Species Composition, Abundance and Distribution of Phytoplankton in the Thermocline Layer in the South China Sea, Area III: Western Philippines

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ABSTRACT

Phytoplankton density, taxonomic composition and distribution in the thermocline layer were investigated to compare with those in the surface layer of 31 stations in the western Philippines during 17 April – 9 May 1998. The samples were collected from surface, thermocline depth (the beginning of thermocline), and chlorophyll maximum depth. In this study, thermocline depth and chlorophyll maximum depth were included in the thermocline layer. Three hundred and thirty-eight taxa, composed of 2 species of blue green alga, 144 species of diatoms and 168 species of dinoflagellates were identified. The occurrence of the species in each sampling depth were recorded. Phytoplankton densities at chlorophyll maximum depth were mostly highest among the sampling depths observed. The most abundance was 20,683 cells/l found at thermocline depth of station 24 due to the blooms of many diatom species. *Oscillatoria* (*Trichodesmium*) *erythraea* and *Chaetoceros lorenzianus* were dominant from surface through chlorophyll maximum depth. Seven species of diatoms presented as the dominant species only in the thermocline layer. The toxic dinoflagellates were found in low cell densities. Diversity and evenness indices of phytoplankton at chlorophyll maximum depth were high.

Keywords : phytoplankton, thermocline layer, chlorophyll maximum, South China Sea, western Philippines

Introduction

A study on distribution, abundance and species composition of phytoplankton in the South China Sea has been carried out since 1995 as one of the Interdepartmental Collaborative Research Program. The pattern of abundance, distribution of phytoplankton species and diversity indices were examined in the Area I (Gulf of Thailand and east coast of Peninsular Malaysia) and Area II (Sabah, Sarawak and Brunei Darussalam). The investigation of the Area III (Western Philippines) is focused on phytoplankton in the thermocline layer.

Very little works has been done about phytoplankton in the deep water layer especially thermocline zone in the South China Sea. Thermocline zone is the productive area and important for tuna fisheries. The thermocline ridges have been found to be the places where tunas aggregate, mainly due to the accumulation of forage organisms [Silas and Pillai (1982)]. Subsurface chlorophyll maxima (SCM) or deep chlorophyll maxima are usually found at the depths around or below the seasonal thermocline. Phytoplankton in this layer of the western North Pacific Ocean was found abundant and high diversity [Furuya and Marumo (1983)].

The purpose of this study is to describe species composition, abundance and distribution of phytoplankton in the thermocline layer (the beginning of thermocline depth and chlorophyll maximum depth) compare with those in the surface layer. Species diversity indices are also determined.

Materials and Methods

Sampling, counting and identification

The survey was carried out on board M.V. SEAFDEC during 7 April – 19 May 1998 in western Philippines. Phytoplankton were collected from 31 stations during 17 April – 9 May 1998 [Fig.1]. Ninety – two sea water samples were taken with Van Dorn water sampler from surface, the beginning of thermmocline or thermocline depth and chlorophyll maximum depth. The sampling depths were determined using ICTD record at each station. The water samples of 20 – 40 l were filtered through 20 µm mesh phytoplankton net and preserved with 1 % formalin immediately. All samples were concentrated by sedimentation. Phytoplankton in the concentrated samples were counted and identified by using a small counting slide (0.25 ml), compound microscope fitted with a phase contrast device, inverted microscope and an electron microscope.

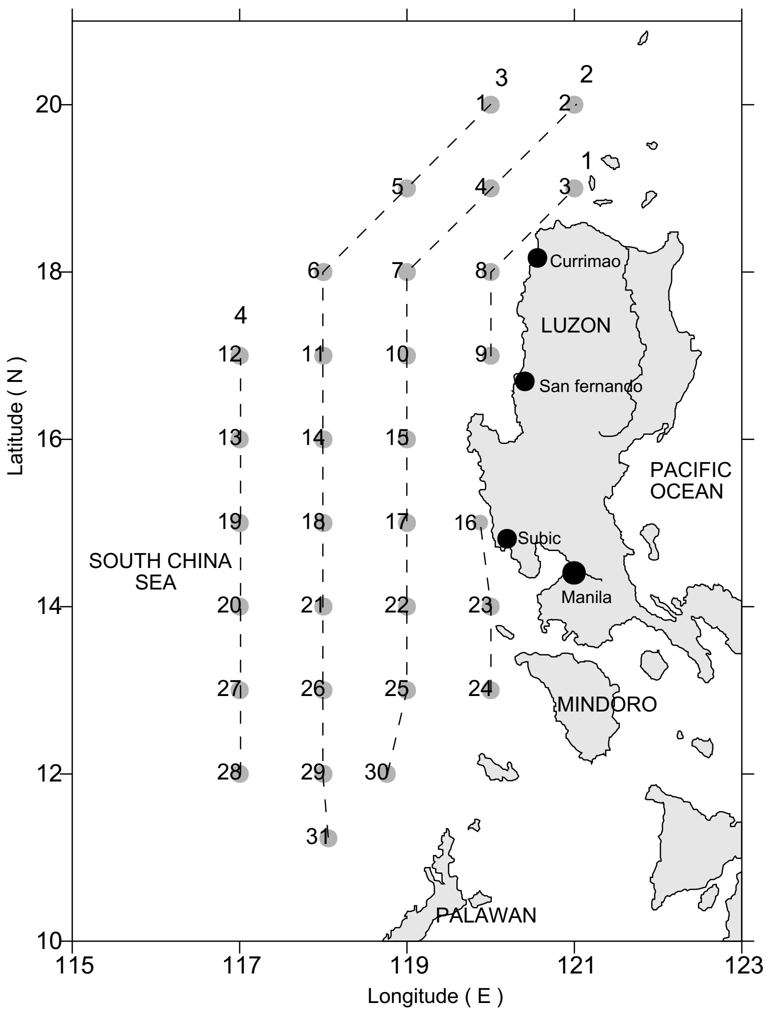

Fig. 1 Location of sampling stations

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 ~ 10 – 75 m. Below the mixed layer, a sharp thermocline was found and extended to ~ 80 – 200 m. The chlorophyll maximum depths were observed below the beginning of thermocline. According to 4 lines of sampling stations in Fig.1, thermocline depths (the depths at the beginning of thermocline) and chlorophyll maximum depths of the line were considered separately. The ranges of thermocline depths of line 1 – 4 were 10 – 45 m, 20 – 50 m, 20 – 58 m and 18 – 75 m respectively. The chlorophyll maximum depths of those lines varied from 40 – 90 m, 60 – 100 m, 65 – 100 m and 80 – 100 m respectively [Table 1] while the sea depths were observed with relatively high variation [Fig. 2].

Identification

A total of 338 taxa were recorded in this study, composed of 2 genera including 2 species of blue green alga, 56 genera representing 144 species of diatoms, and 32 genera, 168 species of dinoflagellates [Table 2].

