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

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Kuala Lumpur, Malaysia

SEAFDEC

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PREFACE

Due to gross over-exploitation and a paucity of adequate information on fishery oceanographic, environmental and biological conditions that sustain the fisheries of the South China Seas region, the fisheries have become greatly impoverished. The deficiency in scientific intelligence has also circumscribed all attempts at substantive and tangible planning or management of fisheries throughout the region. The NAGA Oceanographic Expedition of 1959 – 1961, organized jointly by the United States of America, The Kingdom of Thailand and the erstwhile Republic of Vietnam, achieved pioneering oceanographic work in the Gulf of Thailand and the South China Seas. This invaluable scientific data acquisition was not pursued for a number of reasons, and thus, a holistic and dependable profile of oceanographic conditions and their seasonal variations and patterns failed to develop. Perceiving the vital importance and the deficiency of fundamental information and data for fisheries planning and management, the SEAFDEC Training Department (TD) and the Marine Fishery Resources Development and Management Department (MFRDMD), jointly launched an Inter-Departmental Collaborative Research program in 1995, on evaluating the fisheries resources of the South China Seas as a basal objective in the development of sustainable fisheries.

The first of four defined survey areas in the Gulf of Thailand and the East Coast of Peninsular Malaysia was researched during 1995 – 1996 and the scientific findings published. The second area, covering the waters of Sabah and Sarawak of East Malaysia, and Brunei Darussalam, was investigated during two cruises of the Training & Research Vessel, M.V. SEAFDEC, in July-August 1996 and April-May 1997. Five fields of scientific endeavor were researched by 30 scientists (37 scientists during the second cruise) from TD and MFRDMD together with invited scientists from other research institutions, departments and universities. The analysis of research findings were presented at a Technical Seminar held in Kuala Lumpur, Malaysia, on 14 – 15 December 1998, and are published in these proceedings.

It is fervently hoped that the information compiled in this volume will provide a valuable motivating tool and foundation for fisheries administrators, mangers, Global Information Systems (GIS) programmers and development planners to give shape and substance to feasible fisheries programs in the future and will provide dependable scientific data to realize them.

SEAFDEC wishes to record its appreciation to the Government of Japan for the generous financial assistance provided to facilitate this Research Program, as part of its long-standing support for the operation of the Center, since its inception. Appreciation is also due to all the scientists, the staff of TD and MFRDMD, and the crew of the ship, who spared no efforts to make this scientific expedition a success.

U. Bhatiyasevi

Udom Bhatiyasevi
Secretary-General
SEAFDEC

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Physical Characteristics of Watermass in the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters

NASIR SAADON[1], LIM PHAIK KIN[1],
ANOND SNIDVONGS[2] AND PENJAN ROJANA-ANAWAT[3].

[1] Universiti Putra Malaysia Terengganu, Mengabang Telipot, 21030 Kuala Terengganu, Malaysia
[2] Department of Marine Science, Faculty of Science, Chulalongkorn University,Bangkok 10330, Thailand
[3] Training Department, P.O. Box 97, Phrasamutchedi, Samut Prakan 10290, Thailand

ABSTRACT

This study provides new information on the physical characteristics of water masses in Sabah and Sarawak waters. The aim was to determine the effect of Southwest (SW) monsoon on the variability of water masses, in Sabah and Sarawak waters. Physical characteristics data were obtained using an instrument called "Integrated Conductivity Temperature Depth" (iCTD), during the third (July 1996) and fourth (May 1997) cruises of the MV SEAFDEC research vessel, conducted during the SW monsoon season. Vertical distributions and profiles of temperature, salinity and density were analyzed and their variations between the two cruises compared.

It is concluded that there were no great variations of temperature, salinity and density values in the study area, during both cruises. This is because both cruises were conducted during the SW monsoon season. However, variations of temperature, salinity and density values were observed between shallow and deep waters, as well as coastal and offshore waters. Based on their vertical distributions and profiles obtained during the two cruises, water properties in shallow waters were found to vary slightly from the deeper ones. As a result, in the southern tip of the South China Sea, where the water was shallow, its properties here differed a little from the rest of the study area. This was due to the pronounced mixing effect of surface waves in shallow waters. At the same time, lower salinity and consequently, lower density values were detected in coastal waters, resulting from of the influx of freshwater from Sabah and Sarawak rivers during this monsoon season.

Key words: SW Monsoon, SEAFDEC cruises, iCTD, Temperature, Salinity, Density, Insignificant Variability.

Introduction

South China Sea is influenced to a very large extent by the monsoon system. In fact, almost every feature of the oceanographic environment of the South China Sea is conditioned by the monsoons. This semiannual reversal of large-scale wind system is generated by the difference in atmospheric pressure between the Northern (Asian continent) and the Southern (Australia) Hemispheres [Nasir and Camerlengo (1997) and Nasir and Marghany (1996)]. The southwest (northeast) wind prevails from May to September (November to March) over the South China Sea during the northern summer (winter). Two transitional periods occur between these two monsoons, in April and in October, respectively. They last for about three to seven weeks [Morgan and Valencia (1978)].

The third and fourth cruises - on board MV SEAFDEC - of the SEAFDEC collaborative research programme in the South China Sea, between Malaysia and Thailand, were conducted from 16 to 31 July 1996 and from 1 to 24 May 1997, respectively. The cruises covered the Sarawak, Sabah and Brunei Darussalam waters. The aim of the cruises was to determine the resources and oceanographic parameters of the waters in the South China Sea.

Since the two cruises were conducted during the SW monsoon season, a study on the variability of physical parameters in Sabah and Sarawak waters due to the SW monsoon, was established. For this purpose, vertical distributions and profiles of temperature, salinity and density, from both MV SEAFDEC cruises, were analyzed and compared.

Materials and Methods

Respective in-situ water properties of Sabah and Sarawak waters were recorded, using an iCTD instruments, during the SW monsoon season. The data were collected during the MV SEAFDEC third cruise (10 to 31 July 1996) and fourth cruise (1 to 24 May 1997). For the purpose of this investigation, three transects were selected out of seventy-nine sampling stations that were established (Fig. 1).

Temperature and salinity data were obtained directly from the system, while density data were derived from temperature and salinity data, by using a sigma-t computation table [Knauss (1978)].

Data were analyzed by using a grid-based contouring and three-dimensional plotting graphics program, SURFER (Version 6), from Golden Software Inc., USA. The temperature, salinity and density vertical contours of three selected transects, for both cruises, were plotted, compared and analyzed. Profiles of the same parameters were also plotted using MS Excel.

Results

Temperature, salinity and density contours of Transect 1, 2 and 3, are shown in Figs. 2, 3 and 4, respectively. Each figure is divided into two groups, I and II. Group I represents data collected from MV SEAFDEC third cruise, while data from the fourth cruise are demonstrated in Group II. Each group is then sub-divided again into section A, B and C. Each section portrays temperature, salinity and density contour, respectively.

In general, water temperature, salinity and density did not differ greatly in both cruises. Variations of their vertical distributions, in both cruises, were also insignificant. However, variations of temperature, salinity and density in the surface waters were greater than the deeper ones, as shown in Figs. 2, 3 and 4. Water temperature decreased with increasing depth, while both salinity and density value increased with increasing depth. This increase in salinity and density, along with the decrease in temperature occurred rapidly from below the surface water until certain depth, after which the rate then declined. As a result, thermocline, halocline and pycnocline layers were distinguishable, for all three transects (Figs. 2, 3 and 4) in both cruises. The depth of these layers remained more or less similar in both cruises.

One distinctive variation is observed between coastal and offshore waters. The temperature, salinity and density values were much lower in coastal waters as compared to offshore waters (Fig. 2), in both cruises. Water properties in shallow waters were also found to vary slightly from deeper ones (Fig. 3 and 4).

Profiles of temperature, salinity and density, at all sampling stations for both the third cruise (thick lines) and the fourth cruise (thin lines), are shown in Figs. 5, 6 and 7, respectively. Profiles of parameters in shallow waters, when compared between the two cruises, showed very slight variations. However, in deep waters no variations of parameters with depth, were observed. The reason is that both cruises were conducted during the SW monsoon season.

Discussions

During northern winter season, a high atmospheric pressure system develops in Asian continent due to the cooling of the landmass and the descending of air. At the same time, the Australian continent is experiencing summer. The air rises due to the rapid warming of the continent, and thus a low atmospheric pressure system is enhanced. The combined effects of these two different atmospheric pressure systems result in the air moving from Northern Hemisphere to Southern Hemisphere. Due to the effect of Coriolis force, a northeasterly wind blows over the South China Sea. This phenomenon is generally known as the Northeast monsoon, blowing during the months of November through March.

A reverse atmospheric pressure system prevails during the northern summer season. As a result, the air motion in the South China Sea is from the southwest direction from May to September. This wind is normally known as the Southwest monsoon.

Two transitional periods occur between these two monsoons, in April and in October, respectively. Both transitional periods last from about three to seven weeks [Morgan and Valencia (1978)].

The Northeast monsoon brings heavy rainfall to the northern and remote regions of Sabah, as well as the entire region of Sarawak. The Southwest monsoon, on the other hand, also strongly influences the weather pattern of Sarawak. The winds bring relatively large amount of rainfall to the southwestern portion of the state. This is due to the intense humidification of the winds over the warm South China Sea. In conclusion, Southwest monsoon plays a significant role in the monthly rainfall distribution of Sabah and Sarawak [Camerlengo *et al*. (1997)].

Rainfall during the SW monsoon season result in the influx of freshwaters from Sabah and Sarawak rivers, thus, reducing water salinity and density values along the coast, as shown in Fig. 2. In most deep offshore stations - higher salinity and density values have been recorded.

The SW monsoon enhances mixing effects of surface waves in shallow waters [Wrytki (1961)]. As a result, temperature, salinity and density values of shallow water very slightly from the deeper ones. For the same reason, water properties in the southern part of the South China Sea show slight variations as compared to the rest of the study area (Figs. 3 and 4).

Profiles of temperature, salinity and density obtained during the Matahari Expedition ’87 [Nasir *et al*. (1988)] and ’89 [Nasir *et al*. (1990)] are similar to profiles obtained in the present study. This is because both Matahari Expeditions and the cruises conducted in the present study were done during the SW monsoon but in different years.

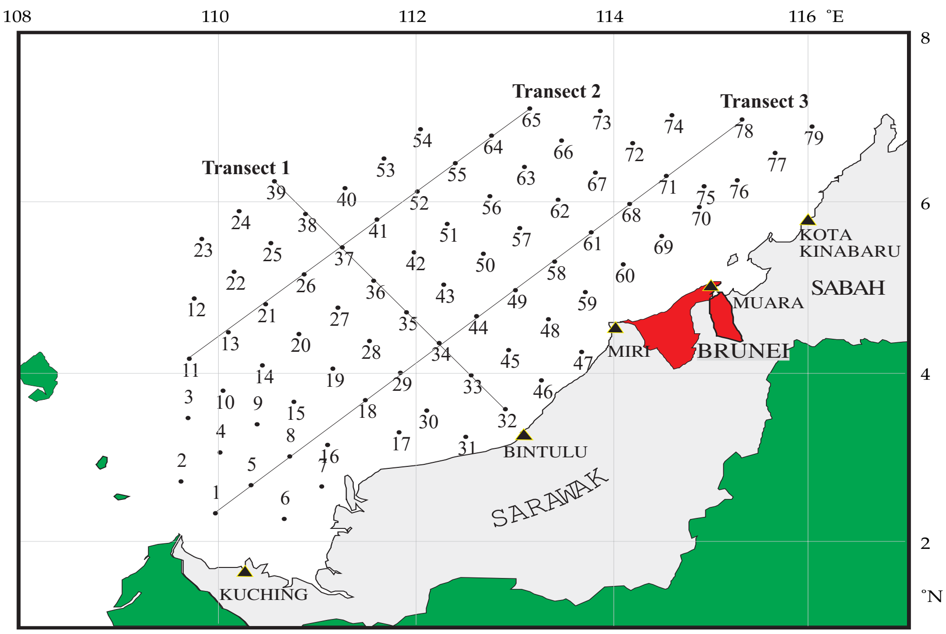


Fig. 1 All sampling stations and three selected transects

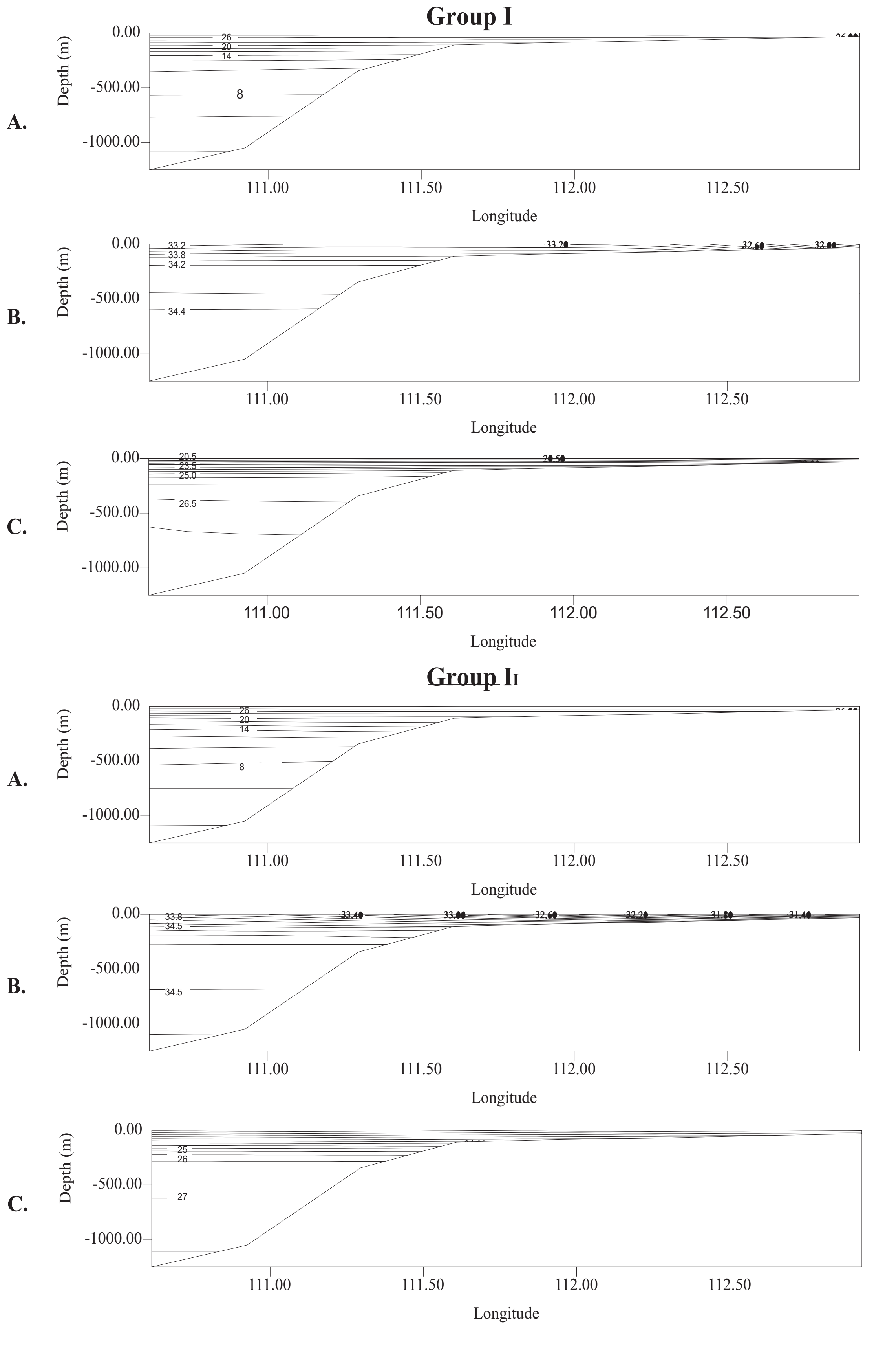


Fig. 2. Transec 1 in : I) M.V.SEAFDEC third cruise and II) M.V.SEAFDEC fourth cruise with: A) Temperature, B) Salinity and C) Density contours.

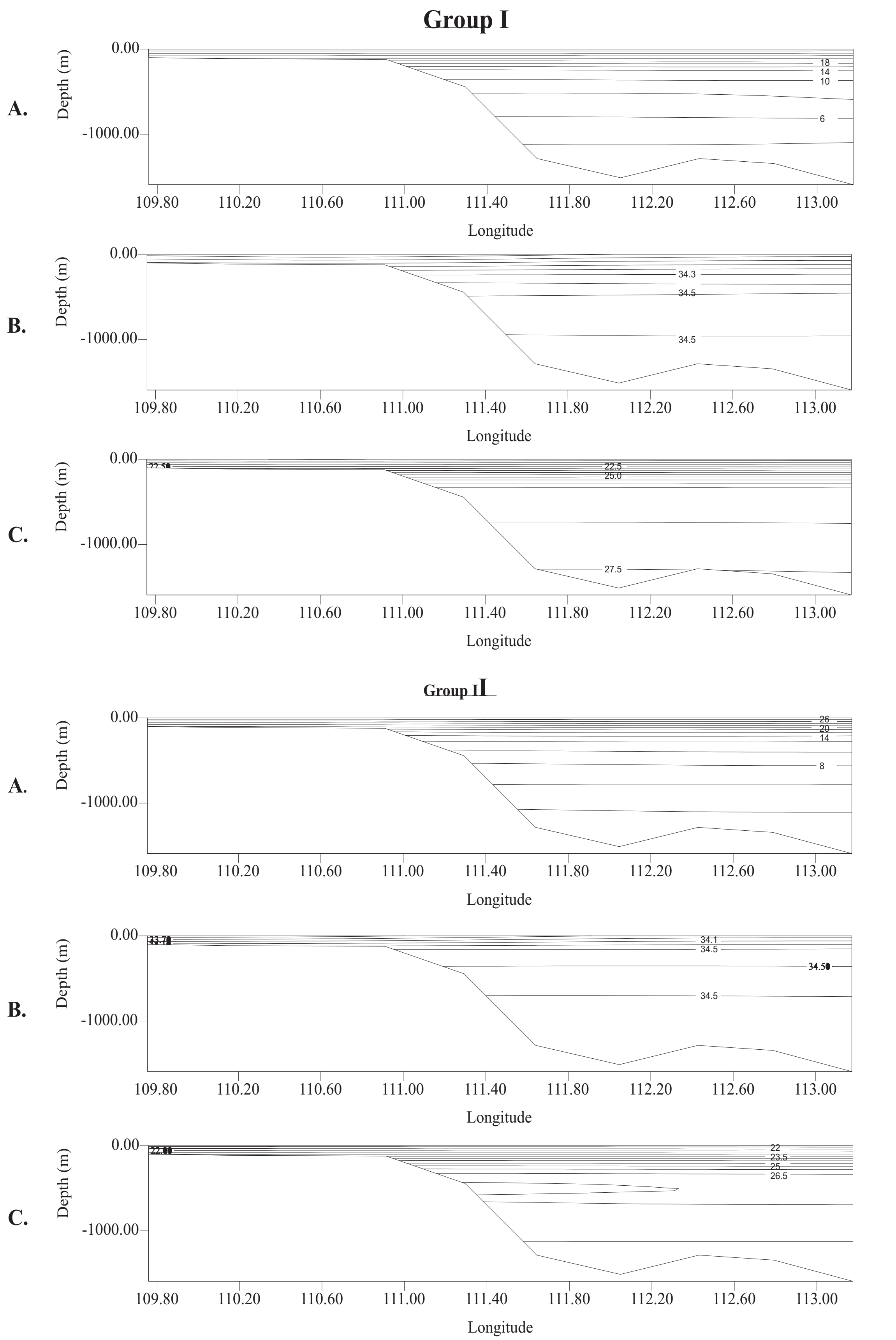


Fig. 3. Transec 2 in : I) M.V.SEAFDEC third cruise and II) M.V.SEAFDEC fourth cruise with: A) Temperature, B) Salinity and C) Density contours.

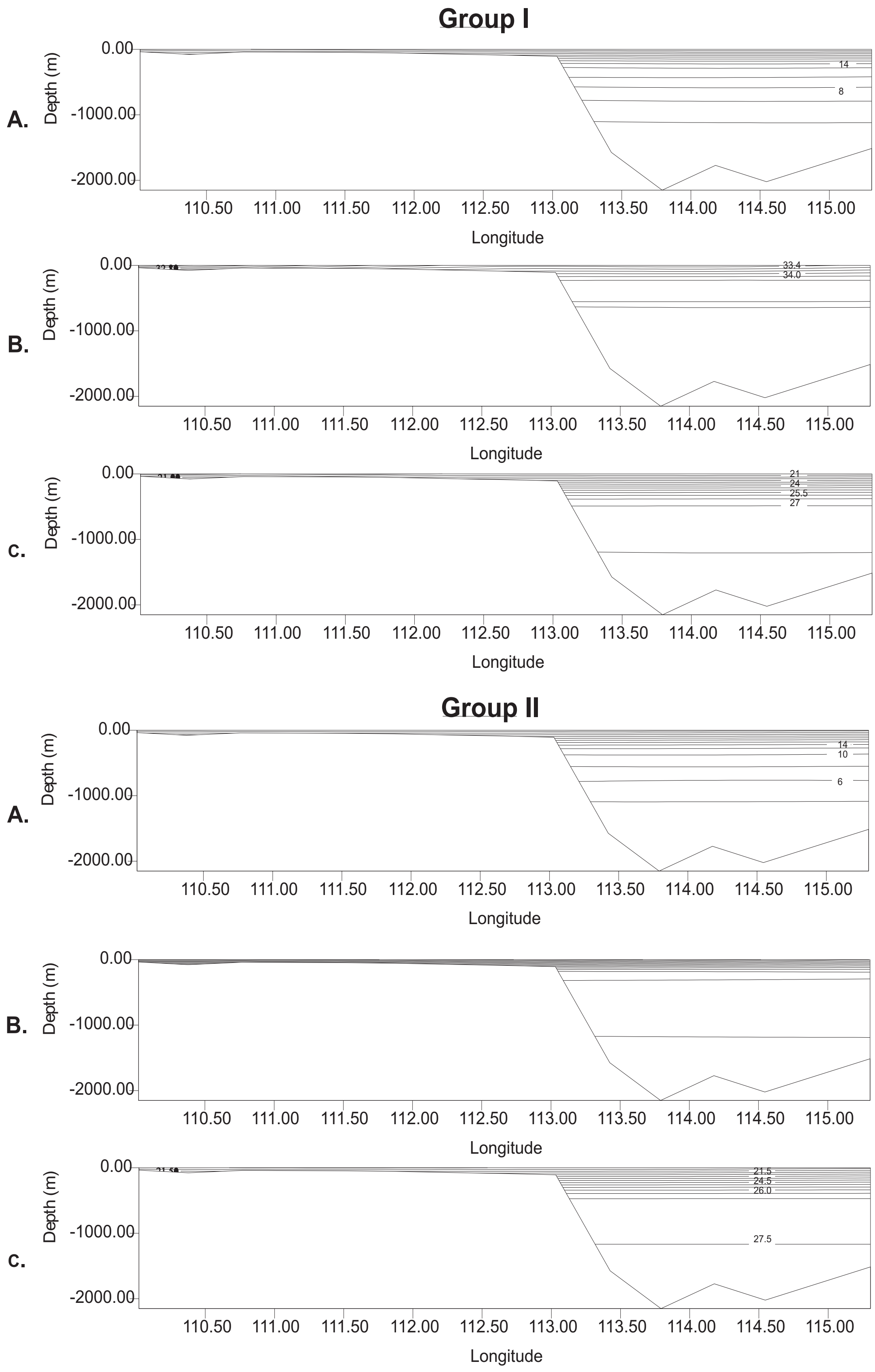


Fig. 4. Transec 3 in : I) M.V.SEAFDEC third cruise and II) M.V.SEAFDEC fourth cruise with: A) Temperature, B) Salinity and C) Density contours.

Conclusions

The vertical distributions and profiles of water properties in Sabah and Sarawak waters resulting from the two cruises, during the SW monsoon, are analyzed and compared. The results show that different periods (i.e. May and July) of the SW monsoon did not cause great variability of physical parameters in Sabah and Sarawak waters. Temperature, salinity and density contours of three selected transects and their profiles at all sampling stations, showed slight variations in the coastal and offshore waters, as well as in the shallow and deep waters. It is concluded that influx of freshwater from Sabah and Sarawak rivers has a pronounced effect of decreasing both salinity and density values of the coastal waters.

Water properties of shallow waters vary slightly from the deeper ones, as vertical mixing is enhanced by surface waves. As the waters are shallower in southern part of the South China Sea, the variability of physical parameters of the water mass is slightly different from the rest of the study area.

Thermocline, halocline and pycnocline layers are apparent in all three transects and profiles (especially deeper stations), for both cruises. Due to the fact that there are only slight differences of water properties in both cruises, the depth of these layers also do not vary greatly.

It is felt that knowledge on oceanographic characteristics of the South China Sea (including Sabah and Sarawak waters) is scarce and limited. As such, more physical oceanographic cruises are needed; so as to have a better understanding on the physical characteristics of Sabah and Sarawak waters.

ACKNOWLEDGEMENT

The authors would like to extend their very special thanks to Universiti Putra Malaysia Terengganu for their cooperation in this research.

REFERENCES

1. A. L. Camerlengo, M. S. Nasir and M. H. Rubani: Monthly distribution of precipitation in Sabah and Sarawak. *Journal of physical science*, 8. 63-67 (1997).
2. J. R. Knauss: Introduction to Physical Oceanography. Prentice-Hall, New Jersey, 1978, 338 p.
3. J. R. Morgan and M. J. Valencia: The natural environmental setting, in “Atlas for marine policy in Southeast Asian Seas” (ed. by J. R. Morgan and M. J. Valencia). University of California Press, 1983, pp. 4-17.
4. M. S. Nasir, H. C. Liew and M. Uchiyama: Salinity and temperature vertical profiles off the Sarawak coast, in “Ekspedisi Matahari ’87” (ed. by A. K. M. Mohsin and MI Mohamed). UPM Occa. Pub. 1988, No. 8, pp. 29 – 36.
5. M. S. Nasir, H. C. Liew and M. Hidaka: Temperatue and salinity profiles in Sabah waters, in “Ekspedisi Matahari ’89” (ed. by A. K. M. Mohsin, M. Z. M. Said and M.I. Mohamed). UPM Occa. Pub. 1990, No. 9, pp. 35 – 45.
6. M. S. Nasir and M. N. Marghany: Surface circulation off Kuala Terengganu in the transitional period between the northeast and southwest monsoons, *Pertanika J. Sci. & Technol.,* 1996, 4(1), 141-148.
7. M. S. Nasir and A. L. Camerlengo: Response of the ocean mixed layer, off the east coast of Peninsula Malaysia, during the northeast and southwest monsoon. *Geoacta*, 1997, 22, 134-143.
8. K. Wrytki: 1961. Physical oceanography of the Southeast Asia Waters. Scientific results of marine investigation of the South China Sea and the Gulf of Thailand, 1959-1961. Naga Reports. Vol. 2. University of California, Scripp Institute of Oceanography, La Jolla, California, 1961, 195 p.

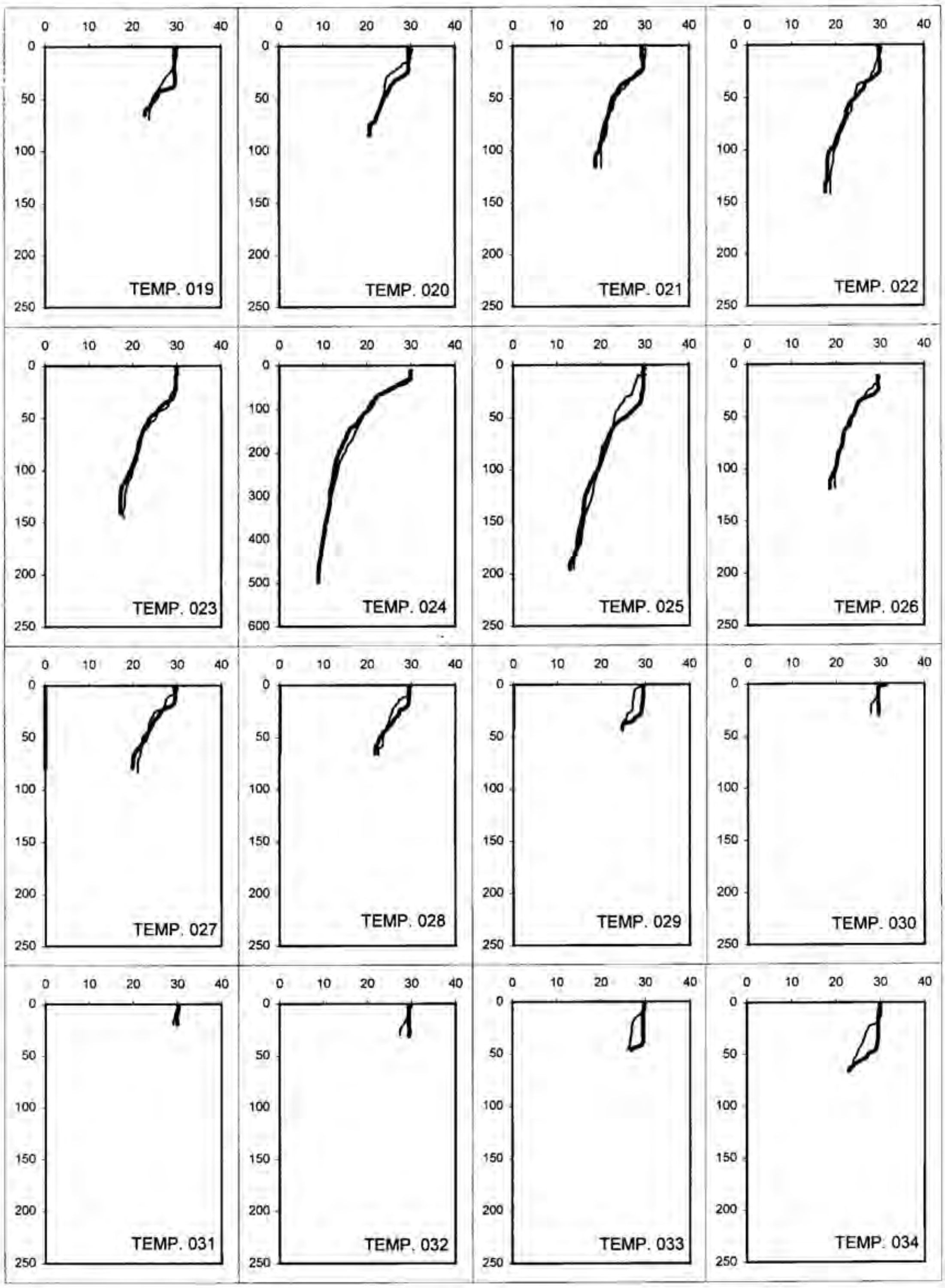
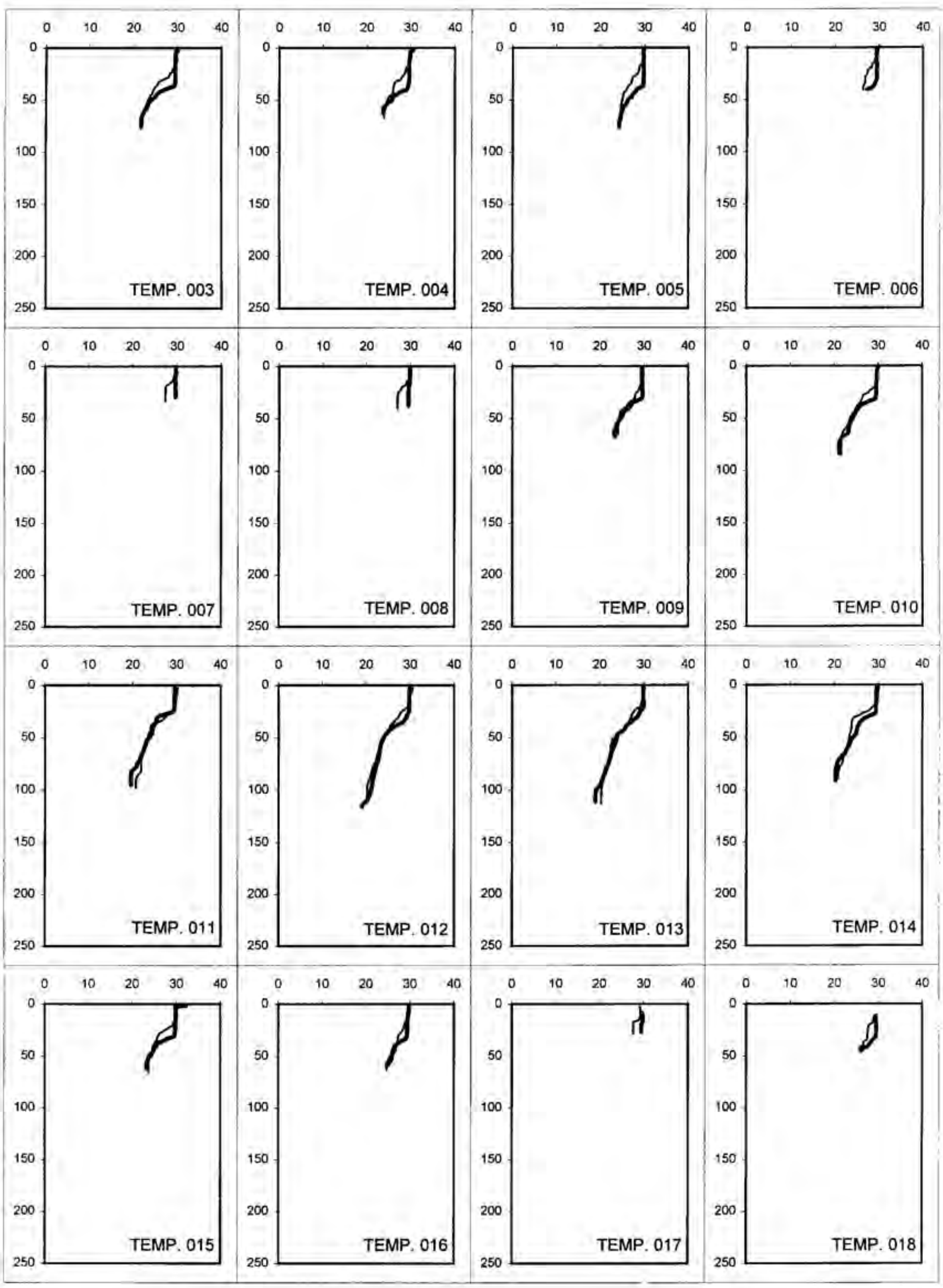


