Southeast Asian Fisheries Development Center

# Species Composition, Abundance and Distribution of Phytoplankton in the Thermocline Layer in the South China Sea, Area IV: Vietnamese Waters

**Sopana Boonyapiwat**

Oceanic Fisheries Division, Department of Fisheries,Parknam, Samutprakarn, 10270.Thailand

## ABSTRACT

One hundred and eighty-five samples of phytoplankton were collected from 58 stations in the Vietnamese waters during 30 April – 29 May 1999 to investigated species composition, abundance and distribution in the thermocline layer compared with those in the surface layer. The samples were taken from surface, thermocline depth and chlorophyll maximum depth. In this study, thermocline depth and chlorophyll maximum depth were included in the thermocline layer. Three hundred and fifty- seven taxa, composed of 2 species of blue green alga, 159 species of diatoms and 161 species of dinoflagellates, were identified. The occurrence of species in each layer were recorded. The cell densities at chlorophyll maximum depth were highest among the sampling depths observed in most stations of the survey. Data obtained from the samples collected from surface to 150 m with 25 m interval to study vertical distribution indicates that maximum cell density of the water column presented between 60 – 110 m. The most abundance was 179,386 cells/l found at chlorophyll maximum depth near the Ca Mau Cape due to the bloom of many diatom species. *Oscillatoria ( Trichodesmium ) erythraea*, *Proboscia alata*, *Pseudosolenia calcar-avis* and *Thalassionema frauenfeldii* were dominant at all sampling depths. Five species of diatoms presented as dominant species only in the thermocline layer. *Alexandrium* was frequently found at surface through chlorophyll maximum depth in the south. Diversity and evenness indices of all sampling depths were high in the Gulf of Tonkin and decreased through the south of Vietnam. These indices were high in the thermocline layer.

**Key words :** Phytoplankton, thermocline layer, South China Sea, Vietnamese waters

## Introduction

A study on distribution, abundance and species composition of phytoplankton in the South China Sea has been carried out since 1995 as one title of the Interdepartmental collaborative Program. The investigations were done in the Area I ( Gulf of Thailand and east coast of Peninsular Malaysia), Area II (Sabah, Sarawak and Brunei Darussalam) and AeraIII (western Pilippines). The last area was focused on phytoplankton in the thermocline layer [Boonyapiwat (1999a, 1999b, 2000].

The earliest study on plankton in Vietnamese waters was reported by Rose (1926). From that time, many surveys have been carried out in both coastal and offshore area [Koi *et al.* (1995)]. After 1963, about 1,700 species of freshwater and marine plankton were arranged for the first time in Vietnam by hand of A. Shirota [Shirota (1966, 1967)]. However, phytoplankton in the thermocline layer and subsurface chlorophyll maxima in this region are unknown.

Subsurface chlorophyll maxima or deep chlorophyll maxima are well known phenomenon in temperate, subtropical and tropical oceanic regions. They are usually found at the depths around or below the seasonal thermocline [Saijo *et al.* (1969), Furuya and Marumo (1983)]. Thermocline zone

is the productive area that thermocline ridges have been found to be the place where tunas aggregate [Silas and Pillai (1982)]. The most abundance of phytoplankton in the water column and high diversity were observed in this layer [Boonyapiwat (1999b, 2000)].

The purpose of this study is to describe species composition, abundance and distribution of phytoplankton in the thermocline layer compared with those in the surface layer and to determine species diversity indices.

## Materials and Methods

*Sampling, counting and identification*

The survey was carried out on board M/V SEAFDEC during 21 April – 5 June 1999 in Vietnamese waters. Phytoplankton samples were collected from 58 stations during 30 April – 29 May 1999 [Fig.1]. The study area was divided into 3 parts as north (stations 1-10), central (stations 11 – 32) and south (stations 33 – 58). One hundred and eighty five samples were taken with Van Dorn water sampler from surface, the beginning of thermocline or thermocline depth and chlorophyll maximum depth. The sampling depths were determined using ICTD record at each station. The samples of 9 stations along 110° E were collected from surface to 150 m with 25 m interval for study on vertical distribution [Fig.1].

The water samples of 30 – 40 l were filtered through 20 mm 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 the electron microscope, both scanning electron microscope (SEM) and transmission electron microscope (TEM). Filament count was done for blue green algae.

*Statistical analysis*

The species diversity indices [richness index (R), diversity index (H) and evenness index (E)] were computed according to the methods in Ludwig and Reynolds (1988). The equations are as follows:

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

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

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

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

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 depth from ICTD records*

The thermocline depths (the depths at the beginning of thermocline) varied from 29 – 45 m, 12 – 50 m and 20 – 60 m in the north, central and south of the study area respectively. The chlorophyll maximum depths were found below thermocline depths and existed in the thermocline layer or thermocline zone. They were in the range of 40 – 72 m , 28 – 110 m and 14 – 90 m in the north, central and south respectively [Table 1]. At shallow stations, thermocline depths were not detected and chlorophyll maximum depths mostly reached near the bottom.

*Identification*

A total of 357 taxa, composed of 2 genera, 2 species of blue green alga, 62 genera, 159 species of diatoms and 37 genera, 161 species of dinoflagellates, were identified from the samples of this survey. The taxonomic list is given in Table 2.

*Abundance and distribution*

Total phytoplankton cell densities of the surface layer were abundant in the coastal area [Fig.2]. The abundance were noticed at the northern part of the study area or the Gulf of Tonkin and the southern part where the highest cell count of 115,925 cells/l near Ca Mau Cape was found. The cell density decreased with distance from the coast. The distribution pattern of blue green algae, diatom and dinoflagellate in the surface layer are shown in Figs. 3 – 5. Blue green algae was abundant and distributed in large area of the Gulf of Tonkin especially in coastal area while densities at the offshore stations were higher than those at the coastal stations in the central part. Like total phytoplankton, distribution and abundance of diatom and dinoflagellate showed the same pattern. The highest cell count of these 2 groups were found at the west coast of Ca Mau Cape.

The cell densities of total phytoplankton at 3 sampling depths shown in Figs. 6 – 8 reveal that highest density of almost all stations were observed at chlorophyll maximum depth except stations 4, 7, 38 & 49 where surface densities were highest. The maximum cell count was 179,386 cells/l found at chlorophyll maximum depth near the Ca Mau Cape. The vertical cross section along 110$^{o}$ E from 8$^{o}$ N – 16$^{o}$ N indicates that the maximum cell density of the water column presented between 60 – 110 m [Fig. 9].

The ranges of phytoplankton density at different depths in 3 parts of study area are shown in Table 1. The densities of 3 groups of phytoplankton (blue green algae, diatom and dinoflagellate) were low at thermocline depth in the whole area. Blue green algae density was high at surface in the Gulf of Tonkin. Diatom densities were relatively high at surface and chlorophyll maximum depth of the southern part while dinoflagellate densities showed less variation. The species number of diatom and dinoflagellate were highest at chlorophyll maximum depth and thermocline depth respectively [Table 3].

