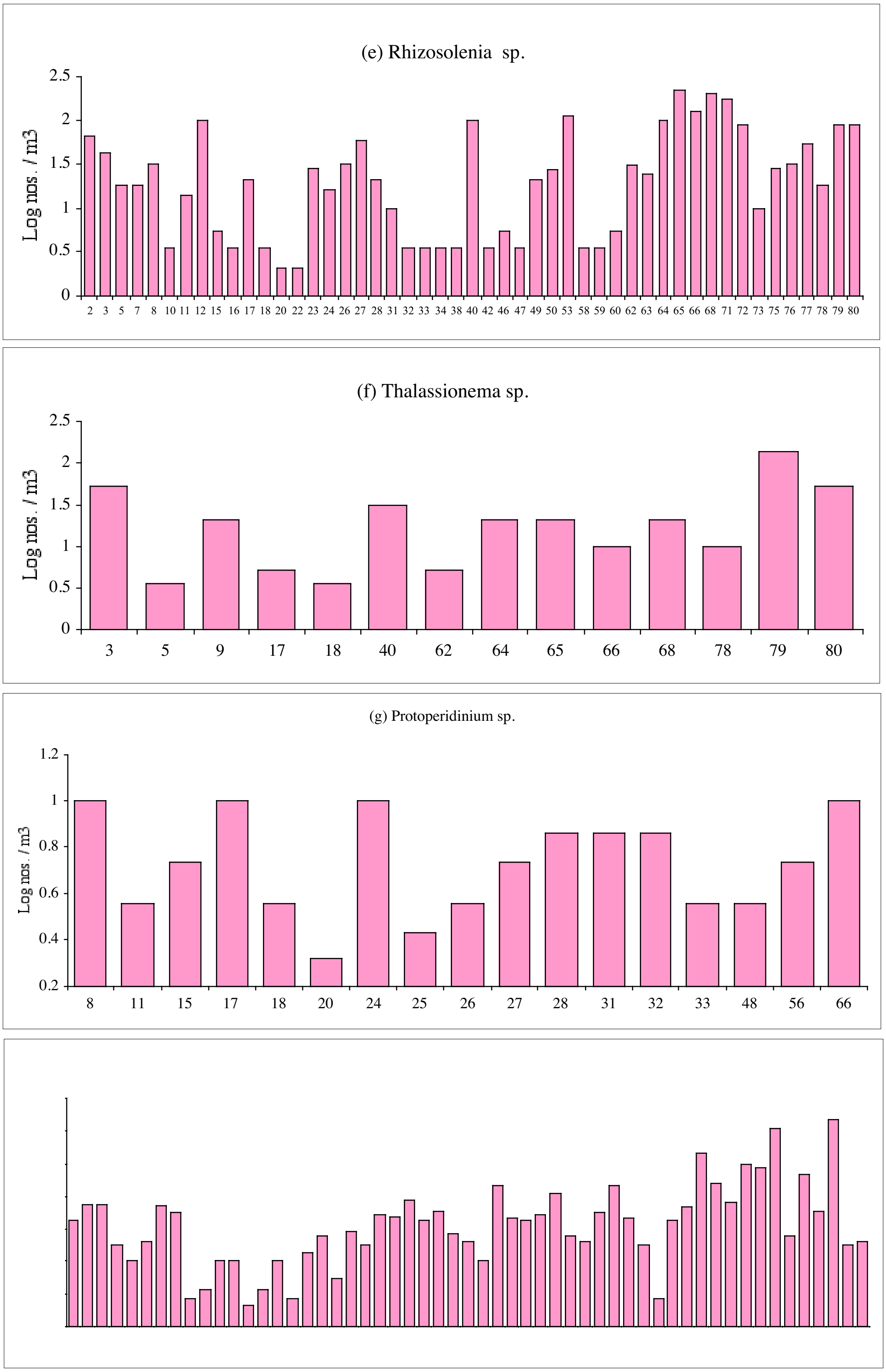


Fig. 3.2 Microplanktonic distribution of various dominant species at different stations during the post monsoon cruise (April/May 1996) in the Gulf of Thailand and waters of peninsular Malaysia of the South China Sea. (a) *Bacteriastrum* sp., (b) *Ceratium* sp., (c) *Chaetoceros* sp., (d) *Coscinodiscus* sp., (e) *Rhizosolenia* sp., (f) *Thalassionema* sp., (g) *Protoperidinium* sp., (h) *Trichodesmium* sp., (i) *Tintinnopsis* sp., (j) Copepod nauplii and (k) *Hemiaulus* sp.



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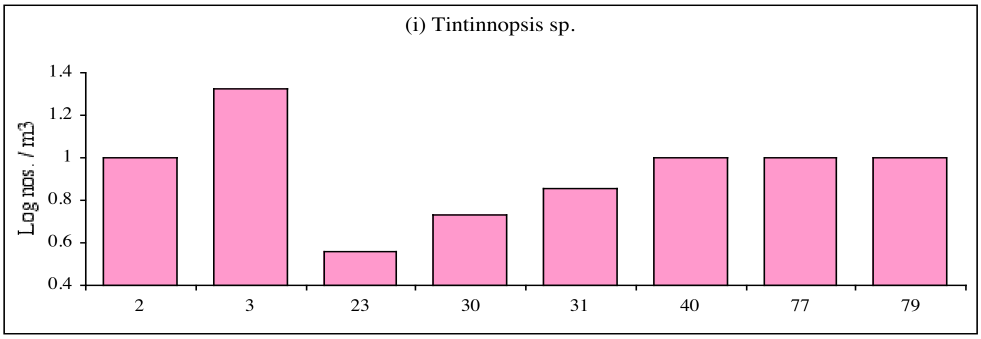