Abundance and distribution

Total phytoplankton densities in the surface layer were high near the coastal area of the western Philippines and decreased with distance from the coast [Fig.3]. Cell densities at station 13 & 14 were lowest (134 cells/l). The highest cell density in the surface layer was 1,386 cells/

Table 1 Ranges of depths, sampling depths and phytoplankton cell densities at 4 lines of sampling stations.

BG : Blue green algae

Line	Depth (m)	Sampling depth (m)	Total (cells /l)	BG (cells /l)	Diatom (cells /l)	Dinoflagellate (cells /l)
1	54 -2,955	S : 2 - 4	146 - 1,386	23 - 331	26 - 1,334	10 - 59
		Th : 10 - 45	145 - 20,683	32 - 1,605	57 - 20,309	25 - 187
		Ch : 40 - 90	219 - 1,752	0 - 33	56 - 1,744	7 - 53
2	671 - 4,657	S : 2 - 4	136 - 298	37 - 245	21 - 98	14 - 82
		Th : 20 - 55	147 - 494	37 - 440	10 - 172	28 - 83
		Ch : 60 - 100	368 - 516	0 - 92	342 - 486	10 - 46
3	555 - 4,034	S : 2 - 4	134 - 184	28 - 80	37 - 86	20 - 61
		Th : 20 - 58	148 - 233	0 - 124	48 - 133	20 - 66
		Ch : 65 - 100	339 - 2,623	0	204 - 2,618	5 - 60
4	720 - 4,042	S : 2 - 4	134 - 154	39 - 178	24 - 79	27 - 56
		Th : 18 - 75	163 - 321	5 - 224	49 - 135	26 - 59
		Ch : 80 -100	338 - 1,306	0 - 103	193 - 1,274	17 - 42

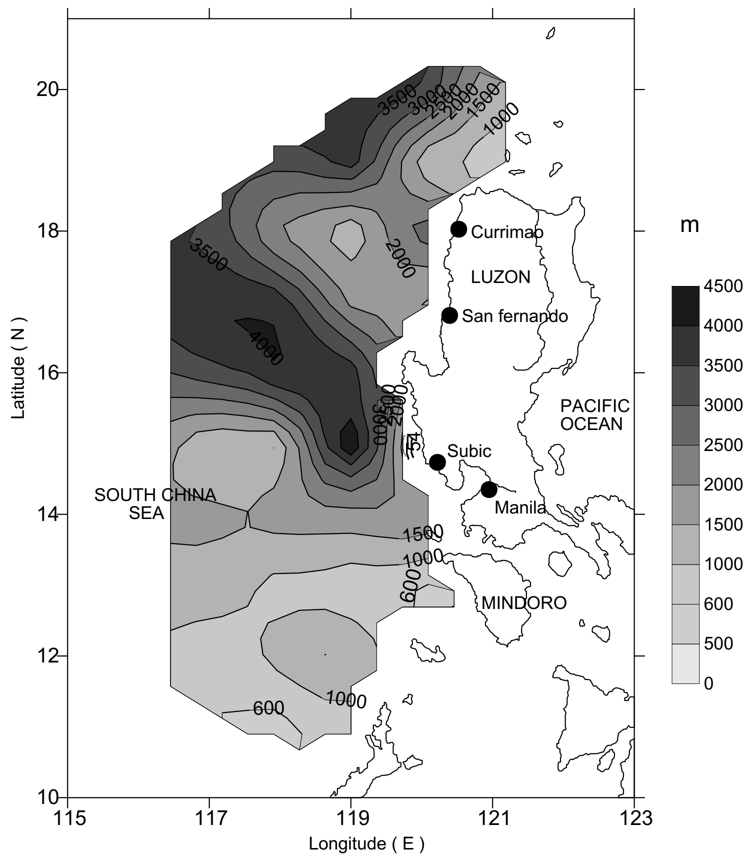

Fig. 2. Depth contour (m) of the study area.

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

Specices	**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)			
Actinocyclus spp.	x	x	x
Actinoptychus senarius (Ehrenberg) Ehrenberg	-	x	x
A. splendens (Shadbolt) Ralfs	x	x	x
Asterolampra marylandica Ehrenberg	xx	xx	xx
Asteromphalus elegans Greville	x	x	-
A. heptactis (Bre'bisson) Greville	xx	x	-
A. sarcophagus Wallich	-	x	x
Azpeitia africana (Janisch ex A. Schmidt) G. Fryxell & T.P. Watkins	-	x	xx
A. nodulifera (A. Schmidt) G. Fryxell & P.A. Sims	x	xx	xx
Bacillaria paxillifera (O.F. Muller) Hendey	x	xx	xx
Bacteriastrum comosum Pavillard	xx	xx	xx
B. delicatulum Cleve	xx	xx	xx
B. elongatum Cleve	x	xx	xx
B. furcatum Shadbolt	x	x	x
B. hyalinum Lauder	x	x	x
B. minus Karsten	x	x	x
Bleakeleya notata (Grunow) Round	-	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. affinis var. *willei* (Gran) Hustedt	xx	xx	xx
C. anastomosans Grunow	x	x	x
C. atlanticus Cleve	x	xx	xx
C. atlanticus var. *neapolitana* (Schroder) Hustedt	x	xx	xx
C. brevis Schütt	x	x	x
C. castracanei Karsten	-	x	-
C. coarctatus Lauder	xx	xx	xx
C. compressus Lauder	xx	xx	xx
C. convolutus Castracane	-	x	-
C. costatus Pavillard	x	x	x
C. curvisetus Cleve	x	-	-
C. dadayi Pavillard	xx	xx	xx
C. decipiens Cleve	x	x	x
C. denticulatus Lauder	x	xx	xx
C. didymus Ehrenberg	xxx	xx	x
C. diversus Cleve	xx	xx	xx
C. laevis Leuduger - Fortmorel	xx	xx	x
C. lorenzianus Grunow	xxx	xxx	xxx
C. messanensis Castracane	xx	xx	xxx
C. peruvianus Brigtwell	xx	xxx	xx
C. pseudocurvisetus Mangin	x	x	x
C. pseudodichaeta Ikari	xx	xx	xx