*Vertical distribution of species*

Most of phytoplankton species presented from surface through chlorophyll maximum depth [Table 2]. The species occurred predominant at all sampling levels were *Oscillatoria (Trichodesmium) erythraea, Proboscia alata, Pseudosolenia calcar – avis* and *Thalassionema frauenfeldii*. Thirty - four species of diatom were found below the mixed layer. Among these species, *Asteromphalus sarcophagus, Cocconeis* spp. and *Coscinodiscus reniformis* occurred only at chlorophyll maximum depth. *Chaetoceros radicans* were never observed at surface but frequently found at thermoclinedepth and occurred as dominant species at chlorophyll maximum depth. Dinoflagellate species were not abundant at any sampling level. Distribution of many species limited by depths. Thirteen species presented

only at surface while 55 species occurred in the thermocline layer (thermocline depth and chlorophyll maximum depth), and 11 species were found only at chlorophyll maximum depth such as *Alexandrium concavum, Ceratium platycorne, Prorocentrum concavum* and *P. emarginatum.*

*Dominant species*

There were 10, 5, and 13 species dominated phytoplankton population at surface, thermocline depth and chlorophyll maximum depth respectively. *Oscillatoria erythraea* distributed with highest relative abundance at surface in most of the study area. *Pseudosolenia calcar – avis* and *Thalassionema frauenfeldii* occurred predominant at surface in the central part while *T. nitzschioides* was abundant at the coastal area [Fig.10]. *Pseudosolenia calcar – avis* also distributed at thermocline depth in large area of the central part and reached to chlorophyll maximum depth at some stations. *Thalassionema frauenfeldii* was the dominant species at chlorophyll maximum depth distributed in most of the study area except the Gulf of Tonkin. [Figs.11& 12].

*Occurrence of toxic dinoflagellate*

Low cell densities of toxic dinoflagellates were observed in this survey. *Alexandrium* was the selected genus for studying its distribution. It was frequently found at surface through chlorophyll maximum depth in the southern part of study area. The highest cell count, 25 cells/l, was observed at chlorophyll maximum depth at station 44 [Fig.13].

*Species diversity indices*

Based on the data obtained from the entire list of taxa at all sampling depths, richness indices, diversity indices and evenness indices were computed and summarized in Table 3. They varied considerably at surface in the Gulf of Tonkin due to the bloom of *Oscillatoria erythraea* at station 7 that led to low diversity and evenness index. In comparison with the Gulf and the central part, the values in the southern part was lowest. High richness indices were found in the central part. The average diversity and evenness indices of all sampling depths were high in the Gulf and decreased through the southern part of study area. These indices high in the thermocline layer.

## Discussion and Conclusion

The thermocline and chlorophyll maximum depth of the present study area except the Gulf of Tonkin were observed in the deeper level than those of the Area II, Sabah, Sarawak and Brunei Darussalam [Boonyapiwat (1999b)] and nearly the same level as those of the Area III, western Philippines [Boonyapiwat (2000)] in the same period of the year. The Gulf of Tonkin is shallower and thermocline layer occurred at some stations that differed from the aforementioned areas.

Previous study of phytoplankton in Vietnamese waters revealed that cell density was less than that of the present study. The review of studies on phytoplankton in the sea waters of Vietnam during 70 years, 1924 – 1994 reported by Koi *et al.* concluded that the peak of density reached to 6,700 cells/l during January – March in the Gulf of Tonkin and 342 species of phytoplankyon with density of 248 cells/l in the south of Vietnam were observed in 1985. Thuoc (1997) found 192 species in Bach Long Vy waters and high density of 1,000 – 10,000 cells/l were determined in October. The present study shows the observation at chlorophyll maximum depth where phytoplankton was abundant and numerous species presented. Furuya and Marumo (1983) investigated phytoplankton community in the subsurface chlorophyll maxima in the western North Pacific Ocean and found that chlorophyll-a concentration of this layer was 2.1 – 7.5 times higher than that of the

surface and high cell counts were observed. Boonyapiwat (1999b, 2000) also reported high cell density in the thermocline layer. The high cell density at surface of some stations in this survey was probably due to the upwelling.

In the post- NE monsoon period, surface current flowed southerly from the north of Vietnam along the coast and from the east coast of the Gulf of Thailand to the Ca Mau Cape [Shirota (1966)]. The current from both directions transported nutrients from the coast especially Mekong Delta to the Cape and caused phytoplankton blooms. The Gulf of Tonkin was the productive area. The present study shows high cell density of most stations in the Gulf. Nutrient – enriched water from land were brought by river – runoff into the Gulf and influenced phytoplankton blooms. Thuoc (1996), studied phytoplankton in the Tien Yen, Bach Dang and Red rivermouths, concluded that cell density in the Red rivermouth was high.

Most of phytoplankton species occurred in the thermocline layer seemed to be similar to those observed in the Area II and Area III and more taxa were observed in the present study [Boonyapiwat (1999b, 2000)]. The succession of *Oscillatoria erythraea* in the southern part of Vietnam was recorded as the characteristic of this area [Shirota (1966)]. Some dominant species were different from those in the Area II and Area III such as *Guinardia flaccida* and *Hemiaulus membranacea. Thalassionema frauenfeldii* and *Chaetoceros lorenzianus* also dominated phytoplankton population in the chlorophyll maximum layer of the East China Sea [Saijo *et al.* (1969)].

Although small number of toxic dinoflagellates were observed, many species presented in this area. The highest cell count (25 cells/l) of *Alexandrium* in this survey was more than that in the Area I (17 cells/l) and Area III (4 cells/l) but less than that in the Area II (36 cells/l) [Boonyapiwat (1999a, 1999b, 2000). It indicates that *Alexandrium* distributed all over the South China Sea.

The diversity and evenness indices of phytoplankton in the thermocline layer of the area were high that was similar to the results of the Area II and Area III [Boonyapiwat (1999b, 2000)]. Furuya and Marumo (1983) reported high diversity (>4.0) and evenness indices (0.8) of the samples collected from the subsurface chlorophyll maximum layer in the western North Pacific Ocean. Owing to the blooms of *Oscillatoria erythraea* at surface and thermocline depth, the species diversity indices were low at some stations.

It is concluded that phytoplankton density in the Vietnamese waters during April – May 1999 was high at surface through chlorophyll maximum depth in the Gulf of Tonkin and near the Ca Mau Cape. Phytoplankton was rather low at surface and high in the thermocline layer in most stations of the survey. The occurrence of some phytoplankton species were limited by depths. Toxic dinoflagellates presented from surface through the thermocline layer in low cell densities. *Alexandrium* distributed throughout the South China Sea. The diversity and evenness indices were high in the thermocline layer. Low indices caused by the blooms of *Oscillatoria erythraea.*

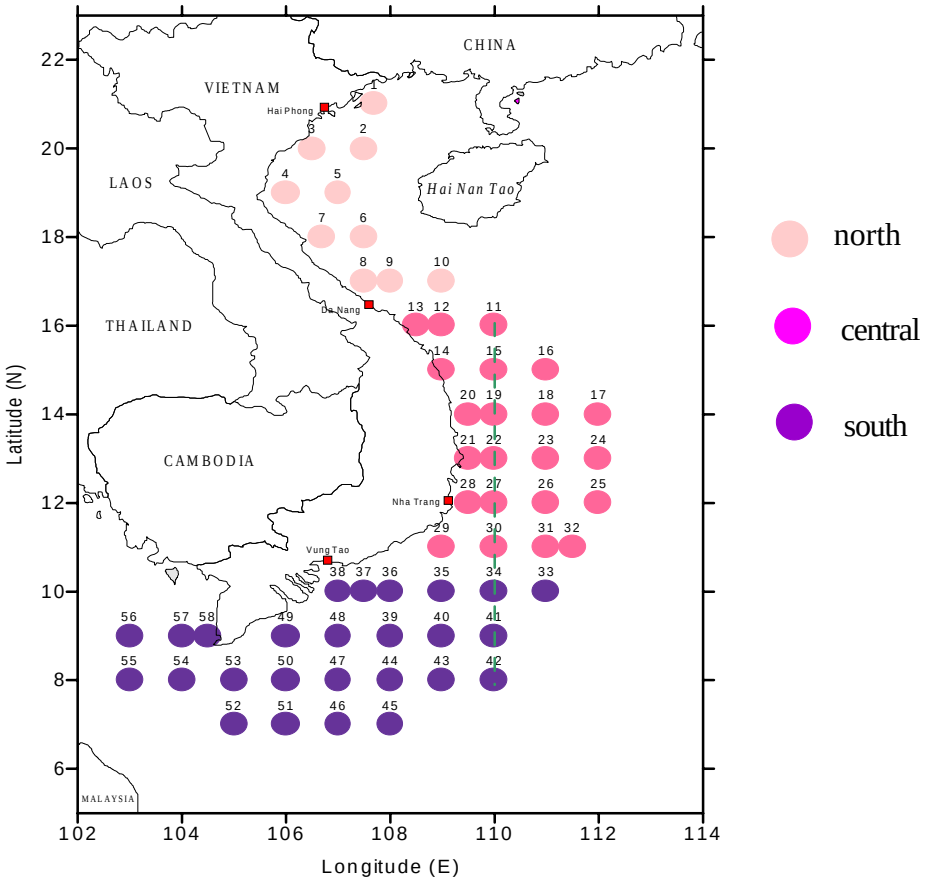


**Fig. 1.** Location of sampling stations in 3 parts of study area. The dashed line indicates the transect where vertical cross section is made.