Fig. 3.2 Continue

centage concentrations of diatom. Bloom of dinoflagellate was detected from the Chao Phraya bay and Thailand offshore waters during the study period with values ranging from 51 to 76% abundance; similar bloom also occurred in Terengganu offshore waters during postmonsoon with a value of ca 66% abundance. Percentage abundance was low at Chao Phraya (3%) and Terengganu offshore waters (6%) during premonsoon. The value was low at Johore nearshore waters (2%) during postmonsoon. Microzooplankton were present in considerable concentrations in nearshore and offshore waters especially in premonsoon period.

Microplankton assemblages and associations

The results from Fig. 13 illustrate that the microplankton species comprise of at least seven species assemblages or associations in cluster analysis on 27 species sampled from the nearshore and offshore stations according to their preference on environmental conditions using the unweighted pair group average (UPGA) Pearsons index analyses. The species assemblages consisted of group A (*Thalassionema, Dinophysis, Hemiaulus, Ceratium, Corethron*); group B (*Bacteriastrum, Chaetoceros, Thalassionema, Rhizosolenia*); group C (*Ditylum, Lauderia, Guirnadia*); group D (*Trichodesmium, Nitzschia*); group E (*Coscinodiscus, Fragilaria*); group F (*Pleurosigma, Tintinnus*); group G (*Protoperidinium, Tintinnopsis*).

Disussion

Earlier studies by Shamsudin *et al.* 1987 in the Malaysian waters of the South China Sea showed that the microphytoplankton from 16 oceanographic stations consisted predominantly of diatoms and blue green algae. The bulk of the diatom species consisted of *Chaetocerus, Rhizosolenia, Melosira, Thalassiothrix, Datyliosolen* and *Guinardia*. Another diatom species, *Planktoniella* was present only at stations further offshore from the coast. However, other diatom species which were also present included those of *Bacteriastrum, Asterionella, Fragilaria, Nitzschia, Skeletonema, Coscinodiscus* and *Pleurosigma*. More than 30 major species of diatom have been identified. The genera *Coscinodiscus, Chaetocerus* and *Rhizosolenia* were found to contain a wide range of species. The Cyanophyta comprised of only a few species among which *Trichodesmium thiebautii* and *T. erytheraeum* were abundant. The diversity index (H) and evenness index (J) values were high at stations near to the coast. In this study, the microplankton species from various stations of the South China Sea consisted of more than 205 taxa consisting predominantly of blue greens (2 species), diatoms (120 species) dinoflagellates (80 species) and microzooplankton (> 30 groups).

Other quantitative studies of microplankton in Malaysian waters including the Straits of Malacca had been conducted by Sewel (1933), Winstead (1961), Pathansali (1968), Chua & Chong (1973), Shamsudin (1987, 1993, 1994, 1997) and Shamsudin & Shazali (1991). Most of these studies were carried out at certain predetermined time and location; however, the present study was carried out

