Distribution, Abundance and Species Composition of Phytoplankton in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam

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ABSTRACT

Four hundred and four samples of phytoplankton were collected from 79 stations in Sabah, Sarawak and Brunei Darussalam waters, during 2 cruises of M.V. SEAFDEC, 10 July - 2 August 1996 and 1 – 24 May 1997. The Samples were collected from surface, seasonal thermocline and chlorophyll maximum depth. Three hundred and ten taxa, composed of 2 species of blue green alga, 139 species of diatoms and 150 species of dinoflagellates, were identified. The occurrence of phytoplankton species in each layer were recorded. The species frequently found predominant in the surface layer were *Oscillatoria erythraea*, *Thalassionema frauenfeldii* and *Pseudosolenia calcar-avis,* and in the chlorophyll maximum layer were *Oscillatoria erythraea*, *Thalassionema frauenfeldii*, *Chaetoceros affinis*, *C. messanensis* and *Fragilariopsis doliolus*. Small numbers of toxic dinoflagelates were observed. Quantity of phytoplankton in the chlorophyll maximum layer was most abundant among the three layers observed. Diversity and evenness indices of phytoplankton in this layer were high during both sampling periods.

Keywords : Phytoplankton, South China Sea, Sabah, Sarawak, Brunei Darussalam.

Introduction

Sabah, Sarawak and Brunei Darussalam waters was defined as the second area of the SEAFDEC collaboratives research program in the South China Sea. Previous studies on phytoplankton in this area were mostly on red tides. The Malaysian state of Sabah and Brunei Darussalam have faced with problem on red tide caused by *Pyrodinium bahamense* var. *compressum* that was associated with paralytic shellfish poisoning (PSP). It has been known to have occurred since 1976. There have been reported of over 300 cases of illness and over 30 deaths. Most PSP cases were reported to have been caused by bivalve while less were attributed to fish (*Sardinella* spp. and *Decapterus* spp.). The outbreaks occurred in June – July and December – January annually particularly in Brunei Bay, Kimanis Bay and Kota Kinabalu [Sang and Ming (1984) , Jaafar *et al*. (1989) ; Ming and Wong (1989) , Usup and Ismail (1989)].

There is little information on phytoplankton species composition in the deep water layer in this area. Subsurface chlorophyll maxima (SCM) are well known phenomenon in temperate, subtropical and tropical oceanic regions. They are found at the depths around or below the seasonal thermocline [Furuya and Marumo (1983)]. The ecological significance of the maximum layer has been studied in relation to primary production [Yamaguchi and Ichimura (1980) , Ishimaru and Fujita (1982)].

The purpose of this study is to describe species composition, abundance and distribution of phytoplankton in different water layers including chlorophyll maximum layer and to determine species diversity indices during 2 sampling periods.

Materials and Methods

Sampling, counting and identification.

The collaborative surveys were carried out on board M.V. SEAFDEC from 4 July – 4 August 1996 and 25 April – 31 May 1997. Phytoplankton were collected from 79 stations during 10 July – 2 August 1996 and 1 – 24 May 1997 [Fig. 1]. Four hundred and four samples were taken by Van Dorn water sampler at surface, seasonal thermocline (below the mixed layer) and chlorophyll maximum depth. The sampling depths followed ICTD record at each station. The chlorophyll maximum depths of all stations were below seasonal thermocline depths. The water samples of 20 – 30 l were filtered by phytoplankton net which its mesh size is 20 µm and preserved with 1% formalin immediately. The samples were concentrated by precipitation. Phytoplankton identification and cell count were made by using a small counting slide (0.25 ml), compound microscope fitted with a phase contrast device, inverted microscope and an electron microscope.

Statistical analysis

The richness index (R), diversity index (H′) and evenness index (E) were computed by the Menhinick index, Shannon index and the modified Hill's ratio respectively according to the methods in Ludwig and Reynolds (1988). The equations are as follows :

$$R = \frac{S}{\sqrt{n}}$$

$$H' = -\sum_{i=1}^{s} \left[(n_i / n) \ln (n_i / n) \right]$$

$$E = \frac{(1/\lambda) - 1}{e^{H'} - 1}$$

$$\lambda = \sum_{i=1}^{s} \frac{n_i (n_i - 1)}{n (n - 1)}$$

where : S = the total number of species

n = the total cell number

n_i = the cell number of species i

Results

Thermocline and chlorophyll maximum

From ICTD records, the mixed layer extended from the surface to ~ 20 – 55 m during the 1st cruise and from the surface to ~ 15 – 50 m during the 2nd cruise. Below this mixed layer, a sharp thermocline was found between 50 – 200 m depth. The chlorophyll maximum depths were observed at depths 18 – 70 m in the coastal area and 45 – 80 m in the offshore area [Table 1].

Identification

A total of 310 taxa was identified from samples of this study. There were 2 species belonging to 2 genera of blue green alga, 139 species of 55 genera of diatoms and 150 species of 37 genera of dinoflagellates. The taxonomic list is given in Table 2.

Table 1 Range of sampling levels
S = Surface, Th = Thermocline depth, Ch = Chlorophyll maximum depth

Date	Area	Sea depth	Sampling level (m)		
		(m)	S	Th	Ch
10 Jul. - 2 Aug. 1996	Coastal	20 - 178	2 - 4	-	18 - 70
	Offshore	65 - 2,893	2 - 4	22 - 55	45 - 80
1 - 24 May 1997	Coastal	20 - 233	2 - 4	-	18 - 65
	Offshore	56 -2,893	2 - 4	15 - 50	45 - 80

Phytoplankton abundance

Phytoplankton cell densities in the surface layer of the coastal area were abundant in both sampling periods [Figs. 2 & 3]. The highest cell count in July 1996 was 3,658 cells/l found at st. 16 and that in May 1997 was found 2,068 cells/ l at st. 47. Figs. 4 –7 show the average cell densities of the coastal stations and the offshore stations at different sampling depths. It was observed that cell densities in the chlorophyll maximum layer were mostly higher than those in the surface and thermocline layer, and the distinct abundance of this layer was found in Sarawak waters in July 1996. In May 1997, cell densities in all sampling layers of the offshore area were very low.

Species occurrence at different sampling levels

The occurrence of phytoplankton species at surface, thermocline and chlorophyll maximum depth is shown in Table 2. Most of diatom species presented from surface through chlorophyll maximum layer. *Oscillatoria erythraea*, *Chaetoceros lorenzianus*, *Proboscia alata*, *Pseudosolenia calcar-avis* and *Thalassionema frauenfeldii* were abundant in all sampling layers. The species found abundant only in the chlorophyll maximum layer were *Azpeitia nodulifera*, *Bacteriastrum comosum*, *B. elongatum*, *Chaetoceros compressus*, *C. radicans*, *Fragilariopsis doliolus*, *Leptocylindrus mediterraneus* and *Planktoniella sol*. About 14 diatom species were absent at surface and presented in the thermocline and chlorophyll maximum layer. The species occurred only at surface were *Asteromphalus elegans*, *Chaetoceros cuvisetus, C. densus, C. distans* and *Thalassiosira thailandica*. In this study, dinoflagellates were not abundant in any sampling layer. The occurrence of many dinoflagellate species related to the sampling depths. The species presented only at surface were *Alexandrium fraterculus*, *A. leei*, *Amphidinium* spp., *Amphisolenia globifera*, *Ceratium arietinum*, *C. limulus*, C. *symmetricum* and *Phalacroma rapa*. Thirty five species were found below the mixed layer.

Phytoplankton at chlorophyll maximum depth reached the maximum species number almost all stations during 2 sampling periods. The range and average of diatom and dinoflagellate species number at different sampling levels in table 3 show that the average diatom species number in the chlorophyll maximum layer of coastal and offshore area were higher than those in the other layers. The dinoflagellate species number in the thermocline layer were high in both periods.