**Table 1.** Ranges of phytoplankton densities at sampling depths in 3 parts of study area.
SD = Sampling depth BG = Blue green algae
S=Surface Th = Thermocline depth Ch = Chlorophyll maximum depth

| Part | Station | Depth (m) | SD (m) | Phytoplankton (cells/l) | BG (filaments/l) | Diatom (cells/l) | Dinoflagllate (cells/l) |
|---|---|---|---|---|---|---|---|
| North (Gulf of Tonkin) | 1-10 | 26-110 | S : 2-4<br>Th : 29-45<br>Ch : 20-72 | 503-62,506<br>632-1,167<br>567-39,811 | 35-11,427<br>90-165<br>0-1,495 | 304-57,821<br>403-615<br>302-40,820 | 67-2,011<br>140-150<br>46-2,219 |
| Central | 11-32 | 42-4,117 | S : 2-4<br>Th : 12-50<br>Ch : 28-110 | 283-12,093<br>306-878<br>532-15, 820 | 0-780<br>0-205<br>'0-684 | 105-9,749<br>71-563<br>395-15,300 | 71-1,188<br>61-249<br>35-1,456 |
| South | 33-58 | 20-3,385 | S : 2-4<br>Th : 20-60<br>Ch : 14-90 | 324-115,925<br>351-1,238<br>578-179,386 | 71-2,600<br>16-1,080<br>0-9,100 | 87-113,290<br>59-548<br>463-176,415 | 48-2,229<br>21-118<br>14-2,414 |

**Table 2.** Taxonomic list and occurrence 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 ) | | | |
| *Achnanthes* spp. | - | x | x |
| *Actinocyclus* spp. | xx | xx | xx |
| *Actinoptychus senarius* ( Ehrenberg ) Ehrenberg | xx | x | x |
| *Asterolampra marylandica* Ehrenberg | xx | xx | xx |
| *Asteromphalus elegans* Greville | x | - | - |
| *A. heptactis* ( Bre'bisson ) Greville | xx | x | - |
| *A. flabellatus* ( Bre'bisson ) Greville | x | x | - |
| *A. sarcophagus* Wallich | - | - | x |
| *Azpeitia africana* ( Janisch ex A. Schmidt ) G. Fryxell & T.P. Watkins | - | x | x |
| *A. nodulifera* ( A. Schmidt ) G. Fryxell & P.A. Sims | xx | x | xxx |
| *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 | xx | xx |
| *B. hyalinum* Lauder | x | x | x |
| *B. minus* Karsten | - | x | x |
| *Bellerochea horologicalis* von Stosch | xx | x | - |
| *B. malleus* (Brightwell) van Heurck | x | x | - |
| *Bleakeleya notata* ( Grunow) Round | - | x | - |
| *Campylodiscus* spp. | x | xx | xx |
| *Cerataulina bicornis* ( Ehrenberg ) Hasle | x | x | x |
| *C. pelagica* ( Cleve ) Hendey | x | x | x |
| *Chaetoceros aequatorialis* Cleve | x | x | - |
| *C. affinis* Lauder | xx | xx | xx |
| *C. affinis* var. *willei* (Gran) Hustedt | - | x | xx |
| *C. anastomosans* Grunow | x | x | - |
| *C. atlanticus* Cleve | x | xx | xx |
| *C. atlanticus* var. *neapolitana* (Schroder ) Hustedt | - | x | xx |
| *C. aurivillii* Cleve | x | xx | - |
| *C. bacteriastroides* Karsten | - | x | - |
| *C. brevis* Schütt | x | - | - |
| *C. buceros* Karsten | x | - | - |
| *C. castracanei* Karsten | - | x | - |
| *C. clavigera* Ostenfeld | x | x | - |
| *C. coarctatus* Lauder | xx | xx | xx |
| *C. compressus* Lauder | xxx | xx | xxx |
| *C. costatus* Pavillard | x | x | - |
| *C. curvisetus* Cleve | x | x | - |
| *C. dadayi* Pavillard | x | x | x |
| *C. danicus* Cleve | - | x | x |
| *C. debilis* Cleve | x | x | - |
| *C. decipiens* Cleve | x | x | x |

**Table 2.** (Continued).

| Specices | Sampling levels | | |
|---|---|---|---|
| | S | Th | Ch |
| *C. densus* (Cleve) Cleve | x | x | - |
| *C. denticulatus* Lauder | xx | xx | xx |
| *C. didymus* Ehrenberg | xx | xx | x |
| *C. diversus* Cleve | xx | xx | xx |
| *C. laevis* Leuduger - Fortmorel | xx | xx | xx |
| *C. lorenzianus* Grunow | xxx | xx | xxx |
| *C. messanensis* Castracane | xx | xx | xxx |
| *Chaetoceros nipponicus* Ikari | x | x | x |
| *C. paradoxus* Cleve | xx | x | - |
| *C. peruvianus* Brigtwell | xxx | xx | xx |
| *C. pseudocurvisetus* Mangin | xxx | xx | xxx |
| *C. pseudodichaeta* Ikari | xx | xx | xx |
| *C. radicans* Shutt | - | xx | xxx |
| *C. rostratus* Lauder | x | x | x |
| *C. seiracanthus* Gran | x | xx | x |
| *C. siamensis* Ostenfeld | x | x | - |
| *C. simplex* Ostenfeld | x | xx | xx |
| *C. socialis* Lauder | x | x | - |
| *C. subtilis* Cleve | x | x | - |
| *C. tetrastichon* Cleve | x | x | x |
| *C. tortissimus* Gran | x | xx | xx |
| *C. weissflogii* Schütt | x | x | - |
| *C. vanheurecki* Gran | x | x | x |
| *Climacodiam biconcavum* Cleve | xx | xx | xx |
| *C. frauenfeldianum* Grunow | xx | xx | xx |
| *Cocconeis* spp. | - | - | x |
| *Corethron hystrix* Hensen | xx | xx | xx |
| *Coscinodiscus centralis* Ehrenberg | x | xx | xx |
| *C. concinniformis* Simonsen | x | - | - |
| *C. concinnus* W. Smith | x | xx | x |
| *C. gigas* Ehrenberg | x | x | xx |
| *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. thorii* Pavillard | x | x | x |
| *C. weilesii* Gran & Angst | x | x | x |
| *Cyclotella* spp. | x | xx | xx |
| *Cylindrotheca closterium* ( Ehrenberg ) Reimann & Lewin | xx | xx | xx |
| *Cymatosira lorenziana* Grunow | - | x | x |
| *Dactyliosolen blavyanus* ( Bergon ) Hasle | - | x | x |
| *D. fragilissimus* ( Bergon ) Hasle | - | x | - |
| *D. phuketensis* ( Sundström ) Hasle | x | x | x |
| *Diploneis* spp. | - | xx | xx |
| *Detonula pumila* ( Castracane ) Gran | x | xx | xx |
| *Ditylum brightwelii* ( West ) Grunow | xx | xx | xx |
| *D. sol* Grunow | xx | xx | xx |
| *Entomoneis* spp. | xx | xx | xx |
| *Eucampia cornuta* ( Cleve ) Grunow | x | x | xx |
| *E. zodiacus* Ehrenberg | x | x | x |
| *Fragilaria cylindrus* Grunow | x | xx | xx |
| *F. oceanica* Cleve | x | x | x |