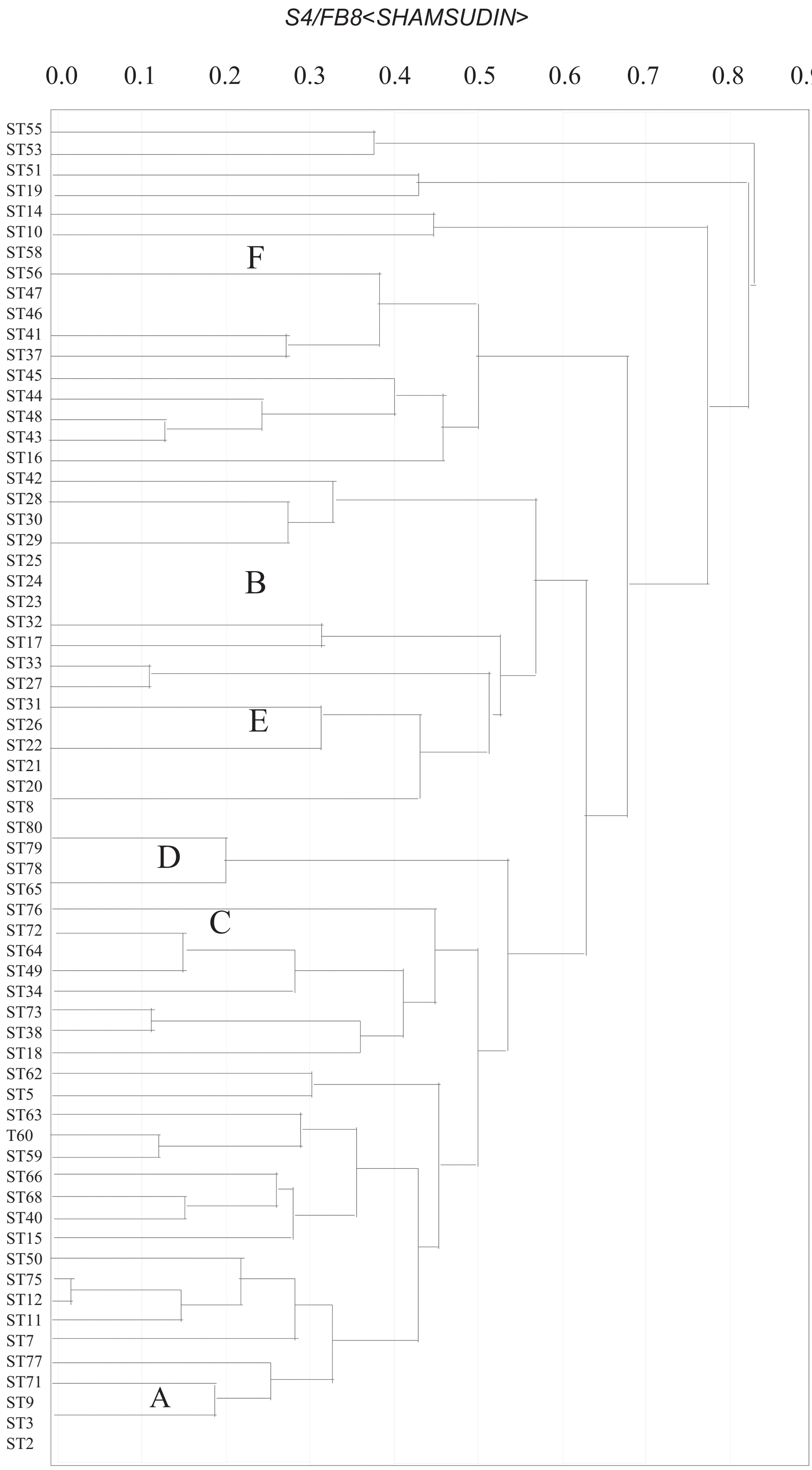

Fig. 4. Tree diagram for stations categorised intostudy sectors in the Gulf of Thailand and the south china Sea . (A- Chao phraya bay, C- Terengganu nearshore water, D- Johore water, E- Thailand offshore and F- Terengganu offshore waters)

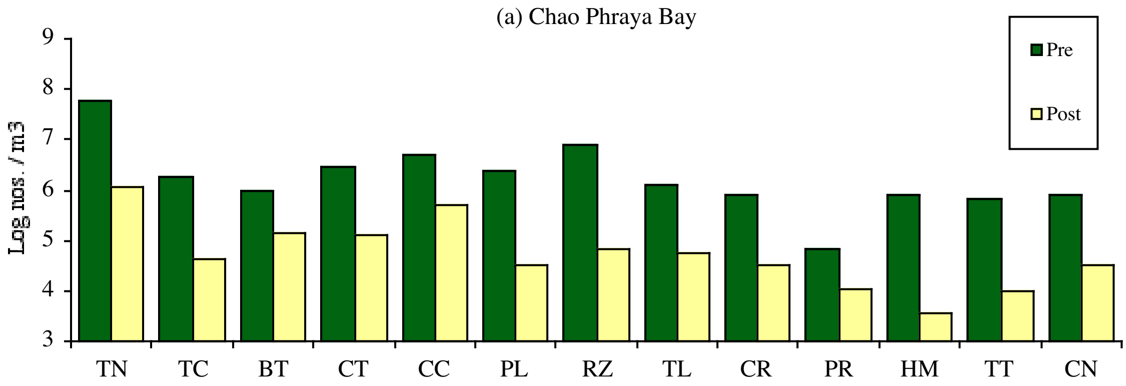

Fig. 5. Cell densities (log nos./m^3) of various microplankton species at stations nearby Chao Phraya Bay of the Gulf of Thailand during pre and post monsoon seasons. (TN-total cell, TC-Trichodesmium erythraeum, BT-Bacteriastrum cosmosum, CT-Chaetoceros lorenzianum, CC-Coscinodiscus jonesianus, PL-Pleurosigma elongatum, RZ-Rhizosolenia calcar-avis, TL-Thalassionema frauenfeldii, CR-Ceratium fusus, PR-Protoperidinium sp., HM-Hemiaulus hauckii, TT-Tintinnopsis sp., CN-Copepod nauplii).

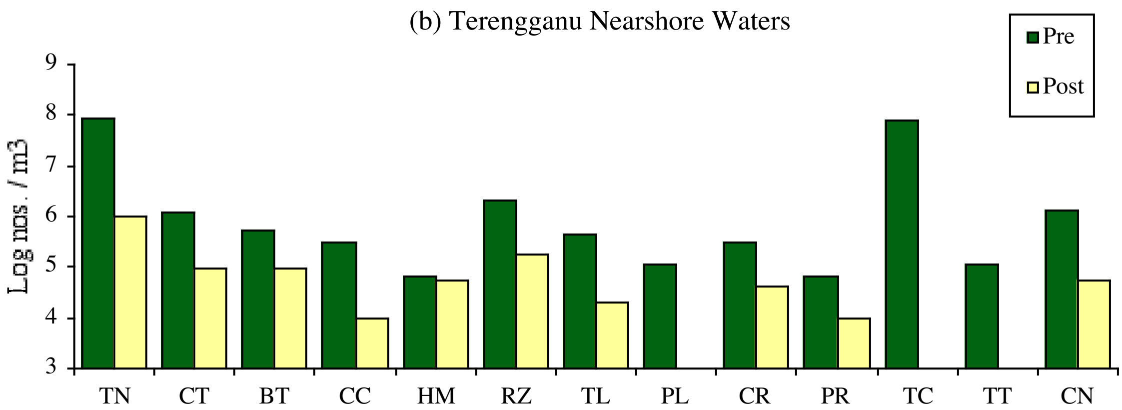

Fig. 6. Cell densities (log nos./m^3) of various microplankton species at stations in Terengganu nearshore waters of the South China Sea during pre and post monsoon seasons. (TN-total cell, CN-Chaetoceros lorenzianum, BT-Bacteriastrum comosum, CC-Coscinodiscus jonesianus, HM-Hemiaulus hauckii, RZ-Rhizosolenia calcar-avis, TL-Thalassionema frauenfeldii, PL-Pleurosigma elongatum, CR- Ceratium fusus, PR-Protoperidinium sp., TC-Trichodesmium erythraeum, TT-Tintinnopsis sp., CN- Copepod nauplii).