Occurrence of dominant species

Phytoplankton population was dominated by 1 species of blue green algae and 16 species of diatoms during 2 sampling periods. Figs. 8 & 9 show the occurrence of dominant species at surface and chlorophyll maximum depth in July 1996. Six species dominated surface phytoplankton, whereas 12 species occurred as dominant species in the chlorophyll maximum layer. *Oscillatoria erythraea* and *Thalassionema frauenfeldii* were abundant at surface in the offshore and coastal area respectively. These species were also dominant in the chlorophyll maximum layer. *Chaetoceros radicans*, was absent at surface, but occurred abundantly in the chlorophyll maximum layer of the offshore area and

Table 2. Taxonomic list and occurence of phytoplanton at different sampling levels.
S = Surface, Th = Thermocline depth, Ch = Chlorophyll maximum depth
x = present, xx = frequent, xxx = abundant

Species	Sampling levels		
	S	Th	Ch
Phylum Cyanophyceae (Blue green algae)			
Calothrix crustacea Schouseboe & Thuret	x	x	x
Oscillatoria (*Trichodesmium*) *erythraea* (Ehrenberg) Kutzing	xxx	xxx	xxx
Phylum Bacillariophyceae (Diatom)			
Achnanthes spp.	-	x	x
Actinocyclus spp.	x	x	x
Actinoptychus senarius (Ehrenberg) Ehrenberg	x	x	x
A. splendens (Shadbolt) Ralfs	x	x	x
Asterolampra marylandica Ehrenberg	xx	xx	xx
Asteromphalus elegans Greville	x	-	-
A. heptactis (Bre'bisson) Greville	xx	x	-
A. flabellatus (Bre'bission) Greville	xx	x	-
A. sarcophagus Wallich	-	x	x
Azpeitia africana (Janisch ex A. Schmidt) G. Fryxell & T.P. Watki	-	x	xx
A. barronii G. Fryxell & T.P. Watkins	-	x	x
A. nodulifera (A. Schmidt) G. Fryxell & P.A. Sims	x	xx	xxx
Bacillaria paxillifera (O.F. Muller) Hendey	x	xx	xx
Bacteriastrum comosum Pavillard	xx	xx	xxx
B. delicatulum Cleve	xx	xx	xx
B. elongatum Cleve	x	xx	xxx
B. furcatum Shadbolt	x	x	x
B. hyalinum Lauder	x	x	x
Campylodiscus spp.	x	x	xx
Cerataulina bicornis (Ehrenberg) Hasle	x	x	x
C. pelagica (Cleve) Hendey	x	x	x
Chaetoceros aequatorialis Cleve	x	x	-
C. affinis Lauder	xx	xxx	xxx
C. anastomosans Grunow	x	x	x
C. atlanticus Cleve	x	xx	xx
C. brevis Schütt	x	x	x
C. cinctus Gran	-	x	x
C. coarctatus Lauder	xx	xx	xx
C. compressus Lauder	xx	xx	xxx
C. costatus Pavillard	x	x	x
C. curvisetus Cleve	x	-	-
C. dadayi Pavillard	xx	xx	xx
C. danicus Cleve	-	x	x
C. debilis Cleve	x	x	-
C. decipiens Cleve	x	x	x
C. densus (Cleve) Cleve	x	-	-
C. denticulatus Lauder	xx	xx	xx
C. didymus Ehrenberg	xxx	xx	x
C. distans Ehrenberg	x	-	-
C. diversus Cleve	xx	xx	xx
C. eibenii Grunow	-	x	x
C. laevis Leuduger - Fortmorel	xx	xx	x
C. lorenzianus Grunow	xxx	xxx	xxx
C. messanensis Castracane	xx	xx	xxx
C. peruvianus Brigtwell	xx	xx	xxx
C. pseudocurvisetus Mangin	xx	xx	xx
C. pseudodichaeta Ikari	xx	xx	xx

Table 2. Continue

Species	Sampling levels		
	S	Th	Ch
Chaetoceros radicans Schütt	-	xx	xxx
C. rostratus Lauder	x	x	x
C. seiracanthus Gran	x	x	x
C. simplex Ostenfeld	x	xx	xx
C. socialis Lauder	x	x	-
C. subtilis Cleve	xx	x	-
C. sumatranus Karsten	xx	xx	xx
C. tetrastichon Cleve	x	x	x
C. tortissimus Gran	x	x	-
C. weissflogii Schütt	x	x	-
C. vanheurecki Gran	x	x	x
Climacodiam biconcavum Cleve	xx	xx	xx
C. frauenfeldianum Grunow	xx	xx	xx
Corethron hystrix Hensen	xx	xx	xx
Coscinodiscus centralis Ehrenberg	x	x	x
C. concinnus W. Smith	x	xx	xx
C. gigas Ehrenberg	x	x	x
C. jonesianus (Greville) Ostenfeld	xx	xx	xx
C. perforatus Ehrenberg	x	x	x
C. radiatus Ehrenberg	x	x	x
C. weilesii Gran & Angst	x	x	x
Cyclotella spp.	x	xx	xx
Cylindrotheca closterium (Ehrenberg) Reimann & Lewin	x	x	x
Dactyliosolen blavyanus (Bergon) Hasle	x	x	x
D. phuketensis (Sundström) Hasle	x	x	x
Delphineis spp.	-	x	x
Diploneis spp.	-	xx	xx
Detonula pumila (Castracane) Gran	x	xx	xx
Ditylum brightwelii (West) Grunow	x	x	x
D. sol Grunow	x	x	x
Entomoneis spp.	x	x	x
Eucampia cornuta (Cleve) Grunow	x	x	x
E. zodiacus Ehrenberg	x	x	x
Fragilaria cylindrus Grunow	x	xx	xx
F. oceanica Cleve	x	x	x
F. striatula Lyngbye	x	xx	xx
Fragilariopsis doliolus (Wallich) Medlin & Sims	x	xx	xxx
Gossleriella tropica Schütt	x	xx	xx
Guinardia cylindrus (Cleve) Hasle	xx	xx	xx
G. flaccida (Castracane) H. peragallo	x	x	x
G. striata (Stolterfoth) Hasle	xx	xx	xx
Halicotheca thamensis (Shrubsole) Ricard	x	x	x
Haslea gigantea (Hustedt) Simonsen	xx	xx	xx
H. wawrikae (Hustedt) Simonsen	xx	xx	xx
Hemiaulus hauckii Grunow	xx	xx	xx
H. indicus Karsten	xx	xx	xx
H. membranacea Cleve	xx	xx	xx
H. sinensis Greville	xx	xx	xx
Hemidiscus cuneiformis Wallich	x	x	x
Lauderia annulata Gran	x	x	x
Leptocylindrus danicus Cleve	x	x	x
L. mediterraneus (H. Peragallo) Hasle	x	xx	xxx
Lioloma delicatulum (Cupp) Hasle	x	xx	xx
L. elongatum (Grunow) Hasle	x	xx	xx