**Table 2.** (Continued).

| Specices | Sampling levels | | |
|---|---|---|---|
| | S | Th | Ch |
| *F. striatula* Lyngbye | x | xx | xx |
| *Fragilariopsis doliolus* ( Wallich ) Medlin & Sims | x | xx | xx |
| *Gossleriella tropica* Schütt | x | xx | xx |
| *Guinardia cylindrus* ( Cleve ) Hasle | xx | xx | xx |
| *G. flaccida* ( Castracane ) H. peragallo | xxx | xx | xxx |
| *G. stiata* ( Stolterfoth ) Hasle | xx | xx | xx |
| *Gyrosigma.* spp. | x | x | x |
| *Halicotheca thamensis* ( Shrubsole ) Ricard | x | x | x |
| *Haslea gigantea (Hustedt)* Simonsen | xx | xx | xx |
| *H. wawrikae* ( Hustedt ) Simonsen | x | xx | xx |
| *Hemiaulus hauckii* Grunow | xx | xx | xx |
| *Hemiaulus indicus* Karsten | x | x | x |
| *H. membranacea* Cleve | xx | xxx | xx |
| *H. sinensis* Greville | xx | xx | xx |
| *Hemidiscus cuneiformis* Wallich | x | x | x |
| *Lauderia annulata* Gran | x | xx | x |
| *Leptocylindrus danicus* Cleve | x | x | x |
| *L. mediterraneus* ( H. Peragallo ) Hasle | x | x | xx |
| *Lioloma delicatulum* ( Cupp ) Hasle | x | x | x |
| *L. elongatum* ( Grunow ) Hasle | - | x | x |
| *L. pacificum* ( Cupp ) Hasle | - | xx | xx |
| *Lithodesmium undulatum* Ehrenberg | x | x | - |
| *Melosira nummuloides* C.A.Agardh | x | x | x |
| *Meuniera membranacea* ( Cleve ) P.C.Silva | xx | xx | xx |
| *Navicula distans* ( W.Smith ) Ralfs | x | x | x |
| *N. transitrans* (Grunow ) Cleve | - | x | x |
| *N.* spp. | x | x | x |
| *Neostreptotheca subindica* von Stosch | x | x | x |
| *Nitzschia bicapitata* Cleve | x | x | x |
| *N. longissima* ( Bre'bisson ) Ralfs | x | x | x |
| *N. frigida* Grunow | xx | xx | xx |
| *N.* spp. | x | x | x |
| *Odontella mobiliensis* ( Bailey ) Grunow | x | xx | xx |
| *O. sinensis* ( Greville ) Grunow | xx | xx | xx |
| *Pachynesis gerlachii* Simensen | x | xx | xx |
| *Palmeria hardmaniana* Greville | - | xx | xx |
| *P. ostenfeldii* ( Ostenfeld ) von Stosch | - | x | - |
| *Paralia sulcata* ( Ehrenberg ) Cleve | xx | xx | xx |
| *Planktoniella blanda* ( A. Schmidt ) Syvertsen & Hasle | - | x | x |
| *P. sol* ( Wallich ) Schütt | x | xx | xx |
| *Pleurosigma angulatum* W. Smith | x | x | - |
| *P. normanii* Ralf | xx | xx | xxx |
| *P.* 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 australis* Frenguelli | x | x | x |
| *P. cuspida* (Hasle) Hasle | - | x | - |
| *P. pseudodelicatissima* ( Hasle ) Hasle | xx | xx | xx |
| *P. pungens* ( Grunow & Cleve ) Hasle | xx | xx | xx |
| *P. subpacifica* ( Hasle ) Hasle | - | x | x |
| *P.* spp. | - | x | x |
| *Pseudosolenia calcar - avis* ( Chultz ) Sundström | xxx | xxx | xxx |

**Table 2.** (Continued).

| Specices | Sampling levels | | |
|---|---|---|---|
| | S | Th | Ch |
| *Rhizosolenia acuminata* ( H. Peragallo ) Gran | x | x | x |
| *R. bergonii* H. Peragallo | x | x | xx |
| *R. castracanei* var. *castracanei* H. Peragallo | x | x | x |
| *R. castracanei* var. *neglecta* Sundström | - | xx | x |
| *R. clevei* var. *clevei* Ostenfeld | xx | xx | x |
| *R. clevei* var. *communis* Sundström | x | x | xx |
| *R. formosa* H. Peragallo | x | x | x |
| *R. hyalina* Ostenfeld | x | xx | xx |
| *R. imbricata* Brightwell | x | x | x |
| *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 | x |
| *T. frauenfeldii* ( Grunow ) Hallegraeff | xxx | xxx | xxx |
| *Thalassionema. nitzschioides* ( Grunow ) Mereschkowsky | xxx | xx | xxx |
| *T. pseudonitzschioides* ( Schuette & Schrader ) Hasle | - | x | x |
| *Thalassiothrix 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 | - |
| *T. lineata* Jouse' | x | x | - |
| *T. oestrupii* ( Ostenfeld ) Hasle | - | x | - |
| *T. subtilis* ( Ostenfeld ) Gran | xx | xx | - |
| *T. thailandica* Boonyapiwat | x | - | - |
| *T.* spp. | xx | xx | xx |
| *Triceratium favas* Ehrenberg | - | x | - |
| *Tropidoneis* sp. | - | x | x |
| Phylum Dinophyceae ( Dinoflagellate ) | | | |
| *Alexandrium affine* ( Inoue & Fukuyo ) Balech | x | - | - |
| *A. compressum* ( Fukuyo, Yoshida & inoue ) Balech | - | x | - |
| *A. concavum* ( Gaarder ) Balech | - | - | x |
| *A. fraterculus* ( Balech ) Balech | x | x | - |
| *A. leei* Balech | x | x | - |
| *A. tamarense* ( Lebour ) Balech | x | x | - |
| *A. tamiyavanichi* Balech | xx | xx | xx |
| *A.* spp. | x | x | x |
| *Amphidinium* spp. | x | x | - |
| *Amphisolenia bidentata* Schroder | xx | xx | xx |
| *A. schauinslandii* Lemmermann | x | x | - |
| *A. trinax* Schütt | - | x | x |
| *Amylex triacantha* ( Jörgensen ) Sournia | - | x | x |
| *Centrodinium* sp. | - | x | x |
| *Ceratium azoricum* Cleve | x | x | - |
| *C. belone* Cleve | x | - | - |
| *C. biceps* Claparede & Lachmann | - | x | x |
| *C. bigelowii* Kofoid | - | x | x |
| *C. boehmii* Graham & Bronikosky | xx | xx | xx |
| *C. candelabrum* ( Ehrenberg ) Stein | xx | x | x |
| *C. carriense* Gourret | xx | xx | xx |
| *C. concillians* Jörgensen | x | x | x |