Fig. 5. Profiles of temperature from the third (thick lines) and the fourth (thin lines) cruise



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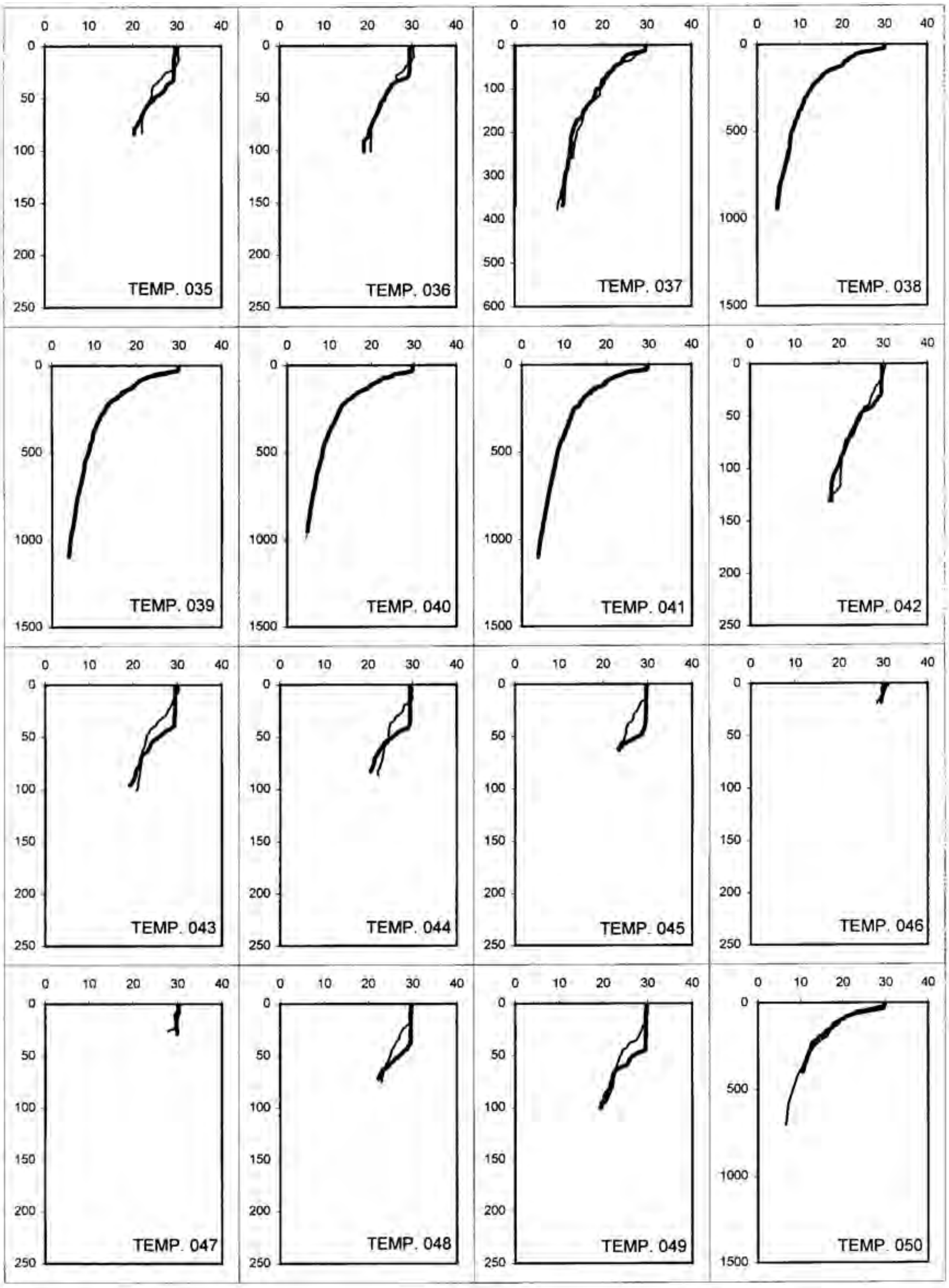

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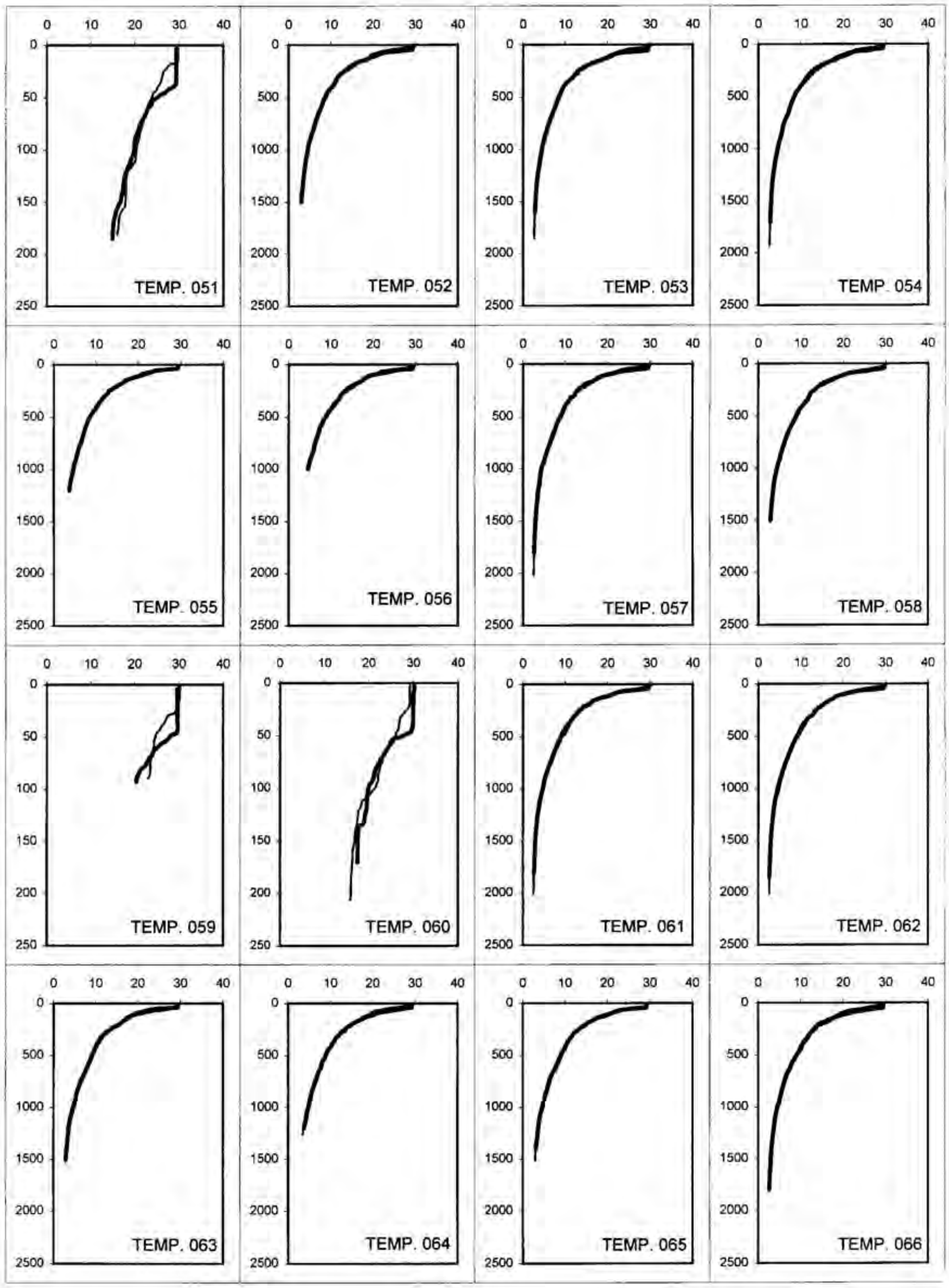

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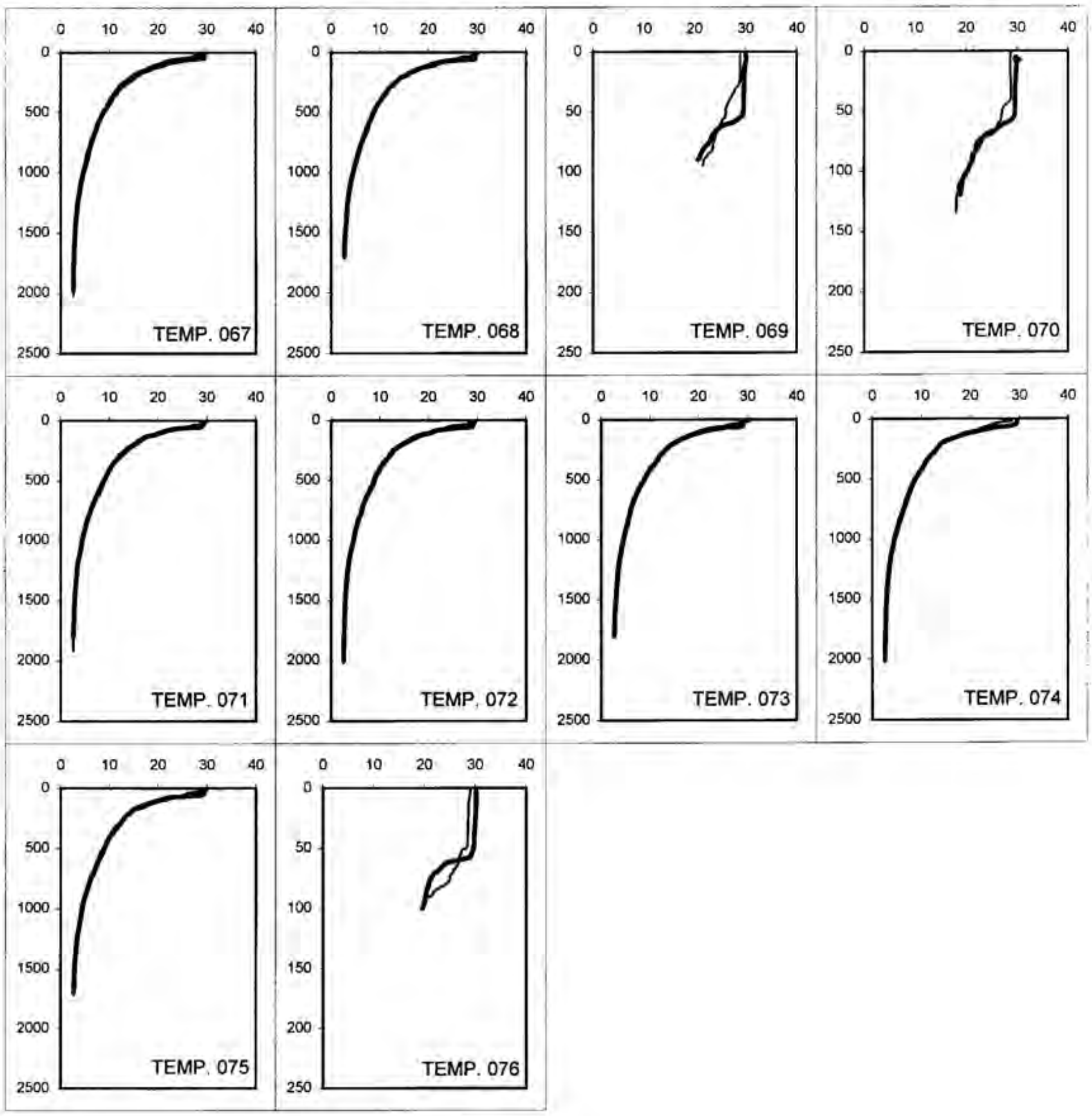

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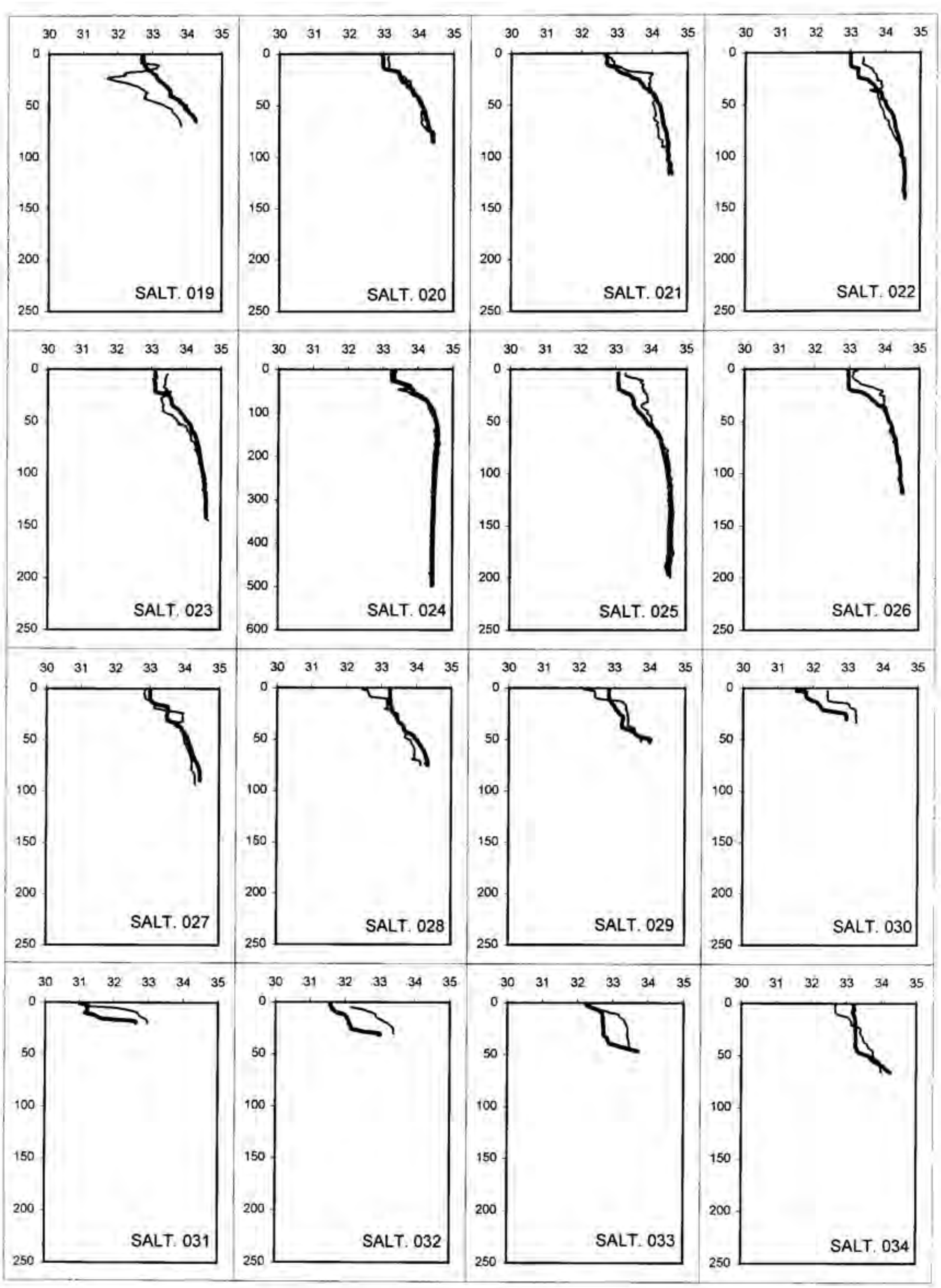
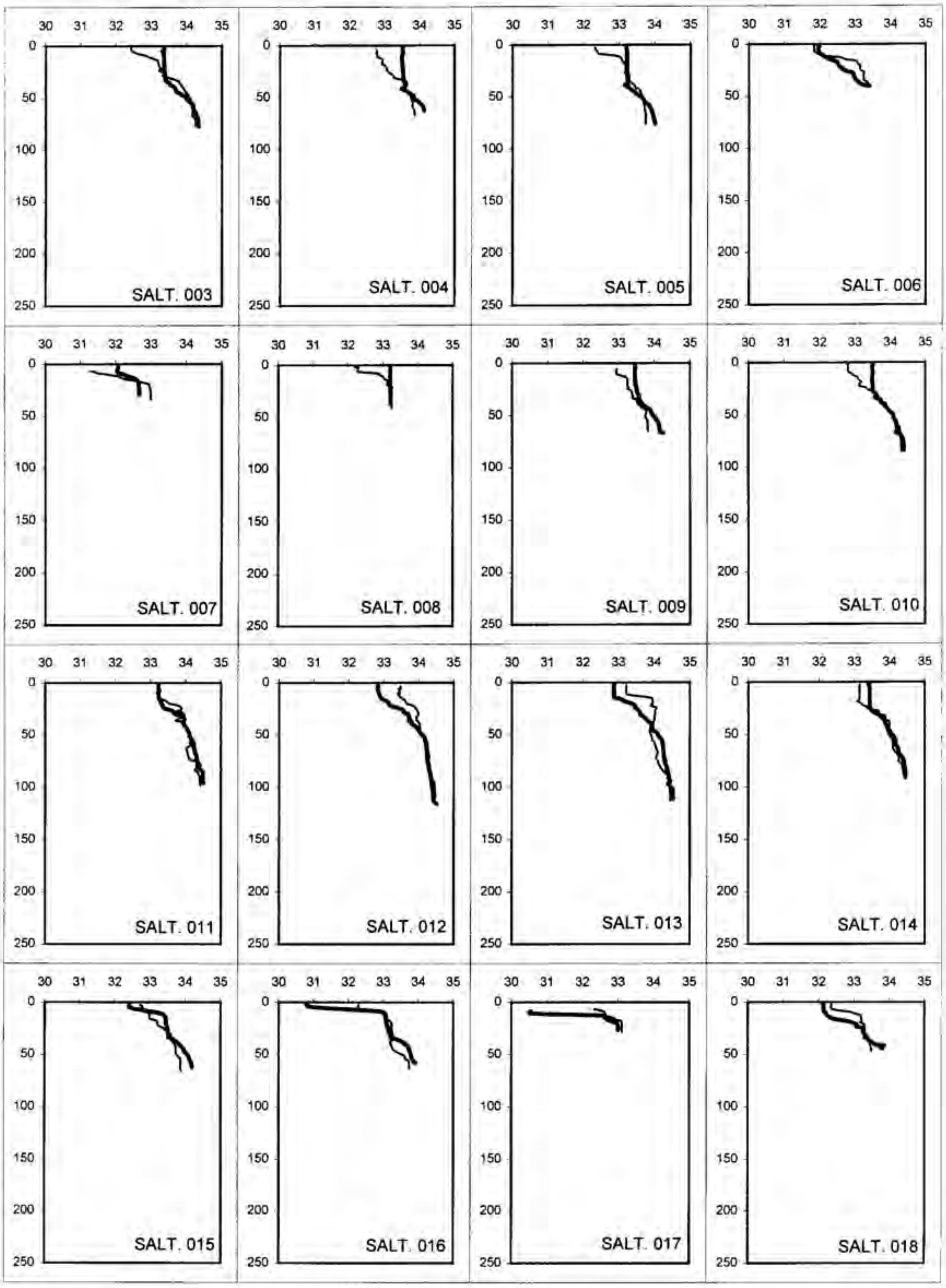


Fig 6. Profiles of salinity from the third (thick lines) and the fourth (thin lines) cruises.



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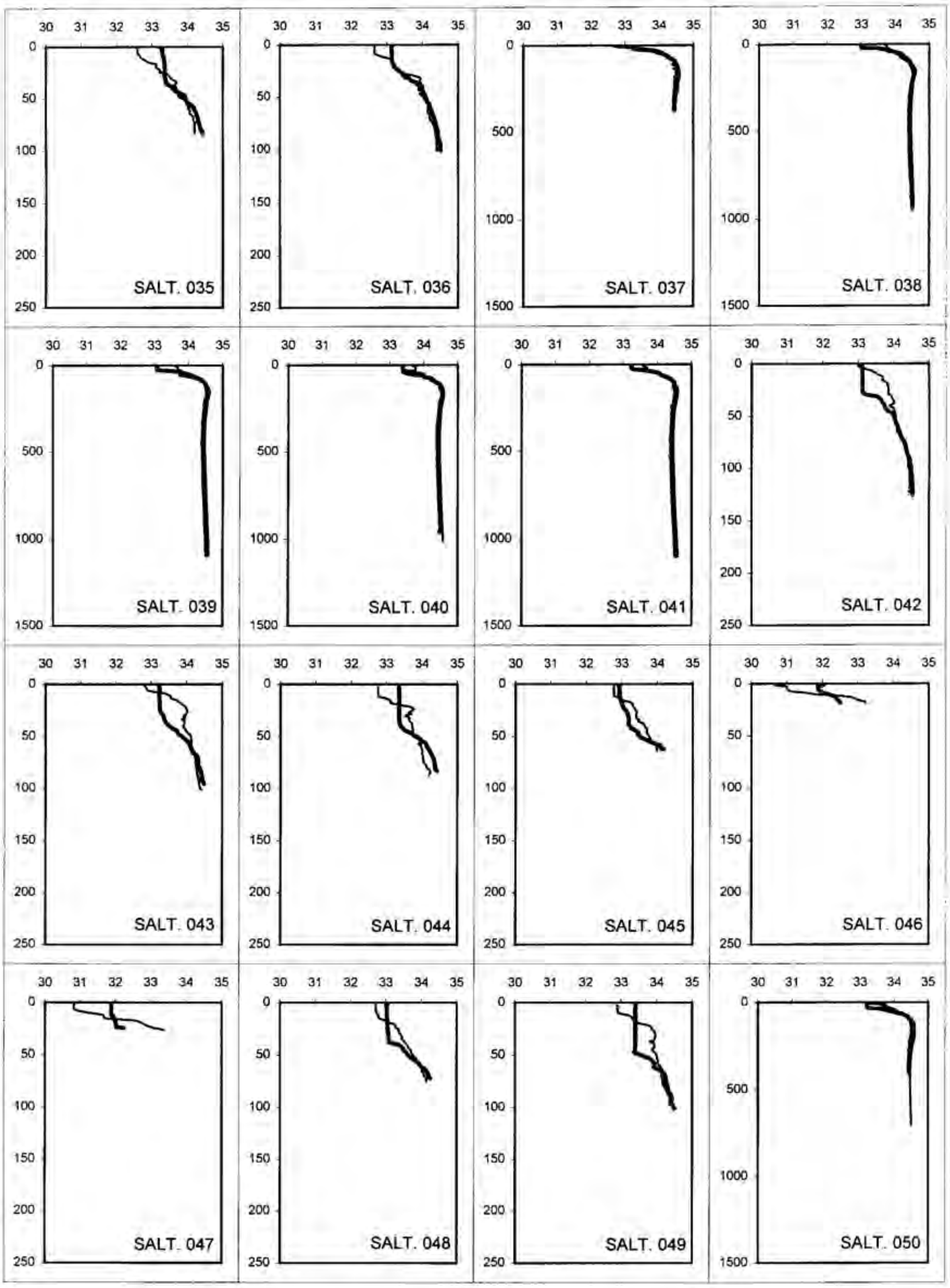

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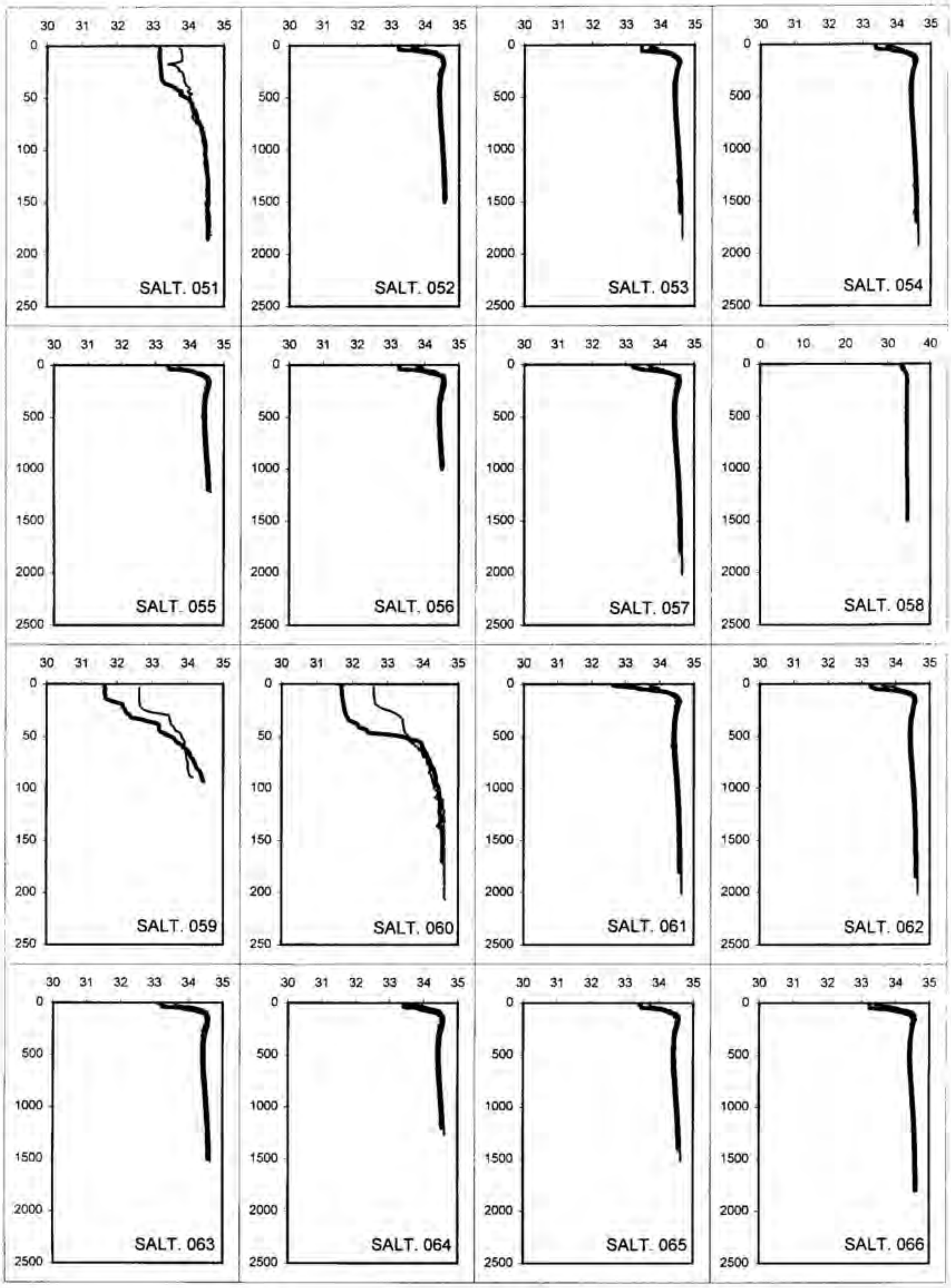

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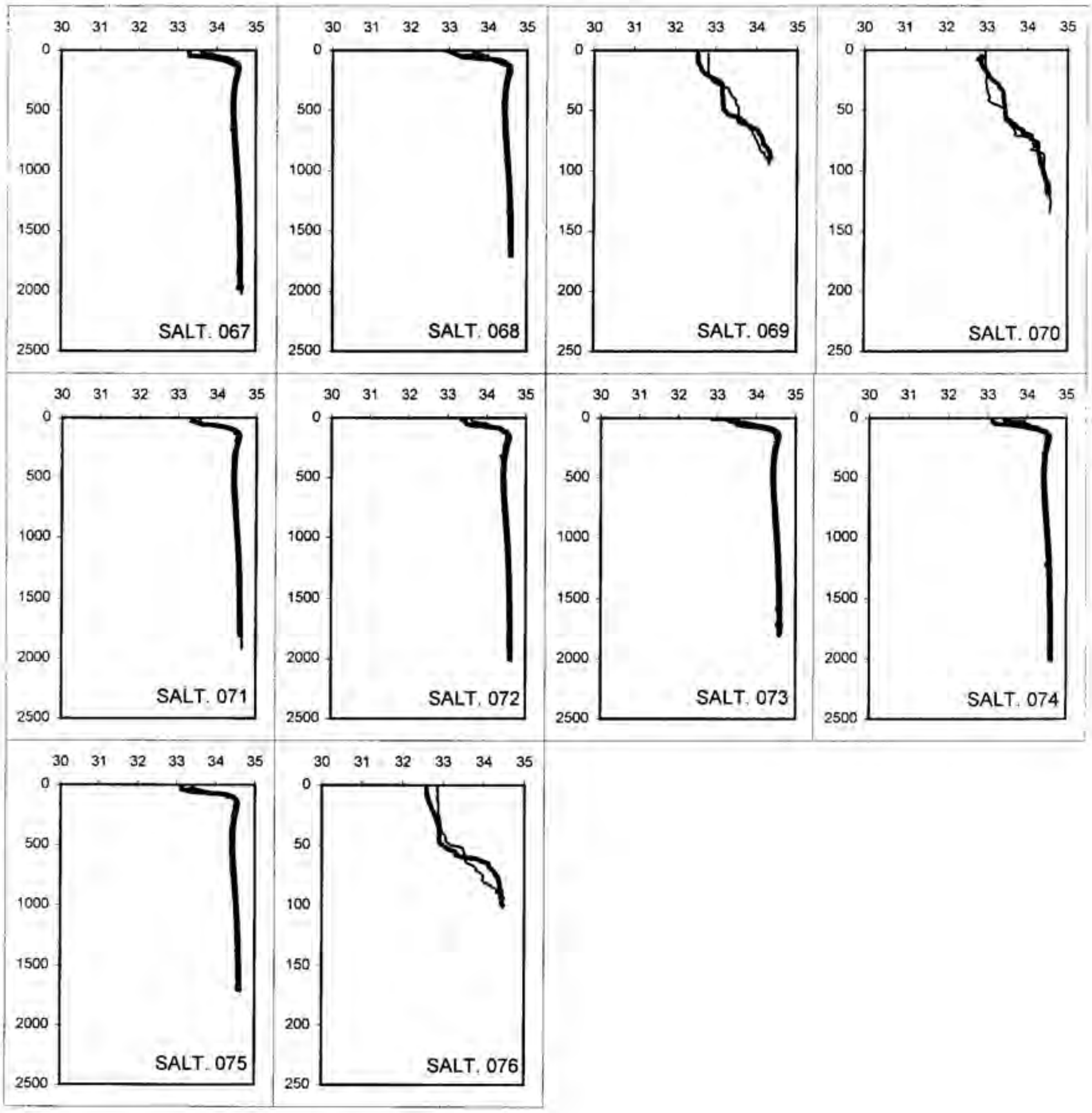