during the pre and post monsoon periods. Thus, the study will show the seasonal change and distribution of the microplankton species due to the monsoon season. Shamsudin *et al.* 1987 showed that the diversity (H) and evenness (J) indices were high in nearshore waters when compared to offshore waters. Similarly, the present study showed similar trend, however the occurrence of *Trichodesmium* and other diatom blooms would influence both the indices, indicating that there was a change in the planktonic community organisation in the water column, which could be represented by a number of species throughout the study period. An increase in the diversity value 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 microplankton species will predominate

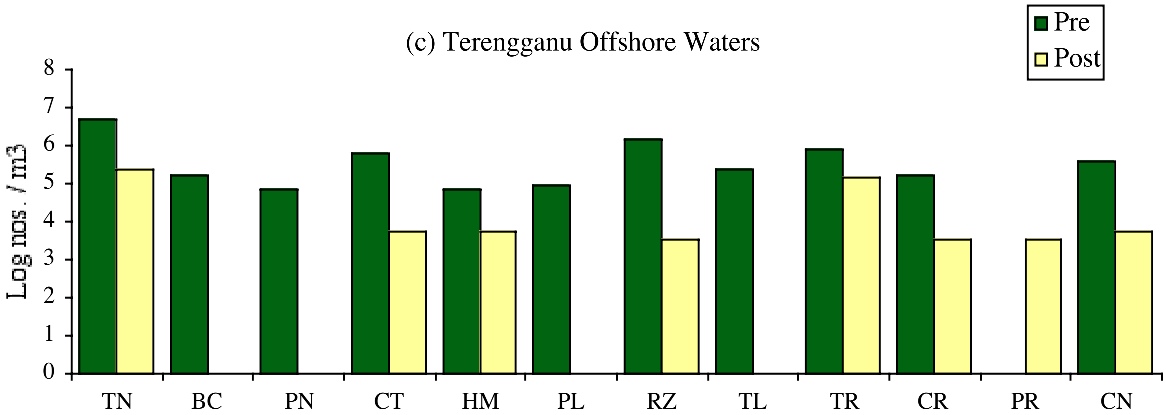

Fig. 7. Cell densities (log nos./m^3) of various microplankton species at stations in Terengganu offshore waters of the South China Sea during pre and post monsoon seasons. (TN. total cell, BT. *Bacillaria paxillifera*, PN. *Planktonella blanda* CT. *Chaetoceros compressum*, HM. *Hemiaulus hauckii*, PL. *Pleurosigma elongstum*, RZ. *Rhizosolenia calcar-avis*, TL. *Thallasionema frauenfeldii*, TR. *Trichodesmium erythraeum*, CR. *Ceratium* sp., PR. *Protoperidinium* sp., CN. Copepod nauplii)

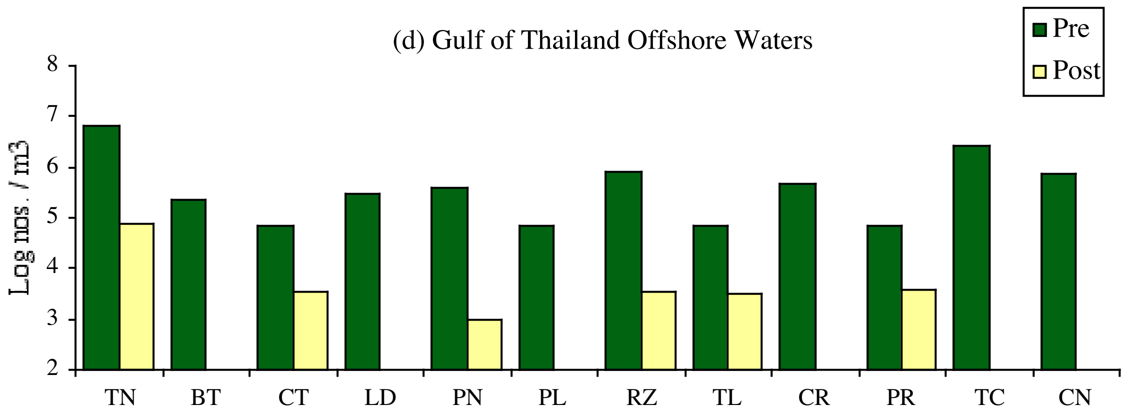

Fig. 8. Cell densities (log nos./m^3) of various microplankton species at stations in Thailand offshore waters of the South China Sea during pre and post monsoon seasons. (TN-total cell, BT-*Bacteriastrum cosmosum*, CT-*Chaetoceros lorenzianum*, LD-*Lauderia* sp., PN-*Planktonella* sp., PL-*Pleurosigma elongatum*, RZ-*Rhizosolenia calcar-avis*, TL-*Thallasionema frauenfeldii*, CR-*Ceratium fusus*, PR-*Protoperidinium* sp., TC-*Trichodesmium erythraeum*, CN-Copepod nauplii)

and thus effect or influence the number of species or the even distribution of individual species.