**Table 2.** (Continued).

| Specices | Sampling levels | | |
|---|---|---|---|
| | S | Th | Ch |
| *C. contortum* var. *contortum* ( Gourret ) Cleve | x | x | - |
| *C. contortum* var. *sultans* ( Shroder ) Jörgensen | x | x | x |
| *C. declinatum* var. d*eclinatum* ( Karsten ) Jorgensen | x | x | x |
| *C. declinatum* var. *angusticornum* ( Karsten ) Jorgensen | xx | xx | xx |
| *C. deflexum* ( Kofoid ) Jörgensen | x | xx | - |
| *C. dens* Ostenfeld & Schmidt | xx | xx | xx |
| *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 | x | x |
| *C. gravidum* Gourret | - | x | x |
| *C. hexacanthum* Gourret | - | x | x |
| *C. horridum* ( Cleve ) Gran | xx | xx | xx |
| *C. humile* Jörgensen | xx | xx | xx |
| *C. incisum* ( Karsten ) Jörgensen | x | - | - |
| *C. inflatum* ( Kofoid ) Jörgensen | x | x | x |
| *C. kofoidii* Jörgensen | xx | xx | xx |
| *C. longipes* ( Bailey ) Gran | x | - | - |
| *C. limulus* Gourret | x | - | - |
| *C. lunula* ( Schimpe ) Jörgensen | x | x | x |
| *C. macroceros* ( Ehrenberg ) Vanholf | xx | x | x |
| *Ceratium massiliense* ( Gourret ) Karsten | x | x | - |
| *C. pentagonum* Gourret | x | x | x |
| *C. platycorne* Daday | - | - | x |
| *C. praelongum* ( Lemmermann ) Kofoid | - | x | x |
| *C. ranipes* Cleve | x | x | xx |
| *C. reflexum* ( Cleve ) | x | - | - |
| *C. schroeteri* Schroder | - | 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 | - |
| *C. gorretii* Paulsen | - | x | x |
| *C. horrida* Stein | xx | xx | xx |
| *Citharisthes regius* Stein | - | x | x |
| *C. apsteinii* Schütt | - | x | - |
| *Corythodinium globosum* Jorgensen | - | x | - |
| *C. tesselatum* ( Stein ) Loeblich Jr. & Loeblich | x | xx | xx |
| *Dinophysis acuminata* Claparede & Lachmann | - | x | x |
| *D. caudata* Saville - Kent | xx | xx | xx |
| *D. hastata* Stein | x | x | - |
| *D. infundibula* Schiller | x | x | x |
| *D. miles* Cleve | x | x | xx |
| *D. recurva* Kofoid & Skorgsberg | x | - | - |
| *D. schuettii* Murray & Whitting | x | x | x |
| *D. uracantha* Stein | x | xx | xx |
| *Diplopsalis lenticulata* Berg | x | x | xx |
| *D.* spp. | - | x | x |
| *Diplopsalopsis* sp. | - | x | x |
| *Fragilidium* spp. | x | xx | xx |
| *Goniodoma polyedricum* ( Pouchet ) Jörgensen | xx | xx | xx |

**Table 2.** (Continued).

| Specices | Sampling levels | | |
|---|---|---|---|
| | S | Th | Ch |
| *Gonyaulax digitale* ( Pouchet ) Jörgensen | x | x | x |
| *G. fragilis* ( Schütt ) Kofoid | - | x | x |
| *G. glyphorhynchus* Murry & Whitting | - | x | x |
| *G. hyalina* Ostenfeld & Whitting | - | xx | x |
| *G. milneri* ( Murray & Whitting ) Kofoid | - | - | x |
| *G. pacifica* Kofoid | - | xx | 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 |
| *Heterocapsa* spp. | x | x | x |
| *Heterodinium blackmanii* ( Murray & Whitting ) Kofoid | x | x | - |
| *H. globosum* Kofoid | - | - | x |
| *Heterodinium rigdenae* Kofoid | - | x | x |
| *Histioneis depressa* Schiller | - | - | x |
| *H. pulchra* Kofoid | - | x | x |
| *H.* spp. | x | x | x |
| *Kofoidnium* sp. | x | x | x |
| *Lingulodinium polyedrum* ( Stein ) Dodge | x | x | x |
| *Ornithocercus formosus* Kofoid | - | x | - |
| *O. heteroporus* Kofoid | - | x | x |
| *O. magnificus* Stein | - | x | x |
| *Ornithocercus quadratus* Schutt | x | x | x |
| *O. splendidus* Schütt | - | x | x |
| *O. steinii* Schutt | - | x | - |
| *O. thumii* ( A. Schmidt ) Kofoid & Skogsberg | xx | xx | xx |
| *Oxytoxum parvum* Schiller | - | x | x |
| *O. scolopax* Stein | xx | xx | xx |
| *O. subulatum* Kofoid | x | xx | xx |
| *Phalacroma acutoides* Balech | x | x | x |
| *P. argus* Stein | x | x | x |
| *P. circumsutum* Karsten | x | x | x |
| *P. doryphorum* Stein | xx | xx | xx |
| *P. favus* Kofoid & Michener | x | x | - |
| *P. parvulum* ( Schütt ) Jörgensen | x | - | x |
| *P. rapa* Stein | x | - | - |
| *P. rotundatum* ( Claparede & Lachmann ) Kofoid & Michener | xx | xx | xx |
| *P. rudgei* Murry & Whitting | - | 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 | - |
| *Prorocentrum balticum* ( Lohmann ) Loeblich | - | x | x |
| *P. compressum* ( Bailey ) Abe' & Dodage | xx | xx | xx |
| *P. concavum* Fukuyo | - | - | x |
| *P. emarginatum* Fukuyo | - | - | xx |
| *P. mexicanum* Tafall | - | - | x |
| *P. micans* Ehrenberg | x | x | x |
| *P. sigmoides* Böhm | x | x | x |

**Table 2.** (Continued).

| Specices | Sampling levels | | |
|---|---|---|---|
| | S | Th | Ch |
| *Protoceratium spinulosum* ( Murray & Whitting ) Schiller | x | x | x |
| *Protoperidinium abei* ( Abe' ) Balech | x | xx | x |
| *P. angustum* P. Dangeard | - | - | x |
| *P. cerasus* Paulsen | - | x | - |
| *P. claudicans* ( Paulsen ) Balech | - | - | x |
| *P. conicum* ( Gran ) Balech | xx | xx | xx |
| *P. crassipes* ( Kofoid ) Balech | xx | x | - |
| *P. curtipes* ( Jörgensen ) Balech | - | x | - |
| *P. depressum* ( Baley ) Balech | xx | xx | xx |
| *P. diabolus* ( Cleve ) Balech | x | x | x |
| *P. divaricatum* ( Meunier ) Balech | - | x | - |
| *P. divergents* ( Ehrenberg ) Balech | xx | xx | xx |
| *P. elegans* ( Cleve ) Balech | xx | xx | xx |
| *P. grande* ( Kofoid ) Balech | xx | xx | xx |
| *P. hirobis* ( Abe' ) Balech | xx | x | - |
| *P. latispinum* ( Mangin ) Balech | x | x | x |
| *P. leonis* ( Pavillard ) Balech | xx | x | - |
| *P. murrayi* ( Kofoid ) Balech | x | x | - |
| *P. minutum* Kofoid | x | - | - |
| *P. nipponicum* ( Abe' ) Balech | x | - | - |
| *P. oceanicum* ( Vanholf ) Balech | xx | xx | xx |
| *P. okamurai* ( Abe' ) Balech | x | x | - |
| *P. ovum* ( Schiller ) Balech | x | x | - |
| *P. pacificum* Kofoid & Michener | xx | xx | xx |
| *P. pallidum* ( Ostenfeld ) Balech | x | xx | x |
| *P. pellucidum* Bergh | x | x | x |
| *P. pentagonum* ( Gran ) Balech | x | x | - |
| *P. quanerense* ( Schroder ) Balech | x | x | x |
| *P. roseum* Balech | - | x | - |
| *P. spinulosum* ( Schiller ) Balech | x | x | x |
| *P. stenii* ( Jörgensen ) Balech | xx | xx | xx |
| *Protoperidinium subinerme* ( Paulsen ) Balech | xx | xx | x |
| *P. subpuriforme* P. Dangeard | - | x | - |
| *P. tennuisimum* Kofoid | - | - | x |
| *P. thorianuum* ( Paulsen ) Balech | - | x | - |
| *P. trisylum* Stein | x | - | - |
| *P. tumidum* Okamura | - | x | - |
| *P.* spp. | xx | xx | xx |
| *Pyrocystis fusiformis* Wyville - Thomson ex Blachman | xx | xx | xx |
| *P. hamulus* Cleve | xx | xx | x |
| *P. lunula* species complex | xx | xx | xx |
| *P. noctiluca* Murray ex Haeckel | xx | xx | xx |
| *Pyrophacus horologium* Stein | x | x | x |
| *P. steinii* ( Schiller ) Wall & Dale | x | x | x |
| *Scripsiella trochoidea* ( Stein ) Balech | xx | xx | x |
| *S.* spp. | xx | xx | xx |
| *Schuettiella mitra* ( Schütt ) Balech | - | x | x |
| *Sinophysis* spp. | x | - | - |
| *Spiraulax kofoidii* Graham | - | x | x |
| *Triposolenia truncata* Kofoid | x | x | x |