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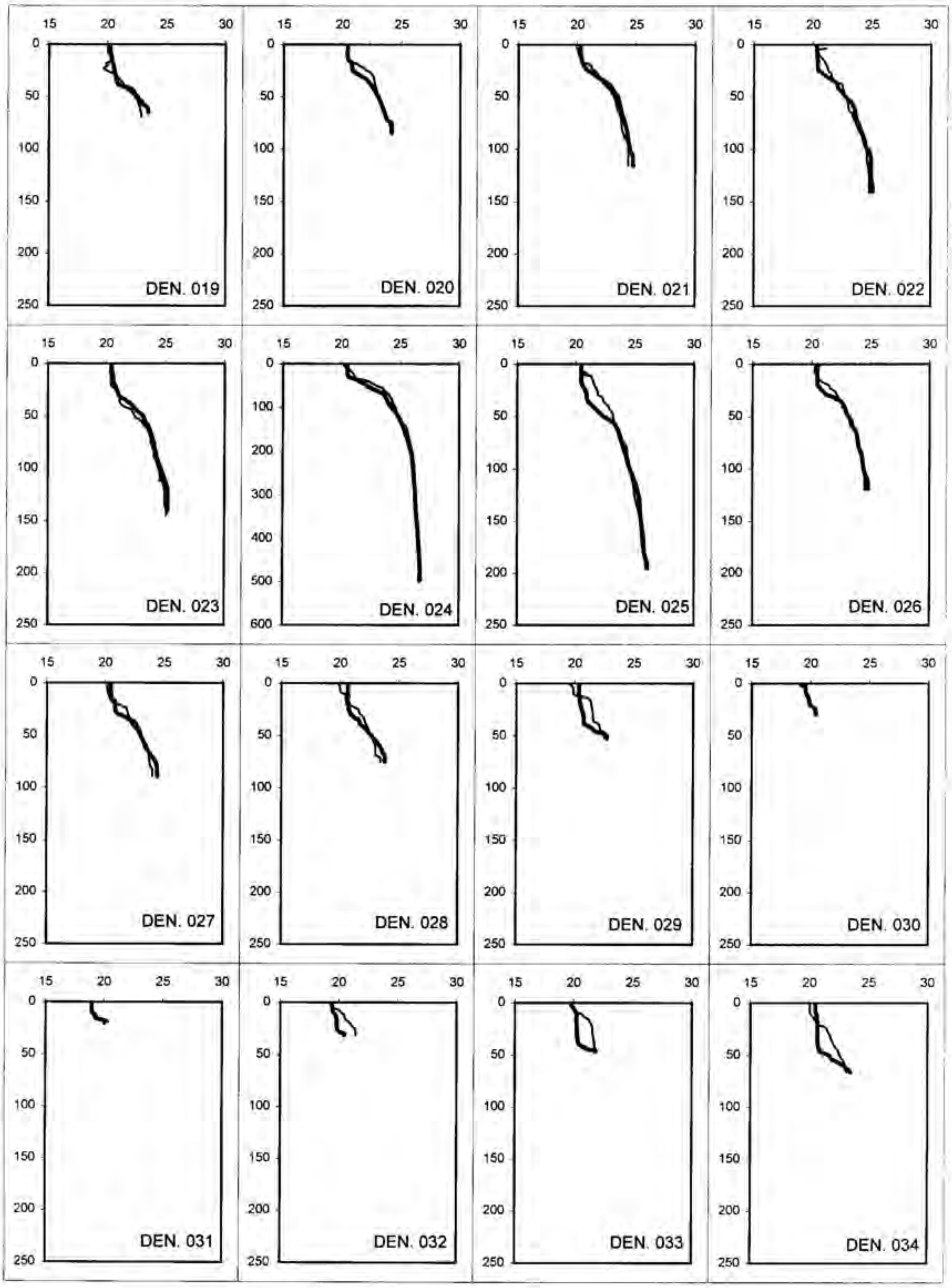
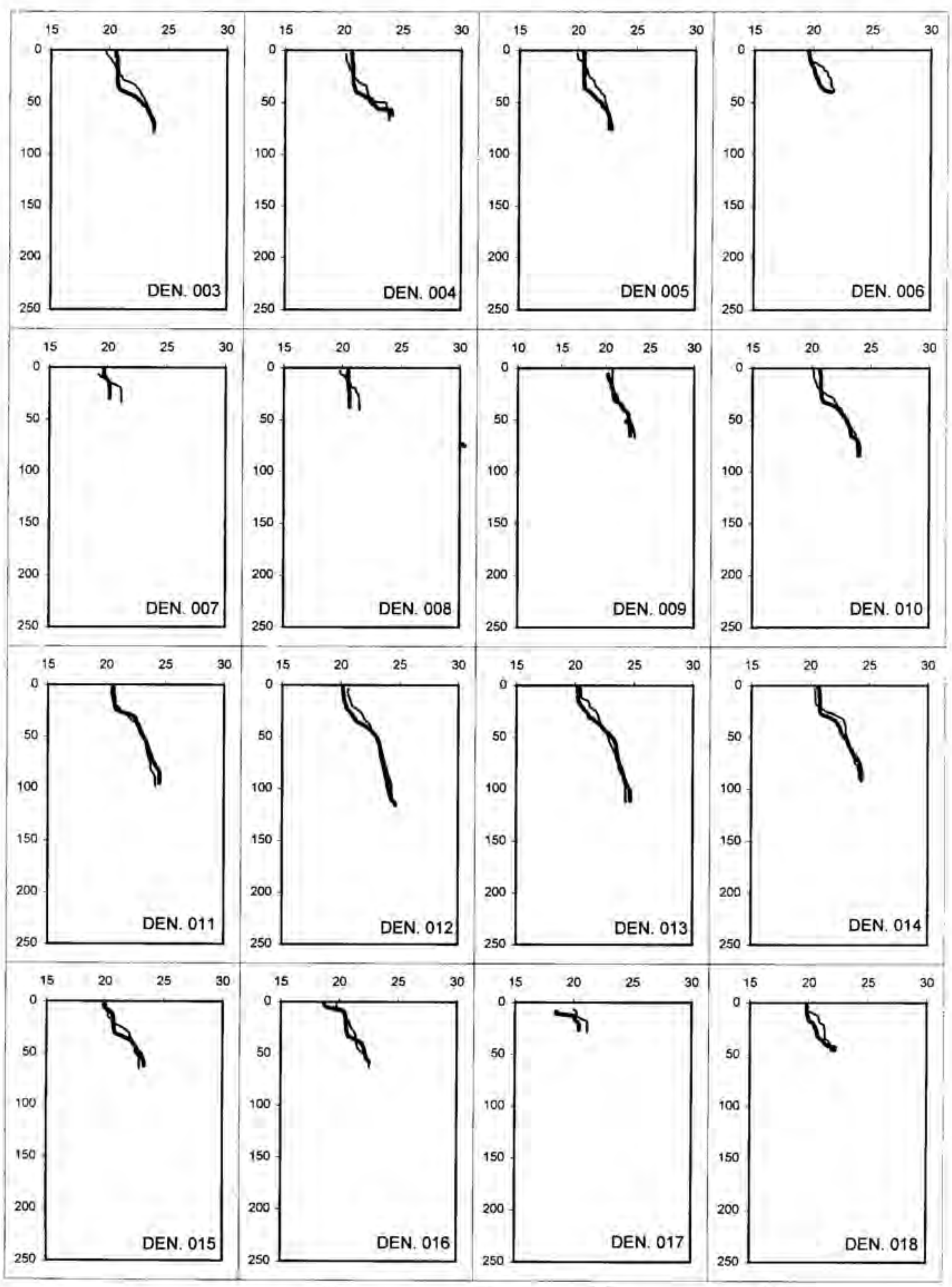


Fig 7 Profiles of density from the third (thick lines) and the fourth (thin lines) crouses.



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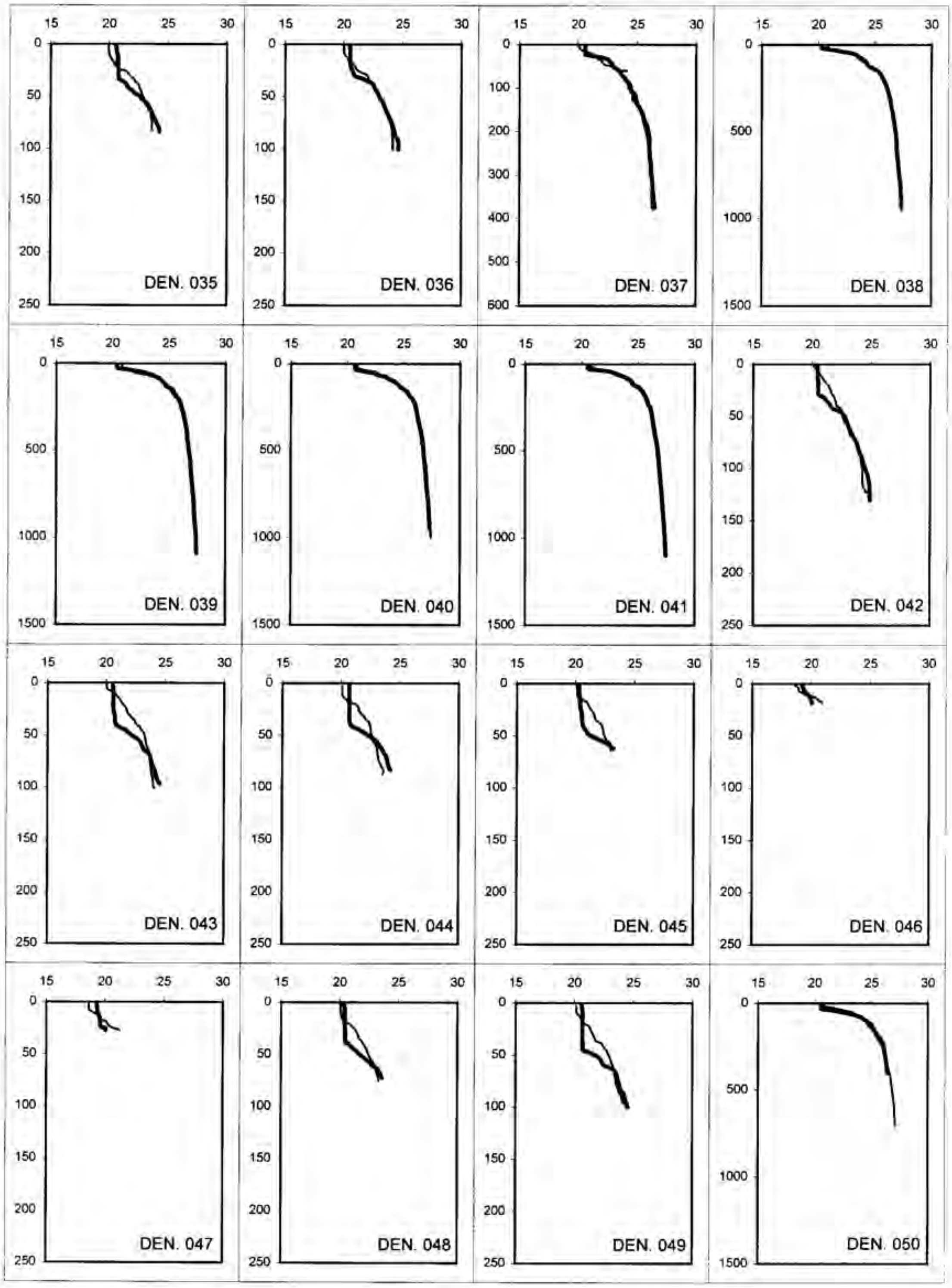

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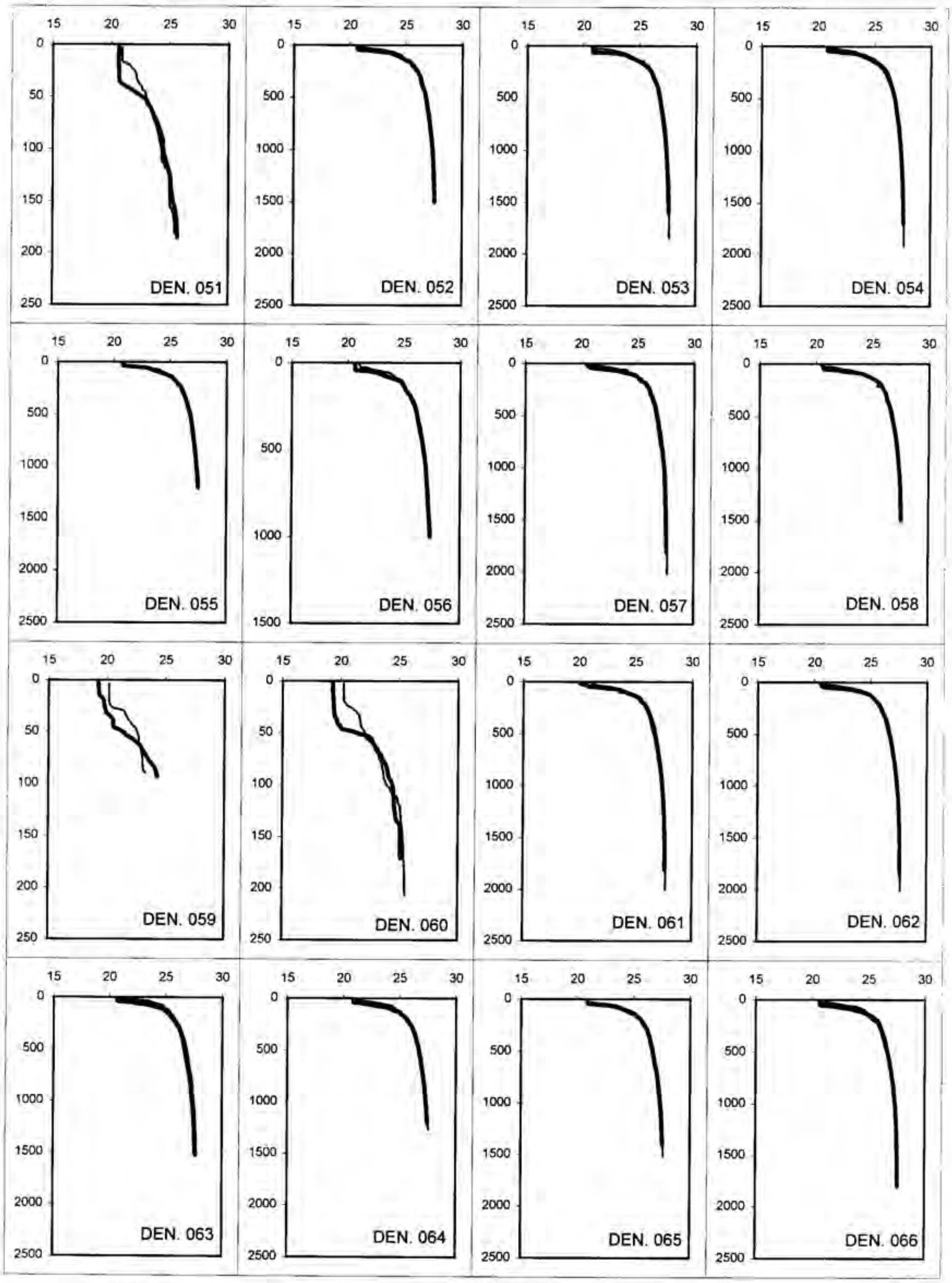

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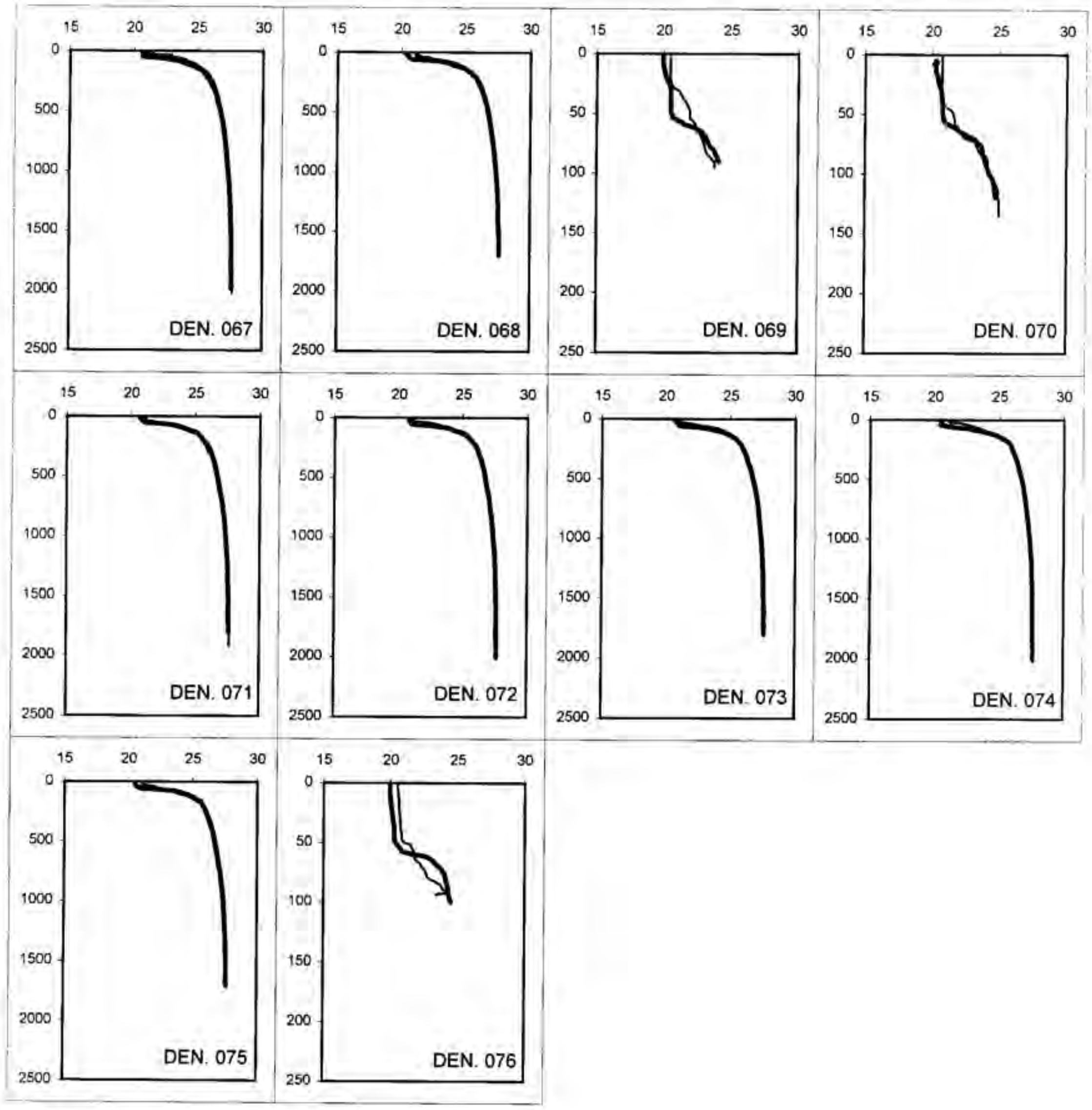

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Geostrophic Current, Divergence and Convergence in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam

Anond Snidvongs

Marine Science Department, chulalongkorn University

ABSTRACT

Current and circulation patterns for the area where water depth exceeded 500 m were calculated from geostrophic balance. Divergence and convergence inferred from horizontal circulation matched quite well with the observed vertical migration of the pycnocline, i.e. an indication of upwelling and downwelling. The spatial circulation pattern for July-August 1996 was quite different from that for May 1997, despite a generally similar prevailing wind. Eddies and meanders were the main features causing the difference. Interpretation of chemical and biological data of the area should take into consideration these local and sporadic physical phenomena.

Introduction

The net current and water circulation are always important factors for the management of fisheries and living resource in the ocean. These factors can be determined by several approaches, each of them has its own advantages, disadvantages and limitations. Due to the nature of this survey, where the vessel spent only 1 to 1.5 hour at each station, direct observation which requires observation duration of at least 25 hours in order to obtain both semi-diurnal and diurnal components of current was not possible, despite the availability of a Doppler instrument on board the vessel M.V. Seafdec.

There are several indirect methods to determine the net movement of water in the marine environment. Numerical modelling using, for examples Nevier-Stoke type equation, advection-diffusion equation, and mass-momentum balance principles, however requires good knowledge of boundary conditions which was not possible in the present study area. Remote sensing approach using sea surface topography can provide some indication of surface over a large area. However a small area of only 6 x 8 degree will cover only a few Topex-Poseidon tracks so even though this is a promising approach it still needs more refinements and adjustments before it can be sufficiently reliable.

The classical geostrophic balance is most appropriate under the condition and limitation of this survey. It requires accurate temperature, salinity and pressure data which could be provided by high resolution CTD deployed at each station. The current obtained from the method will be relative current between 2 layers. In deep ocean where the current speed at a sufficiently deep layer is usually very slow relative to surface current (e.g. less than 0.01 m/s), a deep layer can be assumed to be the level of no motion. The absolute current at any levels above the level of no motion can be obtained.

The Study Area

The study area—the northwest coast of Borneo Island offshore of Sarawak and Sabah, Malaysia and Brunei Darussalam—is a relatively open area subjected to both Southwest and Northeast Monsoons. Among the total of 79 survey stations of both cruises, Cruise 34 (10 July - 2 August 1996) and Cruise 41 (1 May - 24 May 1997), only 27 stations had bottom depth exceeded 500 meter where level of no motion can be assumed. The location of these stations and the bottom topography of the survey area are shown in Fig. 1.

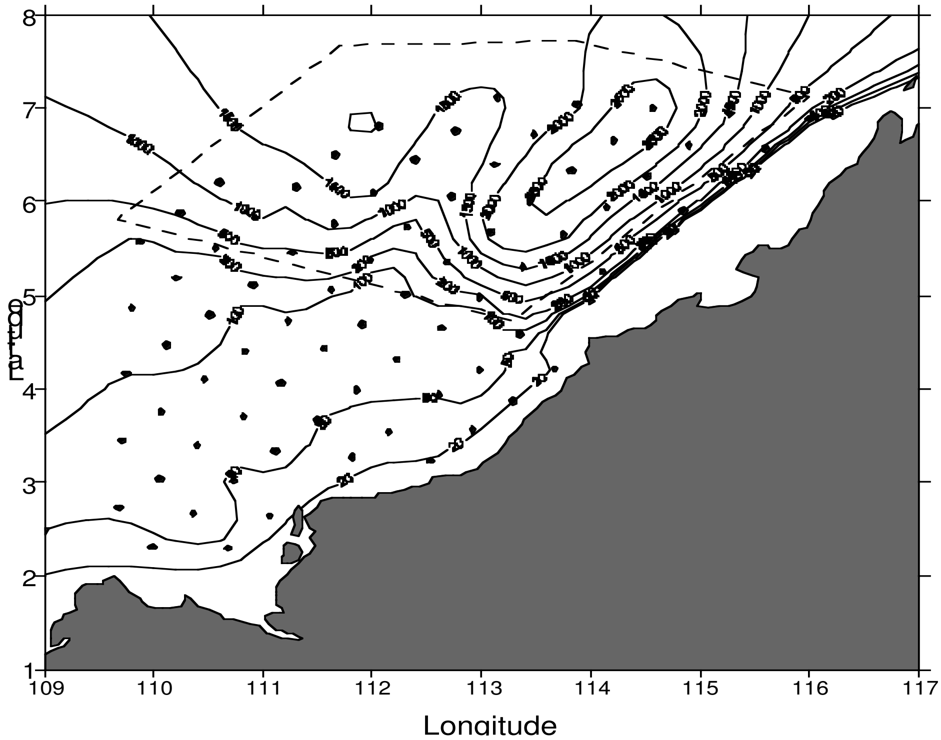


Fig. 1 Depth contour (m) of the study area. The area bound by dashed line is the area where water depth was greater than 500 m and geostrophic balance calculation could be performed.

Dynamic Topography and Geostrophic Balance

The principle of geostrophic balance can be found in any textbooks on physical oceanography, such as Pond and Pickard (1983) and other. The method has been used widely for deep ocean and it may not too exaggerated to say that probably most of the subsurface circulation of the world ocean known to date was obtained by this approach. The basic assumption of this method is that in the case of an isobaric surface, for example, sea surface, to maintain an unequal level then the horizontal pressure gradient force due to gravity (potential energy) must be counteracted or balanced by Coriolis force due the movement of water.

$$f\,u = g\,tan(q) \qquad (1)$$

where f = Coriolis factor (function of latitude)
u = current speed in the direction perpendicular to the pressure gradient
g = gravitational acceleration
q = tilt angle of the interested surface relative to reference surface (e.g. level of no motion)

Because it is more difficult of determine q from direct measurement, it can be calculated from dynamic height difference between 2 stations by defining

$$DYNH = g\,z \qquad (2)$$

where DYNH = dynamic height (in dyn.m)
z = vertical distance between the interested surface and the reference surface (in m)

Thus, combining equations 1 and 2 will give

$$f\,u = (DYNH_1 - DYNH_2) / L \qquad \text{———} (3)$$

where subscript refers to station and L = distance (m) between the 2 stations

Data Collection and Analysis

Raw data for temperature, conductivity and pressure were collected by a Falmouth Scientific CTD on board the vessel using sampling rate of 25 Hz. Temperature was corrected to ITS 90 standard. Salinity was calculated according to PSS 78 scale. Dynamic height relative to the surface was also calculated by the EG&G CTD Post-acquisition Analysis Software at every 1 dbar pressure interval.

The obtained dynamic height was corrected to 500 dbar level, the assumed level of no motion. This observed dynamic height relative to 500 dbar at sea surface, 20, 50, 100 and 200 dbar were converted into gridded data by Krigging Method at 0.2 degree grid size using Surfer (Golden Software). These gridded data were subsequently used to calculate u and v components for each grid cell using the program listed in Appendix 1.

Divergence and convergence were inferred simply from the direction of surface current. In the northern hemisphere the currents that pass each other on the right hand side will create a convergence due to Coriolis effect. Divergence will be created when the surface currents pass each other on their left.

In order to correlate horizontal current field with vertical phenomena that could be important for fisheries purpose, sea surface temperature was taken from CTD data file but to avoid daily heat exchange artifact, the data at 5 m from sea surface was used. The depth of surface mixed layer, another important indicator of upwelling and downwelling processes, was taken from surface to the depth where vertical stratification was strongest as indicated by largest Brunt-Vaisala Stability Frequency at each station.

Results

Current pattern during Cruise 34 (July-August 1996) was dominated by two northward surface plumes. These plumes could be clearly detected down to over 100 dbar but at 200 dbar they were less significant (Figures 2 to 5). A weak anticyclonic eddy was observed near Station 53.

In May 1997 during Cruise 41, there was a strong meander generally from west to east. This meander, however, had quite a shallow core (less than 100 m). There was also a large and strong anticyclonic eddy that covered Station 55, 56, 63 and 64 which penetrated well below 200 m (Figures 6 to 9). The data for dynamic height is given in Appendix 2 and gridded current velocity as u and v components are given in Appendix 3.

Sea surface temperature distribution between the 2 cruises was clearly different. During Cruise 34 (Figure 10), sea surface temperature was ranged from 29.12 to 30.06 ^{o}C while in Cruise 31 (Figure 11) the temperature range increased from to 24.49 to 30.65 ^{o}C. The actual data is given in Appendix 4. The horizontal temperature gradient was generally in north-south direction in July-August 1996 and in east-west direction in May 1996. Sea surface temperature, however, did not appear to have any relationship with neither divergence/convergence zone nor the vertical movement of pycnocline of the area.

The depth of surface mixed layer strongly reflected the divergence and convergence zone in the study areas in both cruises (Figures 12 and 13). Generally the surface mixed layer was deeper on the east side of the survey area during Cruise 34 and the opposite was found in Cruise 41. In most areas where geostrophic circulation suggested a divergence, surface mixed layer tended to be thinner, a good indication of upwelling. Downwelling was also inferred from surface mixed layer to coincide with convergence zones.