Table 2 **(Cont.)**

Species	Sampling levels		
	S	Th	Ch
Chaetoceros radicans Schütt	-	xx	xx
C. rostratus Lauder	x	x	x
C. seiracanthus Gran	x	xx	xx
C. siamensis Ostenfeld	x	-	-
C. simplex Ostenfeld	x	xx	xx
C. socialis Lauder	x	x	-
C. subtilis Cleve	x	x	-
C. sumatranus Karsten	xx	xx	xx
C. tetrastichon Cleve	x	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 argus Hensen	-	-	x
C. centralis Ehrenberg	x	x	x
C. concinnifromis Simonsen	-	x	-
C. concinnus W. Smith	x	x	x
C. gigas Ehrenberg	x	x	x
C. granii Gough	-	-	x
C. jonesianus (Greville) Ostenfeld	xx	xx	xx
C. perforatus Ehrenberg	x	x	x
C. radiatus Ehrenberg	x	x	x
C. reniformis Castracane	-	-	x
C. weilesii Gran & Angst	x	x	x
Cyclotella spp.	x	xx	xx
Cylindrotheca closterium (Ehrenberg) Reimann & Lewin	x	x	x
Dactyliosolen antareticus Castracane	-	x	x
D. blavyanus (Bergon) Hasle	x	x	x
D. fragilissimus (Bergon) Hasle	-	x	x
Delphineis spp.	-	x	x
Diploneis spp.	-	x	x
Detonula pumila (Castracane) Gran	x	x	x
Ditylum brightwelii (West) Grunow	x	x	x
D. sol Grunow	x	xx	xx
Entomoneis spp.	x	x	x
Eucampia cornuta (Cleve) Grunow	x	x	x
E. zodiacus Ehrenberg	x	x	x
Fragilaria cylindrus Grunow	x	x	x
F. striatula Lyngbye	x	xx	xx
Fragilariopsis doliolus (Wallich) Medlin & Sims	x	xxx	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	xx

Table 2 (Cont.)

Specices	Sampling levels		
	S	Th	Ch
Lioloma delicatulum (Cupp) Hasle	x	xx	xx
L. elongatum (Grunow) Hasle	x	x	x
L. pacificum (Cupp) Hasle	-	xx	xx
Lithodesmium undulatum Ehrenberg	x	x	x
Meuniera membranacea (Cleve) P.C Silva	x	x	x
Nanoneis hasleae R.E. Norris	x	xx	xx
Navicula distans (W. Smith) Rafts	x	xx	xx
N. spp.	x	x	x
Neostreptotheca subindica Von Stosch	x	x	x
Nitzschia bicapitata Cleve	x	x	x
N. longgissima (Bre'bissn) Ralfs	x	x	x
N. spp.	x	x	x
Odontella longicruris (Greville)	-	x	-
O. mobiliensis (Bailey) Grunow	x	x	xx
O. sinensis (Greville) Grunow	x	x	x
Pachyneis gerlachii Simonsen	x	x	x
Palmeria hardmaniana Greville	x	x	x
P. ostenfeldii (Ostenfeld) van Stosch	-	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	xx	xx	xx
Pseudoguinardia recta Von Stosch	x	x	x
Pseudo-nitzschia 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	xx	xxx	xx
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. dayana H. peragallo	-	x	-
R. formosa H. Peragallo	x	x	x
R. hyalina Ostenfeld	x	x	x
R. imbricata Brightwell	x	x	x
R. ostenfeldii Sundström	-	-	x
R. robusta Norman	x	x	x
R. setigera Brightwell	x	xx	xx
R. styliformis Brigthwell	xx	xxx	xx
Stephanopyxis palmeriana (Greville) Grunow	x	x	x
Thalassionema bacillare (Heiden) Kolbe	-	x	xx
T. frauenfeldii (Grunow) Hallegraeff	xx	xxx	xxx
T. javanicum (Grunow) Hasle	x	xx	xx
T. nitzschioides (Grunow) Mereschkowsky	xx	xx	xx
T. pseudonitzschioides (Schuette & Schrader) Hasle	-	x	x
Thalssiothrix longissima Cleve & Grunow	x	xx	xx
T. gibberula 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. oestrupii (Ostenfeld) Hasle	x	x	x

Table 2 (Cont.)

Specices	Sampling levels		
	S	Th	Ch
Thalassiosira subtilis (Ostenfeld) Gran	x	x	x
T. spp.	x	x	x
Tropidoneis sp.	-	x	x
Phylum Dinophyceae (Dinoflagellate)			
Alexandrium compressum (Fukuyo , Yoshida, & Inoue) Balech	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	-
A. trinax Schütt	-	x	-
Amylex triacantha (Jörgensen) Sournia	-	x	x
Balechina sp.	x	x	x
Ceratium arietinum Cleve	x	-	-
C. azoricum Cleve	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	-
C. contortum Gourret	x	x	x
C. contortum var. *sultans* (Schröder) Jörgensen	-	-	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	x	xx	xx
C. gravidum Gourret	-	xx	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	-
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	x	x	-
C. massiliense (Gourret) Karsten	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	xx	xx

Table 2 **(Cont.)**

Specices	**Sampling levels**		
	S	**Th**	**Ch**
Ceratium symmetricum Pavillard	x	-	-
C. symmetricum var. *coarctatum* (Pavillard) Graham & Bron	-	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
C. vulture var. *japonicum* (Schröder) Jörgensen	-	x	-
Ceratocorys armata (Schütt) Kofoid	-	x	x
C. gorretii Paulsen	x	x	x
C. horrida Stein	xx	xx	xx
C. magna kofoid	-	-	x
Cladopyxis sp.	x	x	x
Citharisthes apsteinii Schütt	-	x	-
Citharisthes regius Stein	-	x	-
Corythodinium tesselatum (Stein) Loeblich Jr. & Loeblich	x	x	x
Dinophysis acuminata Claparede & Lachmann	x	x	-
D. caudata Saville - Kent	xx	xx	xx
D. exigua Kofoid & Skogsberg	-	x	-
D. hastata Stein	x	x	x
D. miles Cleve	x	x	xx
D. schuettii Murray & Whitting	x	xx	xx
D. uracantha Stein	-	x	x
Diplopsalis lenticulata Berg	xx	xx	xx
D. spp.	x	x	x
Diplopelta parva (Abe') Matsuoka	-	-	x
Diplopsalopsis orbicularis (Paulsen) Meunier	-	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. grindleyi Reinecke	-	x	-
G. hyalina Ostenfeld & Whitting	x	x	x
G. milneri (Murray & Whitting) Kofoid	-	-	x
G. pacifica Kofoid	-	x	x
G. polygramma Stein	xx	xx	xx
G. scrippsae Kofoid	xx	xx	xx
G . spinifera (Claparede & Lachmann) Diesing	xx	xx	xx
G. subulatum Kofoid & Michener	-	x	-
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
Histioneis micheilana Murray & Whitting	-	-	x
H. rigdenae Kofoid	-	x	x
H. sp.	x	x	x
Kofoidnium sp.	x	xx	x
Lingulodinium polyedrum (Stein) Dodge	x	x	x
Ornithocercus heteroporus Kofoid	-	x	x
O. magnificus Stein	x	xx	xx
O. quadratus Schütt	-	x	x
O. splendidus Schütt	-	x	x