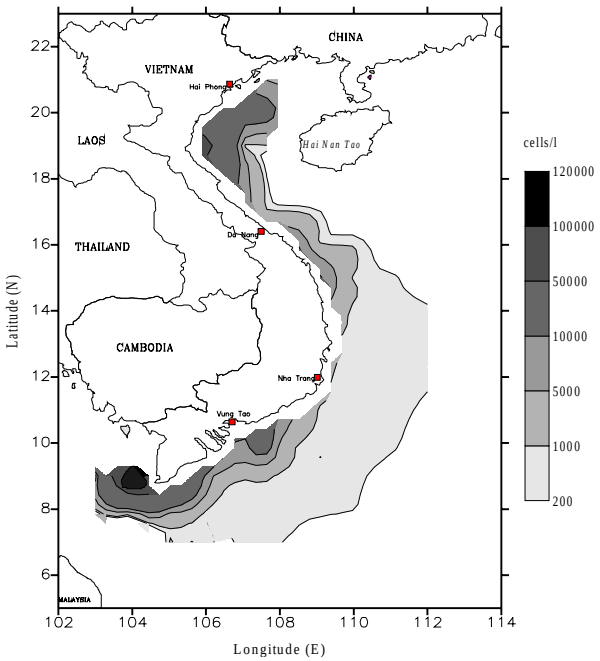


**Fig. 2**. Phytoplankton abundance at surface.

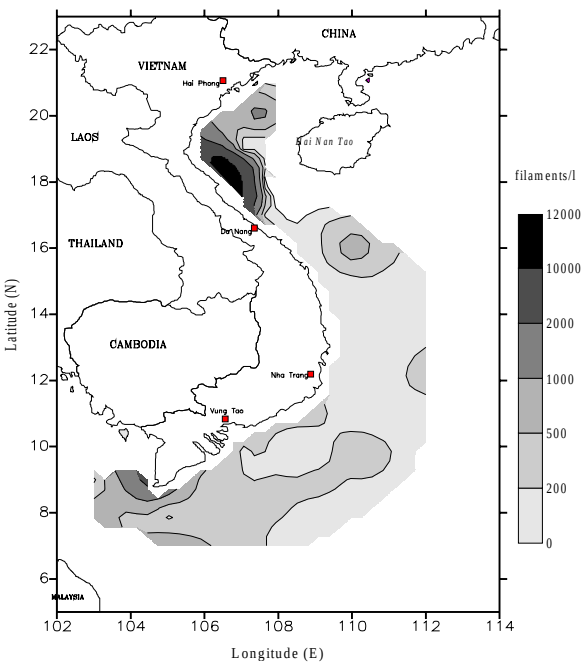


**Fig. 3.** Abundance of blue green algae at surface.

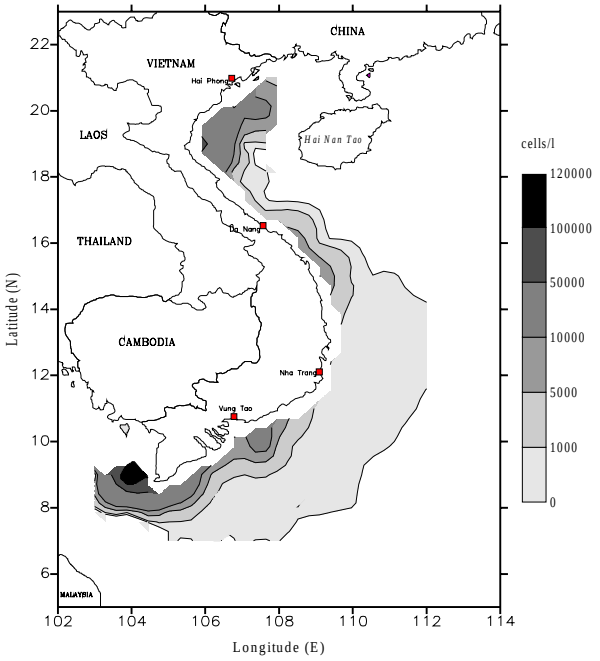


**Fig. 4.** Abundance of diatom at surface.

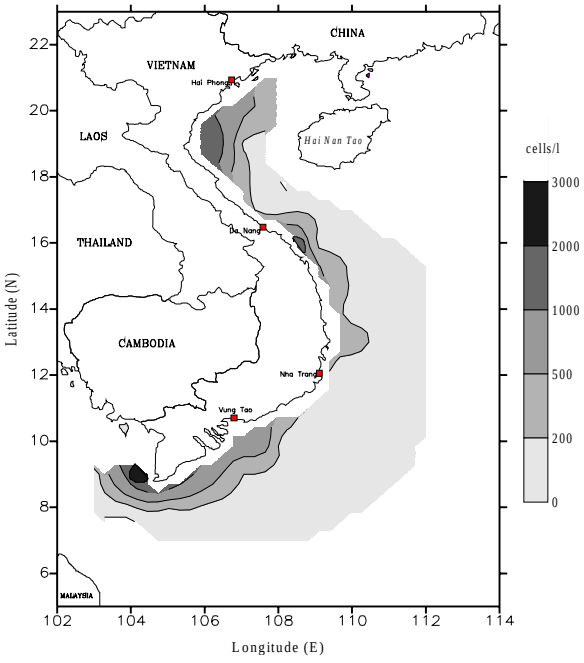


**Fig. 5**. Abundance of dinoflagellate at surface.

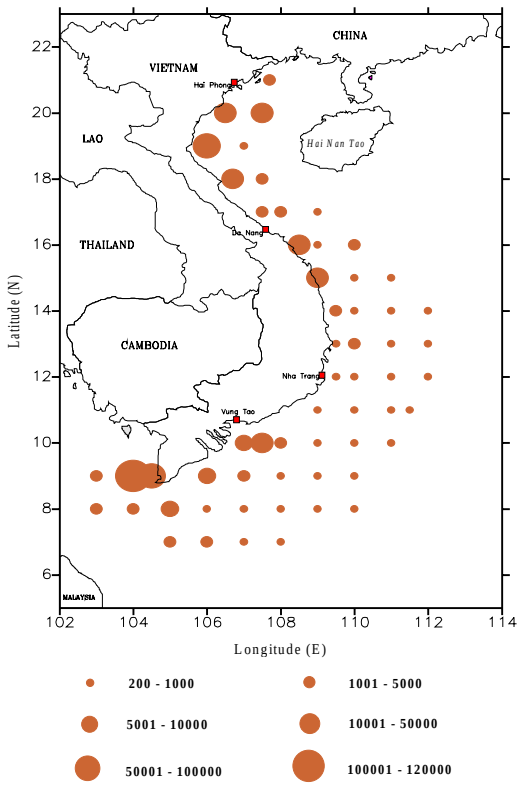


**Fig. 6.** Phytoplankton densities (cells/l) at surface.

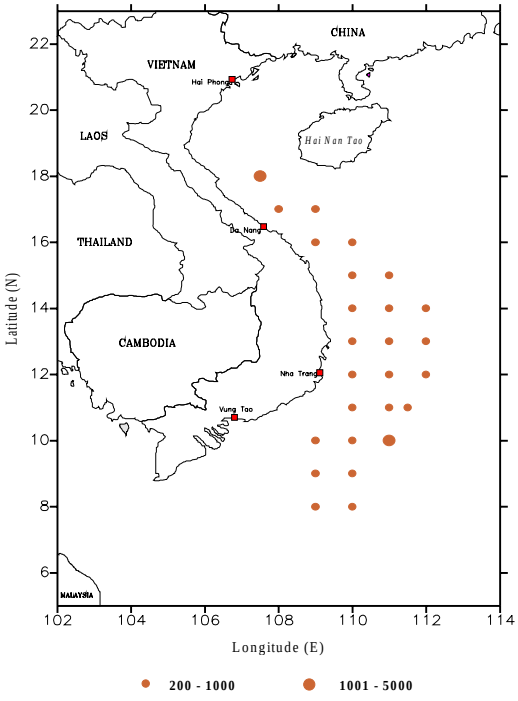


**Fig. 7**. Phytoplankton densities (cells/l) at thermocline depth.

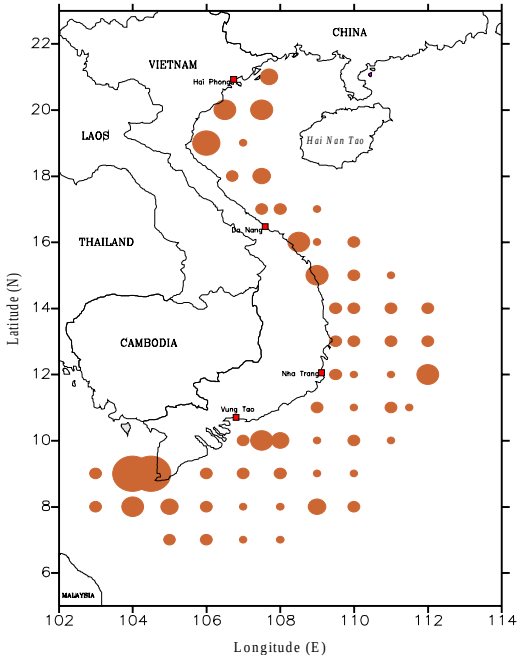


**Fig. 8**. Phytoplankton densities (cells/l) at chlorophyll maximum depth.

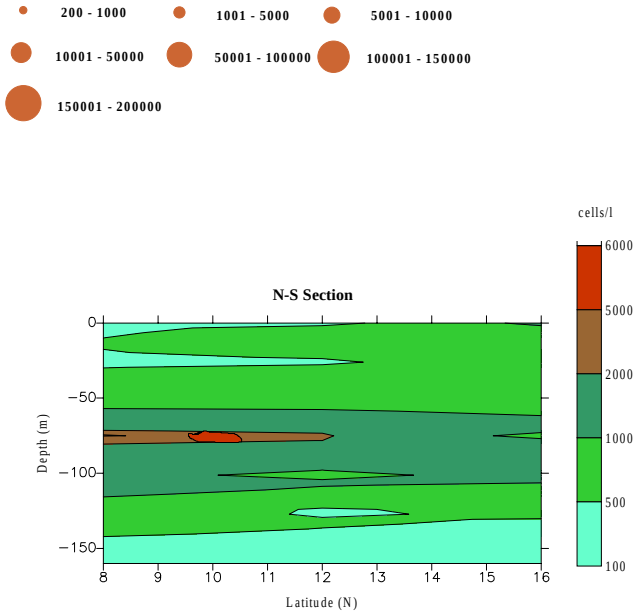


**Fig. 9**. Vertical cross section of phytoplankton density.

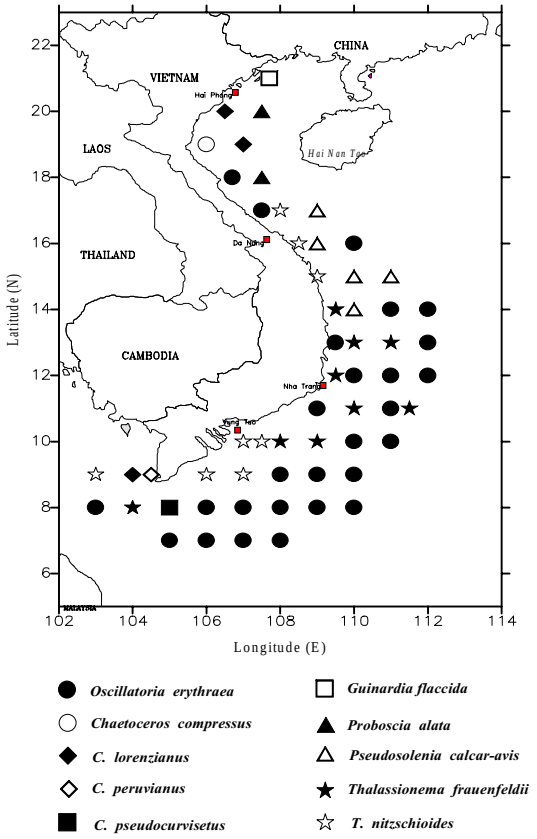


**Fig. 10**. Dominant species at surface.

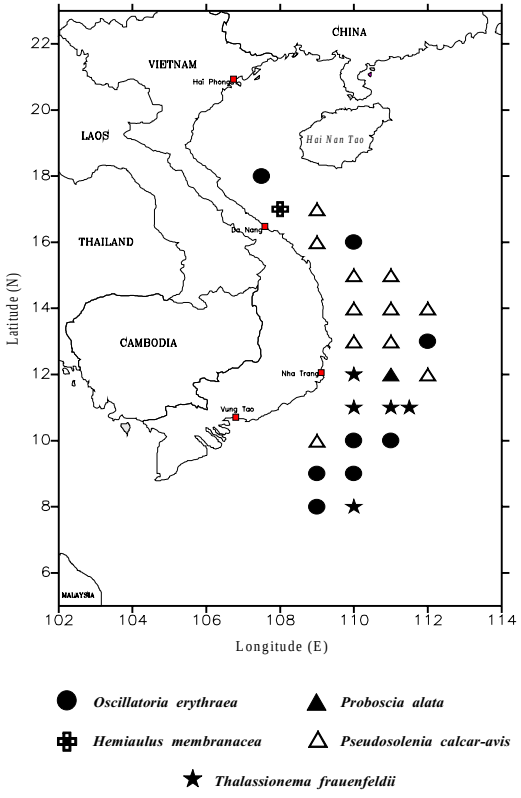


**Fig. 11**. Dominant species at thermocline depth.

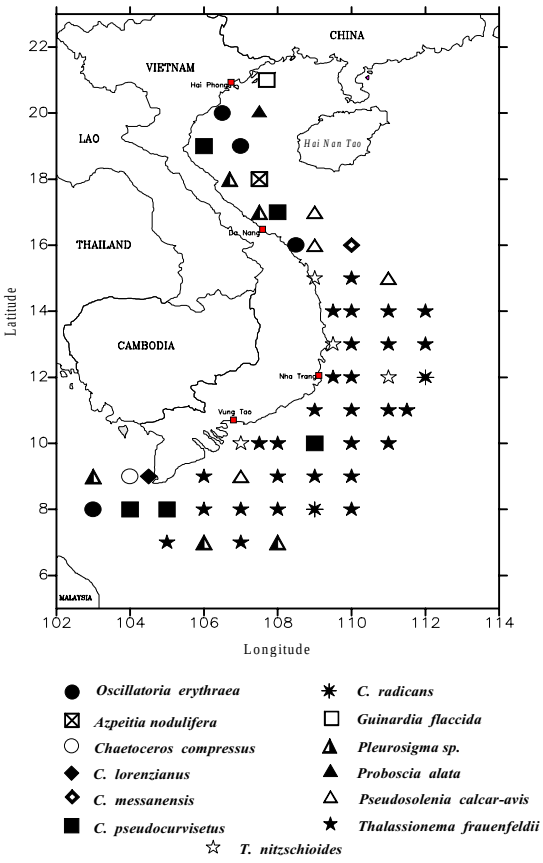


**Fig. 12**. Dominant species at chlorophyll maximum depth.

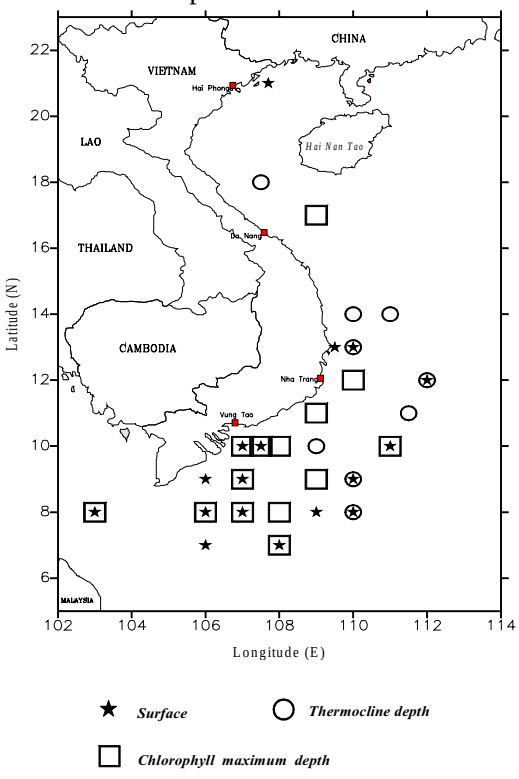


**Fig. 13**. Distribution of *Alexandrium* spp. at different depths.

**Table 3.** Phytoplankton species numbers, richness indices (R), diversity indices(H' ) and evenness indices (E) in 3 parts of study area.

| Part | SD | Species number | | | | R | | H' | | E | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Diatom | | Dinoflagellate | | | | | | | |
| | | Range | Average | Range | Average | Range | Average | Range | Average | Range | Average |
| North | S | 21-49 | 35 | 10-23 | 17 | 1.26-3.41 | 2.47 | 0.89-3.92 | 3.05 | 0.22-0.91 | 0.75 |