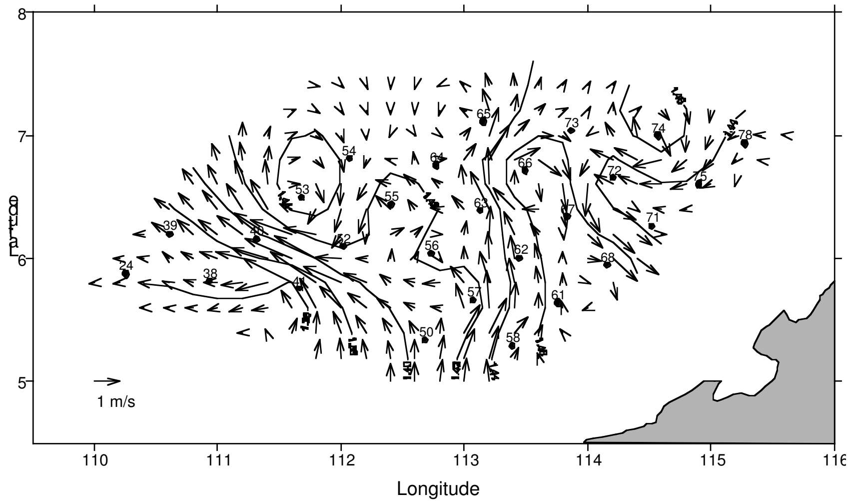


Fig. 2 Dynamic height (dyn.m) at sea surface (0 dbar) for Cruise 34 with current vectors relative to 500 dbar

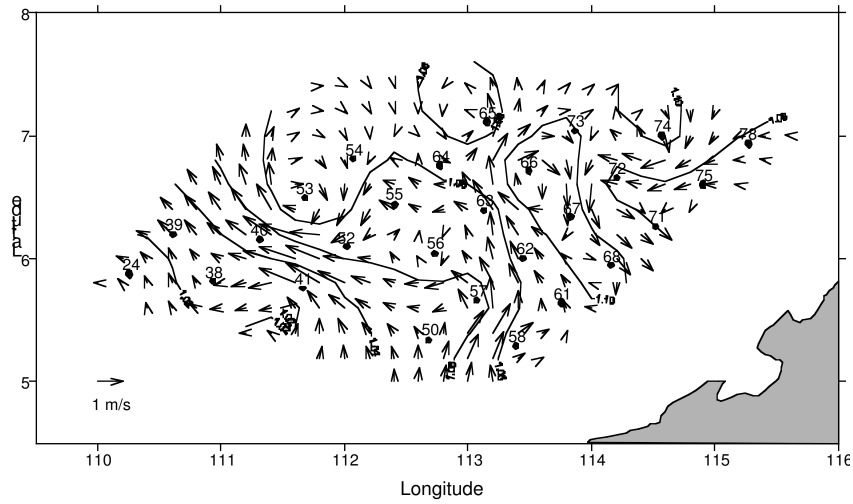


Fig. 3 Dynamic height (dyn.m) at 50 dbar for Cruise 34 with current vectors relative to 500 dbar

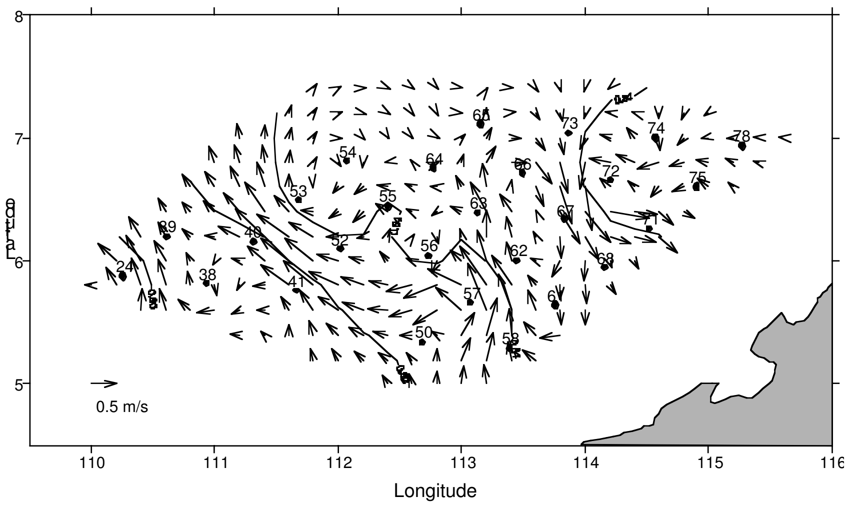


Fig. 4 Dynamic height (dyn.m) at 100 dbar for Cruise 34 with current vectors relative to 500 db

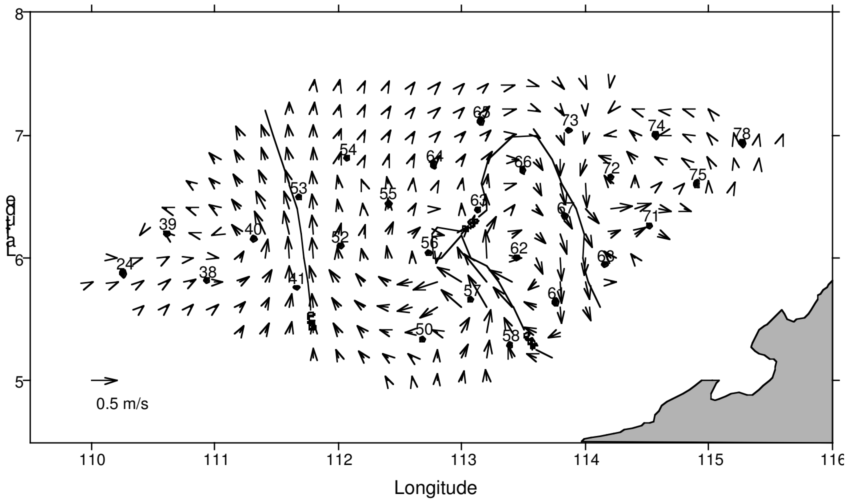


Fig. 5 Dynamic height (dyn.m) at 200 dbar for Cruise 34 with current vectors relative to 500 db

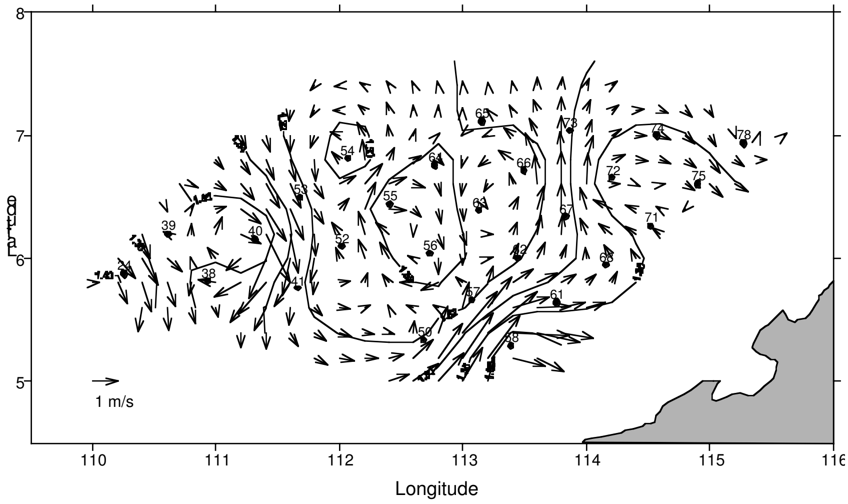


Fig. 6 Dynamic height (dyn.m) at sea surface (0 dbar) for Cruise 41 with current vectors relative to 500 db

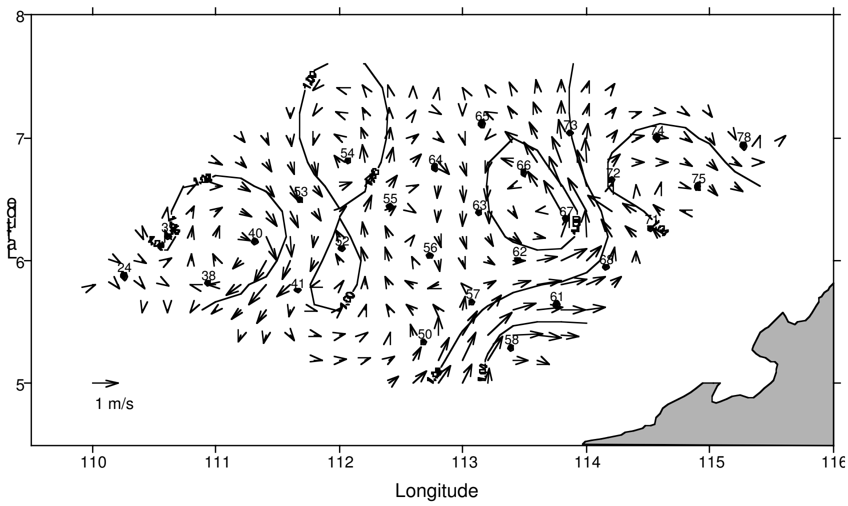


Fig. 7 Dynamic height (dyn.m) at 50 dbar for Cruise 41 with current vectors relative to 500 db

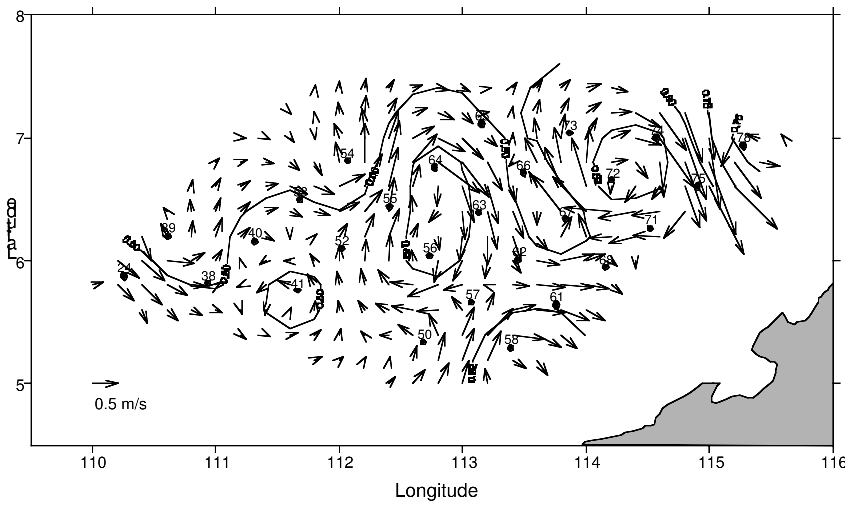


Fig. 8 Dynamic height (dyn.m) at 100 dbar for Cruise 41 with current vectors relative to 500 db

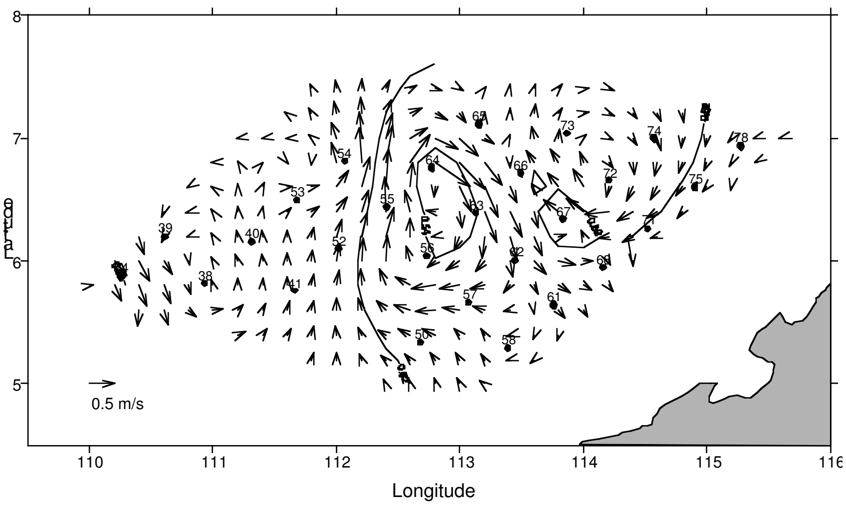


Fig. 9 Dynamic height (dyn.m) at 200 dbar for Cruise 41 with current vectors relative to 500 db

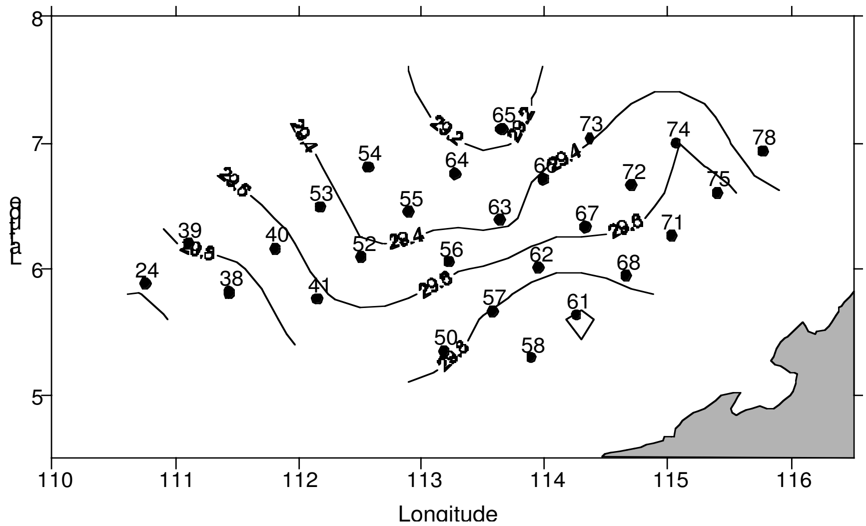


Fig. 10 Sea surface (5m) temperature for Cruise 34

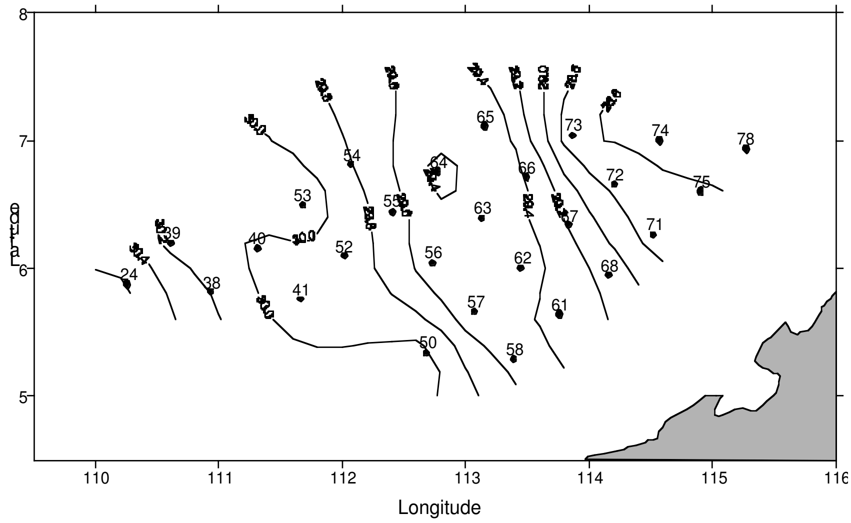


Fig. 11 Sea surface (5m) temperature for Cruise 41

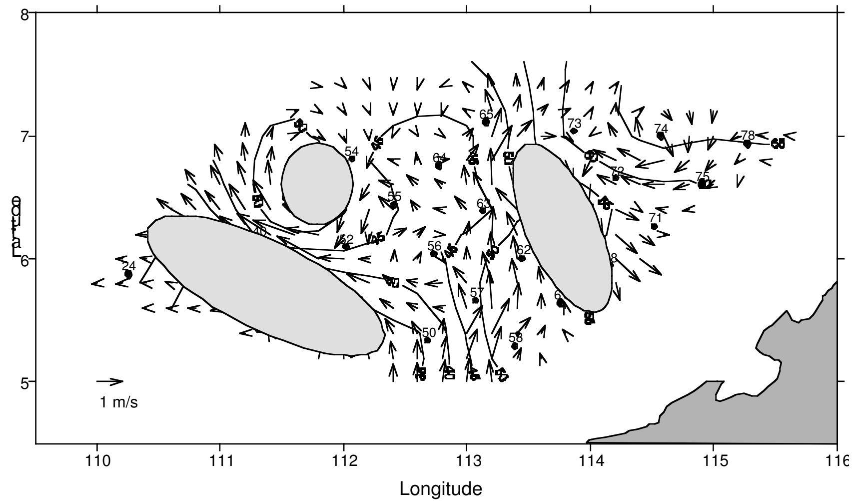


Fig. 12 The depth of stability maximum layer (m) for Cruise 34 with surface current vector relative to 500 dbar. Divergence and convergence zones are shown by vertical hatched and holizontal hatch, respecitive

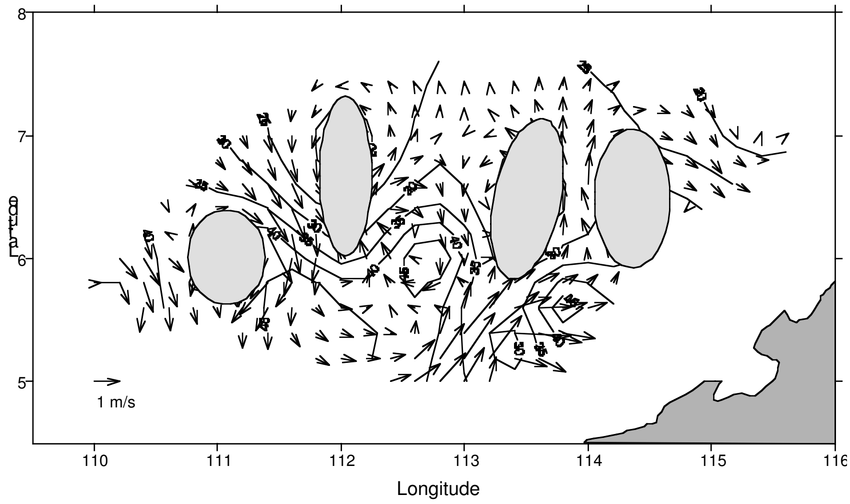


Fig. 13 The depth of stability maximum layer (m) for Cruise 41 with surface current vector relative to 500 dbar. Divergence and convergence zones are shown by vertical hatched and holizontal hatch, respecitive

Discussion and Conclusion

Geostrophic balance calculation appeared to give a reasonably acceptable qualitative result, which was supported by apparent upwelling and downwelling in the survey area. However the absolute magnitudes of several current vectors appeared to be too large to be the net current for this area, i.e. greater than 1 m/s. A possible explanation could be due to the assumption for the level of no motion of 500 dbar. However, with the limited data available not much could be done to correct this problem.

Because the prevailing wind during both cruises was not much different, the wind generally came from the southwest, which could explain the northeastward current in the central part of the survey area. However, eddies and meanders did have strong effect on the circulation pattern in this area. Interpretation of chemical and biological characteristics in this area should take into consideration these local and sporadic physical phenomena which caused apparent circulation pattern to vary from time to time.

APPENDIX 1

```
`
*****************************************************
` PROGRAM TO CALCULATE U AND V FOR EACH GRID AND
` GENERATE SURFER BLN FILE FOR VECTOR FIELD
` GRID DATA FROM LON 109-116 STEP 0.2  LAT 4-8 STEP
0.2
`
*****************************************************
CLS
DIM dynh(37, 21)
pi = 22 / 7
L = 22320          `m
head = .3          `rad
wing = .1           `wing length adjuster
arrow = .4         `arrow stem length adjuster

OPEN “out.dat” FOR INPUT AS #1
OPEN “x.bln” FOR OUTPUT AS #2
OPEN “pos.dat” FOR OUTPUT AS #3
PRINT #3, “LON,LAT,u (m/s),v (m/s)”
10 INPUT #1, lon, lat, z
x = INT((lon - 109) * 5 + .4): y = INT((lat - 4) * 5
.4)
dynh(x, y) = z / 100        `dyn.m
IF NOT EOF(1) THEN 10
FOR x = 0 TO 35
FOR y = 0 TO 20
IF dynh(x, y) > 5 THEN 20
IF dynh(x + 1, y) > 5 THEN 20
IF dynh(x, y + 1) > 5 THEN 20
lon = 109 + .2 * x: lat = 4 + .2 * y
f = 6.342E-08 * SIN(lat * pi / 180)
u = (dynh(x, y) - dynh(x, y + 1)) / f / L
v = (dynh(x + 1, y) - dynh(x, y)) / f / L
dir = pi / 2 - ATN(v / u)
GOSUB 1000
20 NEXT y
30 NEXT x
'40 PRINT “POSITION OF SCALE BAR”
`INPUT “Lat”; lat
`INPUT “Long”; lon
lat = 5
lon = 110
u = .5          `m/s
v = 0
dir = pi / 2 - ATN(v / u)
GOSUB 1000
CLOSE : END

1000 `
PRINT #3, lon; “,”; lat; “,”; u; “,”; v
PRINT “2,0”
PRINT #2, “2,0”
PRINT lon; “,”; lat
PRINT #2, lon; “,”; lat
PRINT lon + arrow * u; “,”; lat + arrow * v
PRINT #2, lon + arrow * u; “,”; lat + arrow * v

PRINT “2,0”
PRINT #2, “2,0”
PRINT lon + arrow * u; “,”; lat + arrow * v
PRINT #2, lon + arrow * u; “,”; lat + arrow * v
x2 = wing * SIN(dir + head): IF u < 0 THEN x2 = -x2
y2 = wing * COS(dir + head): IF u < 0 THEN y2 = -y2
PRINT lon + arrow * u - x2; “,”; lat + arrow * v - y
PRINT #2, lon + arrow * u - x2; “,”; lat + arrow * v
y2

PRINT “2,0”
PRINT #2, “2,0”
PRINT lon + arrow * u; “,”; lat + arrow * v
PRINT #2, lon + arrow * u; “,”; lat + arrow * v
x3 = wing * SIN(dir - head): IF u < 0 THEN x3 = -x3
y3 = wing * COS(dir - head): IF u < 0 THEN y3 = -y3
PRINT lon + arrow * u - x3; “,”; lat + arrow * v - y
PRINT #2, lon + arrow * u - x3; “,”; lat + arrow * v
y3

RETURN
```

Ortho-phosphate in the Sea Water of the South China Sea.
Area II : Sabah, Sarawak and Brunei Darussalam.

Tengku Rozaina bt. Tengku Mohamad[1]
and Mohd. Shukri b. Yusoff[2]

[1]Marine Fishery Resources Development and Management Department
Southeast Asian Fisheries Development Center, Chendering, 21080 Kuala Terengganu, Malaysia.
[2]Fish Health and Quarantine Office, Department of Fisheries, Johor Bahru, Malaysia.

ABSTRACT

The distribution of ortho-phosphate in the South China Sea off Sarawak, Sabah and Brunei Darussalam waters was studied in the SEAFDEC Interdepartmental Collaborative Research Survey : Area II. The samples were collected by M.V. SEAFDEC on 8 July to 3 August 1996 (pre monsoon period) and 1 to 24 May 1997 (post monsoon period). Seventy-nine stations were established in this study. The average concentration of ortho-phosphate of the pre monsoon period at 0-1 meter, 10 meter, 20 meter, 50 meter, 100 meter and 200 meter, 500 meter, 1000 meter and 1500 meter depth of the third survey cruise were 0.14 µM, 0.09 µM, 0.10 µM, 0.09 µM, 0.50 µM, 0.90 µM, 1.94 µM, 2.59 µM and 3.10 µM respectively. The average concentration of ortho-phosphate of the post monsoon period at 0-1 meter, 10 meter, 20 meter, 50 meter, 100 meter, 200 meter, 500 meter, 1000 meter and 1500 meter depth were 0.24µM, 0.28 µM, 0.20 µM, 0.25 µM, 1.15 µM and 2.27 µM, 4.13 µM, 5.19 µM and 5.41 µM respectively. The ortho-phosphate levels were low in the surface water and increase with depth. The results indicated that the deep water of the study area is very rich in phosphate.

Introduction

Information on dissolved inorganic nutrients distribution such as phosphorus and nitrogen in the South China Sea is limited. Some studies of nutrients in the coastal waters off Peninsular Malaysia, Sabah and Sarawak were conducted by Lim (1978), Law and Kamil (1986), Law and Rahman (1987), Ichikawa *et. al* (1987), Law and Zawawi (1988), Saleh et. al (1988), Law (1990) and Mohd. Shukri *et al*. (1997). These nutrients are essential for primary productivity that are required for maintaining our fisheries resources.

Phytoplanktons are primary producer in the sea. They require dissolved inorganic nutrients for their growth. Through photosynthesis, they produce food for supporting all trophic levels in the sea. Phytoplanktons provide food for zooplanktons which are then consumed by organisms higher up in the food chain. Phosphorus such as ortho-phosphate can be considered as a primary nutrient for phytoplankton. (Horne, 1969). Pojed and Kveder (1977) believed that phosphorus was the limiting nutrient in the growth of phytoplankton in the northern Adriatic Sea. Dissolved inorganic phosphate is utilized by all species of phytoplankton (Riley, 1981). Phosphate is taken up by phytoplankton during active photosynthetic activities in the surface water. The objective of this study is to determine ortho-phosphate distribution in the South China Sea off Sabah, Sarawak and Brunei Darussalam waters. Previous studies by Law and Zawawi (1988) and Law (1990) indicated that some of the study area was very rich in ortho-phosphate in the deep water.

Materials and Methods

The third and fourth survey cruises of M.V. SEAFDEC were conducted from 8 July to 3 August 1996 and 1 to 24 May 1997 respectively. This study is one of the projects under SEAFDEC Interdepartmental Collaborative Research Program: Area II. Seventy-nine (79) stations were established in this study, which cover the Sabah, Sarawak and Brunei Darussalam waters. The locations of the sampling stations are shown in Figure 1. Water for ortho-phosphate analysis was obtained at different levels using a Rosette Water Sampler with twelve Niskin (PVC) bottles attached. The water sample was then filtered through a meshed syringe (1.0 µm) into acid washed plastic bottles.

Analysis was done on board for the third survey cruise samples using an Autoanalyzer TRAACS 2000. Samples for the fourth survey cruise were kept frozen in freezer at -20°C. These samples were analysed in the MFRDMD Laboratory using the Autoanalyzer. Determination of phosphate by the Autoanalyzer was based on colorimetric method. A blue colour was formed by the reaction of phosphate, molybdate ion and antimony ion followed by reduction with ascorbic acid. The reduced blue phosphomolybdenum complex was read at 880 nm. Since the water sample was not preserved with acid or digested with strong oxidizing agent prior to analysis, the phosphate analysed in this study was the ortho-phosphate.

Results and Discussion

The concentration of ortho-phosphate of the third and fourth survey cruises at various depths of the sampling stations are presented in Table 1 and Table 2. The average concentration of ortho-phosphate at 0-1 meter, 10 meter, 20 meter, 50 meter, 100 meter and 200 meter, 500 meter, 1000 meter and 1500 meter depth of the third survey cruise were 0.14 µM, 0.09 µM, 0.10 µM, 0.09 µM, 0.50 µM, 0.90 µM, 1.94 µM, 2.59 µM and 3.10 µM respectively. The average concentration of ortho-phosphate for the fourth survey cruise at 0-1 meter, 10 meter, 20 meter, 50 meter, 100 meter, 500 meter, 1000 meter and 1500 meter were 0.24 µM, 0.28 µM, 0.20 µM, 0.25 µM 1.15 µM and 2.27 µM, 4.13 µM, 5.19 µM and 5.41 µM respectively. The depth profiles of ortho-phosphate at each sampling station of the third and fourth survey cruises are presented in Figure 2. The results showed that ortho-phosphate concentrations were lower in the surface and upper layer of water and increase with depth. Similar patterns were found by Law and Zawawi (1988) in the Sarawak waters and Law (1990) in the Sabah waters.

The topographies of the ortho-phosphate distribution in the upper water layer of the study area taken during the third and fourth survey cruise are shown in Figure 3 and 4 respectively. While for the bottom water, the distributions are shown in Figure 5 and 6. The phosphate concentration in surface water is usually low due to uptake by phytoplankton for the active primary productivity which resulted in lowering the phosphate in the water (Law and Zawawi, 1988).

Higher ortho-phosphate concentration was found in the bottom waters as shown in Figure 5 and 6. The high level of phosphate in the bottom water may indicate that active mineralization processes are occurring at these depths (Law and Zawawi, 1988). As phytoplankton and other organisms die, phosphate is regenerated in the water column (Millero, 1996). The organic phosphorus in their tissue is rapidly converted to phosphate (Riley, 1981; Chester, 1990).

A comparison of ortho-phosphate concentration in the surface waters between the present study area and other seas especially in the South China Sea is given in Table 3. Ortho-phosphate concentration in the surface layer of the present study area is much lower than those detected in the Japan Sea (Anon, 1985), Gulf of Thailand (Kaewsripraky & Chantarasakul, 1985), Southern South China Sea off Malaysian coast, cruise 1972 and cruise 1973 (Lim, 1978) and Sabah coastal waters (Law, 1990). The ortho-phosphate concentration is much higher than those found in the coastal waters off Kuala Terengganu (Law & Kamil, 1986) and Western English Channel (Wafar *et. al*. 1983). The concentration of ortho-phosphate in the present study is comparable to that reported by Law & Zawawi (1988) for coastal waters off Sarawak. Average concentration of ortho-phosphate in the third survey cruise and fourth survey cruise at various depths is shown in Table 4. The ortho-phosphate concentration were higher in the fourth survey cruise.

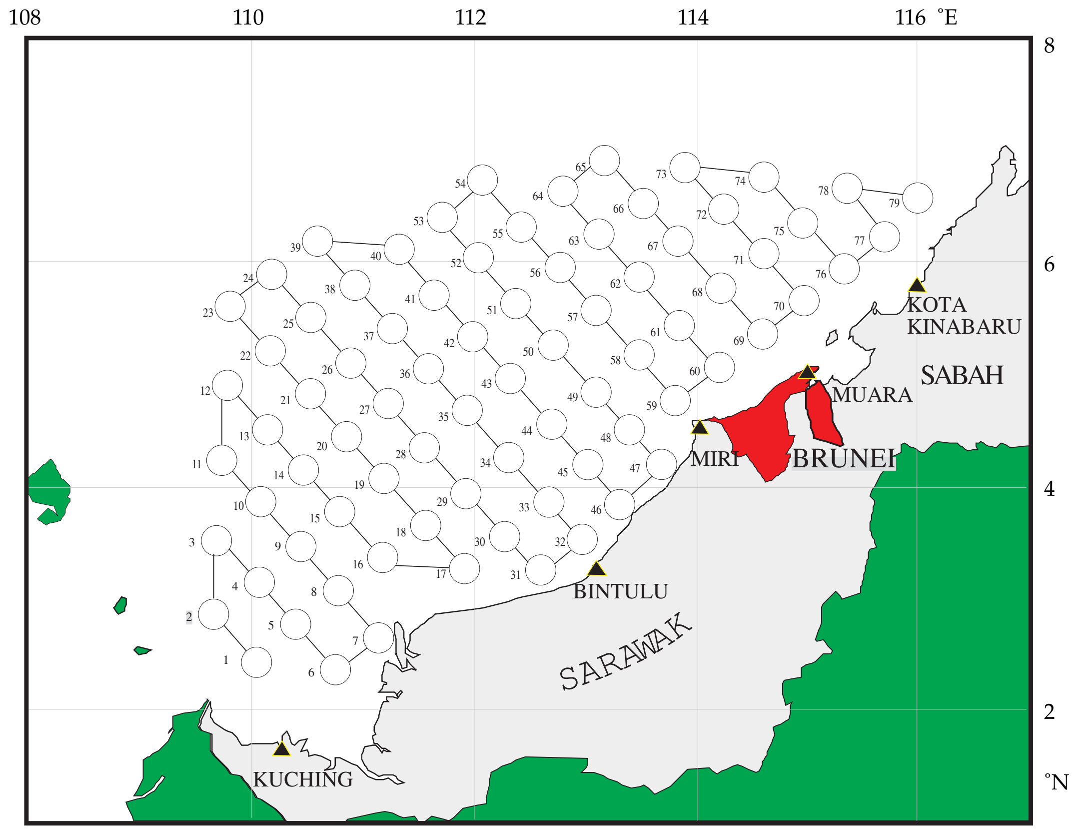


Fig. 1 Locations of the survey stations

Conclusion

The results of this study showed that the Sabah, Sarawak and Brunei Darussalam waters are rich in phosphate. Higher ortho-phosphate concentrations are found in deeper water than surface water. This high concentration in deeper water can be brought to the surface water by upwelling process. Studies on the relationship between nutrients concentration and other oceanographic parameters and then the fisheries resources in this study area are needed.

Acknowledgements

The authors would like to thanks Dr. Anond Snidvong of Chulalongkorn University, Thailand for the data of the third survey cruise and Prof. Dr. Law Ah Theem for reviewing the manuscript and his comments.

Table 1. Ortho-phosphate concentration in the Sabah, Sarawak and Brunei Darussalam waters during July-August 1996 (third cruise).