Table 2 **(Cont.)**

Specices	Sampling levels		
	S	Th	Ch
Ornithocercus steinii Schütt	-	x	x
O. thumii (A. Schmidt) Kofoid & Skogsberg	xx	xx	xx
Oxytoxum parvum Schiller	-	x	x
O. scolopax Stein	x	x	x
O. subulatum Kofoid	x	xx	xx
O. trubo Kofoid	-	x	-
Oxyphysis oxytoxides Kofoid	-	-	x
Palaephalacroma sp	-	x	x
Phaeopolykrikos hartmannii (Zimmerman) Matsuoka & Fukuyo	x	x	-
Phalacroma acutoides Balech	x	x	x
P. argus Stein	-	x	x
P. cuneus (Schütt) Abe'	x	x	-
P. doryphorum Stein	x	xx	xx
P. favus Kofoid & Michener	x	x	x
P. ovum Schütt	-	x	-
P. parvulum (Schütt) Jörgensen	-	x	x
P. rapa Stein	x	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
Polykrikos spp.	x	x	-
Preperidinium meunieri (Pavillard) Elbachter	x	xx	x
Prorocentrum balticum (Lohmann) Loeblich	-	x	-
P. compressum (Bailey) Abe' & Dodage	xx	xx	xx
P. concavum Fukuyo	-	-	x
P. emarginatum Fukuyo	-	-	xx
P. graclie Schütt	x	x	-
P. mexicanum Tafall	-	-	x
P. micans Ehrenberg	x	x	x
P. sigmoides Böhm	x	-	-
Protoceratium spinulosum (Murray & Whitting) Schiller	-	x	x
Protoperidinium abei (Abe') Balech	-	x	x
P. angustum P. Dangeard	-	-	x
P. brochii Kofoid & Swezy	-	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	x
P. diabolus (Cleve) Balech	x	x	-
P. divergents (Ehrenberg) Balech	x	x	x
P. elegans (Cleve) Balech	xx	xx	x
P. excentricum (Paulsen) Balech	x	x	-
P. grande (Kofoid) Balech	x	x	x
P. hirobis (Abe') Balech	x	x	-
P. latispinum (Mangin) Balech	x	x	x
P. leonis (Pavillard) Balech	xx	x	-
P. minutum Kofoid	-	x	-
P. murrayi (Kofoid) Balech	x	x	-
P. nipponicum (Abe') Balech	x	x	-
P. oblongum (Aurivillius) Parke & Dodge	-	x	-
P. obtusum (Aurivillius) Parke & Dodge	-	x	-
P. oceanicum (Vanholf) Balech	x	x	x
P. ovum (Schiller) Balech	x	x	x

Table 2 **(Cont.)**

Specices	Sampling levels		
	S	Th	Ch
Protoperidinium 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. solidicorne (Taylor)	x	x	-
P. spinulosum (Schiller) Balech	x	x	x
P. stenii (Jörgensen) Balech	x	xx	x
P. subinerme (Paulsen) Balech	x	x	x
P. tenuissimum Kofoid	-	-	x
P. thorianum (Paulsen) Balech	-	x	-
P. tristylum Stein	-	x	-
Pyrocystis fusiformis Wyville - Thomson ex Blachman	xx	xx	xx
P. hamulus Cleve	x	x	x
P. lunula species complex	xx	xx	xx
P. noctiluca Murray ex Haeckel	xx	xx	xx
Pyrophacus horologium Stein	x	x	-
P. steinii (Schiller) Wall & Dale	x	xx	-
Schuettiella mitra (Schütt) Balech	-	x	-
Scripsiella trochoidea (Stein) Balech	xx	xx	x
S. spp.	xx	xx	xx
Sinophysis sp.	x	x	-
Spiraulax kofoidii Graham	-	x	x
S. jolliffei Kofoid	-	x	-
Triposolenia truncata Kofoid	-	x	x
T. bicornis Kofoid	-	-	x

l observed at station 16. The distribution patterns of blue green algae, diatom and dinoflagellate in the surface layer are shown in Figs.4 – 6. Blue green algae was abundant near the coastal area of the uppermost part of the study area and near the Manila Bay. High cell density of diatom was found near the Subic Bay and at station off Mindoro, while dinoflagellate was found abundant in the upper part. The cell densities of total phytoplankton at 3 sampling depths shown in Fig.7 indicate that almost every high density of phytoplankton were observed at chlorophyll maximum depth except at station 24 where the density at thermocline depth was relatively high.

The ranges of phytoplankton density at different depths of each line are shown in Table 1. Cell densities of all groups (blue green algae, diatom and dinoflagellate) at thermocline depth in the line 1 varied considerably and the maximum cell counts of these groups were observed. Blue green algae was abundant from surface to thermocline depth and decreased in cell number at chlorophyll maximum depth. However, it was dominant at this depth in some stations [Fig. 10]. The exceptional high cell density (20,309 cells/ l) of diatom at thermocline depth of station 24 in the line 1 caused the density of phytoplankton higher than at chlorophyll maximum depth. In all other lines highest density were found at chlorophyll maximum depth, but dinoflagellate was most abundant at thermocline depth in all lines. The species number of diatom and dinoflagellate were highest at chlorophyll maximum depth and thermocline depth respectively [Table 3].

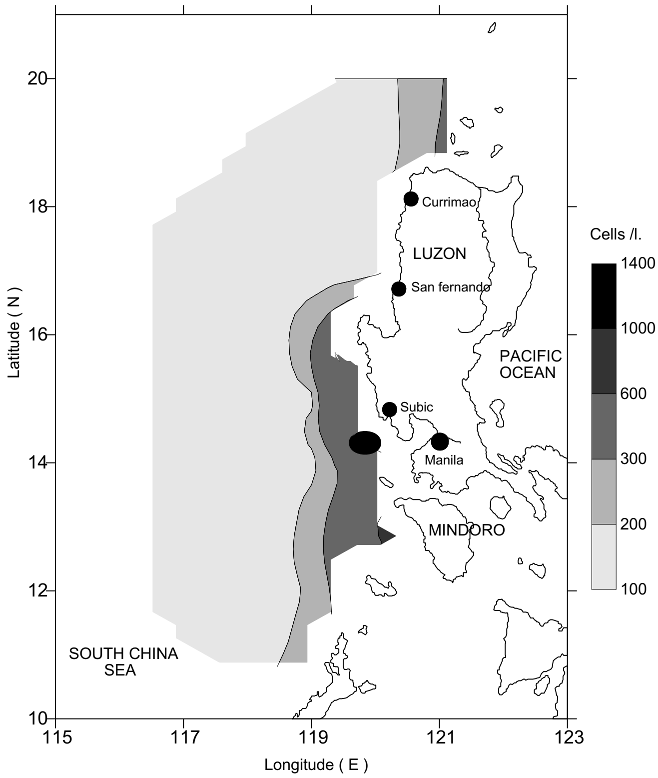

Fig. 3. Phytoplankton abundance at surface.