Table 2. Continue

Species	Sampling levels		
	S	Th	Ch
Lioloma pacificum (Cupp) Hasle	-	xx	xx
Lithodesmium undulatum Ehrenberg	x	x	xx
Meuniera membranacea (Cleve) P.C Silva	xx	xx	xx
Nanoneis hasleae R.E. Norris	x	xx	xx
Navicula distans (W. Smith) Rafts	x	xx	xx
N. transitrans (Grunow) Cleve	-	x	x
N. spp.	x	x	x
Odontella mobiliensis (Bailey) Grunow	x	xx	xx
O. sinensis (Greville) Grunow	xx	xx	xx
Neodelphineis sp.	x	x	x
Neostreptotheca subindica Von Stosch	x	x	x
Nitzschia longissima (Bre'bisson) Ralfs	x	x	x
N. bicapitata Cleve	x	x	x
N. spp.	x	x	x
Planktoniella blanda (A. Schmidt) Syvertsen & Hasle	x	xx	xx
P. sol (Wallich) Schütt	x	xx	xxx
Pleurosigma spp.	xx	xx	xx
Porosira denticulata Simonsen	-	x	x
Proboscia alata (Brightwell) Sundström	xxx	xxx	xxx
Pseudoguinardia recta Von Stosch	x	x	x
Pseudo-nitzschia cuspida (Hasle) Hasle	x	x	x
P. pseudodelicatissima (Hasle) Hasle	x	x	x
P. pungens (Grunow & Cleve) Hasle	xx	xx	xx
P. subpacifica (Hasle) Hasle	x	x	x
P. spp.	x	x	x
Pseudosolenia calcar - avis (Chultz) Sundström	xxx	xxx	xxx
Rhizosolenia acuminata (H. Peragallo) Gran	x	x	x
R. bergonii H. Peragallo	x	x	xx
R. castracanei var. *castracanei* H. Peragallo	x	x	xx
R. castracanei var. *neglecta* Sundström	-	x	x
R. clevei var. *clevei* Ostenfeld	xx	xx	xx
R. clevei var. *communis* Sundström	x	x	x
R. formosa H. Peragallo	x	x	x
R. hyalina Ostenfeld	x	x	x
R. imbricata Brightwell	xx	xx	xx
R. robusta Norman	x	x	x
R. setigera Brightwell	x	xx	xx
R. styliformis Brigthwell	xx	xx	xx
Stephanopyxis palmeriana (Greville) Grunow	x	x	xx
Thalassionema bacillare (Heiden) Kolbe	-	x	xx
T. frauenfeldii (Grunow) Hallegraeff	xxx	xxx	xxx
T. javanicum (Grunow) Hasle	x	xx	xx
T. nitzschioides (Grunow) Mereschkowsky	xxx	xx	xx
T. pseudonitzschioides (Schuette & Schrader) Hasle	-	xx	xx
Thalssiothrix longissima Cleve & Grunow	x	xx	xx
T. gibbura Hasle	-	x	x
Thalassiosira eccentrica (Ehrenberg) Cleve	xx	xx	xx
T. leptopus (Grunow) Hasle & G. Fryxell	x	x	x
T. lineata Jouse'	x	x	x
T. subtilis (Ostenfeld) Gran	xx	xx	x
T. thailandica Boonyapiwat	x	-	-
T. spp.	x	x	x
Tropidoneis sp.	-	x	x

Table 2. Continue

Species	Sampling levels		
	S	Th	Ch
Phylum Dinophyceae (Dinoflagellate)			
Alexandrium concavum (Gaarder) Balech	x	x	-
A. fraterculus (Balech) Balech	x	-	-
A. leei Balech	x	-	-
A. tamarense (Lebour) Balech	x	x	-
A. tamiyavanichi Balech	xx	xx	xx
A. spp.	x	x	x
Amphidinium spp.	x	-	-
Amphisolenia bidentata Schroder	xx	xx	xx
A. globifera Stein	x	-	-
A. schauinslandii Lemmermann	x	x	x
A. trinax Schütt	-	x	x
Amylex triacantha (Jörgensen) Sournia	-	x	x
Ceratium arietinum Cleve	x	-	-
C. azoricum Cleve	x	x	x
C. belone Cleve	x	x	x
C. biceps Claparede & Lachmann	x	x	x
C. bigelowii Kofoid	-	-	x
C. boehmii Graham & Bronikosky	xx	xx	xx
C. candelabrum (Ehrenberg) Stein	xx	xx	xx
C. carriense Gourret	x	x	-
C. concillians Jörgensen	x	x	x
C. contortum Gourret	x	x	x
C. declinatum (Karsten) Jörgensen	x	x	xx
C. deflexum (Kofoid) Jörgensen	x	x	-
C. dens Ostenfeld & Schmidt	x	x	x
C. falcatum (Kofoid) Jörgensen	x	x	x
C. furca (Ehrenberg) Claparede & Lachmann	xx	xx	xx
C. fusus (Ehrenberg) Dujardin	xx	xx	xx
C. gibberum Gourret	xx	xx	xx
C. gravidum Gourret	-	x	x
C. hexacanthum Gourret	x	x	x
C. horridum (Cleve) Gran	xx	xx	xx
C. humile Jörgensen	xx	xx	xx
C. incisum (Karsten) Jörgensen	x	x	x
C. inflatum (Kofoid) Jörgensen	x	x	x
C. kofoidii Jörgensen	x	x	x
C. longipes (Bailey) Gran	x	x	x
C. limulus Gourret	x	-	-
C. lunula (Schimpe) Jörgensen	x	x	x
C. macroceros (Ehrenberg) Vanholf	xx	x	-
C. massiliense (Gourret) Karsten	x	x	x
C. pentagonum Gourret	x	x	x
C. platycorne Daday	-	-	x
C. praelongum (Lemmermann) Kofoid	x	x	x
C. pulchellum Schroder	xx	xx	xx
C. ranipes Cleve	x	x	xx
C. schmidtii Jörgensen	xx	xx	xx
C. schroeteri Schroder	x	x	x
C. symmetricum Pavillard	x	-	-
C. teres Kofoid	xx	xx	xx
C. trichoceros (Ehrenberg) Kofoid	xx	xx	xx
C. tripos (O.F. Muller) Nitzsch	xx	x	x
C. vulture Cleve	x	xx	xx
Ceratocorys armata Schütt Kofoid	-	x	x

Table 2 Continue

Species	Sampling levels		
	S	Th	Ch
Ceratocorys gorretii Paulsen	x	x	x
C. horrida Stein	xx	xx	xx
C. magna kofoid	-	-	x
Citharisthes regius Stein	-	x	-
Corythodinium tesselatum (Stein) Loeblich Jr. & Loeblich	x	x	x
Dinophysis acuminata Claparede & Lachmann	-	-	x
D. caudata Saville - Kent	xx	xx	xx
D. hastata Stein	x	x	x
D. infundibula Schiller	x	x	x
D. miles Cleve	x	x	xx
D. odiosa (Pavillard) Tai & Skogsberg	-	-	x
D. schuettii Murray & Whitting	x	xx	xx
D. uracantha Stein	-	x	x
Diplopsalis lenticulata Berg	xx	xx	xx
D. spp.	x	x	x
Diplopsalopsis sp.	-	x	x
Dissodium asymmetricum (Mangin) Loeblich	x	x	-
Fragilidium spp.	x	x	xx
Goniodoma polyedricum (Pouchet) Jörgensen	xx	xx	xx
Gonyaulax digitale (Pouchet) Jörgensen	x	x	x
G. fragilis (Schütt) Kofoid	-	x	x
G. glyphorhynchus Murry & Whitting	x	x	x
G. hyalina Ostenfeld & Whitting	-	x	x
G. milneri (Murray & Whitting) Kofoid	-	-	x
G. pacifica Kofoid	-	x	x
G. polygramma Stein	xx	xx	xx
G. scrippsae Kofoid	-	xx	x
G. *spinifera* (Claparede & Lachmann) Diesing	xx	xx	xx
G. verior Sournia	-	x	x
G. spp.	xx	xx	xx
Gymnodinium sanguineum Hirasaka	x	x	x
G. spp.	xx	xx	xx
Gyrodinium spp.	x	x	x
Heterocapsa spp.	x	x	x
Heterodinium blackmanii (Murray & Whitting) Kofoid	x	x	x
H. rigdenae Kofoid	-	x	x
H. sp.	x	x	x
Histioneis spp.	x	x	x
Kofoidnium sp.	x	x	x
Lingulodinium polyedrum (Stein) Dodge	x	x	x
Ornithocercus heteroporus Kofoid	-	x	x
O. magnificus Stein	xx	xx	xx
O. quadratus Schütt	-	x	x
O. splendidus Schütt	-	x	x
O. steinii Schütt	-	x	x
O. thumii (A. Schmidt) Kofoid & Skogsberg	xx	xx	xx
Oxytoxum parvum Schiller	-	x	x
O. scolopax Stein	xx	x	x
O. subulatum Kofoid	x	xx	xx
Oxyphysis oxytoxides Kofoid	-	-	x
Phalacroma acutoides Balech	x	x	x
P. argus Stein	x	x	x
P. doryphorum Stein	xx	xx	xx
P. favus Kofoid & Michener	xx	xx	xx
P. parvulum (Schütt) Jörgensen	x	x	x