Station	Depth(m)	Ortho-phosphate(mM)
1	0 - 1	0.05
	10	0.09
	20	0.06
	30	0.09
	35	0.15
2	0 - 1	0.07
	10	0.08
	20	0.01
	30	0.02
	40	0.03
	50	0.16
3	0 - 1	0.20
	20	0.14
	40	0.09
	50	0.15
	60	0.26
	70	0.30
	75	0.40
4	0 - 1	0.18
	10	0.12
	20	0.14
	30	0.13
	40	0.14
	50	0.19
	60	0.32
5	0 - 1	0.20
	15	0.17
	30	0.14
	40	0.16
	45	0.16
	50	0.24
	60	0.36
	70	0.40
	76	0.42
6	0 - 1	0.23
	10	0.17
	20	0.23
	40	0.22
7	0 - 1	0.15
	10	0.15
	20	0.16
	29	0.17
8	0 - 1	0.13
	10	0.18
	20	0.13
	30	0.13
	37	0.14
9	0 - 1	0.13
	20	0.14
	30	0.09
	40	0.18
	50	0.16
	60	0.40
	67	0.45
10	0 - 1	0.13
	30	n.d
	40	n.d
	50	n.d
	60	n.d
	70	0.53
	84	0.57
11	0 - 1	0.47
	30	0.06
	50	0.06
	60	0.03
	70	0.38
	80	0.74
	96	0.93
12	0 - 1	0.06
	20	0.01
	40	0.08
	60	0.02
	70	0.13
	80	0.04
	90	0.31
	100	0.40
	101	0.77
	117	1.26
13	0 - 1	0.09
	10	0.03
	20	0.05
	40	0.08
	60	0.13
	70	0.52
	80	0.29
	90	0.45
	100	0.87
	111	0.87
14	0 - 1	0.09
	10	0.02
	30	0.02
	40	0.00
	50	0.04
	60	0.03
	70	0.33
	80	0.79
	90	0.89
15	0 - 1	0.03
	20	0.04
	30	0.02
	35	0.11
	40	0.04
	50	0.14
	55	0.22
	63	0.22
16	0 - 1	0.13
	10	0.03
	20	0.05

Table 1. Continue

Station	Depth(m)	Ortho-phosphate(mM)
16	30	0.05
	40	0.05
	50	0.09
	59	0.16
17	5	0.07
	10	0.05
	20	0.06
	27	0.04
18	0 - 1	0.05
	10	0.04
	20	0.04
	30	0.04
	35	0.04
	40	0.04
	46	0.13
19	0 - 1	0.14
	10	0.08
	20	0.07
	30	0.04
	40	0.06
	50	0.05
	53	0.11
	65	0.33
20	0 - 1	0.08
	10	0.06
	20	0.03
	30	0.03
	40	0.04
	50	0.06
	60	0.09
	70	0.30
	80	0.60
	85	0.93
21	0 - 1	0.13
	10	0.07
	30	0.06
	40	0.05
	50	0.08
	60	0.11
	70	0.23
	80	0.42
	90	0.52
	100	0.72
	110	0.81
	116	0.86
22	0 - 1	0.14
	20	0.08
	40	0.10
	60	0.23
	70	0.25
	80	0.30
	100	0.69
	120	0.96
	141	1.12
23	0 - 1	0.15
	20	0.10
	40	0.07
	58	0.24
	70	0.35
	100	0.68
	120	1.04
	141	1.00
24	10	0.14
	20	0.07
	40	0.10
	60	0.11
	80	0.21
	100	0.39
	120	0.89
	150	1.15
	300	1.85
	500	2.19
25	0 - 1	n.d
	20	n.d
	40	n.d
	55	0.02
	65	0.12
	90	0.39
	140	1.12
	196	1.63
26	0 - 1	0.14
	20	0.04
	30	0.01
	50	0.02
	65	0.25
	80	0.35
	100	0.06
	119	0.96
27	0 - 1	0.07
	20	0.03
	40	0.00
	50	0.01
	62	0.15
	70	0.52
	80	0.78
	89	0.83
28	0 - 1	0.26
	10	0.10
	20	0.10
	30	0.07
	40	0.09
	50	0.06
	60	0.19
	70	0.41
	75	0.42
29	0 - 1	0.13
	10	0.12
	20	0.14

Table 1. Continue

Station	Depth(m)	Ortho-phosphate(mM)
29	30	0.14
	45	0.16
	52	0.24
30	0 - 1	0.13
	10	0.13
	20	0.14
	29	0.14
31	0 - 1	0.14
	10	0.15
	20	0.14
	15	0.14
32	0 - 1	0.16
	10	0.16
	20	0.15
	31	0.21
33	0 - 1	0.15
	10	0.14
	20	0.14
	30	0.13
34	0 - 1	0.12
	10	0.13
	20	0.13
	45	0.14
	55	0.18
35	0 - 1	0.21
	20	0.14
	30	0.15
	40	0.14
	60	0.15
	70	0.21
36	0 - 1	0.16
	10	0.14
	20	0.14
	30	0.14
	40	0.15
	61	0.18
37	0 - 1	0.14
	20	0.13
	39	0.14
	180	1.42
	254	1.74
	300	1.92
	378	1.40
38	0 - 1	0.22
	20	0.14
	30	0.15
	40	0.13
	65	0.17
	80	0.16
	200	1.40
	300	1.88
	500	2.50
	950	1.76
39	0	0.13
	20	0.11

Station	Depth(m)	Ortho-phosphate(mM)
39	40	0.13
	55	0.16
	70	0.13
	150	1.05
	200	1.39
	300	1.88
	500	2.45
	800	2.79
	1100	2.85
40	0 - 1	0.13
	15	0.13
	31	0.12
	50	0.24
	67	0.21
	150	1.15
	300	1.84
	600	2.67
	950	2.94
	140	1.12
	300	1.84
	700	2.70
	1100	2.99
41	0 - 1	0.15
	20	0.14
	40	0.14
42	0 - 1	0.07
	20	n.d
	40	n.d
	50	n.d
	63	0.06
	80	0.32
	100	0.72
	130	1.04
43	0 - 1	0.18
	10	0.02
	20	0.03
	30	0.02
	40	n.d
	50	0.02
	62	0.12
	75	0.37
	85	0.66
	95	0.87
44	0 - 1	0.17
	10	0.04
	20	0.06
	40	n.d
	50	0.07
	57	0.11
	70	0.52
	80	0.85
45	10	0.15
	20	0.05
	30	n.d
	40	0.01

Table 1. Continue

Station	Depth(m)	Ortho-phosphate(mM)
45	45	0.02
	53	0.11
	63	0.39
46	0 - 1	0.07
	10	0.04
	18	0.03
47	0 - 1	0.02
	10	0.02
	20	0.01
	27	0.05
48	0 - 1	0.07
	10	0.06
	20	0.05
	30	0.06
	40	0.06
	50	0.08
	60	0.08
	72	0.30
49	0 - 1	0.15
	10	0.08
	20	0.05
	30	0.02
	40	0.04
	50	0.03
	60	0.07
	67	0.15
	80	0.30
	100	0.14
50	0 - 1	0.20
	20	0.05
	30	0.08
	40	0.01
	50	0.04
	58	0.09
	100	0.58
	200	0.70
	300	0.82
	400	0.89
51	0 - 1	0.11
	20	0.04
	40	0.05
	50	0.05
	62	0.17
	80	0.46
	90	0.39
	100	0.64
	140	0.58
	185	****
52	0 - 1	0.14
	10	0.16
	20	0.05
	40	0.05
	60	0.08
	79	0.38
	300	1.93
52	500	2.55
	1000	2.44
	1500	3.50
53	0 - 1	0.23
	10	0.10
	20	0.07
	50	0.04
	70	0.06
	500	2.80
	1000	2.47
	1600	1.78
54	0 - 1	0.07
	10	0.04
	20	n.d
	30	n.d
	40	n.d
	60	n.d
	80	0.26
	100	0.21
	200	1.13
	500	0.87
	1000	3.30
	1700	1.37
55	20	0.10
	61	0.06
	150	2.33
	400	2.02
	600	1.01
	800	3.03
	1000	2.77
	1200	1.61
56	20	0.18
	50	0.10
	71	0.10
	100	0.42
	300	0.80
	500	1.83
	700	1.02
	1000	2.61
57	20	0.15
	50	0.13
	75	0.18
	100	0.35
	500	2.52
	800	1.96
	1000	1.42
	1800	2.81
58	0 - 1	0.24
	20	0.16
	40	0.13
	70	0.11
	100	0.18
	150	0.65
	200	0.31
	300	1.48

Table 1. Continue

Station	Depth(m)	Ortho-phosphate(mM)
58	500	0.67
	700	2.21
	1000	2.67
	1500	2.71
59	0 - 1	0.06
	10	0.03
	20	0.02
	30	0.02
	45	0.01
	60	0.01
	70	0.25
	80	0.21
	93	0.22
60	0 - 1	0.02
	10	0.00
	30	n.d
	47	n.d
	80	0.27
	100	0.57
	130	0.90
	170	0.81
61	10	0.06
	50	0.01
	63	0.01
	200	0.15
	600	1.41
	1000	2.58
	1500	2.77
	1800	2.93
62	20	0.26
	30	0.11
	50	0.04
	70	0.14
	100	0.50
	200	0.97
	500	2.15
	1000	2.77
	1850	2.04
63	0 - 1	0.12
	20	0.02
	40	0.02
	60	0.02
	80	0.19
	100	0.68
	200	1.12
	300	1.46
	500	2.38
	800	2.69
	1000	2.47
	1500	3.72
64	0 - 1	0.22
	20	0.11
	40	0.08
	60	0.09
	74	0.15

Station	Depth(m)	Ortho-phosphate(mM)
64	100	0.36
	200	0.97
	300	1.49
	500	1.82
	800	2.87
	1000	2.60
	1200	2.11
65	0 - 1	0.16
	20	0.08
	40	0.08
	60	0.10
	70	0.21
	80	0.35
	100	0.55
	200	0.90
	300	****
	500	0.77
	1000	2.69
	1400	2.76
66	0 - 1	0.12
	20	0.10
	40	0.05
	60	0.06
	80	0.15
	100	0.29
	200	0.96
	300	1.29
	500	1.44
	1000	2.62
	1400	2.30
	1800	2.47
67	0 - 1	0.21
	20	0.13
	40	0.10
	60	0.68
	80	0.36
	100	1.02
	200	0.54
	500	2.22
	800	0.95
	1000	2.68
	1500	2.80
	2000	3.11
68	0 - 1	0.24
	20	0.13
	40	0.10
	60	0.10
	80	0.28
	100	0.51
	200	1.10
	400	2.03
	600	2.44
	800	2.65
	1000	2.80
	1700	2.25

Table 2. Ortho-phosphate concentration in the Sabah, Sarawak and Brunei Darussalam waters during May 1997 (fourth cruise).

Station	Depth (m)	Ortho-phosphate(mM)
1	0 - 1	0.12
	6	0.13
	10	0.11
	20	0.10
	27	0.03
	33	0.11
2	0 - 1	0.11
	10	0.10
	20	0.04
	25	0.10
	30	0.08
	35	0.04
	40	0.12
	51	0.16
3	10	0.08
	20	0.04
	25	0.08
	30	0.06
	40	0.08
	50	0.15
	60	0.44
	70	0.65
	78	0.82
4	0 - 1	0.16
	10	0.14
	20	0.11
	30	0.12
	40	0.12
	50	0.25
	60	0.24
	67	0.33
5	0 - 1	0.15
	10	0.14
	20	0.10
	30	0.14
	40	0.22
	50	0.28
	60	0.25
	74	0.11
6	0 - 1	0.10
	10	0.13
	15	0.10
	20	0.10
	30	0.06
	35	0.11
	40	0.25
7	0 - 1	0.12
	10	0.12
	20	0.17
	25	0.29
	33	0.26
8	0 - 1	0.11
	5	0.09
	10	0.06
	20	0.14
	30	0.10
	40	0.08
9	0 - 1	0.11
	10	0.08
	30	0.12
	40	0.14
	45	0.22
	50	0.25
	60	0.31
	65	0.35
10	0 - 1	0.13
	10	0.12
	30	0.15
	40	0.15
	50	0.15
	60	0.46
	70	0.70
	80	0.97
11	0 - 1	0.15
	10	0.19
	30	0.15
	50	0.28
	60	0.23
	70	0.28
	80	0.76
	90	1.16
12	0 - 1	0.31
	10	0.17
	30	0.24
	40	0.27
	50	0.31
	60	0.66
	70	0.60
	80	0.58
	100	1.12
	110	1.33
13	0 - 1	0.33
	10	0.16
	30	0.29
	50	0.19
	70	0.32
	80	0.55
14	0 - 1	0.17
	10	0.14
	20	0.14
	30	0.14
	40	0.11

Table 2. continue

Station	Depth (m)	Ortho-phosphate(mM)
14	50	0.13
	65	0.30
	80	0.85
	88	0.93
15	0 - 1	0.15
	10	0.70
	20	0.70
	30	0.63
	40	0.62
	50	0.68
	64	0.67
16	0 - 1	0.60
	10	0.57
	20	0.58
	30	0.60
	40	0.58
	50	0.66
	63	0.66
17	0 - 1	0.57
	10	0.57
	18	0.51
	25	0.55
	28	0.61
18	0 - 1	0.50
	10	0.46
	20	0.48
	30	0.50
	35	0.50
	40	0.47
	45	0.49
19	0 - 1	0.44
	10	0.43
	30	0.45
	40	0.45
	50	0.43
	60	0.49
	68	0.48
20	0 - 1	0.44
	10	0.42
	20	0.38
	30	0.43
	40	0.39
	50	0.43
	60	0.51
	70	0.66
	80	1.16
	85	1.14
21	0 - 1	0.42
	20	0.33
	30	0.35
	40	0.41

Station	Depth (m)	Ortho-phosphate(mM)
21	50	0.43
	60	0.49
	70	0.57
	80	0.67
	90	1.15
	100	1.12
	116	1.20
22	0 - 1	0.39
	20	0.36
	40	0.30
	50	0.29
	60	0.28
	70	0.48
	80	0.57
	90	0.82
	100	1.08
	120	1.67
	140	1.75
23	0 - 1	0.33
	20	0.29
	40	0.18
	60	0.27
	80	0.70
	100	1.20
	120	1.57
	144	1.64
24	0 - 1	0.32
	20	0.20
	40	0.22
	60	0.22
	70	0.30
	80	0.66
	100	0.95
	120	1.26
	150	1.59
	200	2.17
	300	2.57
	511	2.90
25	0 - 1	0.46
	10	0.30
	30	0.18
	50	0.22
	70	0.44
	80	0.66
	100	0.57
	150	1.31
	197	1.23
27	0 - 1	0.15
	10	0.14
	30	0.10
	50	0.08

Table 2. continue

Station	Depth (m)	Ortho-phosphate(mM)
27	60	0.25
	70	0.27
	80	0.31
	93	0.58
28	0 - 1	0.15
	20	0.07
	30	0.17
	40	0.17
	50	0.19
	65	****
	77	0.42
29	0 - 1	0.12
	10	0.11
	20	0.17
	30	0.19
	40	0.13
	50	0.22
30	0 - 1	0.07
	10	0.09
	20	0.12
	25	0.06
	33	0.11
31	0 - 1	0.05
	5	0.09
	10	0.02
	15	0.14
	19	0.16
32	0 - 1	0.09
	10	0.09
	15	0.07
	20	0.06
	25	0.12
	31	0.19
33	0 - 1	0.04
	10	0.05
	15	0.04
	20	0.07
	30	0.06
	40	0.07
	50	0.10
34	0 - 1	0.05
	10	0.04
	20	0.03
	30	0.06
	35	0.09
	50	0.10
	60	0.24
	71	0.32
35	0 - 1	0.03
	10	0.05
	20	0.07

Station	Depth (m)	Ortho-phosphate(mM)
35	30	0.04
	40	0.05
	50	0.08
	60	0.19
	70	0.49
	80	0.55
	85	0.61
36	0 - 1	0.13
	10	0.13
	30	0.10
	40	0.12
	50	0.12
	60	0.33
	70	0.48
	80	0.63
	100	0.92
	108	0.95
37	0 - 1	0.20
	20	0.12
	40	0.13
	50	0.20
	60	0.48
	70	0.62
	80	0.70
	100	1.23
	150	1.75
	200	2.18
	300	2.95
	409	****
38	0 - 1	0.36
	20	0.21
	40	0.21
	50	0.23
	60	0.18
	80	0.37
	100	0.96
	200	2.22
	300	3.04
	500	****
	700	****
	1006	****
39	0 - 1	0.51
	20	0.30
	40	0.26
	60	0.23
	80	0.58
	100	1.10
	150	1.80
	200	2.25
	300	3.03
	500	****

Table 2. continue

Station	Depth (m)	Ortho-phosphate(mM)
39	700	****
	1100	****
40	0 - 1	0.14
	20	0.11
	40	0.10
	60	0.09
	80	0.49
	100	0.87
	150	1.66
	200	2.63
	300	3.53
	500	****
	700	****
	1000	****
41	0 - 1	0.56
	20	0.32
	40	0.23
	60	0.48
	80	0.98
	100	1.58
	150	1.98
	200	2.66
	300	3.58
	500	****
	750	****
	1100	****
42	0 - 1	0.54
	20	0.41
	40	0.34
	50	0.34
	60	0.31
	70	0.55
	80	0.98
	100	1.27
	120	1.23
	131	1.69
43	0 - 1	0.19
	20	0.26
	30	0.25
	40	0.25
	50	0.35
	60	0.32
	70	0.75
	80	0.85
	90	0.98
	100	1.19
44	0 - 1	0.24
	20	0.17
	30	0.13
	40	0.12
	50	0.13

Station	Depth (m)	Ortho-phosphate(mM)
44	60	0.32
	70	0.23
	80	0.55
	86	0.73
45	0 - 1	0.16
	20	0.09
	30	0.09
	40	0.16
	50	0.19
	63	0.27
46	0 - 1	0.10
	10	0.09
	15	0.09
	19	0.08
47	0 - 1	0.04
	10	0.07
	15	0.07
	20	0.04
	26	0.10
48	0 - 1	0.06
	10	0.05
	20	0.03
	30	0.05
	40	n.d
	50	0.07
	70	0.46
	75	0.59
49	0 - 1	0.08
	20	0.09
	30	0.56
	40	0.14
	50	0.14
	60	0.15
	70	0.35
	80	0.64
	90	0.96
	101	1.50
50	10	0.18
	30	0.13
	50	0.19
	60	0.31
	70	0.74
	80	0.90
	100	1.44
	150	1.91
	200	2.12
	300	3.39
	500	****
	700	****
51	10	0.45
	30	0.31

Table 2. continue

Station	Depth (m)	Ortho-phosphate(mM)
51	50	0.30
	60	0.33
	70	0.49
	80	0.93
	100	1.26
	120	1.68
	150	1.80
	180	2.21
52	10	0.13
	40	0.17
	70	0.83
	100	1.47
	150	1.78
	200	2.56
	300	3.34
	500	****
	1000	****
	1450	****
53	10	0.52
	40	0.29
	60	0.56
	80	1.09
	100	1.16
	150	1.83
	200	2.59
	500	****
	1000	****
	1840	****
54	10	0.37
	30	0.33
	50	0.29
	60	0.54
	80	0.93
	100	1.42
	150	1.72
	200	2.47
	300	3.46
	500	****
	1000	****
	1900	****
55	10	0.43
	30	0.31
	50	0.19
	60	0.53
	80	1.06
	100	1.29
	150	1.91
	200	2.28
	300	3.25
	500	****
	1000	****

Station	Depth (m)	Ortho-phosphate(mM)
55	1200	****
56	10	0.44
	30	0.32
	50	0.62
	70	1.01
	100	1.61
	200	2.12
	285	3.03
	465	****
	685	****
	950	****
57	10	0.46
	30	0.29
	60	0.52
	100	1.56
	200	2.34
	300	3.34
	500	****
	1000	****
	1500	****
	2000	****
58	10	0.48
	30	0.31
	50	0.28
	60	0.29
	70	0.38
	100	0.83
	150	1.30
	200	1.74
	300	3.04
	500	****
	990	****
	1500	****
59	0 - 1	0.19
	10	0.13
	20	0.13
	30	0.08
	40	0.21
	50	0.16
	60	0.16
	70	0.16
	80	0.19
	86	0.20
60	10	0.43
	20	0.25
	40	0.20
	50	0.16
	60	0.13
	80	0.50
	100	0.90
	150	1.67

Table 2. continue

Station	Depth (m)	Ortho-phosphate(mM)
60	195	2.06
61	10	0.25
	50	0.18
	80	0.76
	100	1.32
	200	2.05
	300	3.11
	500	****
	1000	****
	1500	****
	2000	****
62	10	0.12
	20	0.11
	50	0.13
	70	0.83
	100	1.19
	150	1.92
	200	2.37
	300	3.03
	500	4.35
	1000	5.22
	1500	5.58
	1995	5.57
63	10	0.49
	30	0.38
	50	0.18
	70	1.09
	100	1.39
	150	1.39
	200	2.08
	300	2.71
	500	3.79
	700	3.29
	1000	5.13
	1500	3.35
64	10	0.17
	30	0.14
	70	0.85
	100	0.18
	150	1.31
	200	1.39
	300	2.38
	500	2.77
	700	3.56
	1000	2.86
	1250	4.88
65	10	0.40
	30	0.31
	50	0.30
	70	0.85
	100	1.13
65	150	1.63
	200	2.08
	300	3.14
	500	4.13
	700	4.90
	1000	5.48
	1500	5.20
66	10	0.75
	30	0.36
	50	0.38
	70	0.90
	100	1.25
	150	1.70
	200	2.24
	300	2.88
	500	3.66
	1000	5.22
	1500	4.68
	1800	5.20
67	10	0.51
	30	0.36
	50	0.44
	70	0.92
	100	1.38
	180	1.90
	200	2.45
	300	3.48
	500	4.35
	1000	5.15
	1500	5.47
	2000	4.73
68	10	0.51
	30	0.30
	50	0.34
	70	0.85
	100	1.37
	150	1.74
	200	2.24
	250	2.72
	500	4.17
	1000	5.24
	1500	5.49
	1700	5.45
69	0 - 1	0.59
	10	0.16
	20	0.24
	30	0.18
	40	0.25
	50	0.18
	60	0.13
	70	0.22

Table 2. continue

Station	Depth (m)	Ortho-phosphate(mM)
69	80	0.37
	90	0.82
70	10	0.18
	20	0.15
	40	0.09
	50	0.18
	60	0.14
	80	0.61
	100	1.12
	120	1.59
	130	1.50
71	10	0.16
	30	0.16
	50	0.12
	70	0.47
	100	1.23
	150	2.02
	200	2.16
	300	3.31
	1000	5.33
	1500	5.86
	1900	5.74
72	10	0.61
	30	0.32
	50	0.37
	70	0.66
	100	1.16
	150	1.93
	200	2.41
	300	3.54
	500	4.82
	1000	5.62
	1500	6.09
	2000	6.22
73	10	0.57
	30	0.31
	50	0.39
	70	0.84
	100	1.44
	150	2.13
	200	2.64
	300	3.64
	1000	5.90
	1500	6.16
	1750	6.23
74	10	0.75
	50	0.50
	70	0.74
	100	1.23

Station	Depth (m)	Ortho-phosphate(mM)
74	200	2.68
	300	3.50
	500	4.90
	1000	5.94
	1500	6.24
	2000	6.30
75	10	0.58
	30	0.34
	50	0.25
	70	0.40
	100	0.97
	200	2.60
	300	3.66
	500	4.81
	1000	6.17
	1700	6.45
76	10	0.58
	20	0.27
	40	0.19
	50	0.22
	60	0.15
	70	0.27
	90	1.15
77	0 - 1	0.25
	10	0.15
	20	0.10
	40	0.03
	50	0.04
	60	0.12
	70	0.30
	80	0.42
78	0 - 1	0.45
	20	0.22
	30	0.11
	50	0.14
	70	0.11
	100	0.42
	150	1.11
	200	1.89
	300	2.75
	500	3.66
	1000	4.25
	1450	6.19
79	10	0.51
	20	0.39
	30	0.18
	35	0.17
	50	0.20

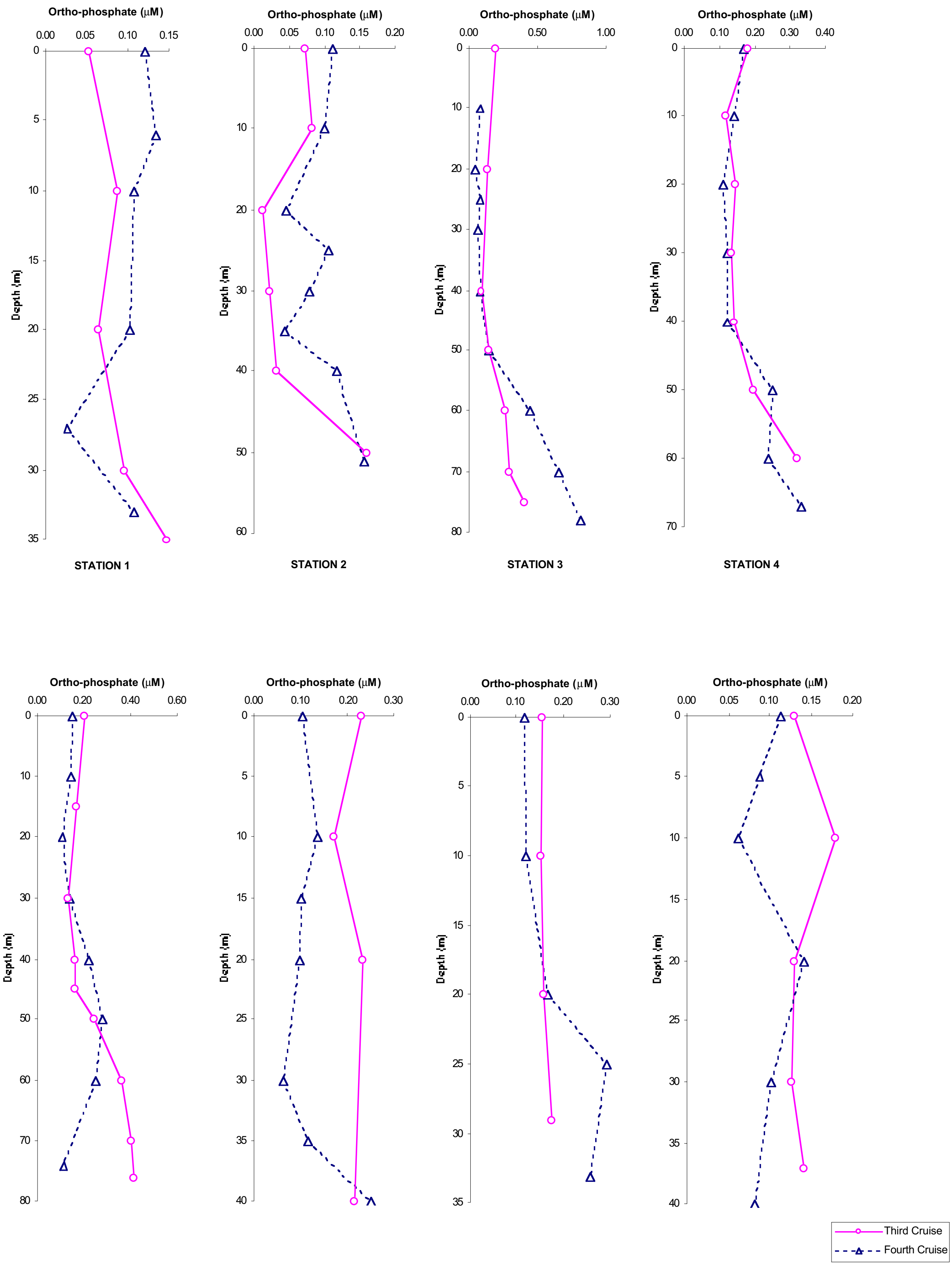
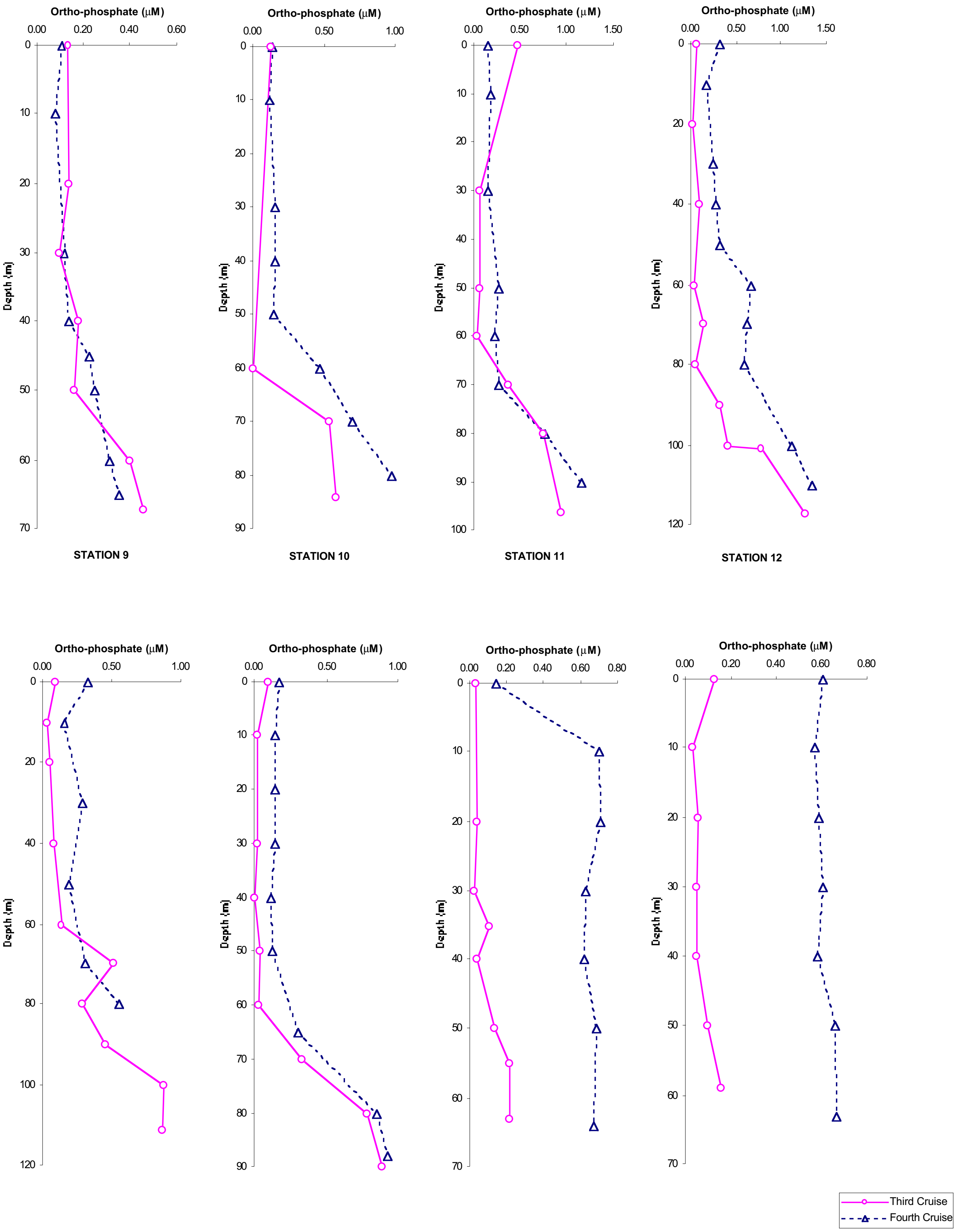


Fig. 2 Depth profiles of ortho-phosphate at the sampling stations during the third and fourth cruises



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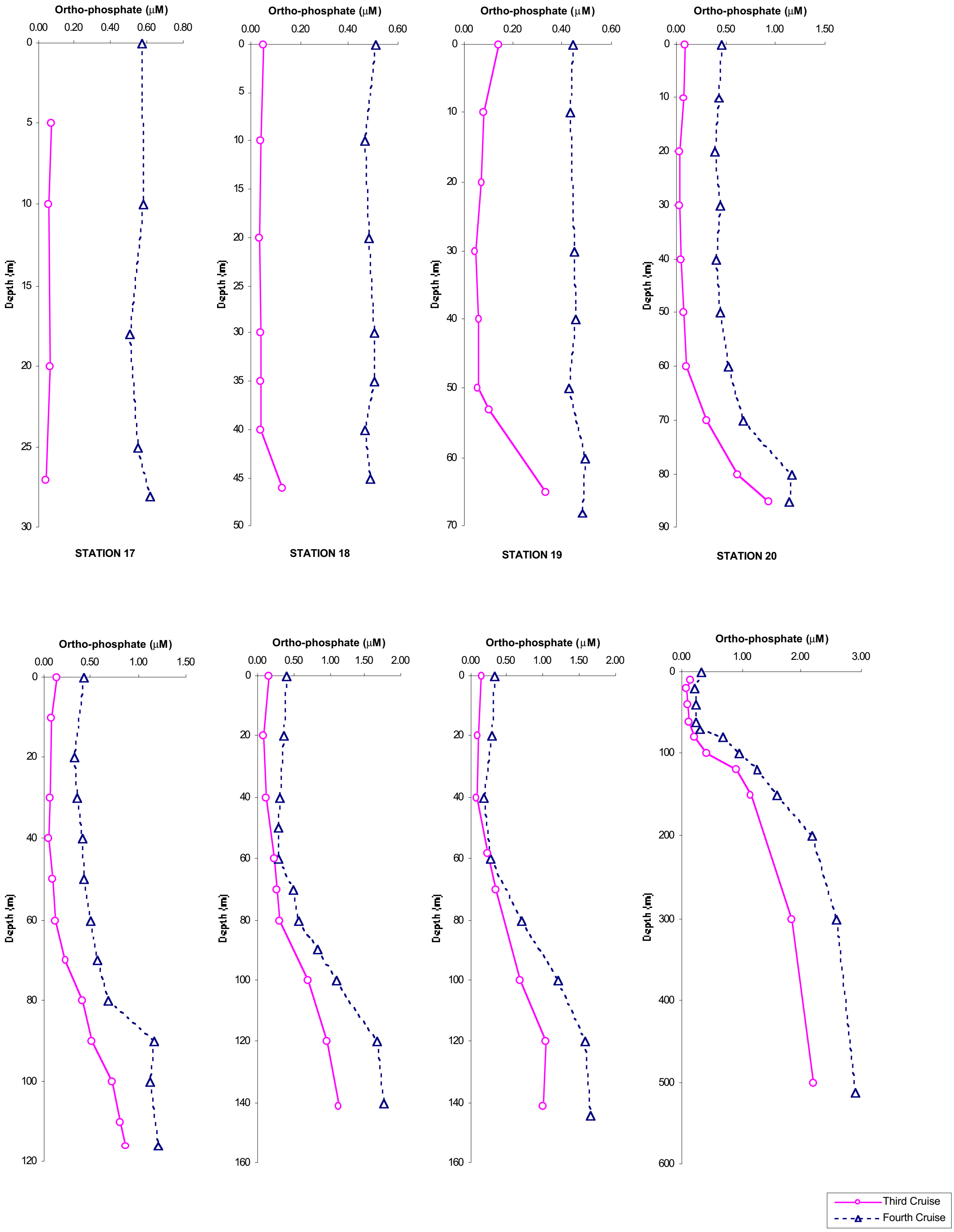