Premonsoon microplankton population

The present study also shows that the sampling stations can be categorised into 6 sectors in terms of similarities in species composition according to the two seasons (pre and postmonsoon periods) using cluster analyses . During the premonsoon, microplankton densities were high in the Chao Phraya bay, Pattany bay, Terengganu nearshore and the southern tip of peninsular Malaysia around Johore waters. There is a good correlation between the total microplankton and the diatom densities for both the seasons. The blue green (*Trichodesmium erythraeum*) developed bloom in Thailand offshore waters, Terengganu offshore waters as well as Johore waters. However, dinoflagellate species were dominant in the Chao Phraya bay and Johore waters. The offshore diatom species, *Bacillaria paxillifera* was dominant in the offshore waters of the South China Sea.

The chain forming diatom with long setae projection, *Bacteriastrum comosum* and *B. furcatum* were found in high concentrations in the nearshore waters of Malaysia and Thailand; similarly *Thalassionema frauenfeldii* was abundant in nearshore waters of the South China Sea. *Chaetoceros lorenzianus* was the dominant diatom in the Chao Phraya bay and the southern tip of peninsular Malaysia in Johore waters. Certain diatom species was dominant in certain study sectors; namely, *Chaetoceros pseudocurvisetum* with *Coscinodiscus jonesianus* in the Chao Phraya bay; *Chaetoceros compressum* in the Pattany bay and Malaysia nearshore waters; *Thalassionema nitzschioides* in nearshore waters of Thailand; *Trichodesmium erythraeum* occurred usually in offshore waters of the South China Sea. The two species of *Rhizosolenia* (*R. calcar-avis, R. alata*) occurred oceasionally in nearshore waters in high concentrations. *Thalassiosira subtilis* showed up in considerable concentrations in nearshore waters of Terengganu and Johore. The dinoflatellate species (especially *Ceratium fusus, Protoperidinium* sp.) were high in nearshore waters (Pattany bay, Terengganu nearshore, Johore waters) and Terengganu offshore waters with values ranging from 23 to 33% abundance out of the total cell count. The microzooplankton (comprising of copepods nauplii, *Tintinnopsis* sp., *Tintinnus* sp., crustacean larvae) were also present especially in nearshore waters.

The dominant species association available at the Chao Phraya bay comprised of *Chaetoceros lorenzianum, Thalassionema frauenfeldii, C. curvisetum* and *Coscinodiscus jonesianus* whereas at Pattany bay the species assemblage comprised of only three species (*Bacillaria, Trichodesmium erythraeum, Th. frauenfeldii*). Other species association occurred at various sectors namely, a) Terengganu nearshore waters (*Bacteriastrum comosum, Bacteriastrum furcatum, Th. frauenfeldii, T. erythraeum*); b) Johore waters had only 2 species (*Th. frauenfeldii, Thalassiosira subtilis*); c) Thailand offshore waters (*T. erythraeum, Th. frauenfeldii, Bacillaria paxillifera, C. lorenzianum*); d) Terengganu offshore waters (*Bacillaria paxillifera, Th. frauenfeldii, T. erythraeum, Pleurosigma* sp.).

Postmonsoon microplanton population

During the postmonsoon season, the diatom species (12 species) and 1 species of blue green (*Trichodesmium erythraeum*) were dominant. Diatom populations were high in nearshore waters (Chao Phraya bay, Pattany bay, Johore waters, Terengganu nearshore) with percentage abundance values ranging from 38 to 82% abundance. The dominant species encountered at Terengganu nearshore waters comprised of *Chaetoceros lorenzianus, C. compressum* and *Thalassionema frauenfeldii* ; whereas at the Pattany bay the species assemblages or association comprised of *Pleurosigma elongatum, Bacillaria paxillifera, Chaetoceros lorenzianum, C. didynum, Thalassionema frauenfeldii* and *Trichodesmium erythraeum*. Only two species association (*Skeletonema costatum, Chaetoceros lorenzianum*) was detected at the Johore waters while there was four species association (*Chaetoceros compressum, C. lorenzianum, C. pseudocurvisetum, Rhizosolenia alata*) at the Chao Phraya bay. Terengganu offshore waters had three species association (*Trichodesmium erythraeum, Chaetoceros compressum, Ceratium fusus*) while Thailand offshore waters had five species association (*T. erythraeum, Rhizosolenia calcar-avis, Chaetoceros coarctatum, Bacteriastrum cosmosum, Nitszchia closterium*).

Trichodesmium bloom occurred both at nearshore waters (Chao Phraya bay) and offshore waters (Terengganu and Thailand waters). Dinoflagellate (*Ceratium fusus, Protoperidinium* sp.) bloom occurred at Thailand offshore waters and nearshore waters (Terengganu and Johore waters).