Table 2. Continue

Species	Sampling levels		
	S	Th	Ch
Phalacroma rapa Stein	x	-	-
P. rotundatum (Claparede & Lachmann) Kofoid & Michener	x	xx	xx
P. rudgei Murry & Whitting	x	x	x
Podolampas bipes Stein	xx	xx	xx
P. palmipes Stein	xx	xx	xx
P. spinifera Okamura	xx	xx	xx
Preperidinium meunieri (Pavillard) Elbachter	x	xx	xx
Prorocentrum arcuatum Issel	-	-	x
P. balticum (Lohmann) Loeblich	-	x	-
P. compressum (Bailey) Abe' & Dodage	xx	xx	xx
P. concavum Fukuyo	-	-	x
P. emarginatum Fukuyo	-	-	xx
P. micans Ehrenberg	x	x	x
P. sigmoides Böhm	x	x	-
Protoceratium spinulosum (Murray & Whitting) Schiller	-	x	x
Protoperidinium abei (Abe') Balech	-	x	x
P. angustum P. Dangeard	-	-	x
P. conicum (Gran) Balech	xx	xx	xx
P. crassipes (Kofoid) Balech	xx	x	x
P. curtipes (Jörgensen) Balech	-	x	x
P. depressum (Baley) Balech	xx	xx	xx
P. diabolus (Cleve) Balech	x	x	x
P. divergents (Ehrenberg) Balech	xx	xx	xx
P. elegans (Cleve) Balech	xx	xx	xx
P. globulum (Stein) Balech	x	x	x
P. grande (Kofoid) Balech	xx	xx	xx
P. hirobis (Abe') Balech	x	x	-
P. latispinum (Mangin) Balech	x	x	x
P. leonis (Pavillard) Balech	xx	x	-
P. murrayi (Kofoid) Balech	x	x	-
P. nipponicum (Abe') Balech	x	x	-
P. oceanicum (Vanholf) Balech	xx	xx	x
P. ovum (Schiller) Balech	x	x	x
P. pacificum Kofoid & Michener	xx	xx	xx
P. pallidum (Ostenfeld) Balech	x	x	x
P. pellucidum Bergh	x	x	x
P. pentagonum (Gran) Balech	x	x	x
P. quanerense (Schroder) Balech	xx	x	x
P. roseum Paulsen	-	x	x
P. spinulosum (Schiller) Balech	x	x	x
P. stenii (Jörgensen) Balech	xx	xx	xx
P. subinerme (Paulsen) Balech	x	x	x
P. thorianum (Paulsen) Balech	-	x	-
Pyrocystis fusiformis Wyville - Thomson ex Blachman	xx	xx	xx
P. hamulus Cleve	xx	xx	xx
P. lunula species complex	xx	xx	xx
P. noctiluca Murray ex Haeckel	xx	xx	xx
Pyrophacus horologium Stein	xx	x	-
P. steinii (Schiller) Wall & Dale	x	x	-
Scripsiella trochoidea (Stein) Balech	xx	xx	x
S. spp.	xx	xx	xx
Sinophysis sp.	x	x	-
Spiraulax kofoidii Graham	-	x	x
Triposolenia truncata Kofoid	-	x	x

frequently found below the mixed layer [Table 2].

In May 1997, surface phytoplankton was dominated *by Oscillatoria erythraea* in most of the offshore stations, while *Thalassionema frauenfeldii* and *Chaetoceros didymus* were the dominant species in the coastal area [Fig. 10]. There were 10 species presented in highest cell densities in the chlorophyll maximum layer. The occurrence of these species is shown in Fig. 11.

The species frequently found predominantly at surface were *Oscillatoria erythraea*, *Thalassionema frauenfeldii* and *Pseudosolenia calcar-avis* and in the chlorophyll maximum layer were *Oscillatoria erythraea*, *Thalassionema frauenfeldii*, *Chaetoceros affinis*, *C. messanensis* and *Fragilariopsis doliolus*.

Occurrence of some toxic dinoflagellates

Toxic dinoflagellates were found in low cell densities. Among them, *Alexandrium tamiyavanichi* occurred in highest cell density (36 cells/l) at surface of station 19 in May 1997. Figs 12 & 13 show the distribution of *Alexandrium* spp. in 3 layers during 2 sampling periods. They occurred in all sampling layers and were frequently observed in the surface layer.

Species diversity indices

The richness indices of phytoplankton in the chlorophyll maximum layer varied considerably through the study area during 2 sampling periods. The highest richness index (3.30) was found in this layer of the offshore station in May 1997. All of species diversity indices are shown in Table 4. Wide ranges of diversity indices in the offshore area were observed. The average values of diversity indices and evenness indices calculated from the samples taken from the chlorophyll maximum layer were high.

Discussion and Conclusion

Phytoplankton in the present study was less abundant than those in the Area I where the great blooms occurred at many stations [Boonyapiwat (1997)]. The Gulf of Thailand (Area I) is the semi-enclosed bay which enrich with nutrients by water run-off from land [Piyakarnchana *et al*. (1991)] whereas the sampling stations of this study area, the Area II, were mostly located in the open sea.

Olivieri (1983) studies phytoplankton communities of the Cape Peninsular, South Africa and noted that higher cell counts in the subsurface chlorophyll maxima (SCM) were associated with high concentration of chlorophyll-a. Furuya and Marumo (1983) reported about high cell densities in the SCM in the western North Pacific Ocean and chlorophyll-a concentrations were 2.1 – 7.5 times higher than that of the surface. The result from this study also shows that phytoplankton densities in the chlorophyll maximum layer was highest compared with those in other sampling layers during July 1996 and May 1997.

During the southwest monsoon in July, the surface current flowed northeasterly from the west coast of Borneo along the coast of Sarawak through Sabah [O'Neil and Eason (1982)]. Nutrients were stirred up and transported by the strong southwesterly and southerly winds. The cell densities observed in July 1996 were high especially those in the surface layer of the coastal area. Siripong (1984), analyzed the surface current measured by GEK and ship's drift in the South China Sea, concluded that the surface current during the transition period between northeast and southwest monsoons in May was weaker and varied in direction than in ordinary monsoons. It was found in the present study that phytoplankton concentration in this period (May 1997) was very low in the offshore area.

Many phytoplankton species were observed at the depths below the mixed layer, and absent in the surface layer. *Chaetoceros radicans* was the dominant species in the chlorophyll maximum layer of 4 stations but never found in the surface sample. Then it was not observed in the area I because only surface phytoplankton was collected from this area [Boonyapiwat (1997)]. *Planktoniella*

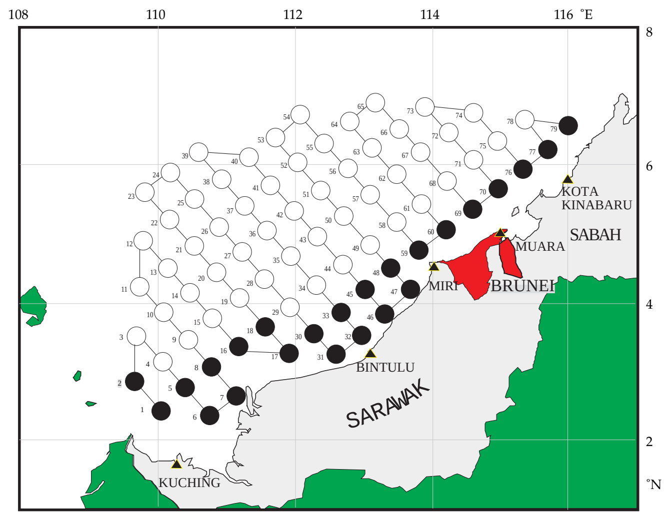

Fig. 1. Location of sampling station.

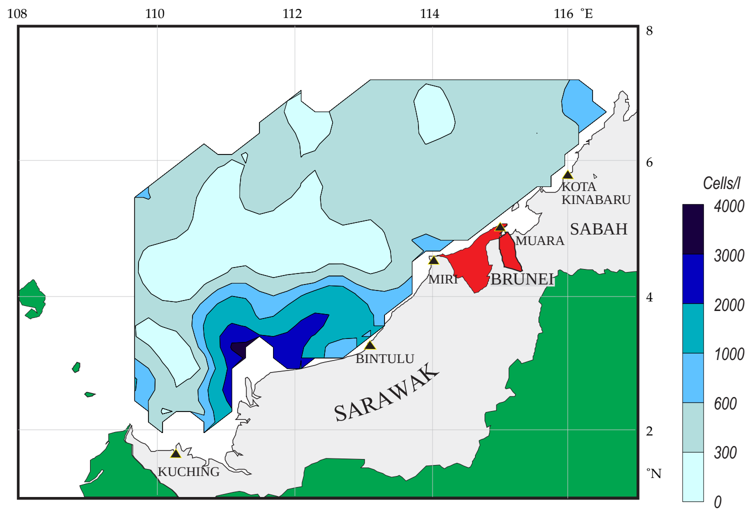

Fig. 2. Phytoplankton density in the surface layer in July 1996.