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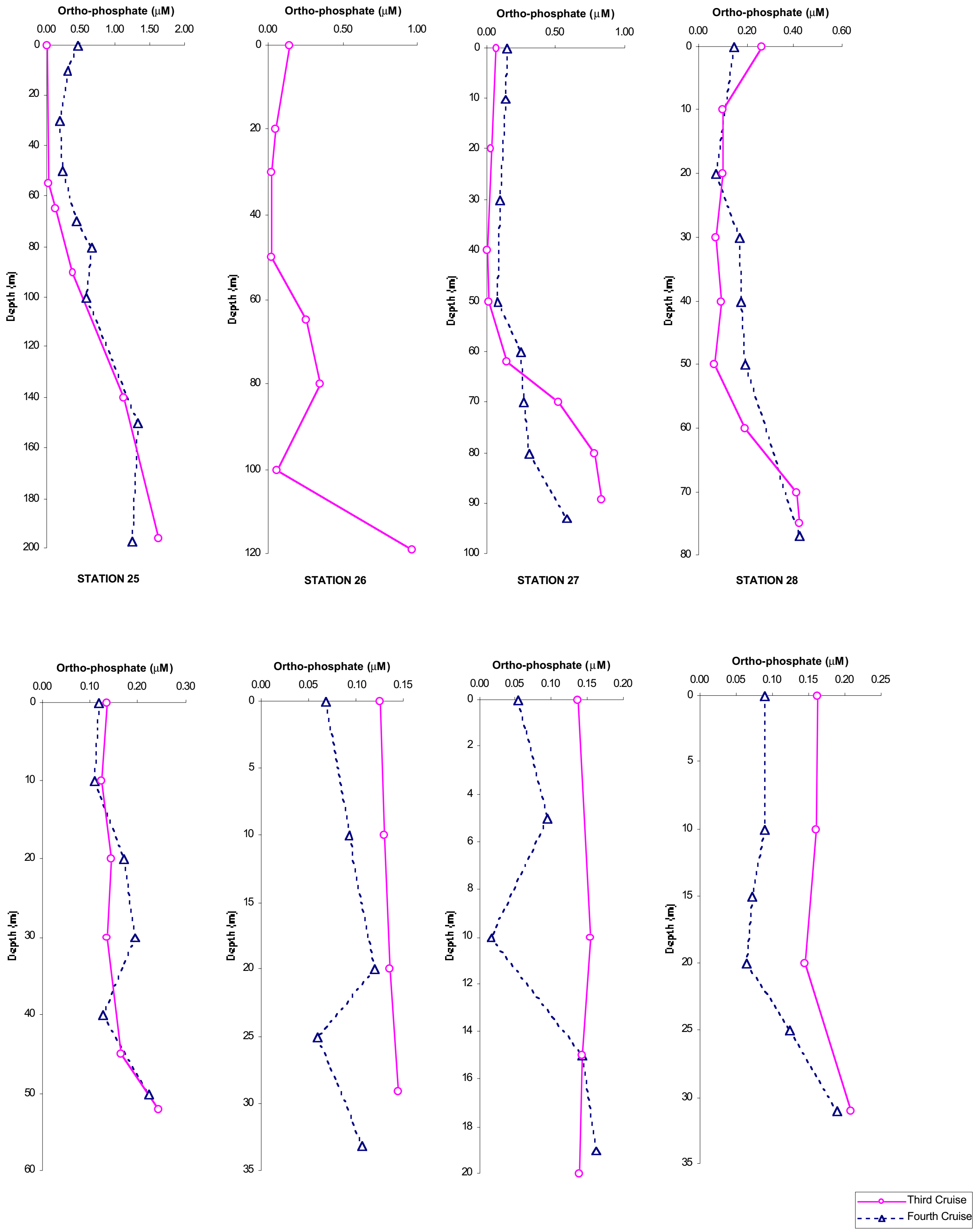

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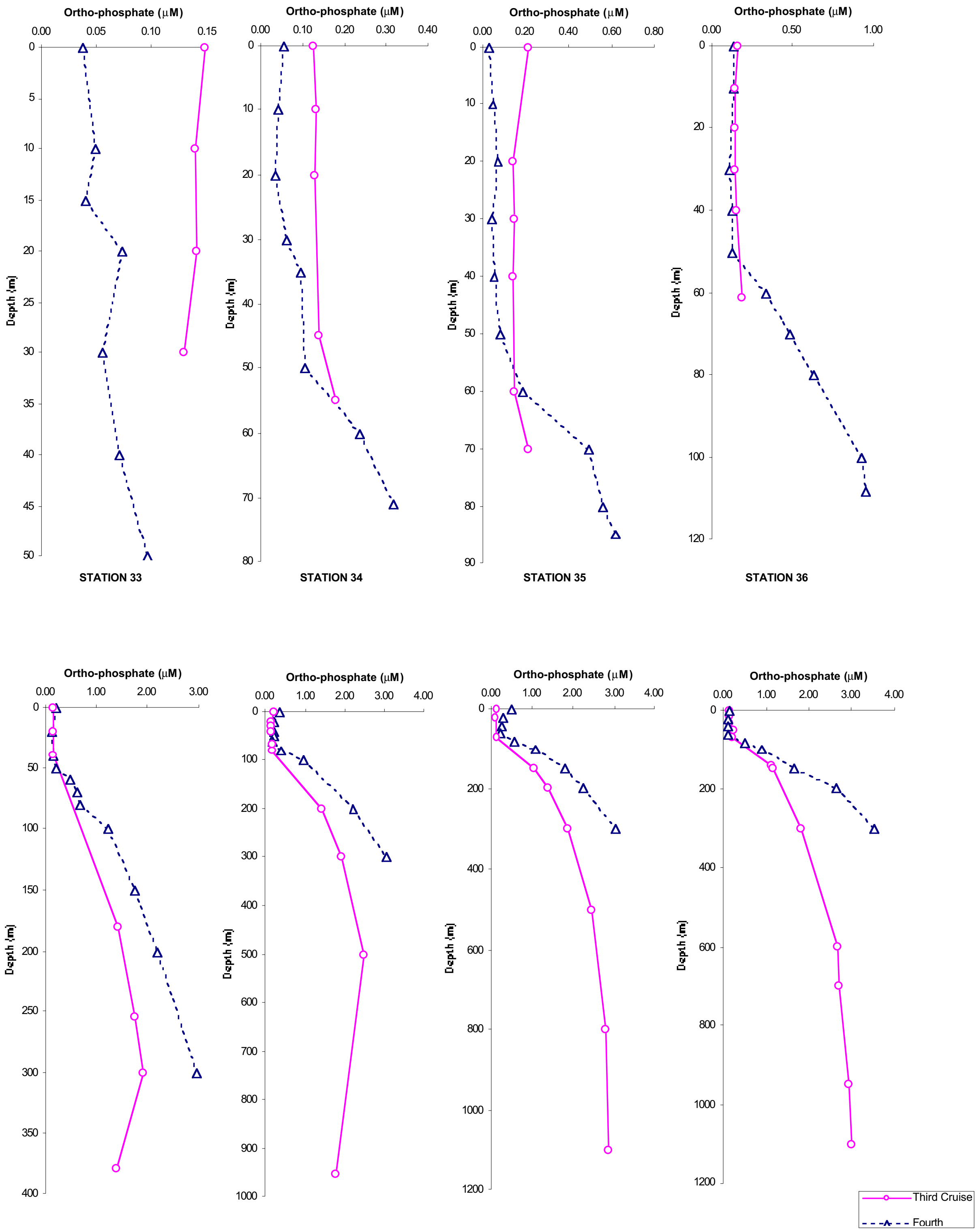

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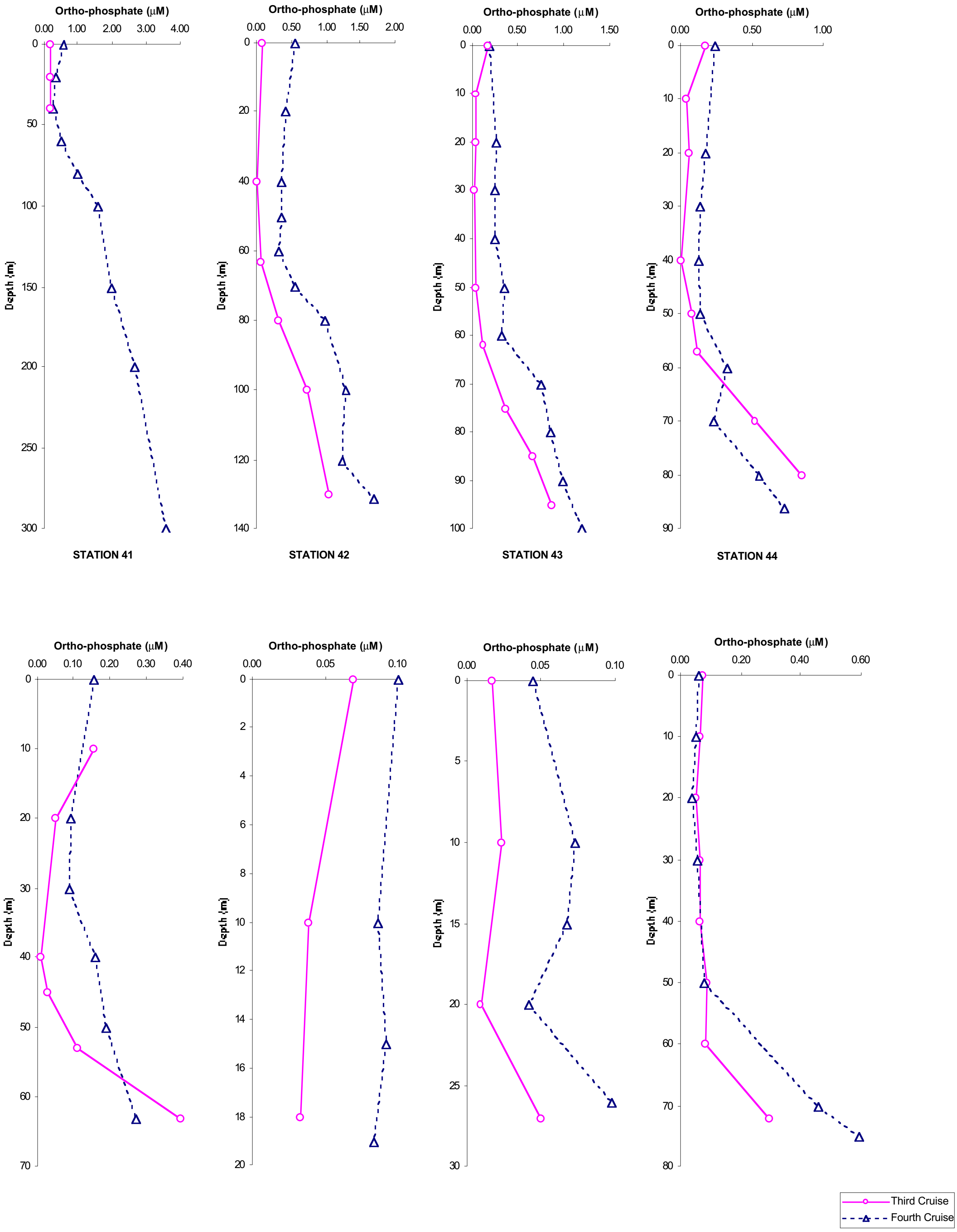

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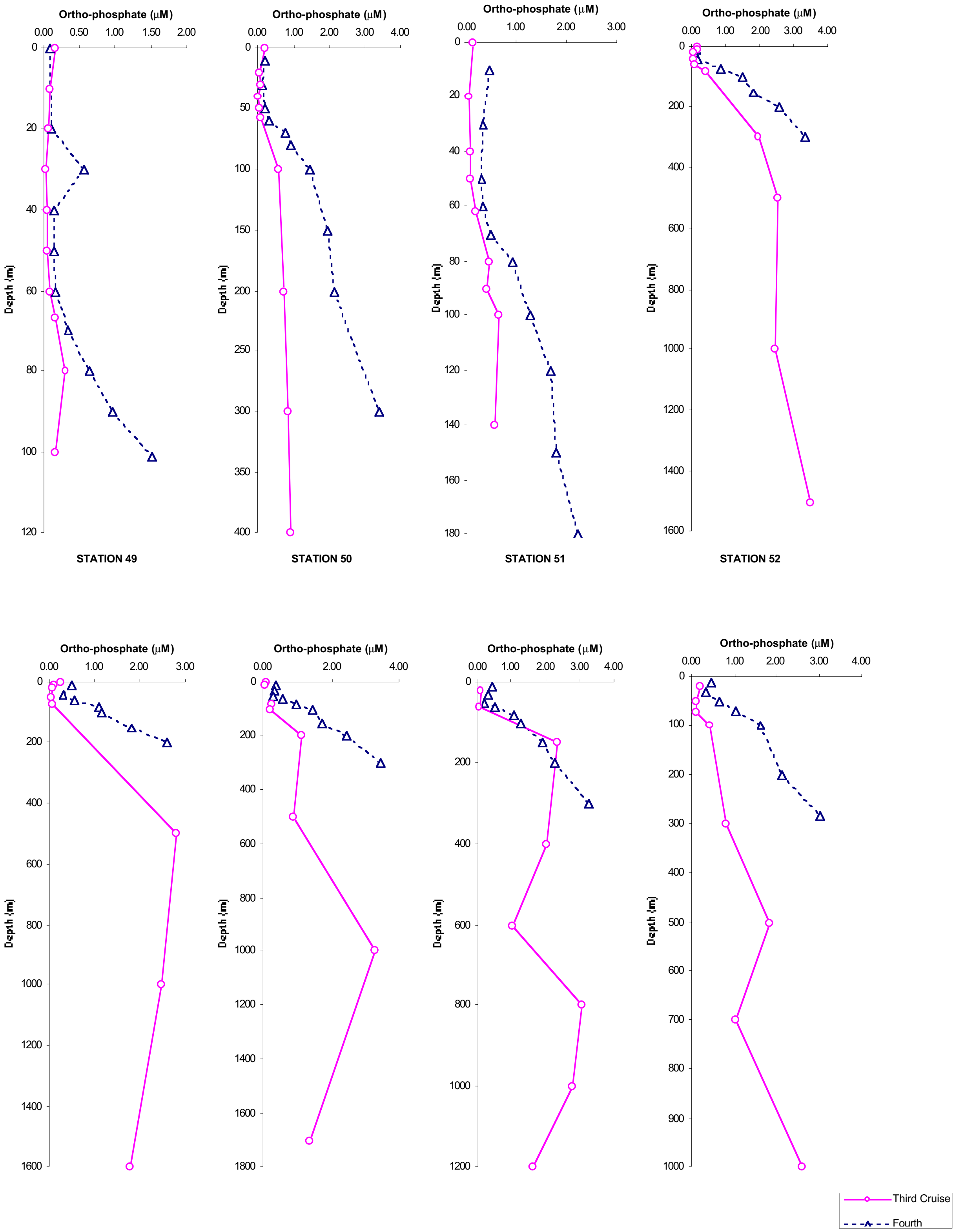

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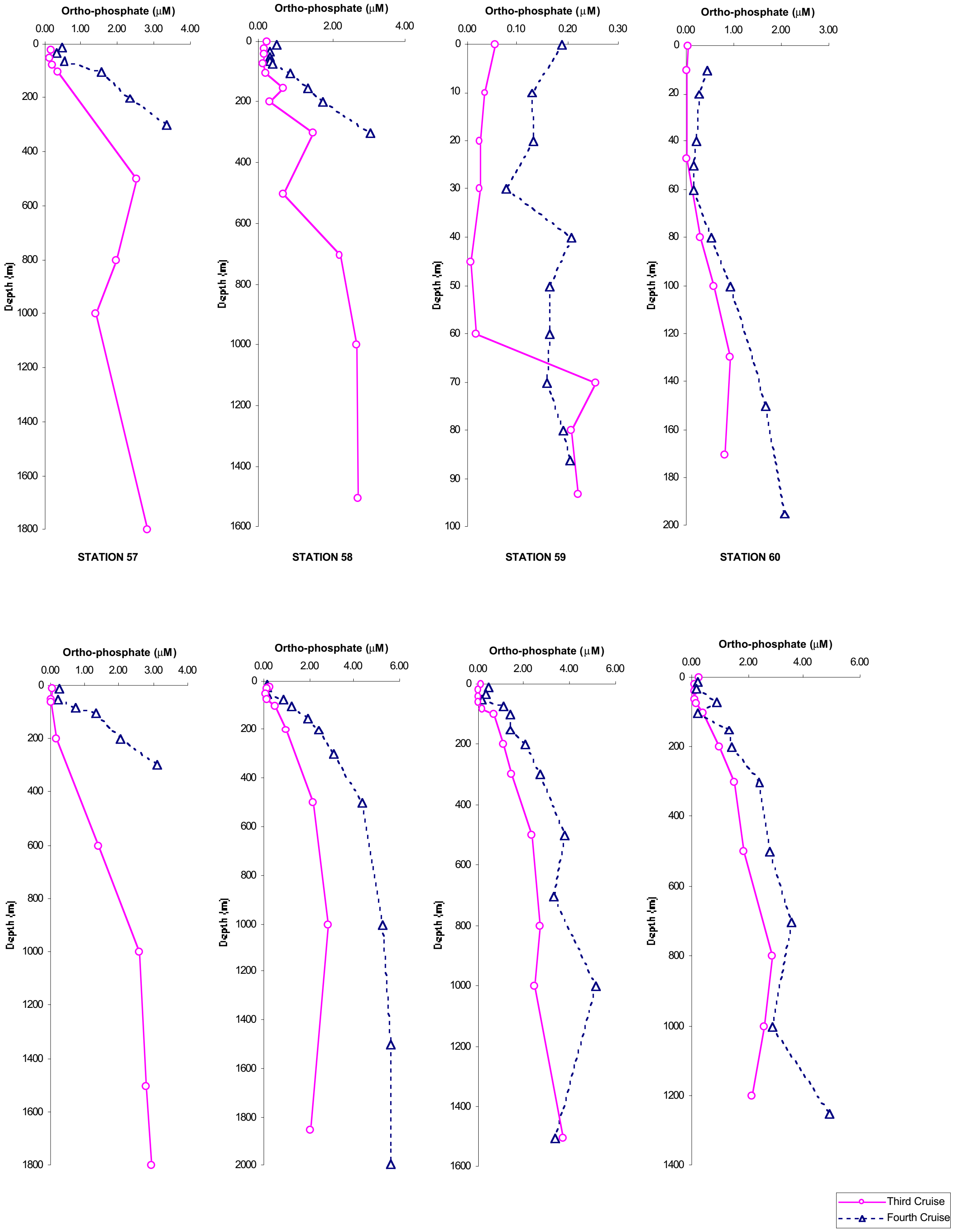

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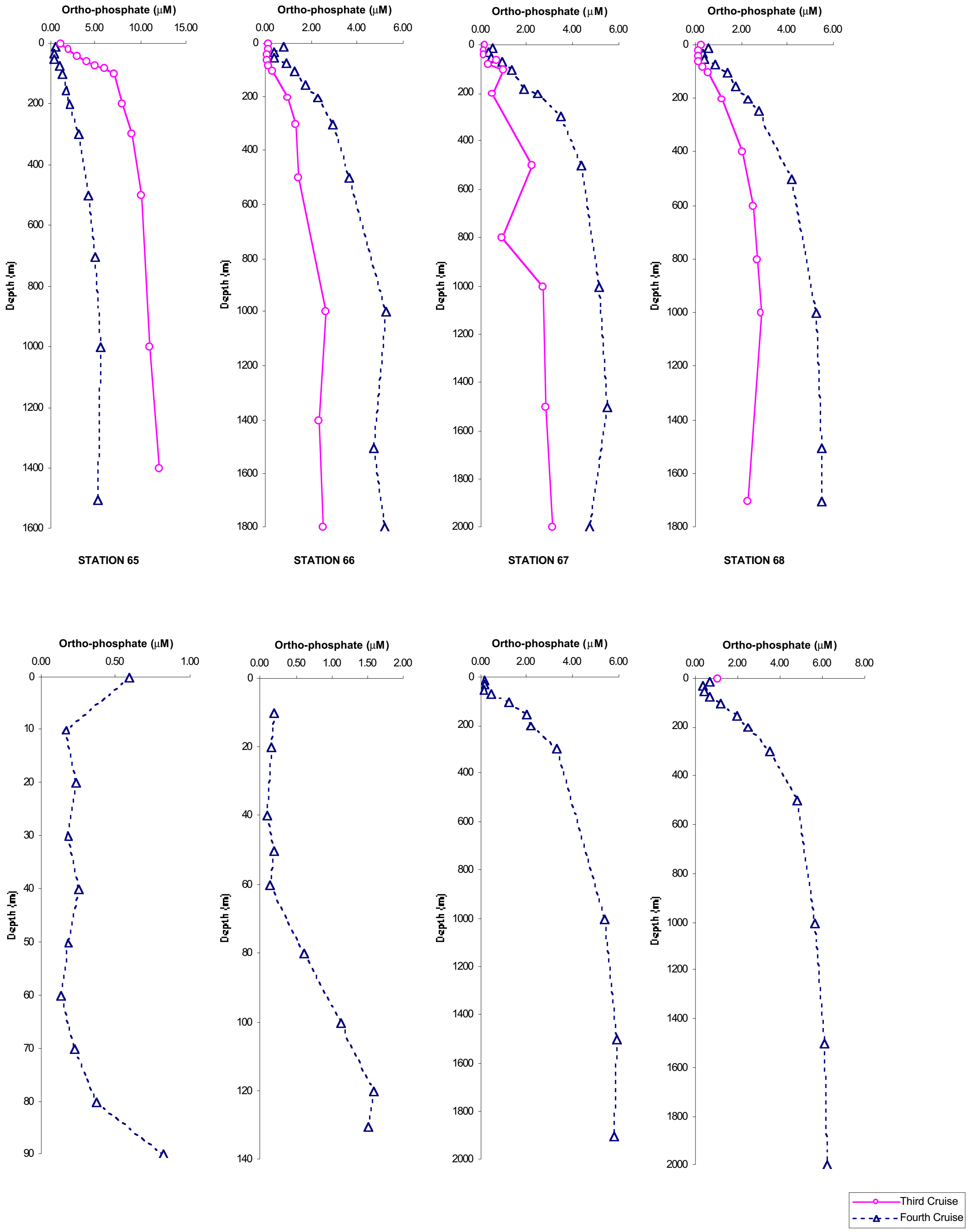

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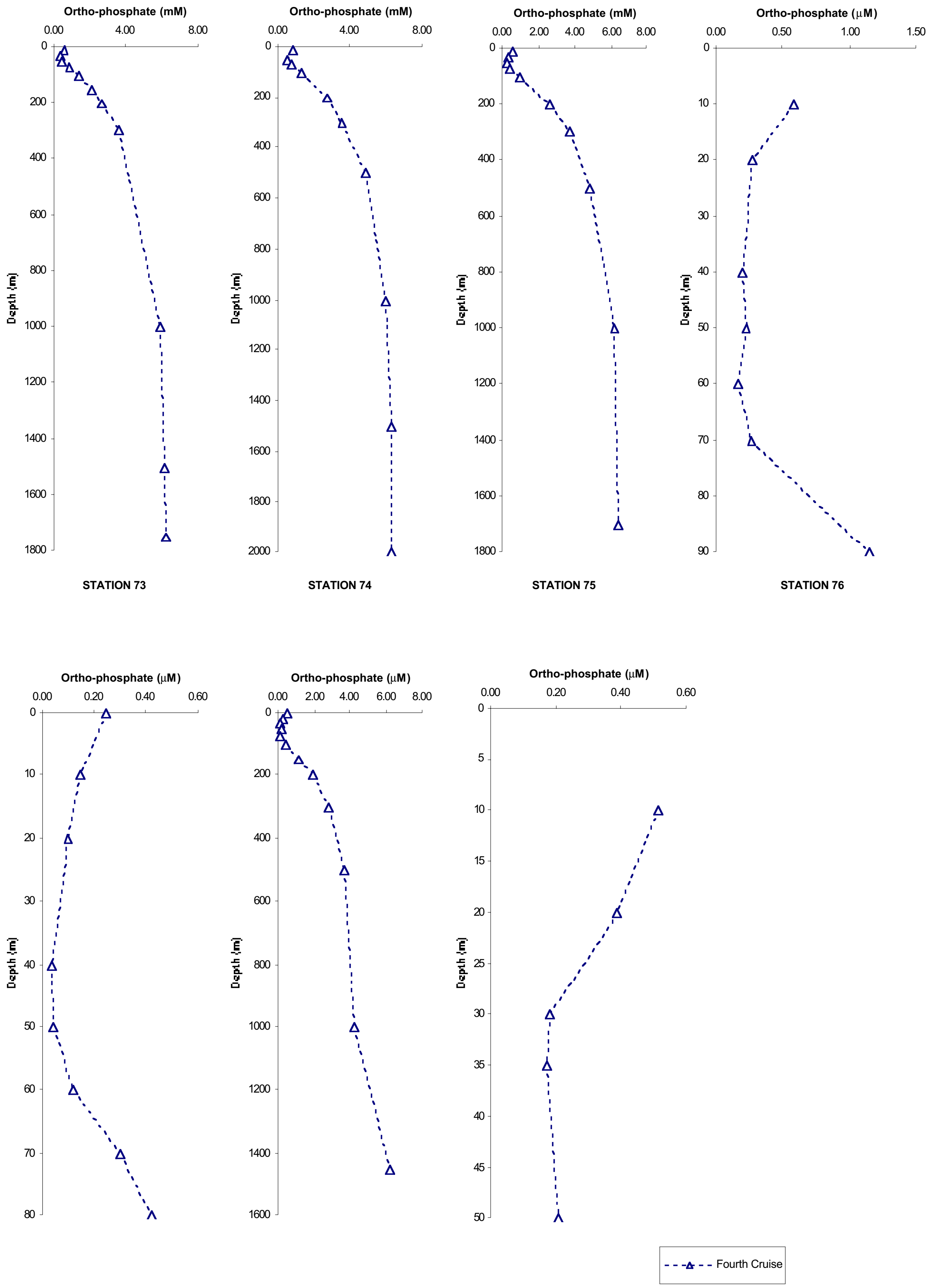

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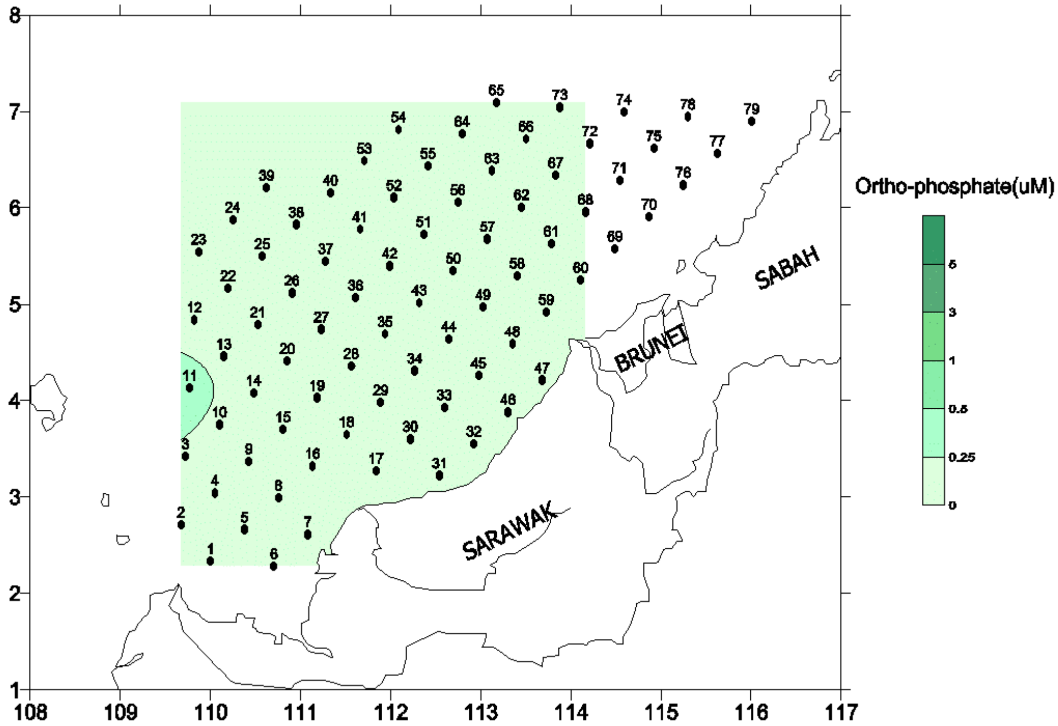

Fig. 3 Ortho-phosphate concentration in the upper layer of the sampling stations during July- August 1996 (third cruise).

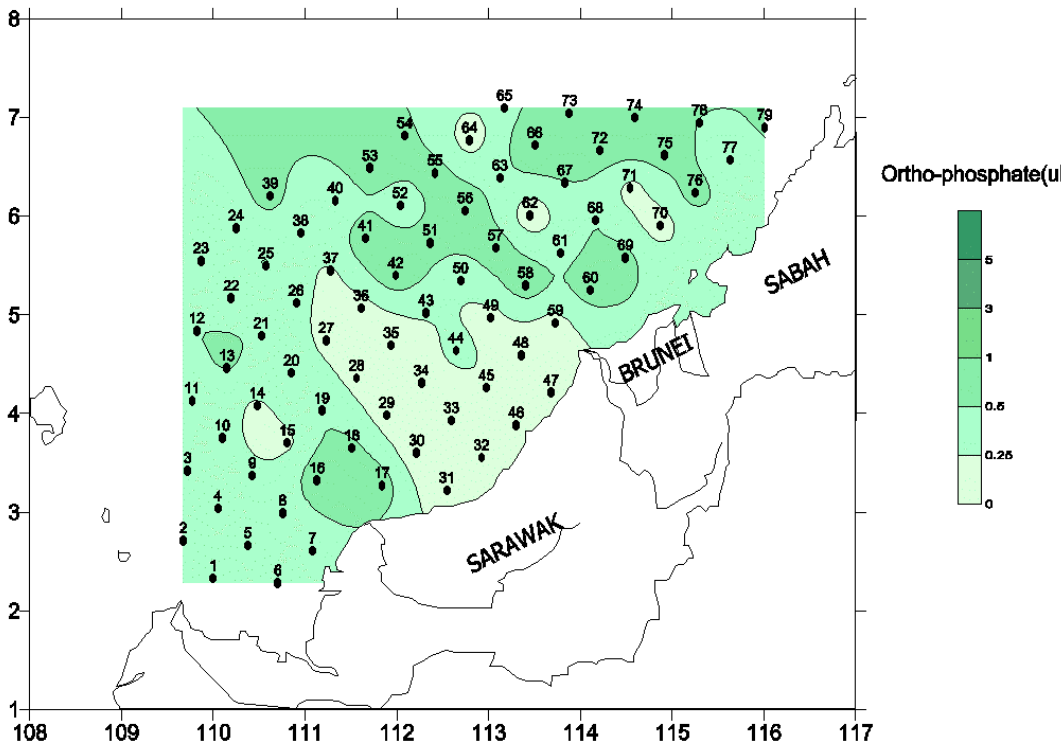

Fig. 4 Ortho-phosphate concentration in the upper layer of the sampling stations during May 1997 (fourth cruise).

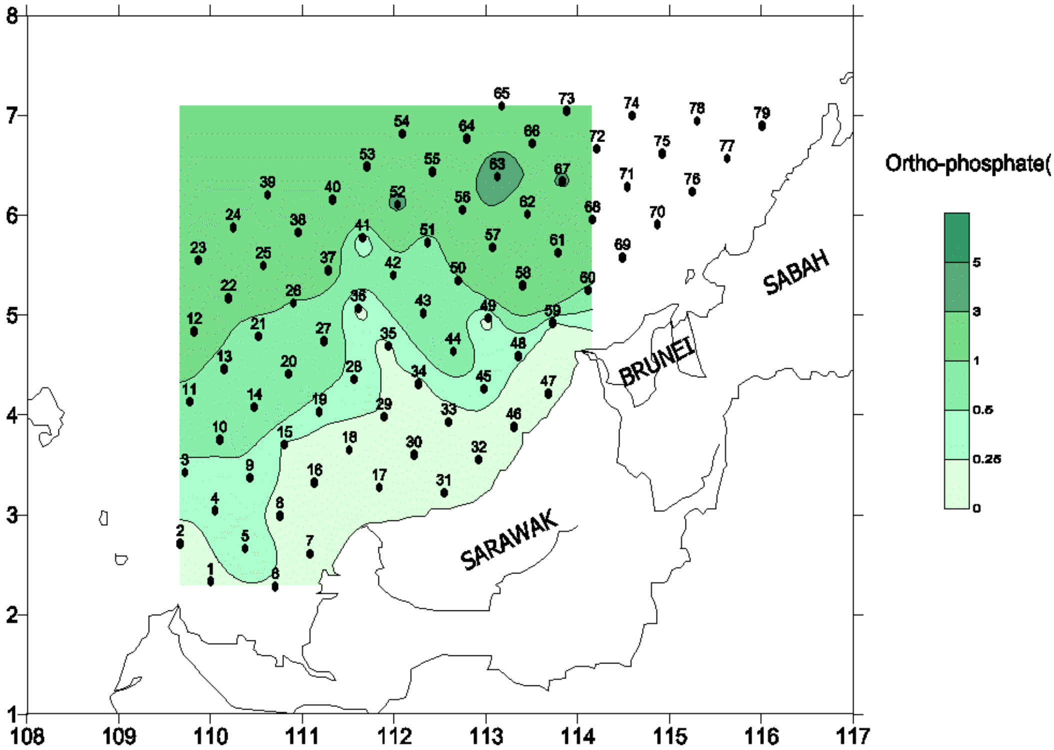

Fig. 5 Ortho-phosphate concentration in the bottom layer of the sampling stations during July-August 1996 (third cruise).