| (Gulf of | Th | 20-38 | 27 | 14-23 | 19 | 1.86-2.82 | 2.49 | 2.99-3.42 | 3.15 | 0.79-0.83 | 0.82 |
| Tonkin) | Ch | 20-54 | 37 | 6-29 | 17 | 1.35-2.94 | 2.27 | 2.15-3.47 | 2.98 | 0.58-0.84 | 0.76 |
| Central | S | 9-45 | 19 | 9-33 | 19 | 1.45-3.32 | 2.48 | 1.55-3.37 | 2.70 | 0.43-0.87 | 0.74 |
| | Th | 10-33 | 18 | 10-33 | 20 | 1.93-3.12 | 2.67 | 1.78-3.16 | 2.77 | 0.52-0.87 | 0.78 |
| | Ch | 14-53 | 35 | 5-26 | 14 | 1.37-3.13 | 2.14 | 2.12-3.32 | 2.80 | 0.60-0.87 | 0.78 |
| South | S | 8-44 | 22 | 8-25 | 13 | 1.09-3.09 | 1.97 | 1.66-3.17 | 2.44 | 0.48-0.83 | 0.68 |
| | Th | 7-21 | 14 | 11-20 | 14 | 1.21-3.12 | 1.94 | 0.73-3.05 | 1.86 | 0.22-0.82 | 0.55 |
| | Ch | 15-50 | 30 | 2-26 | 11 | 1.01-2.42 | 1.68 | 1.67-3.34 | 2.58 | 0.41-0.84 | 0.70 |

## References


Boonyapiwat, S. 1999a. Distribution, Abundance and Species Composition of Phytoplankton in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia, in Proceedings of the First Technical seminar on Marine Fishery Resources Survey in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. 24 – 26 Nov. 1997. Bangkok. SEAFDEC, pp. 111 - 134.

Boonyapiwat, S. 1999b. Distribution, Abundance and Species Composition of Phytoplankton in the South China Sea,Area II: Sabah, Sarawak and Brunei Darussalam, in Proceedings of the Second Technical Seminar on Marine Fishery Resources Survey in the South China Sea, Area II: West Coast of Sabah, Sarawak and Brunei Darussalam, 14 – 15 Dec. 1998, Kuala Lampur, SEAFDEC, pp. 177 - 196.