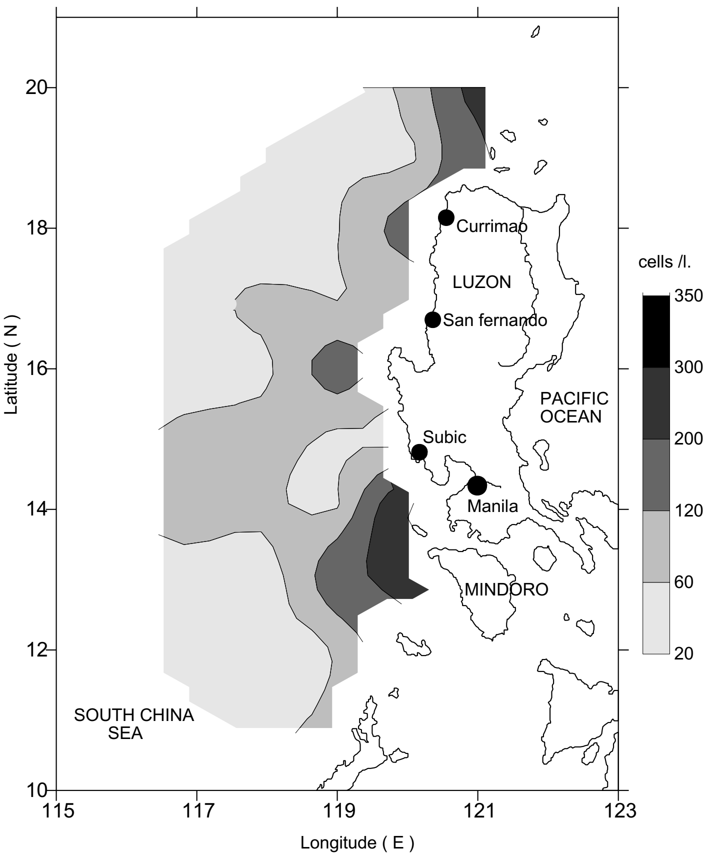

Fig. 4. Abundance of blue green algae at surface.

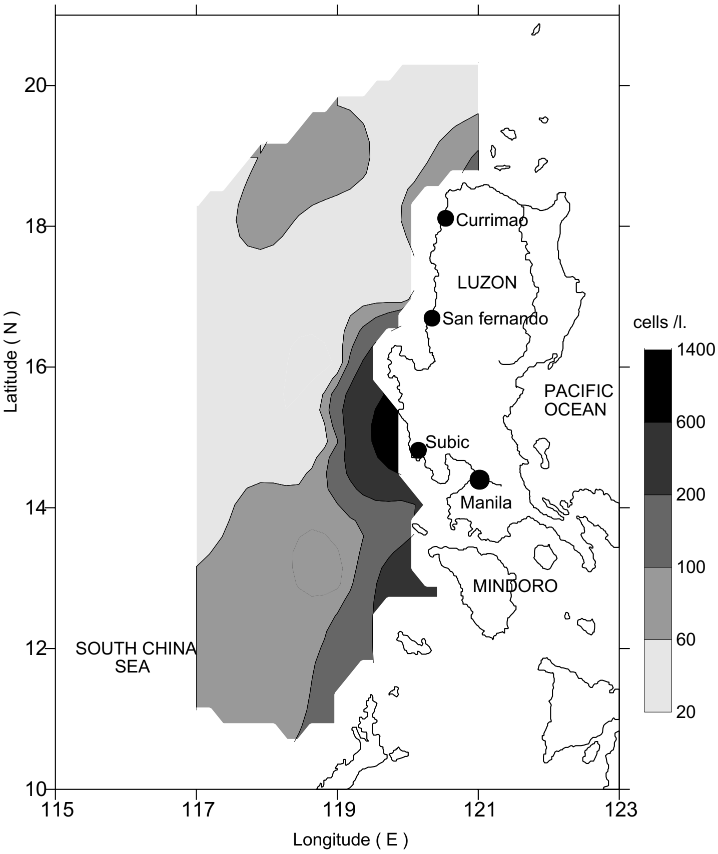

Fig. 5. Abundance of diatom at surface.

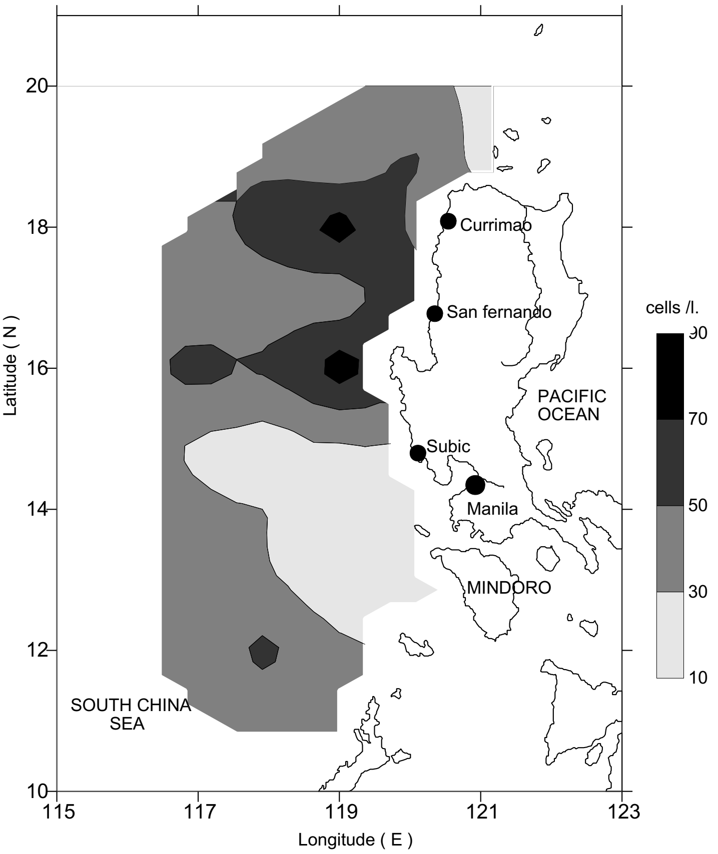

Fig. 6. Abundance of dinofagellate at surface.

Table 3 Phytoplankton species number, richness indices(R), diversity indices (H') and evenness indices (E) at 4 lines of sampling stations.