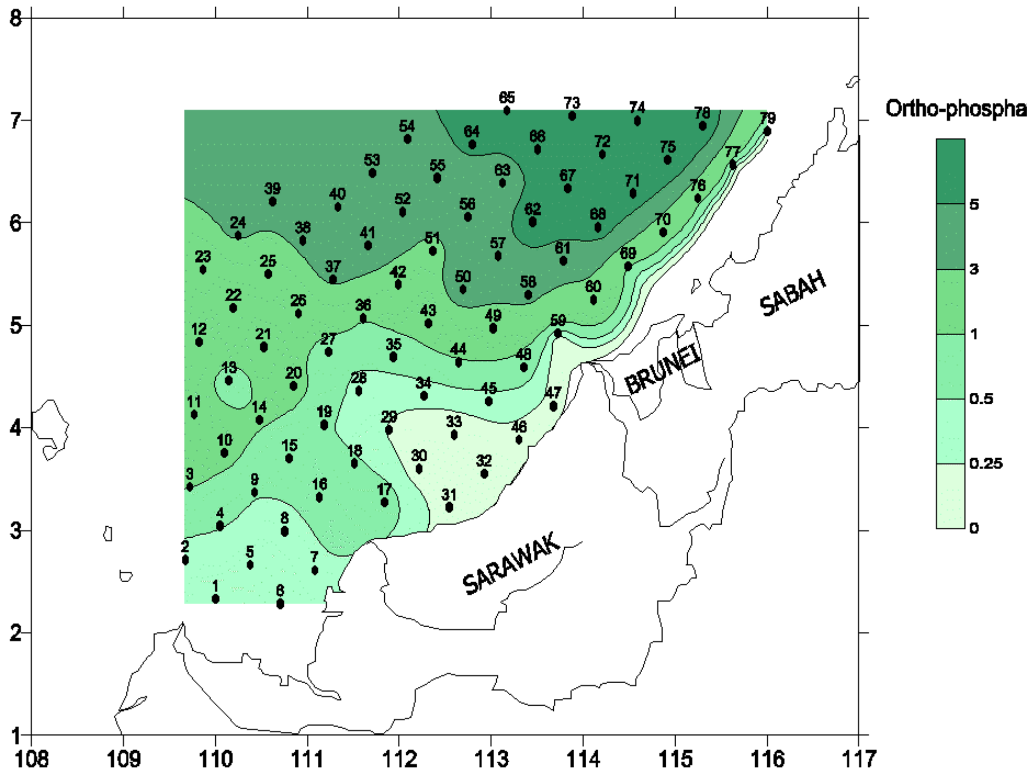

Fig. 6 Ortho-phosphate concentration in the bottom layer of the sampling stations during May 1997 (fourth cruise).

Table 3 Comparison of phosphate concentration (μM) in the world ocean and seas

Author(s)	Location	Surface layer
Kaewsripraky & Chantarasakul 1985*	Gulf of Thailand	0.88
Anon 1985*	Japan Sea	0.55
	Pacific Waters off Japan	0.22
Wafar *et al.* 1983*	Western English Channel	0.11
Law & Kamil 1986*	Malaysian EEZ off Kuala Terengganu, South China Sea	0.07
Lim 1978*	Southern South China Sea, off Malaysian coast	
	1971 cruise	0.26
	1972 cruise	0.38
	1973 cruise	0.68
Hirata *et al.* 1983*	Oceanic Region, North Solomon Island, South Pacific Ocean	0.21
Makita *et al.* 1984*	Oceanic Region between Gilbert and the Fiji Islands, South Pacific Ocean	0.20
Hirata *et al.* 1984*	Oceanian Region, North of Solomon Island, South Pacific Ocean	0.21
Law & Rahman 1987*	Malaysian EEZ Coastal waters off Kuantan to Pulau Tioman	0.18
Law & Zawawi 1988*	Malaysian EEZ Coastal waters off Sarawak, South China Sea	0.32
Law 1989*	Malaysian EEZ off Sabah, South China Sea	0.62
Law & Chu 1990	Coastal waters off Port Dickson, Straits of Malacca	0.18
Mohd. Shukri *et al.* 1997	Gulf of Thailand and East Coast of Peninsular Malaysia	0.14
Present study	Sabah, Sarawak and Brunei Darussalam waters, South China Sea	
	Third Cruise (1996)	0.14
	Fourth Cruise (1997)	0.31

Note : * Source from Table 3 in Law and Rahman (1987)

Table 4 Comparison of average concentration of Ortho-phosphate in the third cruise and fourth cruise

Depth (m)	Ortho-phosphate (μM)	
	Third cruise	Fourth cruise
0-1	0.14	0.24
10	0.09	0.28
20	0.1	0.2
50	0.09	0.25
100	0.5	1.15
200	0.9	2.27
500	1.94	4.13
1000	2.59	5.19
1500	3.1	5.41

References

Anon, (1985). Summary of the investigation of pollution in the adjacent seas of Japan. Water Quality Bureau Environmental Agency of Japan. Invergovernmental Oceanographic Commission (of UNESCO). Report of First Meeting of Western Pacific (Westpac) Task Team on Marine Pollution Research and Monitoring. 17-19 April 1985. Townsville, Australia. Department of Science, Australia.

Chester, R. (1990). Marine Geochemistry. Unwin Hyman Ltd., London.

Horne, R. A. (1969). Marine Chemistry. The Structure of Water and the Chemistry of the Hydrosphere. Wiley-Interscience, New York.568pp.

Ichikawa, T., A.T. Law, Mohd. Raffee bin Jusoh and Azhar Othman (1987) Nitrogen Distribution in the South Western portion of the South China Sea. In : Mohsin, A.K.M., Ridzwan Abd. Rahman and Ambak, M.A. (eds.). Matahari Expedition '86: A study on the offshore waters of the Malaysian EEZ. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia, Occasional Publication No. 4.,197pp.

Kaewsripraky L. and Chantarasakul W. (1985). Distribution of nutrients and dissolved organic carbon in the Gulf of Thailand. Thai-SEAFDEC Joint Fishery Oceanographic Survey in the Central Gulf of Thailand. Vol. I. Southeastern Asian Fisheries Development Center.

Law, A.T. (1990). Phosphorus and Inorganic Nitrogen Distribution in the Coastal Waters off Sabah, South China Sea. In : Mohsin, A.K.M., Mohd Zaki and Mohd Ibrahim (eds.). Matahari Expedition '89: A study on the offshore waters of the Malaysian EEZ. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia, Occasional Publication No.9,107pp.

Law, A. T. and Mohd. Kamil Abd. Rashid (1986). Inorganic nitrogen and phosphate distribution in the South China Sea. In : Mohsin, A.K.M., Mohd Ibrahim and Ambak, M.A. (eds.). Matahari Expedition '85: A study on the offshore waters of the Malaysian EEZ. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia, Occasional Publication No. 3.,233pp.

Law, A. T. and Abd. Rahman Shaik (1987). Phosphate distribution in the south-western portion of South China Sea. In : Mohsin, A.K.M., Ridzwan Abd. Rahman and Ambak, M.A. (eds.).

Matahari Expedetion' 86 A study on the offshore waters of the Malaysian EEZ. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia, Occasional Publication No. 4., 197pp.

Law, A. T. and Zawawi b. Mohamad (1988). Phosphate distribution in the South China Sea of Sarawak. In : Mohsin, A.K.M., Mohd Ibrahim Hj. Muhamed (eds.). Matahari Expedition '87: A study on the offshore waters of the Malaysian EEZ. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia, Occasional Publication No. 6. ,168pp.

Law, A.T. and C.H. Chu (1989). Chemical oceanography observation in the coastal waters off Port Dickson, Malaysia. In : Mohd. Ibrahim Hj. Mohamed, Patimah Ismail, A.T. Law and S.C. Cheah (eds.) Advances in Fisheries and Marine Sciences. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia. 265pp.

Lim, L.C. (1978). MFRD oceanographic data report. Marine Fisheries Research Department, South-east Asian Fisheries Development Center, Singapore. 179pp.

Millero, F. J. (1996) Chemical Oceanography, Second Edition. CRC Press, Inc., New York. 469pp.

Mohd. Shukri,Y., Solahuddin, A.R. and Abdul Hamid,Y. (1997). Dissolved Inorganic Nutrient in the Sea Water of South China Sea. Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. Report presented at the SEAFDEC Technical Seminar on the Interdepartmental Collaborative Research Program in the South China Sea, Area I: Gulf of Thailand and Eastern Peninsular Malaysia, 17-19 February 1997,Bangkok.

Pojed, I and S.Kveder. (1977). Investigation of nutrient limitation of phytoplankton production in northern Adriatic. Rapp.P.-V.Reun. Comm. Int. Explor. Mer. Mediterr. 24(8):47-48.

Riley, J.P. and Chester, R. (1981). Introduction to Marine Chemistry. Academic Press, London. 465pp.

Saleh, U.,A.T. Law and Othman Ali (1988). Nitrogen Distribution in Water and Sediment in the South China Sea off Sarawak. In : Mohsin, A.K.M., Mohd Ibrahim Hj. Muhamed (eds.). Matahari Expedition '87: A study on the offshore waters of the Malaysian EEZ. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia, Occasional Publication No. 6. ,168pp.

Wafar, M.V.M., LeCorre, P. and Birrien, J.L. (1983). Nutrients and primary production in Permanently well-mixed temperate coastal waters. Estuarine, coastal and shelf science 17:431-446.

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Dissolved Carbonate-Carbon Dioxide in Sea Water of the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam

Anond Snidvongs

Marine Science Department, chulalongkorn University

Abstract

Dissolved carbonate species in seawater are determined from pH and total alkalinity. The data clearly pointed out the significance of Rajang River as a source of organic matters that were subsequently decomposed and cause CO_2 gas to evade from nearshore water in its vicinity into the atmosphere while most offshore surface water was the sink of atmospheric CO_2. The total alkalinity profiles indicated dissolution of carbonate minerals, believed to be high magnesian calcite, below 500 m, which reinforce CO_2 storing capacity of these waters.

Introduction

Dissolved inorganic carbon (DIC) comprises of carbon dioxide gas (CO_2), carbonic acid (H_2CO_3), bicarbonation (HCO_3^-) and carbonation (CO_3^{2-}). The total concentration of DIC and ratios among all species are influenced by several factors, particularly partial pressure of CO_2, total and carbonate alkalinity, and physical factors such as temperature, salinity and pressure. The net effect on speciation of the species results in the observed pH of seawater.

Photosynthesis consumes CO_2 gas and thus decreases partial pressure of CO_2 while respiration and decomposition of organic matter do the opposite. Dissolution of carbonate mineral uses up CO_2, CO_3^{2-} and lowers total alkalinity while calcification does the opposite. By understanding the carbonate system in seawater, these processes can be explained.

Methods

Seawater was collected at eachstation during Cruise 34 (10 July – 2 August 1996) and 41 (1-24 May 1997) at selected depths by water sampler attached to a rosette system. The methods for pH and total alkalinity determination and calculation for dissolved carbonate species were given in Rojana-anawat and Snidvongs (1997).

To compare the horizontal concentration of each species so that non-conservative processes could be seen, the concentrations on isopycnal surfaces, i.e. the surface that frictionless water can flow without any energy loss or gain; four isopycnal surfaces were chosen at sigma theta (density anomaly) of 23.0, 25.0, 27.0 and 27.5 kg m^{-3} plus sea surface.

Results

<u>Vertical Distribution</u>

In this area, pH of seawater decreased from about 8.2 at the surface is 7.7 at about 500 m. Between 500 and 2000 m, pH changed only slightly (Figure 1). This type of pH profile for both cruises implied strong biological activities, photosynthesis and respiration, between subsurface and 500 m.

The total alkalinity increased quite rapidly from about 2.2 meq l^{-1} at the surface to about 2.35 at 150 m. Below 150 m, total alkalinity gradually increased, although the increasing rate was smaller than in the subsurface zone (Figure 2). This evidence suggested that different processes controlled pH and total alkalinity of seawater in this area though these processes could be well interrelated. Dissolution of carbonate mineral was likely to be the cause of alkalinity increasing in deep water.

The total concentration of dissolved inorganic carbon in seawater increased from less than 2 mM at sea surface to more than 2.3 mM at 2000 m (Figure 3), due mainly to respiration in the water column. Dissolved bicarbonate (HCO_3^-) accounted for 88 - 97 % of the total dissolved inorganic carbon.

The concentration of dissolved carbonate, although a minor specie of dissolved inorganic carbon, determined the stability of different carbonate minerals exposed to the water. Despite the fact that all water samples collected from this area were supersaturated with respect to pure calcite and aragonite minerals, seawater below 500 m was undersaturated with respect to high magnesian calcite (Figure 4). Dissolution of these calcite minerals containing more than 5 mol% of Mg could explain the gradual increase in total alkalinity with depth.

Partial pressure of dissolved carbon dioxide gas in surface seawater of the study area was generally near equilibrium with the present day atmospheric partial pressure of 360 matm. The partial pressure below 1000 m was around 1400 matm with the range of 1200 - 1600 matm (Figure 5).

<u>Horizontal Distributions</u>

Isopycnal surface was usually more depressed offshore and to the east of Sabah (Figures 11A-D). However, deep water pycnocline depression below 1000 m was found along longitude 112°E (Figure 11E). Intermediate water (q_t = 23 - 25 kg m^3) was found between 50 - 140 m while deep water (q_t >27 kg m^3) was found below 600 m.

pH of surface water was low nearshore especially near Kuching (Figure 6A) suggesting the decay of terrestrial organic matters delivered by the river. The pH of intermediate water was also generally lower off Kuching and Sabah (Figures 6B and C). There was little variation of pH of deep water (Figures 6D and E).

Freshwater discharge from Kuching area also caused total alkalinity of surface water to decrease (Figure 7A). However, this effect could be only slightly detected in intermediate water (Figures 7B and C) and deep water (Figures 7D and E). It seems quite clear that the dissolution of carbonate mineral was the main source of alkalinity than river input.

Although decomposition of organic material input by Rajang River was a major source of inorganic carbon to the surface water of Kuching area, the total dissolved inorganic carbon actually observed in surface water was low (Figure 8A). This was because the water had low alkalinity and thus less capacity is store inorganic carbon as negative charge ions, such as HCO_3^- and CO_3^{2-}. Dissolved inorganic carbon in intermediate water (Figures 8B and C) was less subjected to input/output and the concentration was quite homogeneous horizontally. Deep water had high concentration of dissolved inorganic carbon due to the net respiration while high pressure and low temperature favored more CO_2 to be dissolved.

The concentration of dissolved carbonate in surface and intermediate waters which was always higher than 0.1 mM (Figures 9A - C) clearly indicated that these waters were supersaturated with respect to all major carbonate minerals. However, deep water in the study area that had carbonate concentration less than 0.1 mM could be undersaturated with respect to high magnesian calcite.

Partial pressure of dissolved carbon dioxide in surface water also pointed out that nearshore water the influence from Rajang River which had the partial pressure higher than 360 matm was the source of CO_2 to the atmosphere while offshore water was generally the sink of atmospheric CO_2 (Figure 10A). Partial pressure of dissolved CO_2 in intermediate water reflected local processes that also highly varied with time (Figures 10B - C). However, the distribution pattern of deep water pCO_2 was quite the same for both cruises, although the absolute pressure varied slightly, that might indicate a rather stable process involving CO_2 in deep water layer.

Discussion and Conclusion

The major findings in this study were that Rajang River was a major source of organic matters that subsequently decayed and caused CO_2 to evade from nearshore into the atmosphere, while most offshore water was the sink of atmospheric CO_2. Dissolution of carbonate mineral, believed to be high magnesian calcite, took place below 500 m. This suggested that high magnesian calcite such as coccolith and foraminifera shells would be absent from sediment samples below 500 m. In general, this area is important as a sink for atmospheric CO_2 and deserved more precise estimation of flux and processes involved.

References

Rojana-Anuwat, P. and Sninddvongs, S. 1997 Dissoved oxygen and carbonate-carbon dioxide in sea water of the south China sea, Area I : Gulf of Thailand and the East Coast of Peninsular Malaysia, SEAFDEC Collaborative Proceeding (in press)

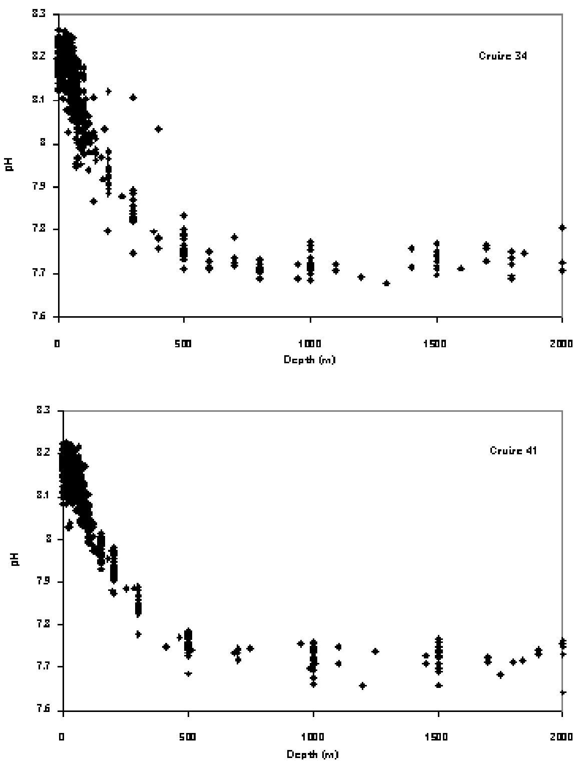


Fig. 1 Pooled vertical pH profliles for Cruises 34 and 41

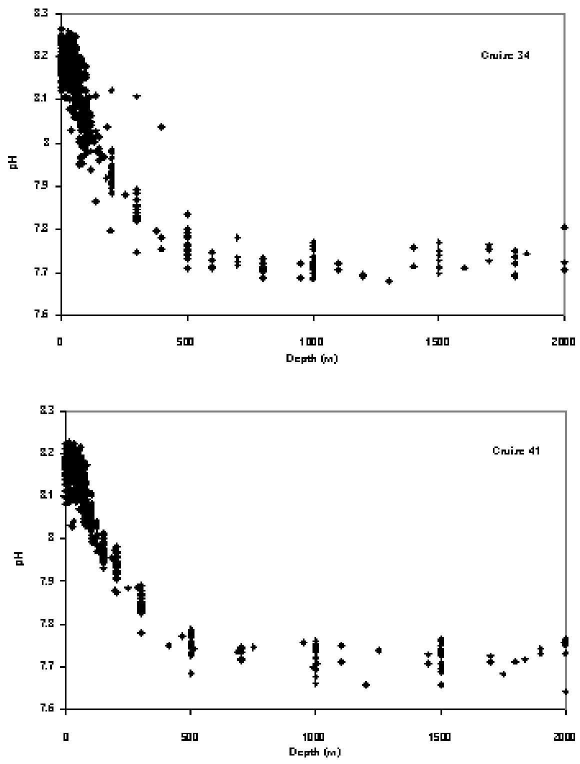


Fig. 2 Pooled vertical profiles of total alkalinity for Cruises 34 and 41

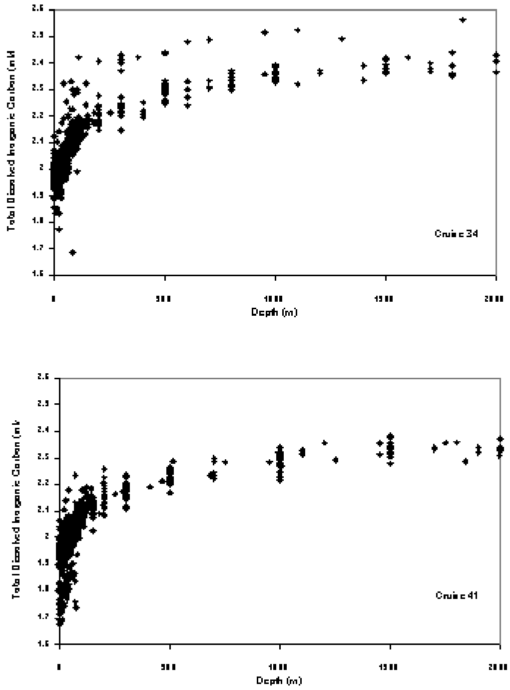


Fig. 3 Vertical profiles of total dissolved inorganic carbon for Cruises 34 and 41

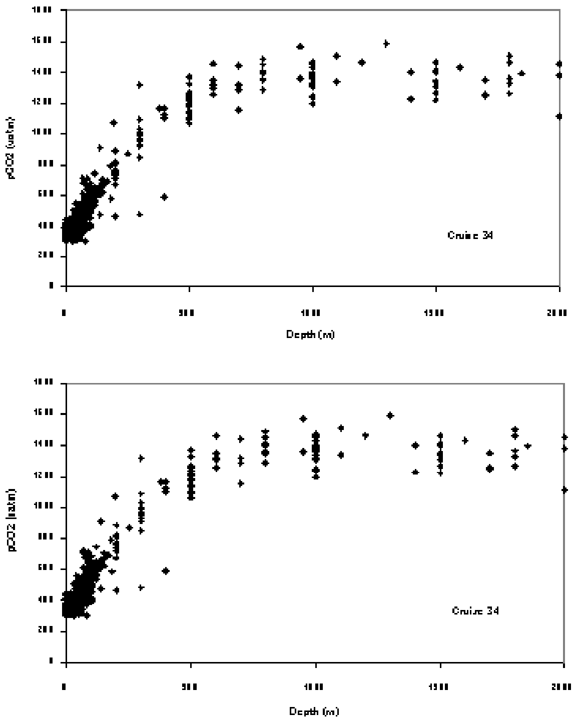


Fig. 5 Pooled vertical profiles of dissolved carbon dioxide partial pressure for Cruise 34 and 41

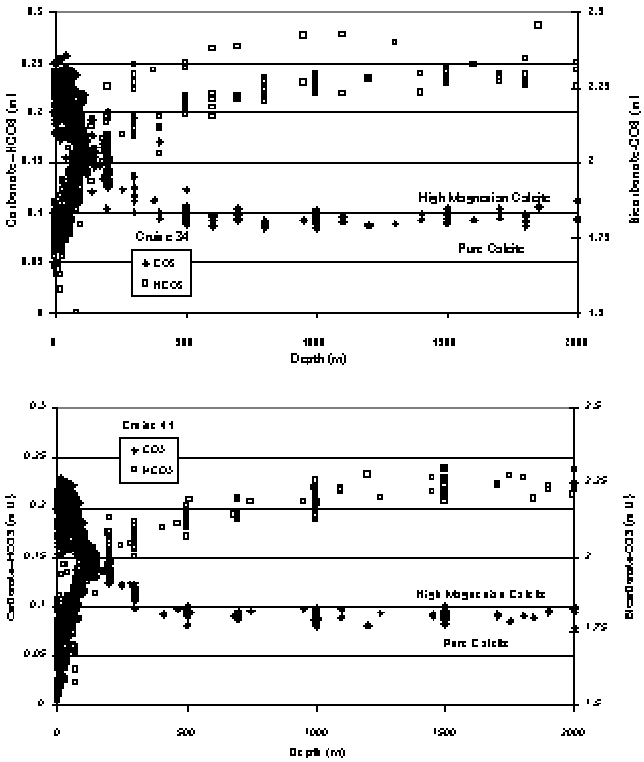


Fig. 4 Pooled vertical profiles of dissolved bicarbonate and carbonate. Equilibrium concentrations of carbonate with repected to pure calcite and “high” magnesian calcites are shown at 0.05 and 0.1 mM

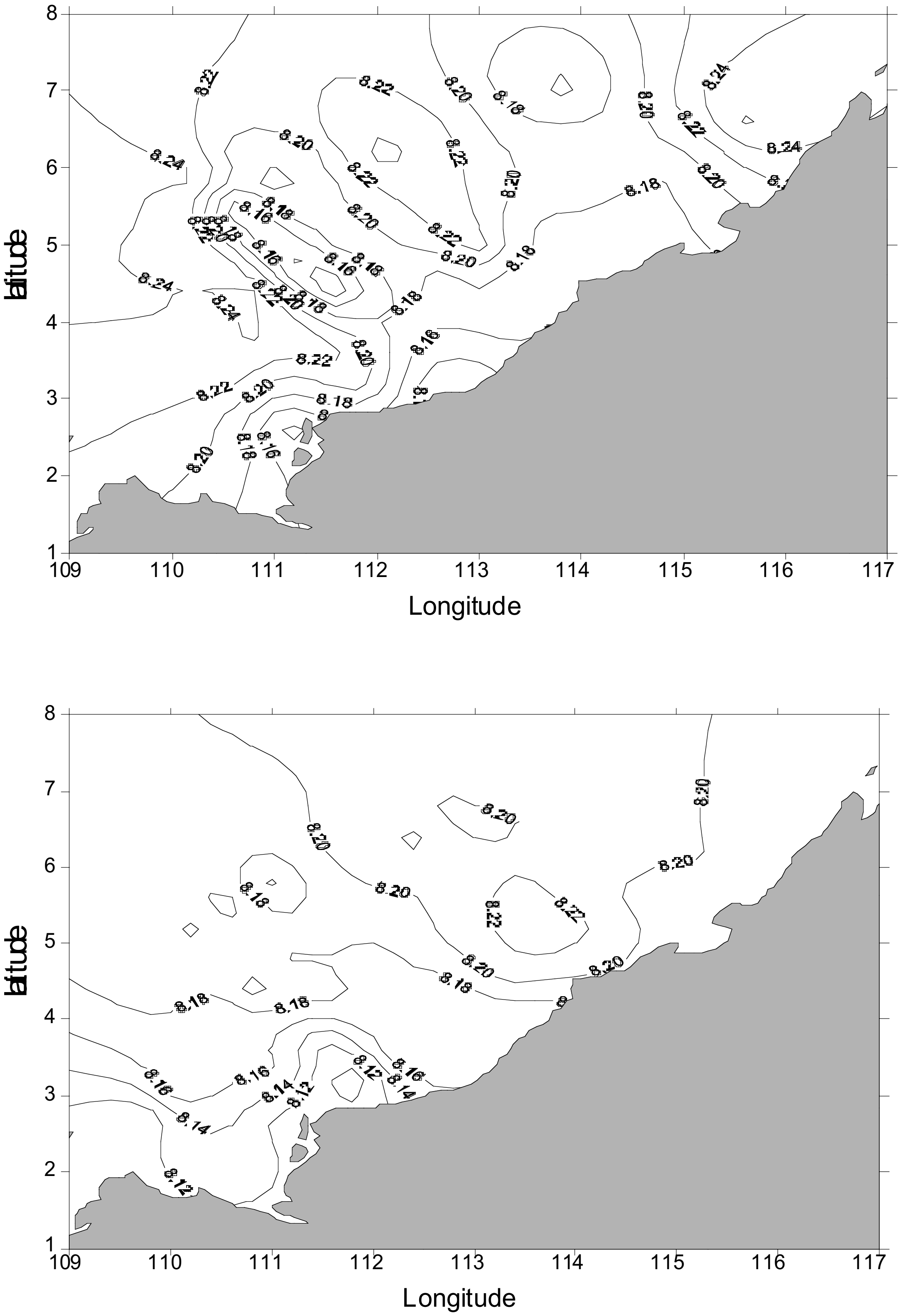
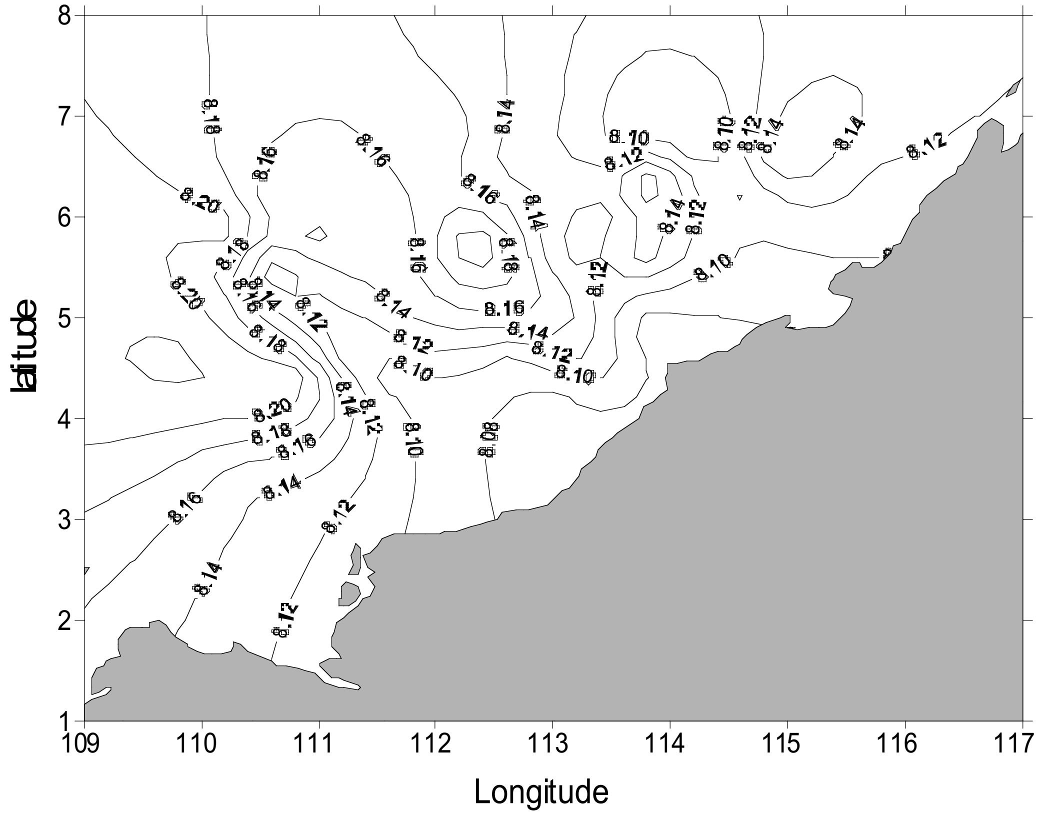