Species assemblages by cluster analysis

Shamsudin (1987) showed that the diversity (H) and evennes (J) indices of microplankton population were high in Malaysian nearshore waters of the South China Sea during the study period

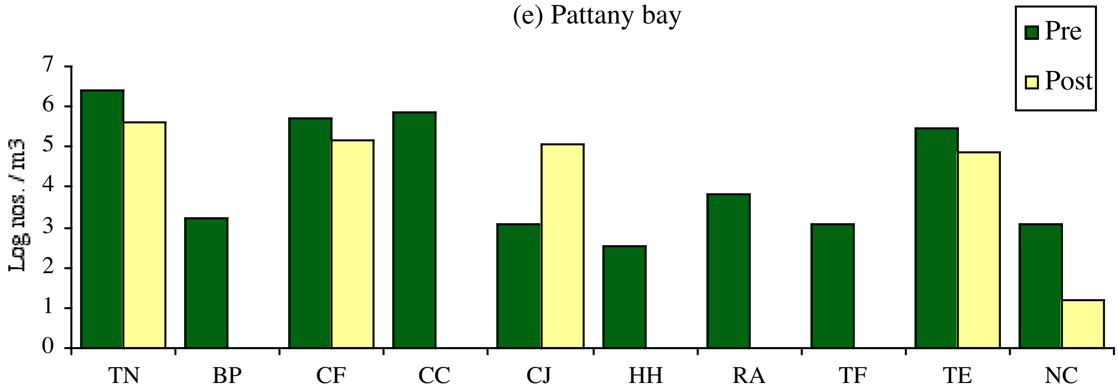

Fig. 9. Mean cell densities (log nos./m^3) of various species at Pattany bay sector during pre and post seasons (BP-*Bacillaria paxillifera*, CF-*Ceratium fusus*, CC-*Chaetoceros comosun*, CJ-*Coscinodiscus jonesianus*, HH-*Hemiaulus hauckii*, RA-*Rhizosolenia alata*, TF-*Thalassionema frauenfeldii*, TE-*Trichodesmium erythraeum*, NC- Copepod nauplii).

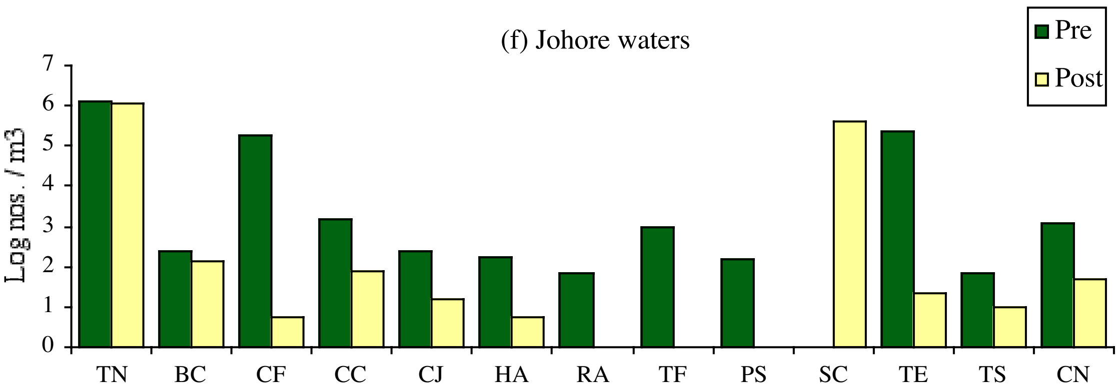

Fig. 10. Mean cell densities (log nos./m^3) of various species at Johore waters sector during pre and post seasons (PS-*Pleurosigma* sp., TS-*Thalassiosira subtilis*, SC-*Skeletonema costatum* the rest similar to Fig. 9).

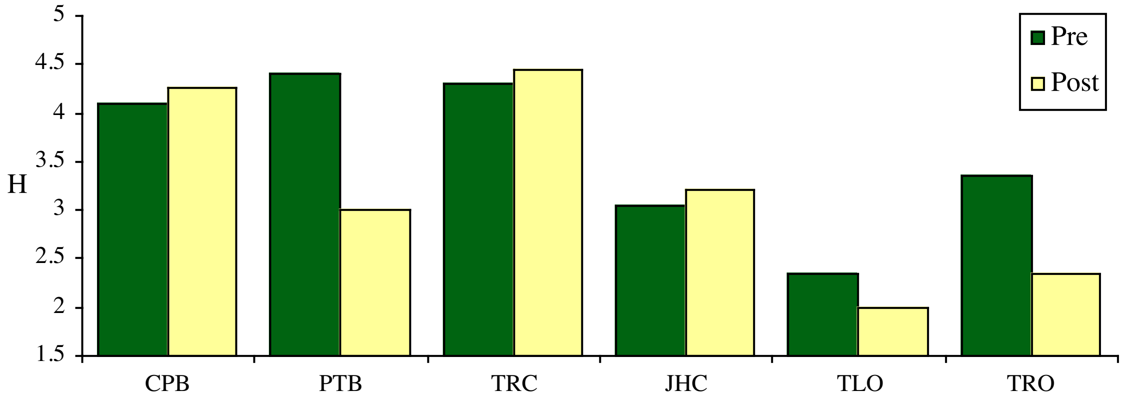

Fig. 11. The diversity (H) index at the six sectors (CPB - Chao Phraya Bay, PTB - Pattaya bay, TRC - Terengganu nearshore waters, JHC - Johore nearshore waters, TLO - Thailand offshore waters, TRO - Terengganu offshore waters