SD = Sampling depth S = Surface Th = Thermocline depth Ch = Chlorophyll maximum depth

Line	SD	Species number				R		H'		E	
		Diatom		Dinoflagellate							
	(m)	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
1	S	9 - 30	20	6 - 25	17	1.15 - 3.22	2.06	1.16 - 2.84	2.26	0.28 - 0.60	0.40
	Th	14 - 50	22	9 - 28	17	0.42 - 3.27	1.82	0.71 - 3.07	2.20	02.26 - 0.5	0.43
	Ch	11 - 56	39	3 - 16	9	1.17 - 2.27	1.74	2.44 - 3.20	2.86	0.45 - 0.92	0.63
2	S	6 - 14	10	8 - 33	18	1.39 - 2.74	2.2	0.98 - 2.83	2.20	0.26 - 0.73	0.44
	Th	5 - 17	10	13 - 31	20	1.17 - 2.97	2.12	0.67 - 3.07	2.19	0.27 - 0.69	0.50
	Ch	19 - 43	29	5 - 15	8	1.29 - 2.62	1.96	2.55 - 3.33	2.94	0.54 - 0.81	0.61
3	S	8 - 12	11	9 - 22	15	1.47 - 2.83	2.16	2.16 - 3.31	2.57	0.37 - 0.72	0.58
	Th	9 - 17	13	7 - 28	17	1.30 - 2.29	2.37	1.88 - 3.09	2.54	0.33 - 0.73	0.54
	Ch	25 - 44	34	1 - 22	10	0.59 - 2.77	1.89	2.58 - 3.22	2.97	0.46 - 0.76	0.64
4	S	7 - 12	10	13 - 26	16	2.02 - 3.03	2.39	2.08 - 2.70	2.41	0.37 - 0.67	0.47
	Th	12 - 17	13	11 - 21	16	1.40 - 2.87	1.94	1.56 - 3.13	2.45	0.28 - 0.76	0.56
	Ch	28 - 43	35	6 - 17	11	1.38 - 2.56	1.76	2.81 - 3.25	3.03	0.46 - 0.75	0.66

Species occurrence at different sampling levels

Phytoplankton species mostly occurred from surface through chlorophyll maximum depth. Table 2 shows the occurrence of all species at surface, thermocline depth and chlorophyll maximum depth. *Oscillatoria* (*Trichodesmium*) *erythraea* and *Chaetoceros lorenzianus* were dominant in all sampling layers. Twenty-six species of diatom were not found in surface but presented below the mixed layer. Among these species, *Coscinodiscus argus*, *C. granii*, *C. reniformis* and *Rhizosolenia ostenfeldii* occerred only at the chlorophyll maximum depth. *Chaetoceros radicans* was never found at surface, but it was frequently found below the mixed layer through the chlorophyll maximum depth. Dinoflagellate species were not abundant at any sampling levels. The occurrences of many species related to sampling depths. The dinoflagellate that presented only at surface were *Alexandrium compressum*, *A. fraterculus*, *A. leei*, *Amphidinium* spp., *Amphisolenia globifera*, *Ceratium arietinum, C. limulus, C. symmetricum* and *Prorocentrum sigmoides*. There were 57 species occurred below the mixed layer.

Occurrence of dominant species

Only 2 species of phytoplankton, *Oscillatoria erythraea* and *Chaetoceros lorenzianus*, were dominant at surface. The first species dominated phytoplankton population and distributed to all over the study area except station 16 where the second species was dominant [Fig.8].

At thermocline depth, there were 7 species occurred as the dominant species [Fig.9]. The study area was mainly dominated by *Oscillatoria erythraea*. The other species, *Chaetoceros peruvianus*, *Fragilariopsis doliolus* and *Pseudoselenia calcar-avis*, were found predominantly at stations located in the upper part whereas *Chaetoceros lorenzianus*, *Rhizosolenia styliformis* and *Thalassionema frauenfeldii* were abundant in the lower part of the study area.

Six species comprised of *Oscillatoria erythaea*, *Chaetoceros lorenzianus*, *C. messanensis*, *Fragilariopsis doliolus*, *Planktoniella sol* and *Thalassionema frauenfeldii* presented with highest cell counts at chlorophyll maximum depth [Fig.10]. *Thalassionema frauenfeldii* was the dominant species observed at most of the sampling stations.