Boonyapiwat, S. 2000. Species Composition, Abundance and Distribution of Phytoplankton in the Thermocline Layer in the South China Sea, Area III: Western Philippines, in Proceedings of the Third Technical Seminar on Marine Fishery Resources Survey in the South China Sea, Area III: Western Philippines, 13 - 15 July 1999, Metro Manila, SEAFDEC, pp. 197 – 216.

Furuya, K. and R. Marumo. 1983. The structure of the phytoplankton community in the sub – surface chlorophyll maxima in the western North Pacific Ocean. *J. Plank. Res.*,5, 393 – 406.

Koi, N. V., N. Cho and N. N. Lam. 1995. Review of studies on plankton in the sea waters of Vietnam during 70 years, 1924 – 1994. *Collection of Marine Reseach Works*, VI, 81 – 90.

Ludwig, J. A. and J. F. Renoldsn. 1988. Statistical Ecology. A primer on Methods and Computing.A Wiley Interscience Publication. John Wiley and Sons, New York, 337p.

Rose, M. 1926. Some remarks on plankton from the coast of Vietnam and Gulf of Siam, Imprimarie Nauvelle Albert Portail. Saigon, 7 p.

Saijo, Y.,S. Iizuka and O. Asaok. 1969. Chlorophyll maxima in Kuroshio and adjacent area. *Mar.Biol.*, 4, 190 – 196.

Shirota, A. 1966. The Plankton of South Vietnam – Freshwater and Marine Plankton. Over. Tech. Coop. Agen. Japan, 489 p.

Shirota, A. 1967. Reflection on the contents of plankton studies in Vietnam. *Information Bulletin on Planktology in Vietnam.* Vol. 1, No. 1, 1 – 6.

Silas, E. G. and P. P. Pillai. 1982. Resources of tunas and related species and their fisheries in the Indian Ocean. CMFRI Bulletin 32, Cochin, 173 p.

Thuoc, C. V. 1996. Phytoplankton in the Tien Yen, Bach Dang and Red Rivermouths. *Marine Resources and Environment.* Tome III. P.242.

Thuoc, C. V. 1997. Phytoplankton in Bach Long Vy waters. *Marine Resources and Environment* Tome IV, p. 237.