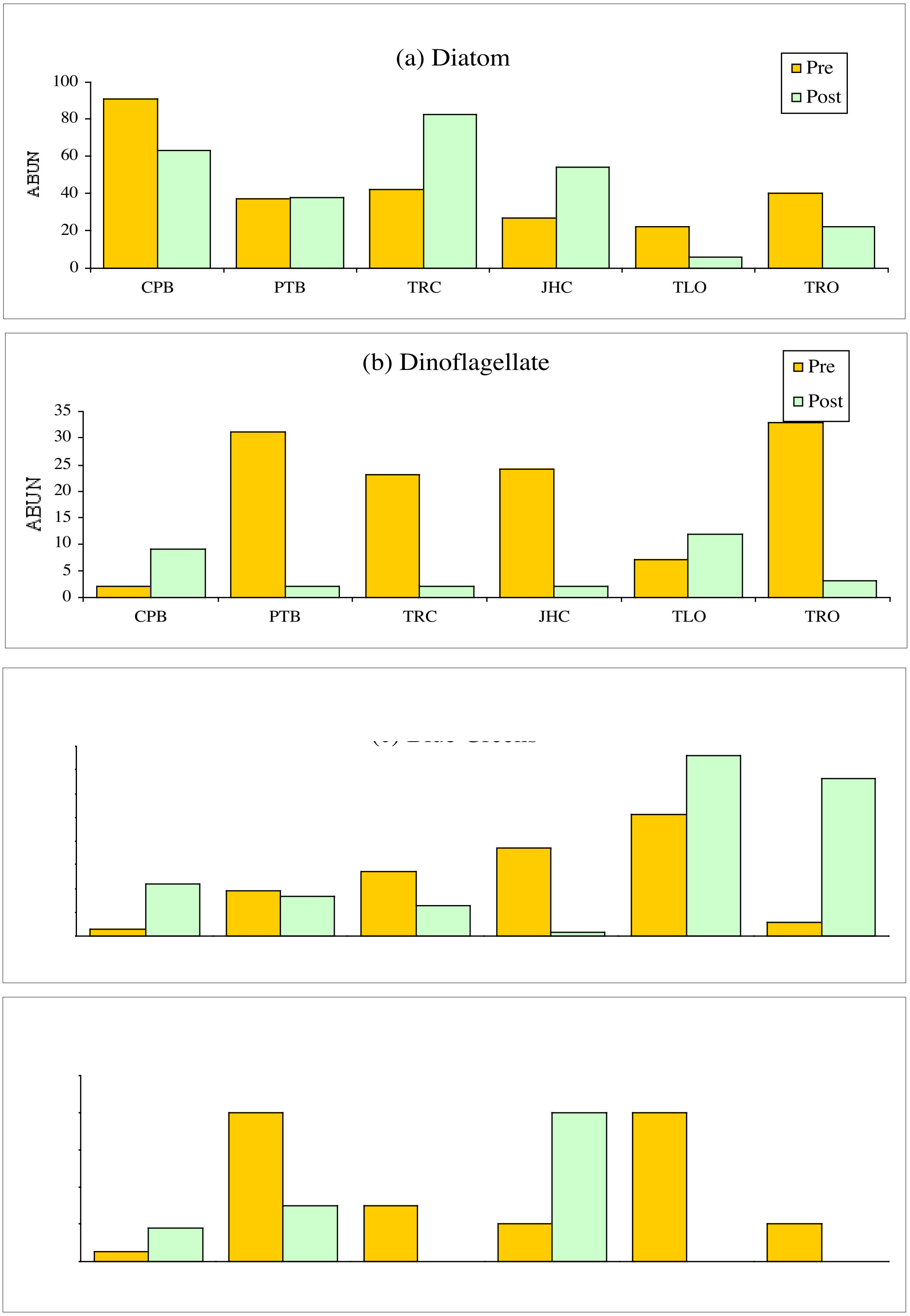

Fig. 12. The percentage abundance (expressed as percentage of total cell density) of diatom, dinoflagellate, blue green and microzooplankton at the six sectors (Name of sectors as shown in Fig. 11). (ABUN - abundance).