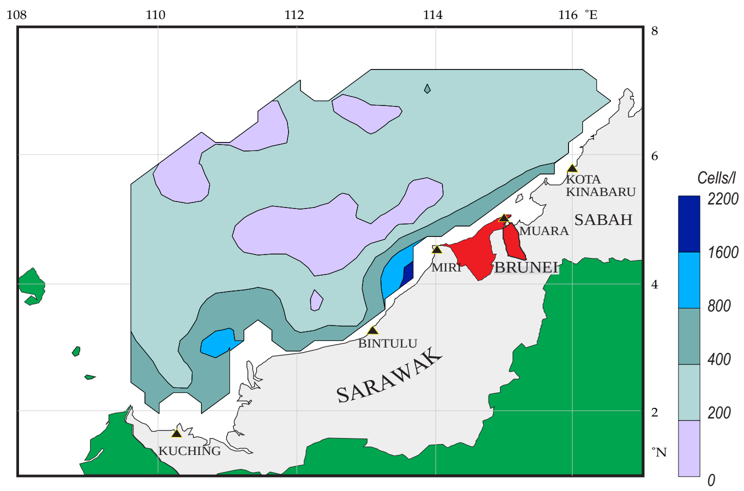

Fig. 3. Phytoplankton density in the surface layer in May 1997.

Table 3. Range and average of phytoplankton species number of different sampling levels.

Date	Area	Sampling level	Species number			
			Diatom		Dinoflagellate	
			Range	Average	Range	Average
10 Jul. - 2 Aug. 1996	Coastal	Surface	19 - 48	28	5 - 26	13
		Chl. Max.	19 - 62	41	5 - 25	13
	Offshore	Surface	4 - 33	19	7 - 27	15
		Thermocline	10 - 45	20	6 - 46	17
		Chl. Max.	12 - 56	32	2 - 35	14
1 - 24 May 1997	Coastal	Surface	5 - 33	18	5 - 26	13
		Chl. Max.	11 - 57	33	5 - 25	13
	Offshore	Surface	4 - 19	10	9 - 25	16
		Thermocline	1 - 36	10	7 - 25	17
		Chl. Max.	10 - 32	26	6 - 25	12

Table 4. Range and average of species diversity indices [richness indices (R), diversity indices (H') and evenness indices (E)] for two phytoplankton samping periods.

Date	Area	Sampling level	R		H'		E	
			Range	Average	Range	Average	Range	Average
10 July-2 August 1996	Coastal	Surface	0.55 - 2.48	1.72	1.825 - 3.610	2.707	0.3445 - 0.7062	0.567
		Chl.max.	0.50 - 2.93	1.62	2.679 - 3.5148	2.937	0.3137 - 0.7345	0.548
	Offshore	Surface	0.77 - 3.10	1.97	0.6650 - 3.9796	2.247	0.2697 - 0.6682	0.447
		Thermocline	1.15 - 3.19	1.93	0.7078 - 3.2786	2.092	0.2499 - 0.6876	0.406
		Chl.max.	0.27 -3.13	1.71	0.5239 - 3.9895	2.712	0.2410 - 0.7381	0.532
1 - 24 May 1997	Coastal	Surface	0.85 - 3.08	1.66	1.1339 - 2.9845	2.035	0.2905 - 0.7018	0.463
		Chl.max.	0.54 - 2.64	1.68	1.0160 - 3.2729	2.574	0.2901 - 0.7341	0.518
	Offshore	Surface	1.11 - 2.79	1.76	0.6703 - 2.8981	1.799	0.1628 - 0.7024	0.391
		Thermocline	1.00 - 2.43	1.62	0.6476 - 3.0990	1.380	0.2606 - 0.6370	0.323
		Chl.max.	0.92 - 3.33	1.84	1.2207 - 3.2765	2.566	0.2335 - 08245	0.539

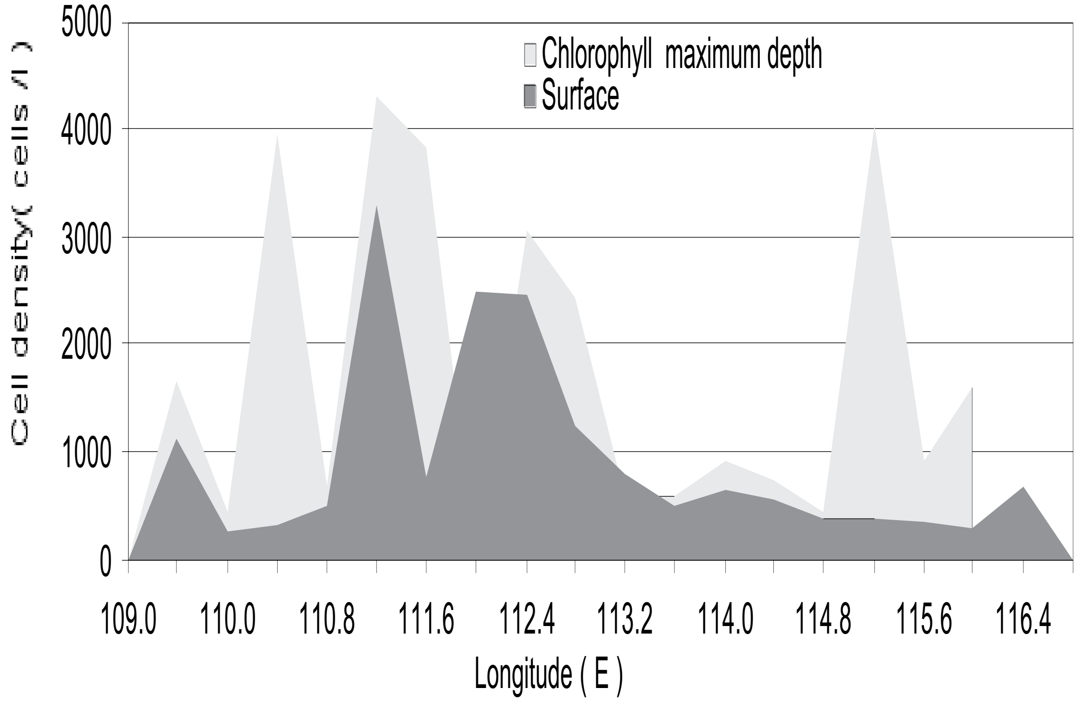

Fig. 4. Phytoplankton abundance in the coastal area of Sabah, Sarawak and Brunei Darussalam in July 1996.

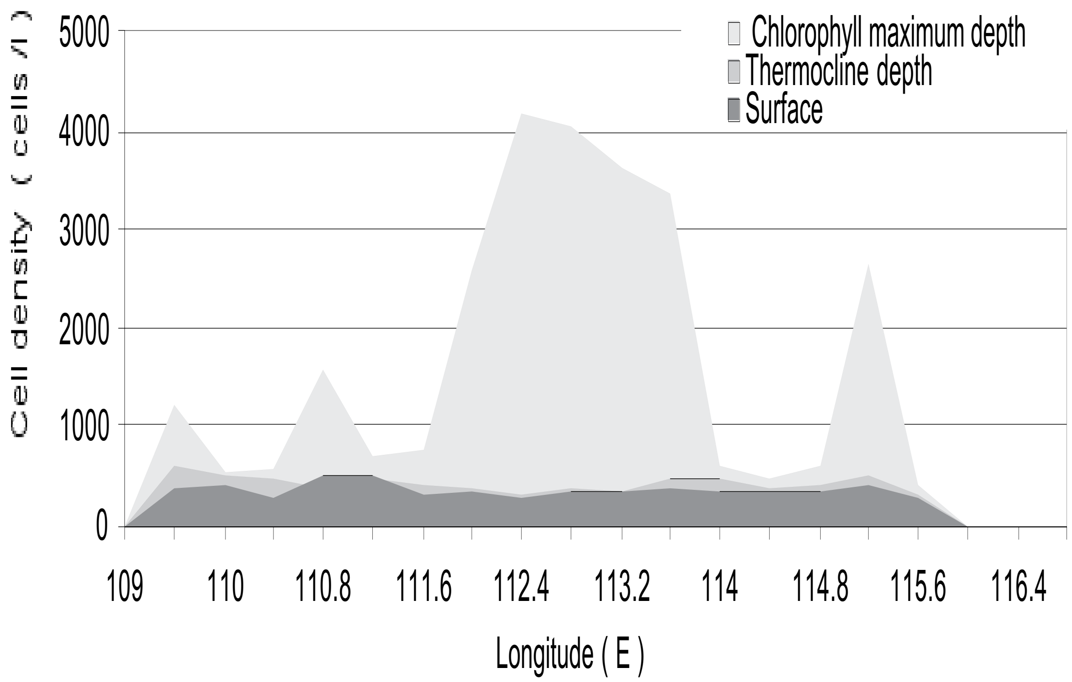

Fig. 5. Phytoplankton abundance in the offshore area of Sabah, Sarawak and Brunei Darussalam in July 1996.