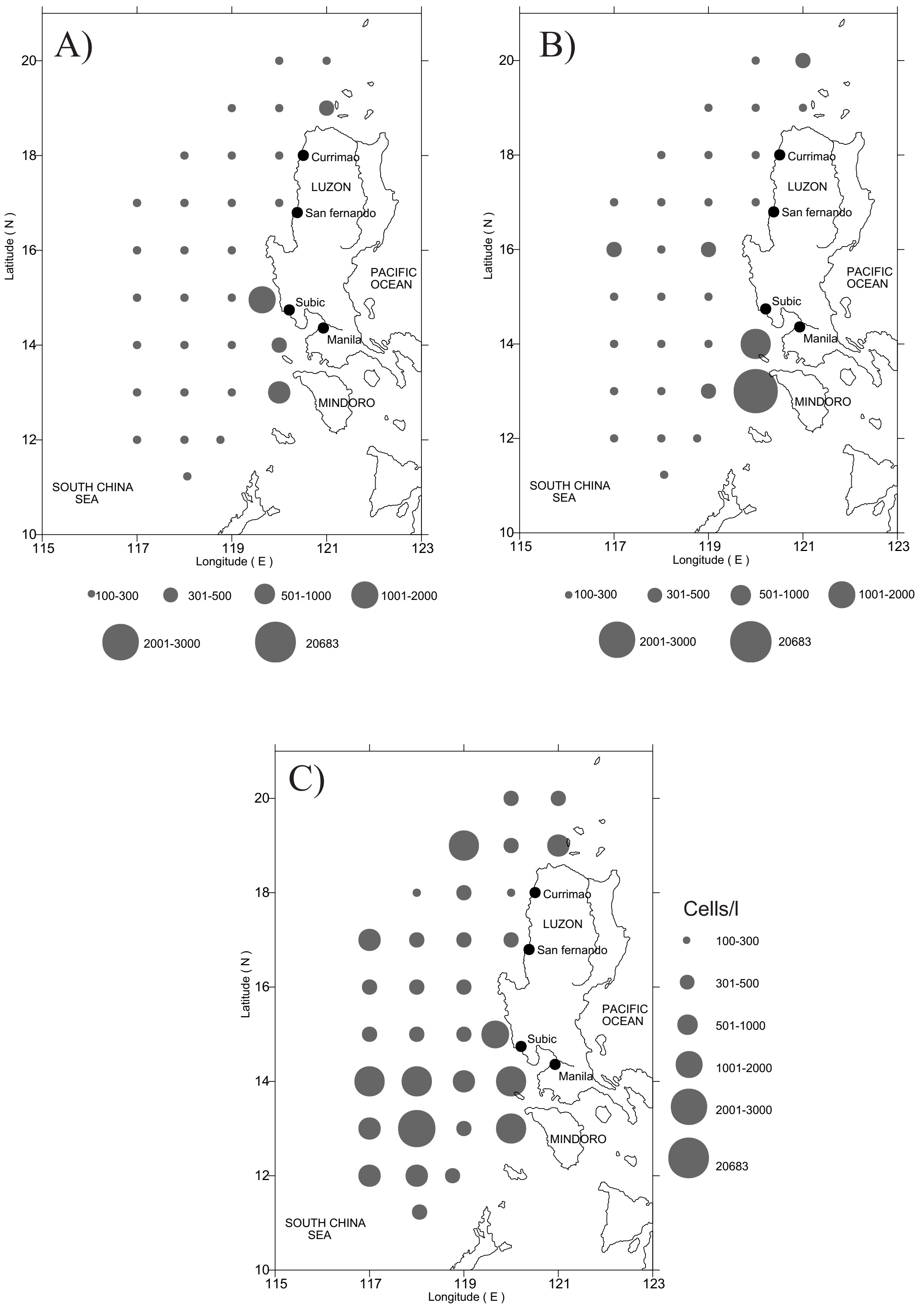

Fig. 7. Phytoplankton densities at different depths.
A: Surface , B: Thermocline depth, C: Chlorophyll maximum depth

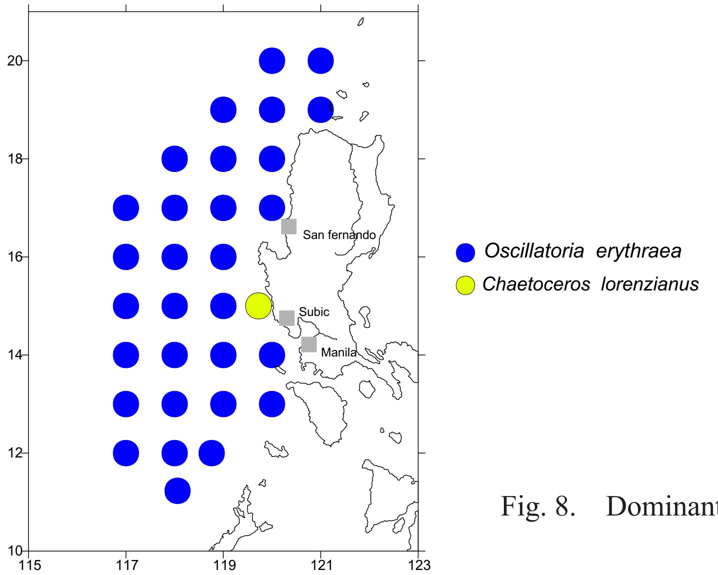

Fig. 8. Dominant species at surface

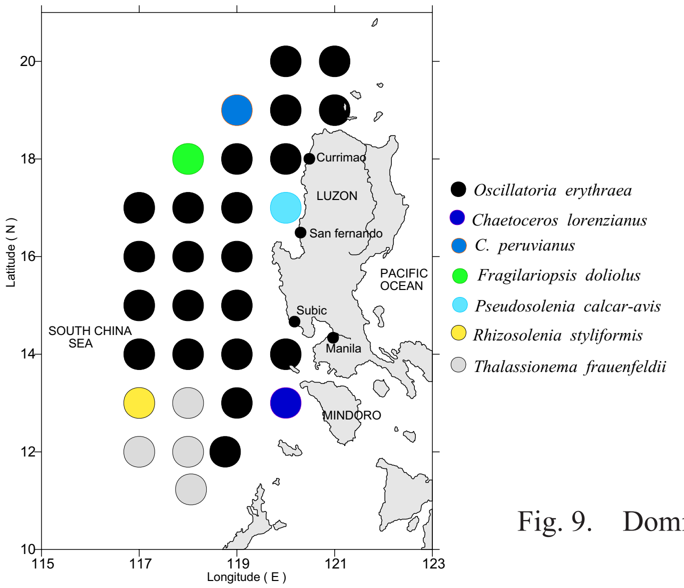

Fig. 9. Dominant species at thermocline depth.

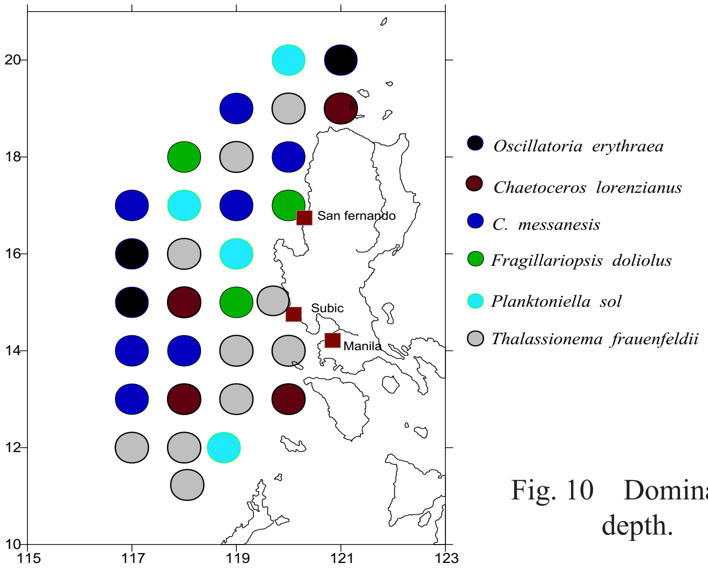

Fig. 10 Dominant species at chlorophyll maximum depth.

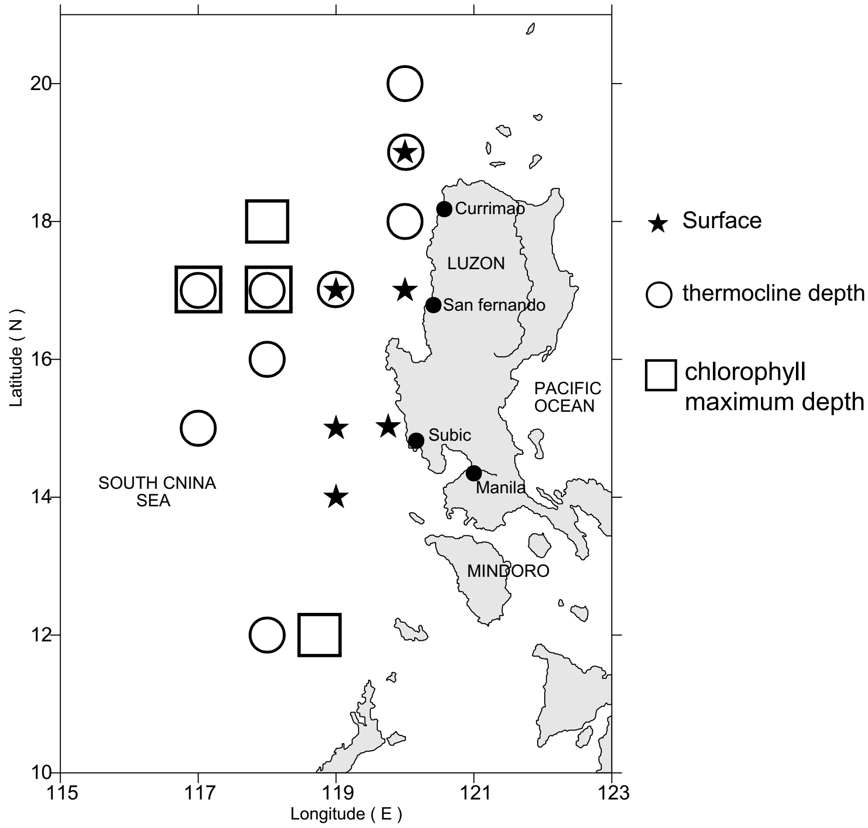

Fig. 11 Distribution of *Alexandium* spp (1-4 cells/l)