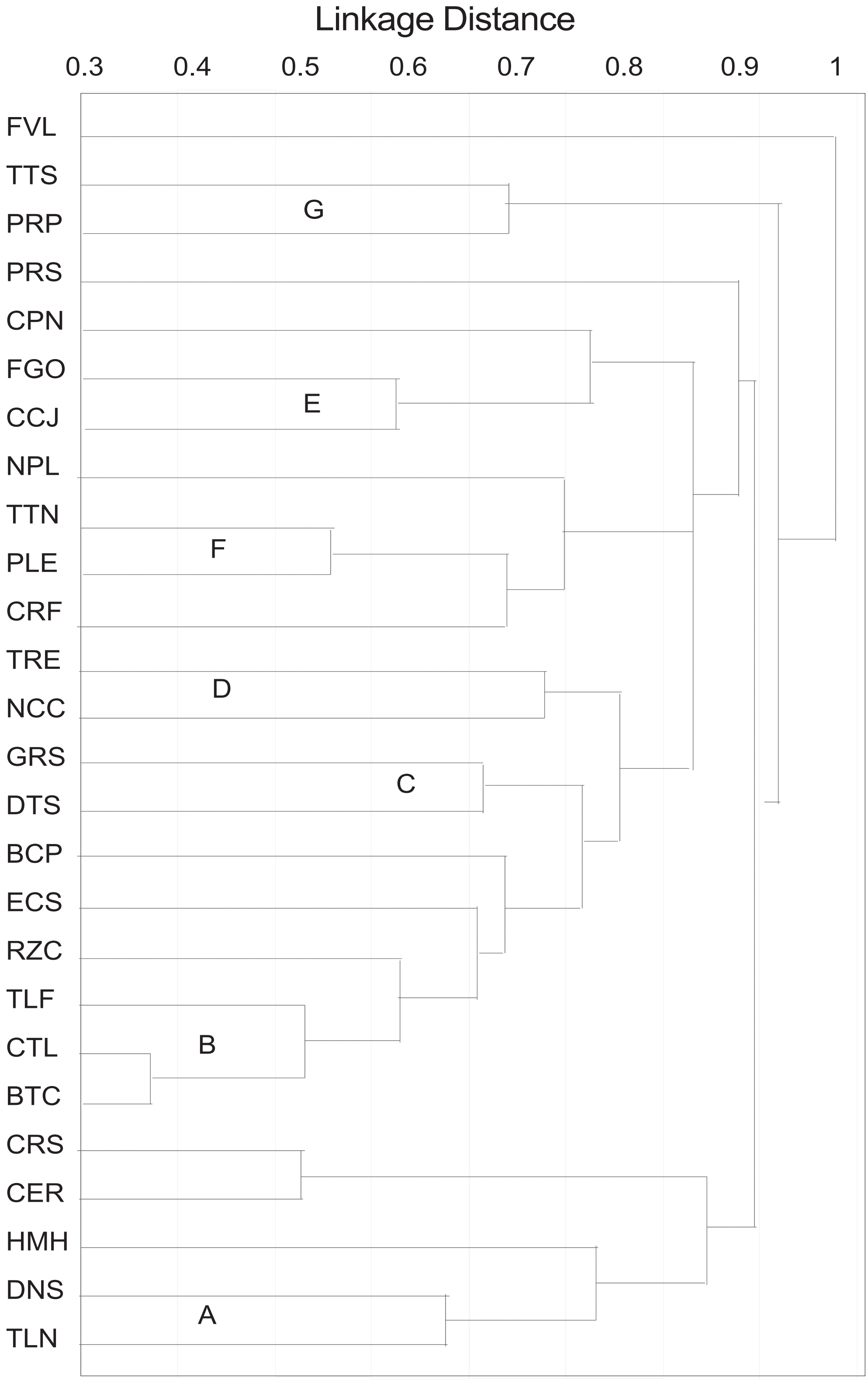

Fig. 13. Tree diagram for microplankton speciess associations using cluster analyses (unweighted pair group average - Pearson Index). Group A :Thalassionema nitzschioides, Dinophysis sp., Hemiaulus hauckii, Group B : Bacteriastrum comosum................

(March 1988 to April 1989); however, the sampling areas were not divided into sectors as a basis of comparison in species composition and association. The present study showed that the microplankton exhibited species associations or assemblages based on cluster analysis on species collected from 80 stations according to their preference on environmental conditions. These species can be classified into at least 7 groups using cluster analysis; namely group A (*Thalassionema nitzschioides, Hemiaulus hauckii, Dinophysis* sp.); group B (*Bacteriastrum comosum, Chaetoceros lorenzianus, Thalassionema frauenfeldii, Rhizosolenia calcar-avis, Eucampia* sp.); group C (*Ditylum sol, Lauderia borealis*); group D (*Nitzschia closterium, Trichodesmium erythraeum*); group E (*Coscinodiscus jonesianus, Fragilaria* sp., Copepod nauplii); group F (*Pleurosigma elongatum, Ceratium fusus, Tintinnus* sp.); group G (*Tintinnopsis* sp., *Protoperidinium* sp.). The species association between *Trichodesmium erythraeum* and *Nitzschia closterium* was obvious in offshore water of the Gulf of Thailand offshore waters. In a similar manner, the sampling stations containing various microplankton species composition and distribution can be classified into various sectors (at least six) according to species preference on environmental conditions. Markina (1972) reported that Peridinians around the tropical northern coast of Australia were represented less in species number than those of the diatoms which were mostly oceanic forms. *Ceratium deflexum* was found to occur in north Australian waters (Zernova, 1964; Semina, 1967) but the species was absent in the present study.

Microzooplankton population

The bulk of the microzooplankton species consisted of more than 30 different groups with several dominant species namely, copepod (> 50% of the total microzooplankton count); Chaetogratha (5%), Ostracod (3%), Siphonophora (2%), Cilliophora (4%) and Foraminifera (2-3%). The Ciliphora consisted of a few genera (*Tintinnopsis, Tintinnus, Favella, Codonellopsis*) while Foraminifera consisted mainly of the *Globigerina* species which is considered as an indicator tropical species. *Amphisolenia* (Fam.: Peridinidae) and *Ceratocorys* species were detected in considerable amount in nearshore stations. The dinoflagellate *Ceratium fusus* had intimate association with the blue green *Trichodesmium erythraeum* found especially around the Pattany bay. Only a few toxic species of *Protoperidinium* and *Alexanderium* were found around the Chao Phraya bay with a mean population of 2-19 x $10^3/m^3$.

The dominant copepod nauplii were abundant (ranging from 720-980 x $10^3/m^3$) in nearby Malaysian waters, especially Terengganu and Johore waters. *Chaetognatha* larvae had very similar distribution to that of copepod. Ostracod was abundant at nearshore waters of (Pattany bay, Terengganu). Siphonophora larvae was also encountered along Terengganu and Johore nearshore waters. Numerous larvae of shrimp, stomatopod, brachyura, gastropod, bivalve, lucifer, pteropod and larvacean were found especially in nearshore waters of the South China Sea.

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