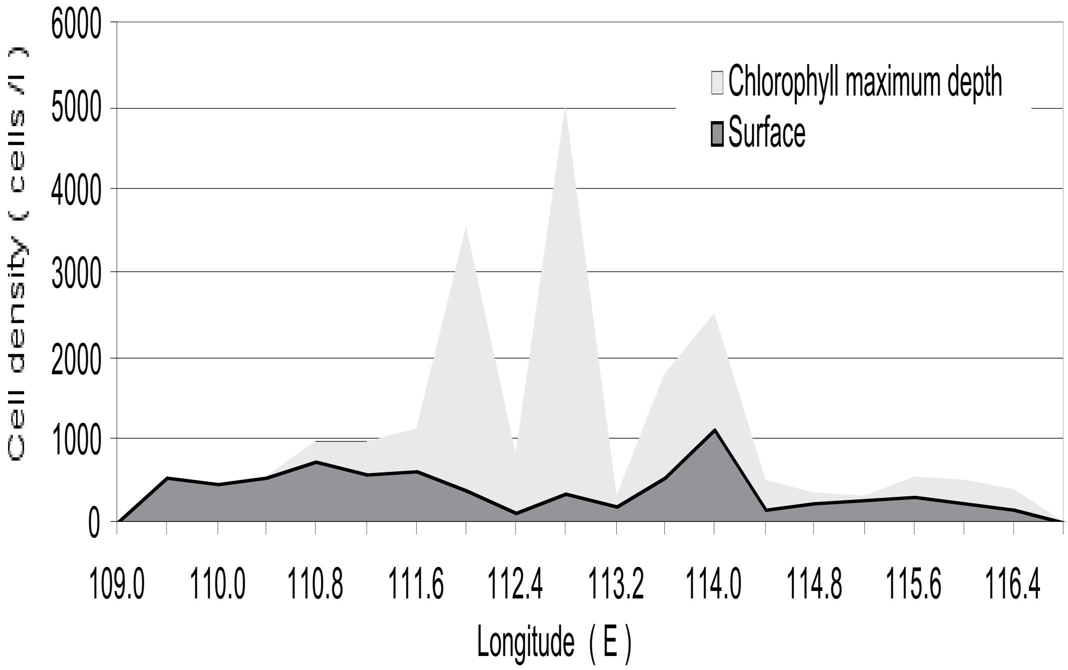

Fig. 6. Phytoplankton abundance in the coastal area of Sabah, Sarawak and Brunei Darussalam in May 1997.

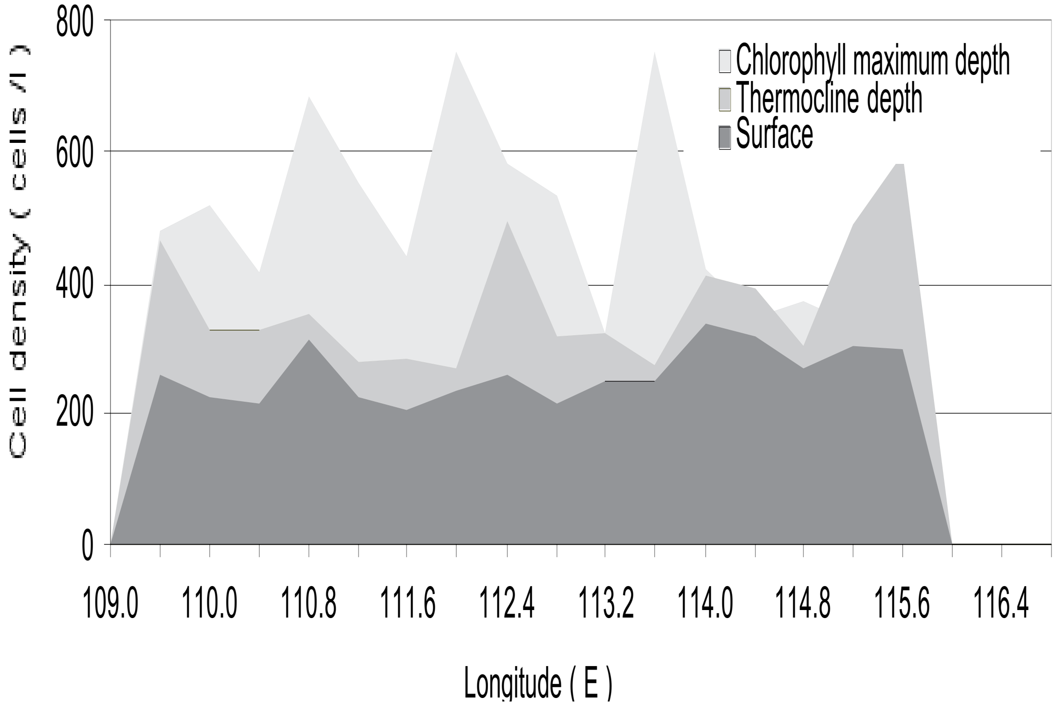

Fig. 7. Phytoplankton abundance in the offshore area of Sabah, Sarawak and Brunei Darussalam in May 1997.

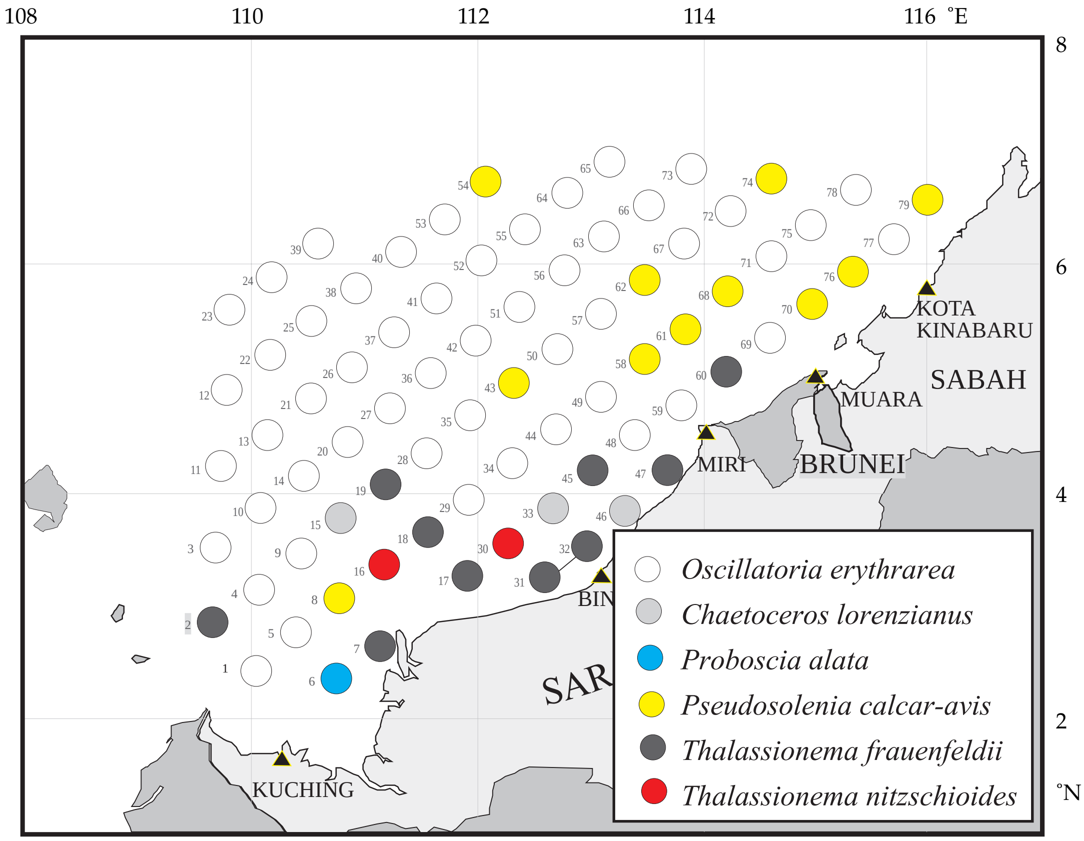

Fig. 8. Occurrence of dominant species in the surface layer in July 1996.