Occurrence of toxic dinoflagellate

Many species of toxic dinoflagellate were found in this survey. All of them occurred in low cell densities. *Alexandrium* was the selected genus to study its distribution which is shown in Fig.11. Highest cell count observed during this survey was 4 cells /l. This genus presented at surface of the stations near Luzon and distributed to the deeper layer of the farther stations.

Species diversity indices

The richness indices, diversity indices and evenness indices calculated from the entire list of taxa presented at surface, thermocline depth and chlorophyll maximum depth were summarized and shown in Table 3. The average richness indices of surface samples of all lines and those of sample taken from thermocline depth in lines 2 & 3 were high. The lowest value of each line was found at chlorophyll maximum depth. However, the lowest richness value was observed at thermocline depth of station 24. The average diversity index computed from the samples of each line was high at chlorophyll maximum depth and increased with distance from the coast. The average evenness indices were low at surface and increased through chlorophyll maximum depth of all sampling lines except line 3 that the average value of surface samples was rather high.

Discussion and Conclusion

The chlorophyll maximum is found in the thermocline, not always where the density gradient is greatest, but usually in a depth considerably lower [Saijo *et al*. (1969)]. In this area studied, both thermocline depth and chlorophyll maximum depth were in the thermocline layer.

The chlorophyll maximum depth varied from the level near the upper to the lower thermocline and mainly observed in the deeper level than those reported of the Area II [Boonyapiwat (1999 b)].

Phytoplankton density in the surface layer of the western Philippines (Area III) was rather low in comparison with those observed in the same period of the year in the Area I : Gulf of Thailand and east cost of Peninsular Malaysia [Boonyapiwat (1999 a)] and the Area II : Sabah, Sarawak and Brunei Darussalam [Boonyapiwat (1999 b)]. The Area I is the shallow water area and it has been known as a semi-enclosed sea where nutrients enrichment caused phytoplankton highly productive [Suvapepun *et al*. (1980)]. Although the sampling sites of the Area II and the present study area were both situated in the open sea, more abundance was found at surface and thermocline depth of the Area II but the cell density at chlorophyll maximum depth of this area was lower. This might be due to the difference of bottom topography of these areas. There are many elevations of the seafloor in the western Philippines waters. Then sea depths of this area varied considerably during sampling period. Furuya *et al*. (1995) investigated the effects of a seamount on phytoplankton production in the western Pacific Ocean and found high chlorophyll a patch in the subsurface chlorophyll maximum layer (SCM) above seamount. They concluded that the topography – current interactions above seamount induced perturbations in nutrients distribution and enhanced upward transport of nutrients into the bottom of euphotic zone. The enrichment was occasionally accompanied by elevated amounts of chlorophyll a downstream of the seamount. The increase was most pronounced in the SCM, but occasionally effects were observed near the surface [Furuya *et al*. (1995)]. The massive bloom of phytoplankton, observed at thermocline depth of station 24 where the seafloor was found elevated, might be caused by the process mentioned above.

Phytoplankton densities at chlorophyll maximum depth were mostly highest among the sampling depths observed. Olivieri (1983) investigated phytoplankton communities of the Cape Peninsula, South Africa and found that most of high cell concentrations corresponded with high level of chlorophyll a. High cell counts were also observed in the SCM in the western Pacific Ocean [Furuya and Marumo (1983)] and the suspended particles around this layer were richer in phytoplankton than those in the upper layers [Furuya (1990)].

The occurrence of phytoplankton species at 3 sampling depths seemed to be similar to those observed in the Area II and more taxa were found in the present study [Boonyapiwat (1999 b)]. *Chaetoceros affinis* var. *willei* presented from surface through the thermocline layer of all stations but it was not found in any sample of the Area I and Area II [Boonyapiwat (1999 a & 1999 b)].

The number of dominant species occurred in the present study area was rather low owing to the succession of *Oscillatoria erythraea* almost all the area during sampling period. All of dominant species (*Oscillatoria erythraea*, *Chaetoceros lorenzianus*, *C. messanensis*, *Fragilariopsis doliolus*, *Planktoniella sol* and *Thalassionema frauenfeldii*) found at chlorophyll maximum depth were similar to those in the Area II (Boonyapiwat, 1999 b). *Chaetoceros lorenzianus* was also reported as dominant species in the chlorophyll maximum layer of the East China Sea [Saijo *et al*. (1969)].

Toxic dinoflagellates recorded in this study were scarcely found. *Alexandrium* was a genus consisted of many toxic species [Balech (1995)]. One of them, *A. tamiyavanichi* was observed in lower cell concentration compared with that in the Area I and Area II [Boonyapiwat (1999 a & 1999 b)]. It might distributed throughout the South China Sea in this period of the year.

The diversity and evenness indices of phytoplankton in the chlorophyll maximum layer of the other regions were higher than those in the other layers. Boonyapiwat (1999 b) reported that diversity and evenness indices of phytoplankton from chlorophyll maximum layer of Sabah, Sarawak and Brunei Darussalam waters in May 1997 were high, in the range of 1.22 – 3.28 and 0.23 – 0.82, respectively. The values of the present study were slightly higher than in the Area II and diversity indices increased seaward. Furuya and Marumo (1983) noted that both diversity and evenness indices of the SCM samples collected from the western North Pacific Ocean were very high, > 4.0 and 0.8, respectively.

It is concluded that phytoplankton density in the western Philippines during April – May 1998 was rather low at surface and high in the thermocline layer (thermocline depth & chlorophyll maximum depth). The occurrence of some phytoplankton species were limited by depths. Toxic dinoflagellates presented from surface through the thermocline layer in low cell densities. At chlorophyll maximum depth, the richness index of phytoplankton was low but diversity and evenness index were high. The results of this investigation may benefit for the studies of marine ecology, red tides and marine fisheries of the Philippines and neighboring countries.

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