sol, which is known to be a 'shade flora' [Furuya and Marumo (1983)] was mostly found in the deep water layer. It dominated phytoplankton population in the chlorophyll maximum layer of the offshore station in May 1997. Venrick *et al.* (1973) reported the phytoplankton species in the subsurface chlorophyll maxima in the Pacific Oceanic north of latitude 40–N, were the same as those in the upper waters, whereas south of 38–N samples from this layer were dominated by species did not occur in shallower samples. *Asteromphalus sarcophagus* was observed in the western North Pacific Ocean at the depths below 80 m where irradiance was <0.8 % of that of the surface [Furuya and Marumo (1983)]. It has been recorded at depths of 60 – 100 m in the Indian Ocean [Thorrington – Smith (1970)]. This species also found below the mixed layer in both sampling periods. *Thalssionema frauenfeldii* was the dominant species from the surface through chlorophyll maximum layer and *T. nitzchioides* was dominant in the surface layer and frequently observed in the deeper layers. They were also the dominant species in the surface layer of the Area I [Boonyapiwat (1997)]. In contrary, these species were recorded by Furuya and Marumo (1983) that they were found only around and below SCM.

The harmful dinoflagellate, *Pyrodinium bahamnse* was not observed in any sample. This species caused the red tide problem in the coastal area of Sabah and Brunei Darussalam as mentioned before. Thus, its distribution may confined to the coastal area. Many species of *Alexandrium* were toxic [Balech (1995)]. *A. tamiyavanichi* was found in highest number of all toxic dinoflagellate observed in the Gulf of Thailand (Area I) during pre-NE monsoon season or September [Boonyapiwat (1997)]. It also occurred in high cell density in May in the present study area. This indicated the spreading of *A. tamiyavanichi* in the Gulf of Thailand through the adjacent region.

Furuya and Marumo (1983) revealed that the diversity indices and evenness indices of the SCM samples collected from the western North Pacific Ocean were very high, > 4.0 and 0.8, respectively, showing that the SCM of this area were not composed of dominant species. These

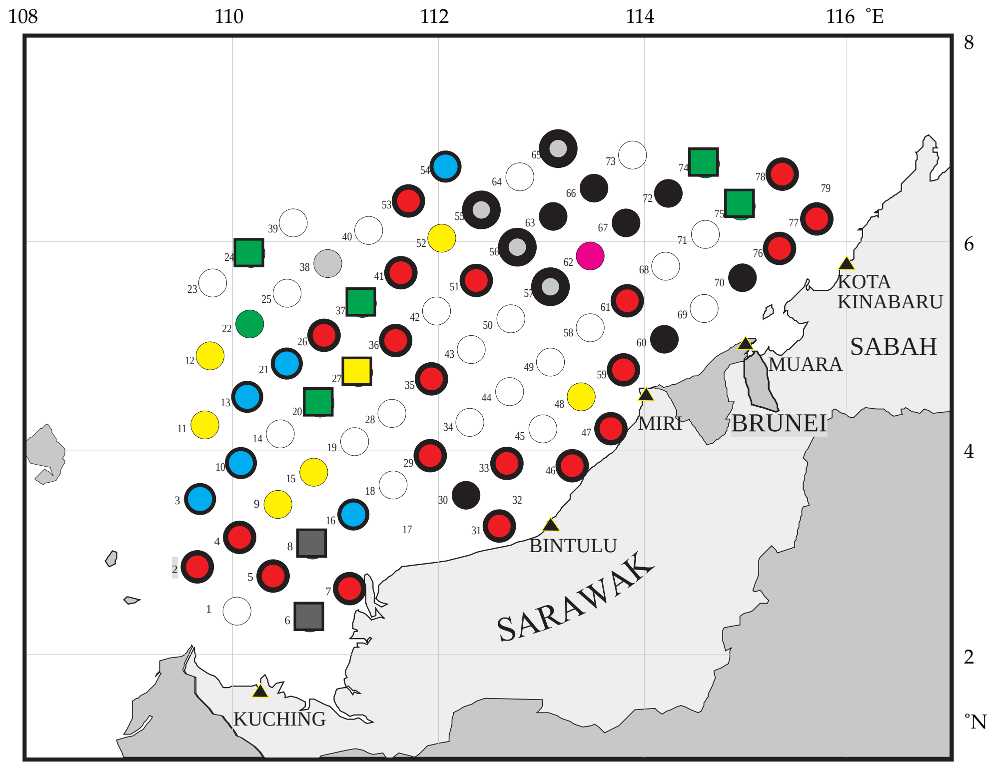

Fig. 9. Occurrence of dominant species in the chlorophyll maximum layer in July 1996.

- *Oscillatoria erythraea*
- *Bacteriastrum comosum*
- *B. elongatum*
- *Chaetoceros affinis*
- *C. compressus*
- *C. lorenzianus*
- *C. messanensis*
- *C. radicans*
- *Fragilariopsis doliolus*
- *Leptocylindrus mediterraneus*
- *Pseudosolenia calcar-avis*
- *Thalassionema frauenfeldii*

values calculated from the chlorophyll maximum samples in the present study were much lower because of the occurrence of dominant species. However, the average values were higher than those computed from the other layers. The high diversity and evenness indices of both surface and chlorophyll maximum samples in the coastal area during July 1996 probably due to the surface water circulation during the southwest monsoon.

It is concluded that the southwest monsoon in July influenced the abundance of phytoplankton population. The chlorophyll maximum layer was productive with phytoplankton abundance and high species diversity. The occurrence of some phytoplankton species were limited by depths. Toxic dinoflagellate presented from surface to the deep water layer in low cell densities. The results of this investigation will be of useful for the studies on marine ecology, red tides and marine fisheries of Malaysia, Brunei Darussalam and neighboring countries.

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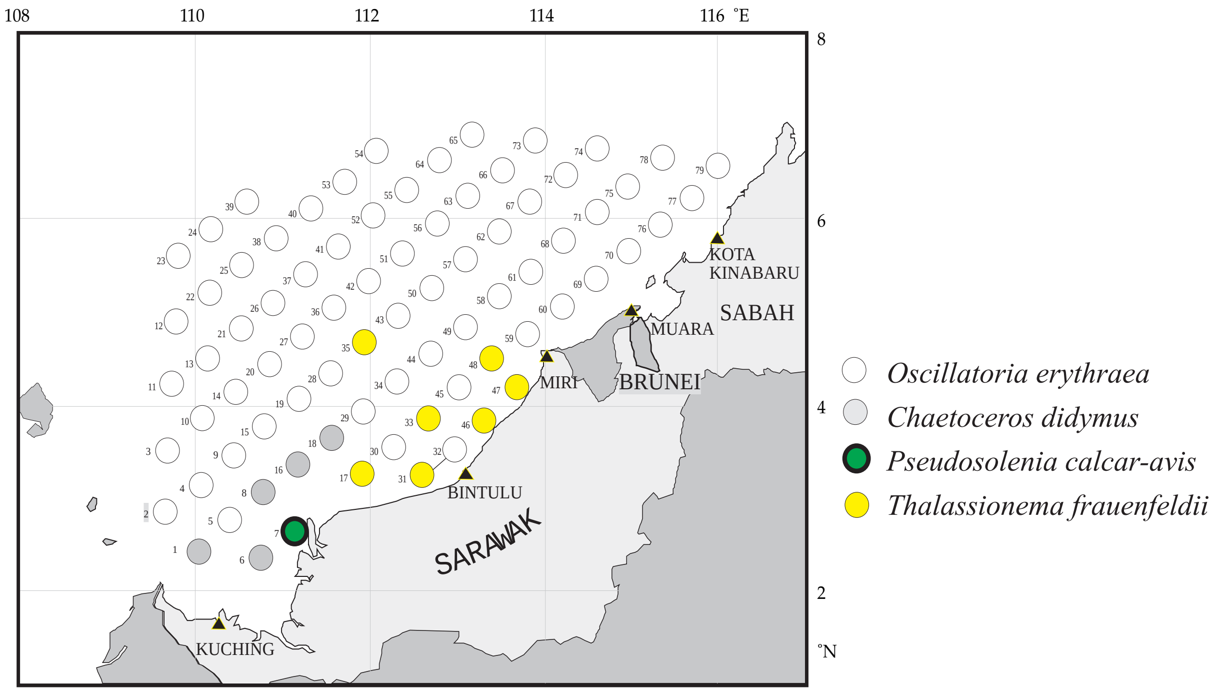

Fig. 10. Occurrence of dominant species in the surface layer in May 1997.

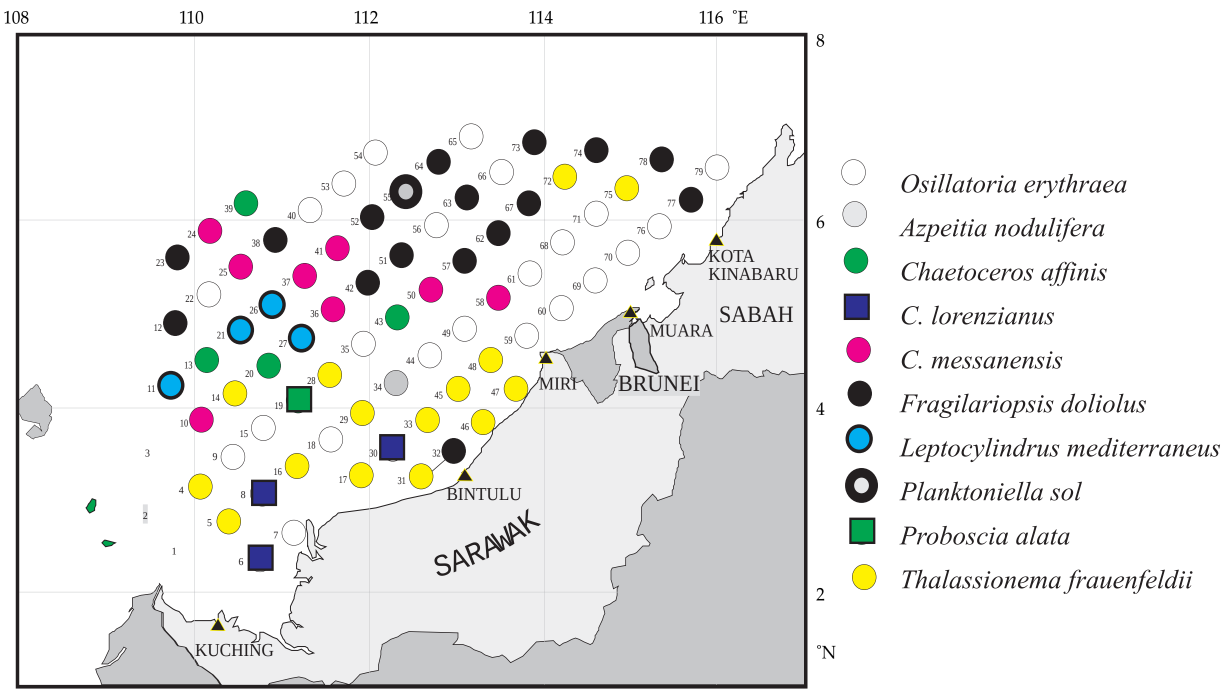

Fig. 11. Occurrence of dominant species in the chlorophyll maximum layer in May 1997.

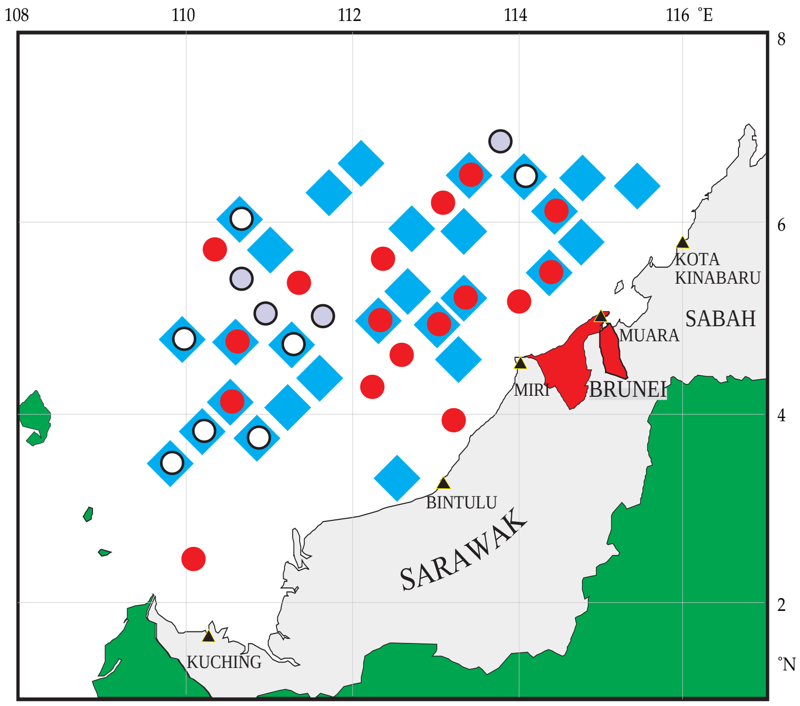

Fig.12. Distribution of *Alexandrium* spp. in July 1996 (1-36 cells/l).

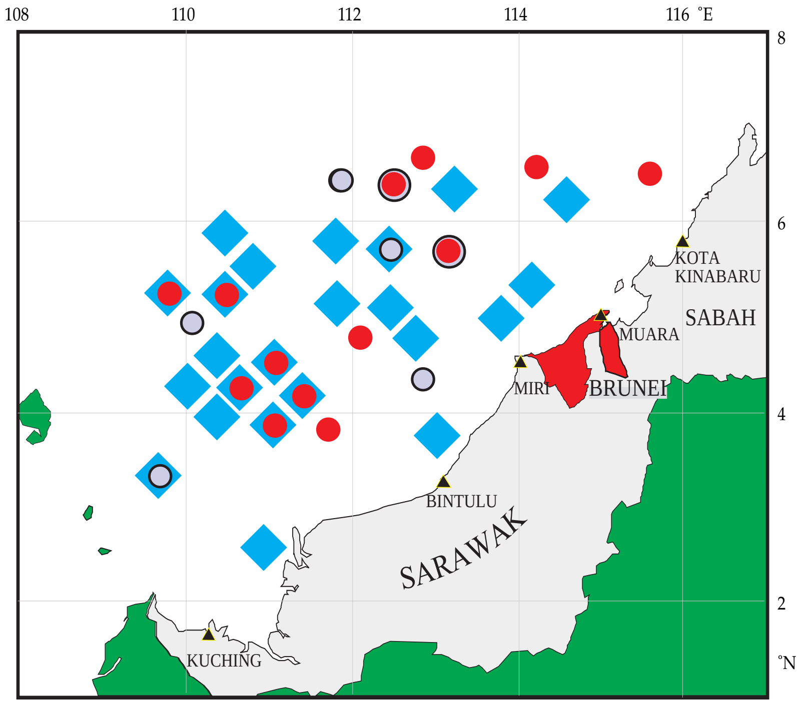

Fig.13. Distribution of *Alexandrium* spp. in May 1997 (1-36 cells/l).

◆ Surface

● Thermocline depth

○ Chlorophyll maximum depth

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