Fig. 6A pH at sea surface



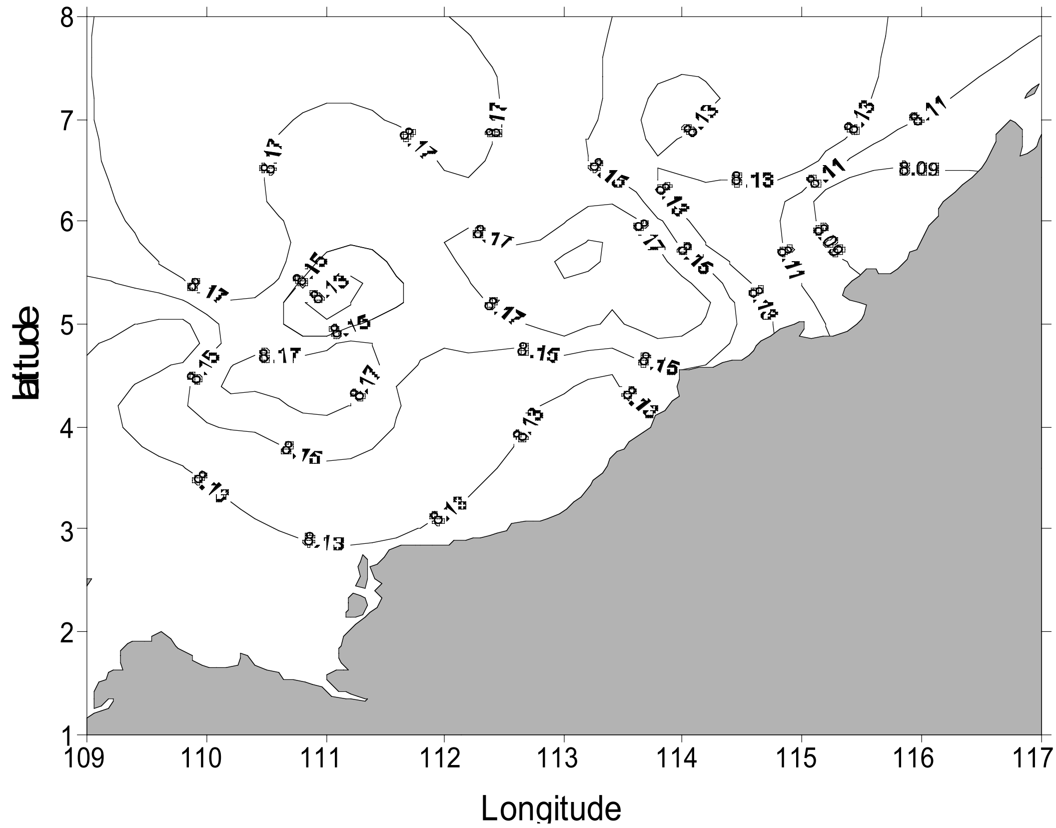


Fig. 6B pH on the 23.0 kg/m^3 isopycnal surface

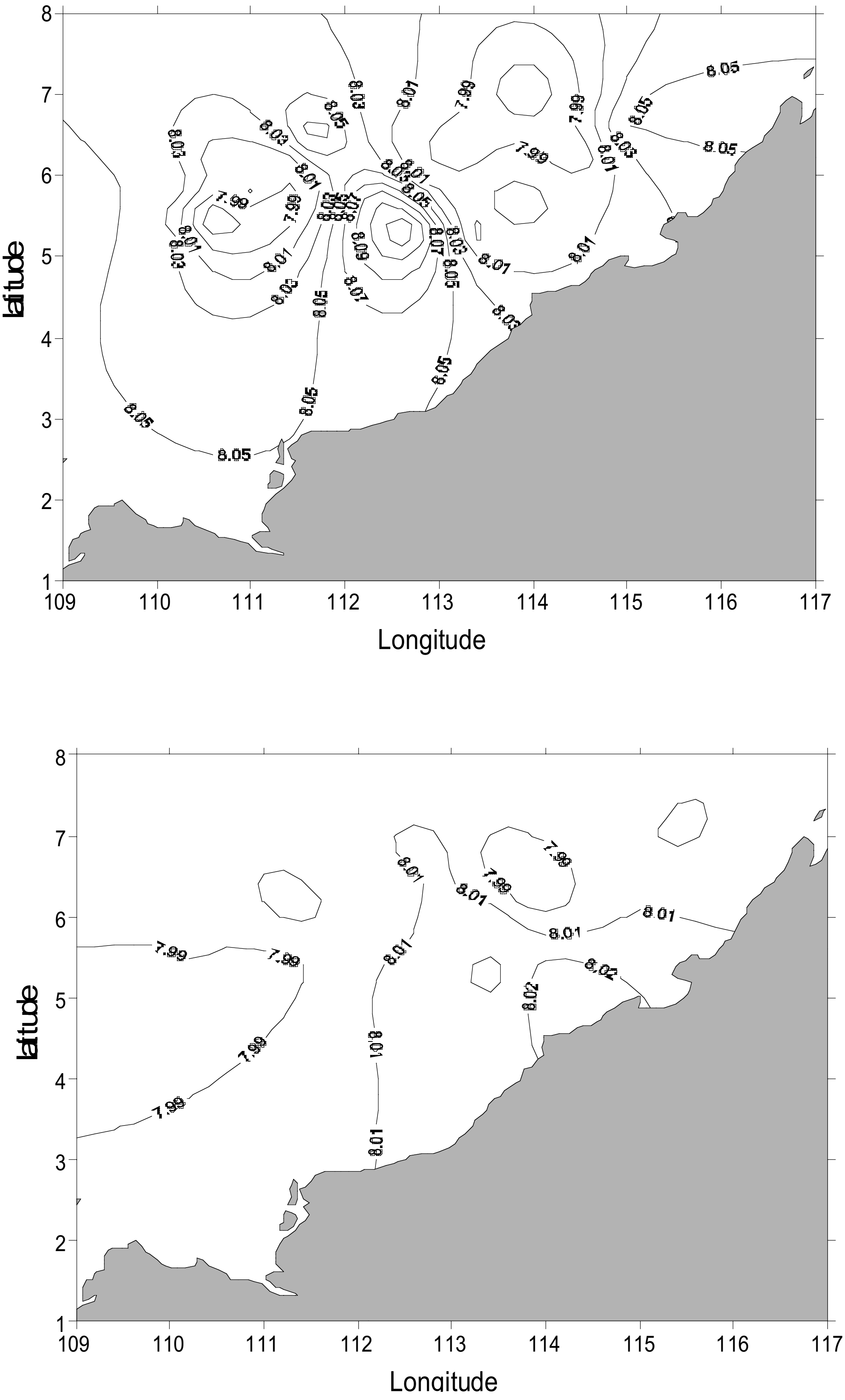


Fig. 6C pH on the 25.0 kg/m³ isopycnal surface

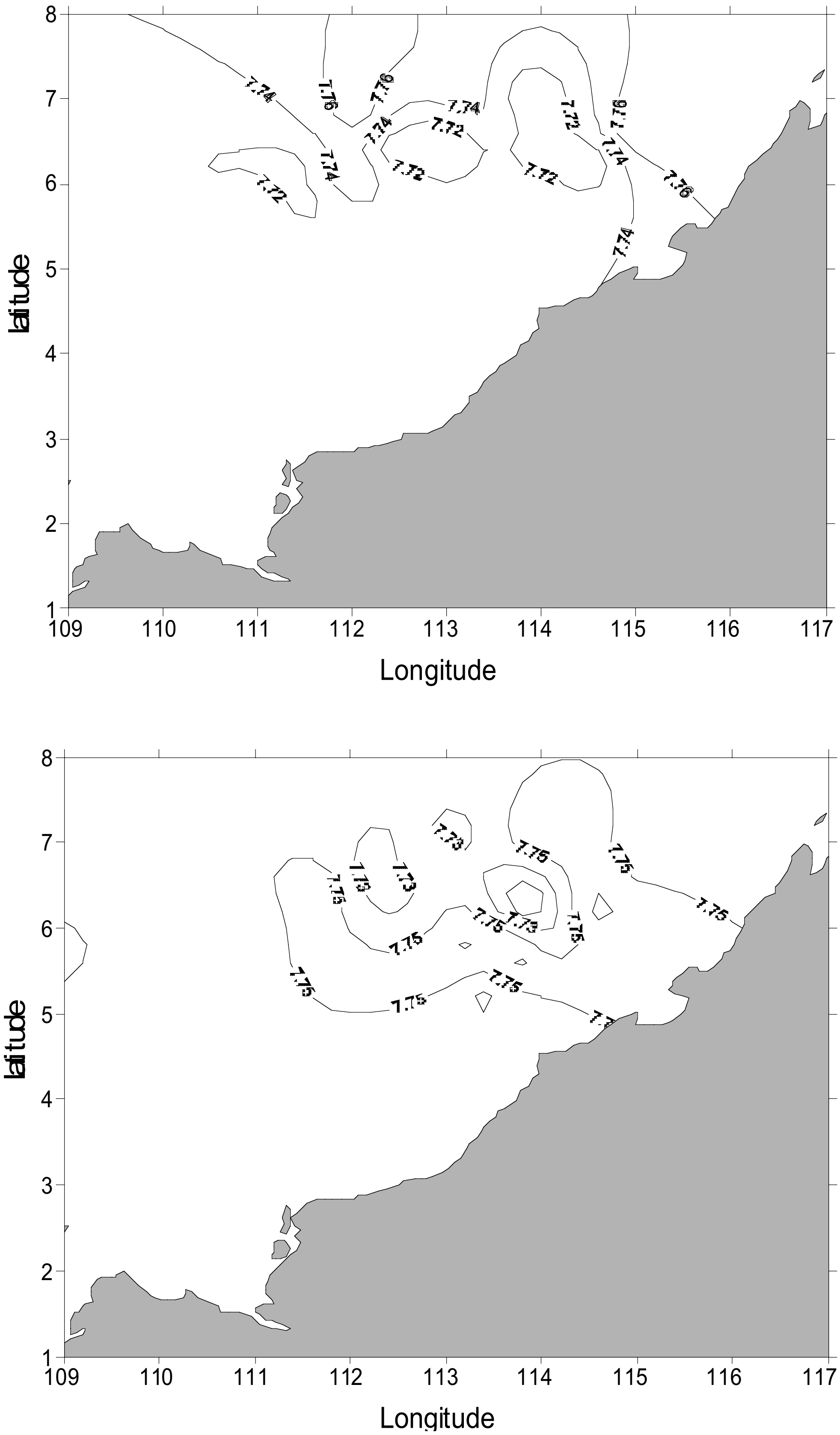
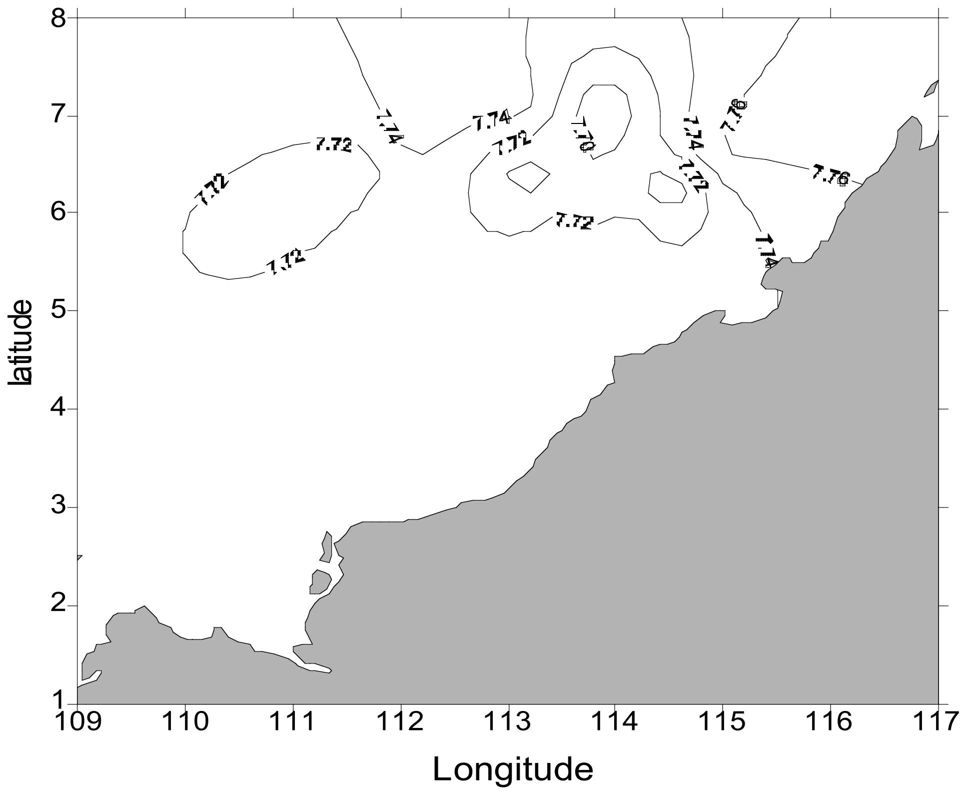


Fig. 6D pH on the 27.0 kg/m^3 isopycnal surface



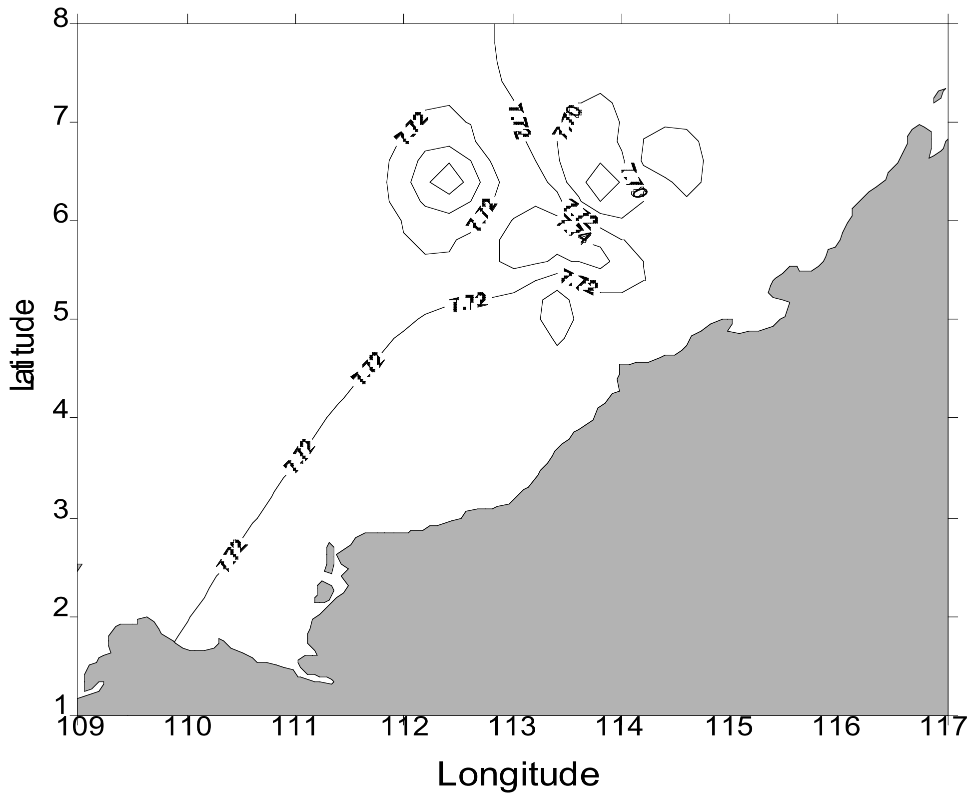


Fig. 6E pH on the 27.5 kg/m³ isopycnal surface

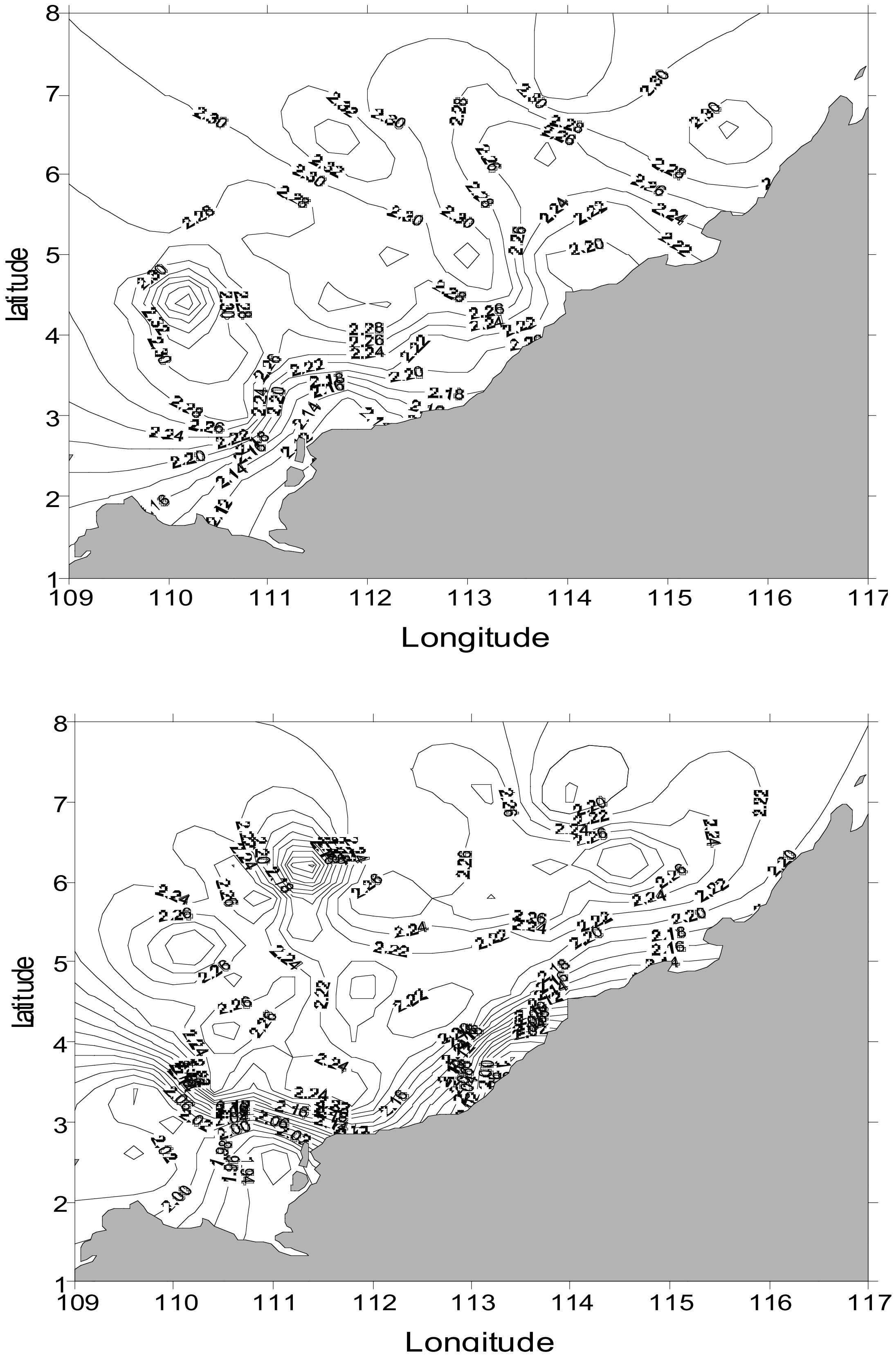


Fig. 7A Total alkalinity at sea surface

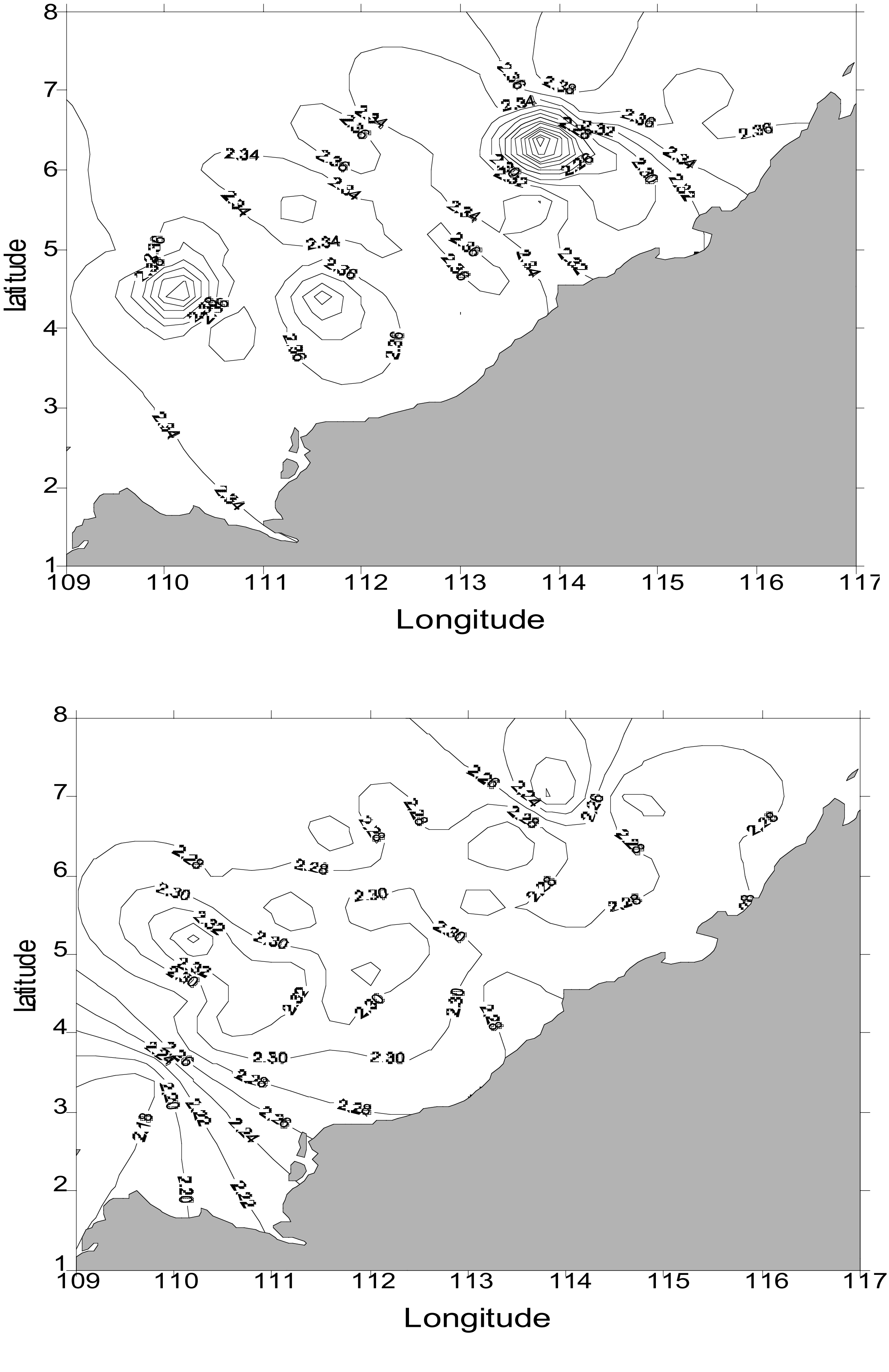


Fig. 7B Total alkalinity on the 23.0 kg/m^3 isopycnal surface

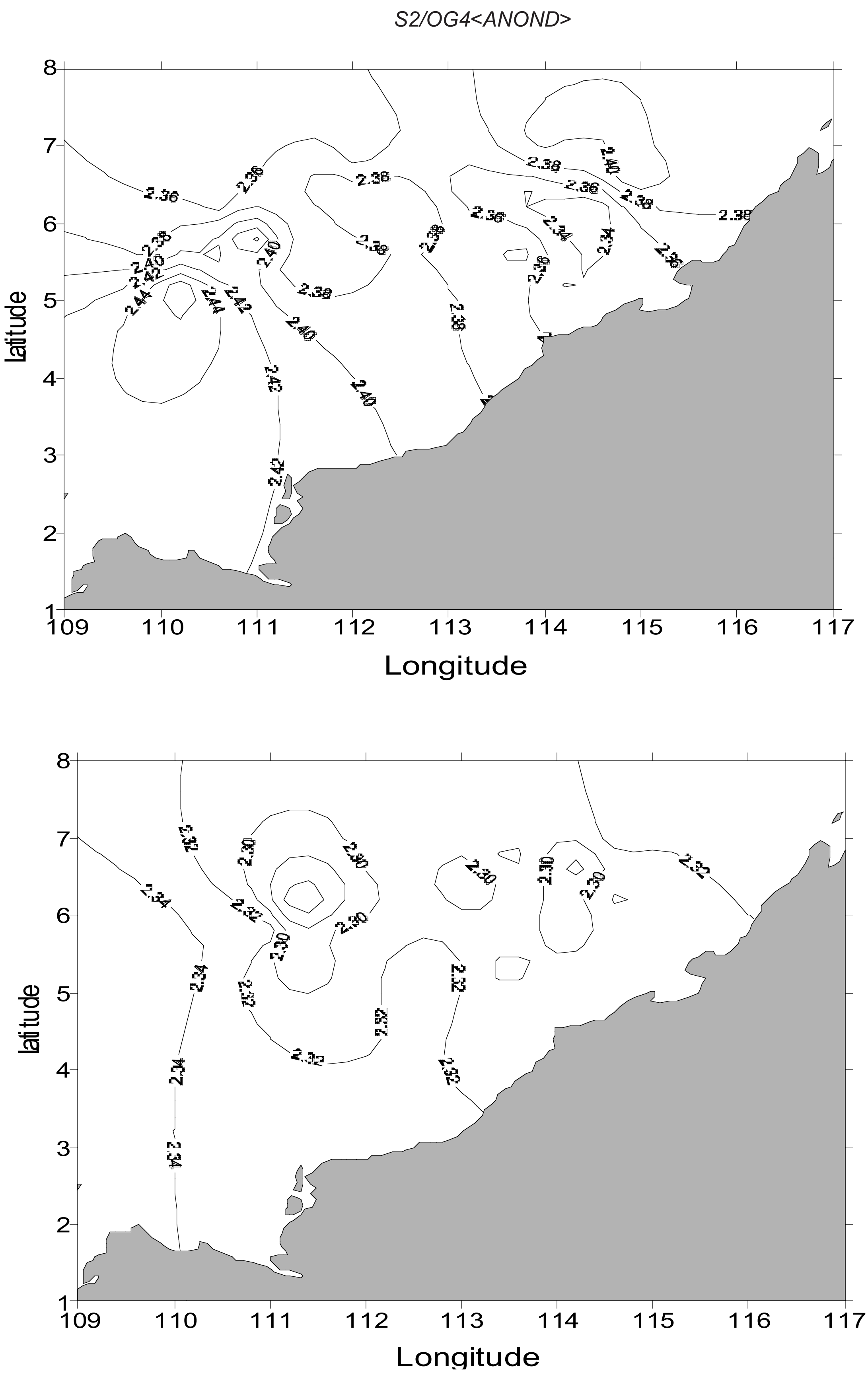


Fig. 7C Total alkalinity on the 25.0 kg/m³ isopycnal surface

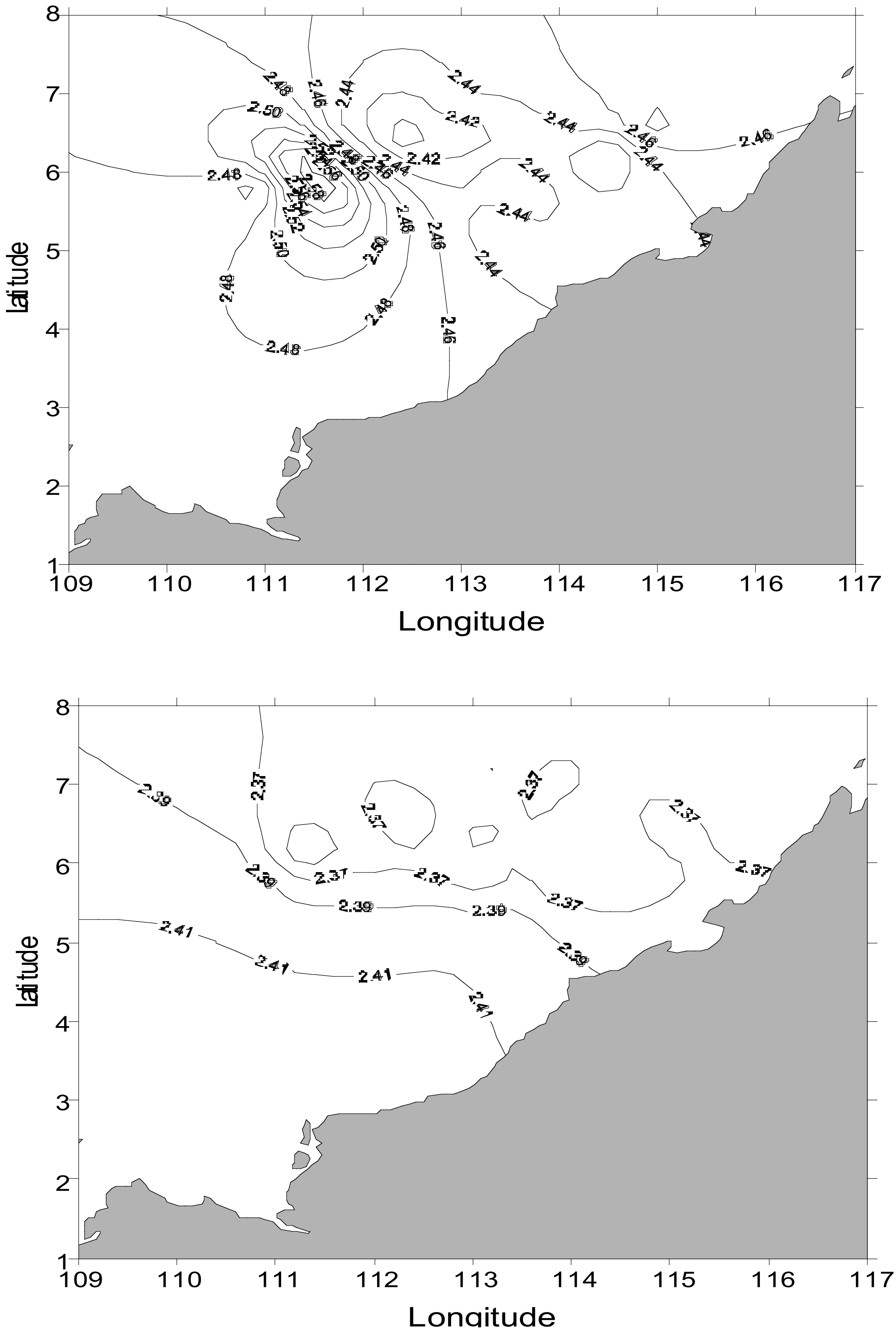


Fig. 7D Total alkalinity on the 27.0 kg/m^3 isopycnal surface

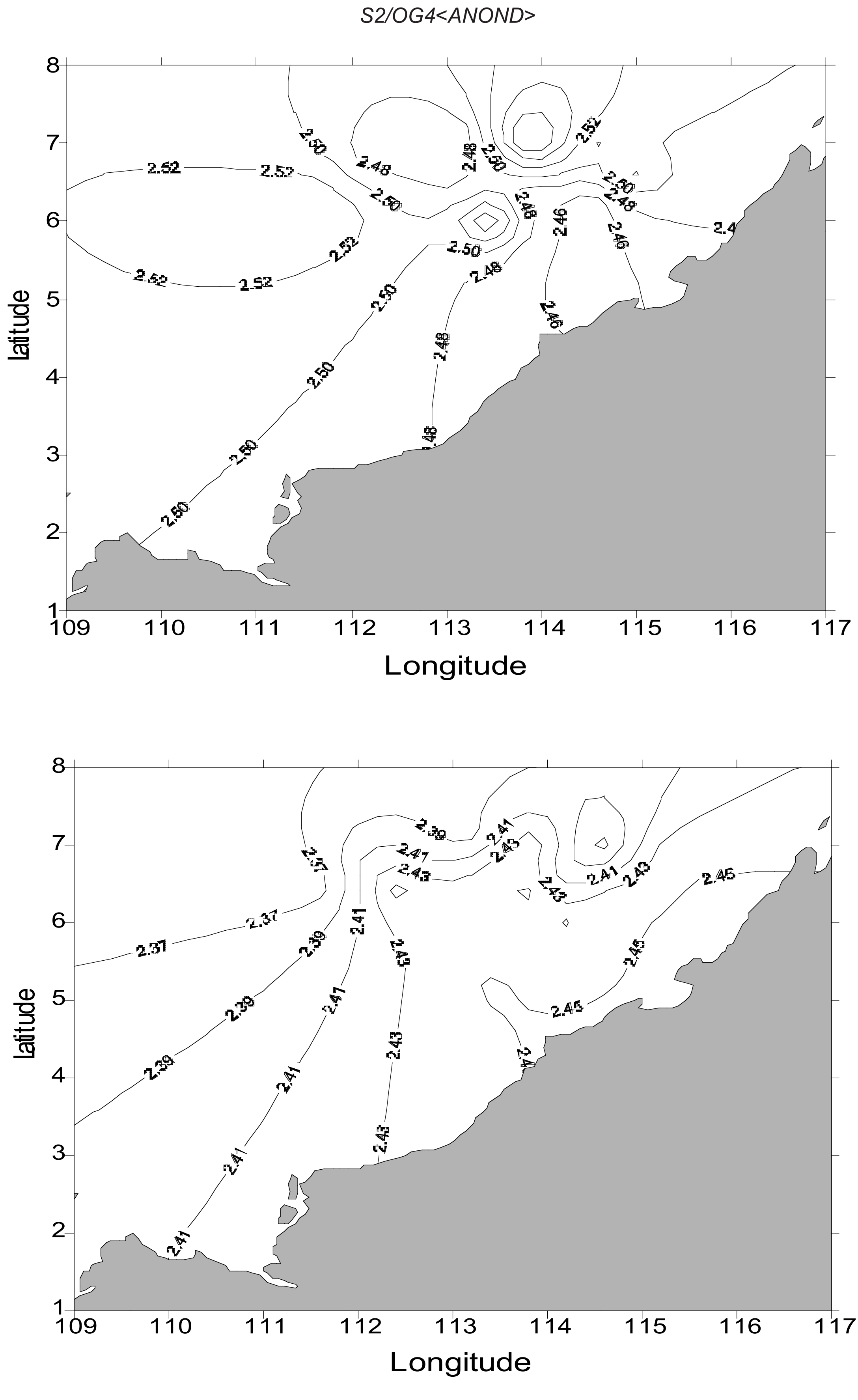


Fig. 7E Total alkalinity on the 27.5 kg/m^3 isopycnal surface

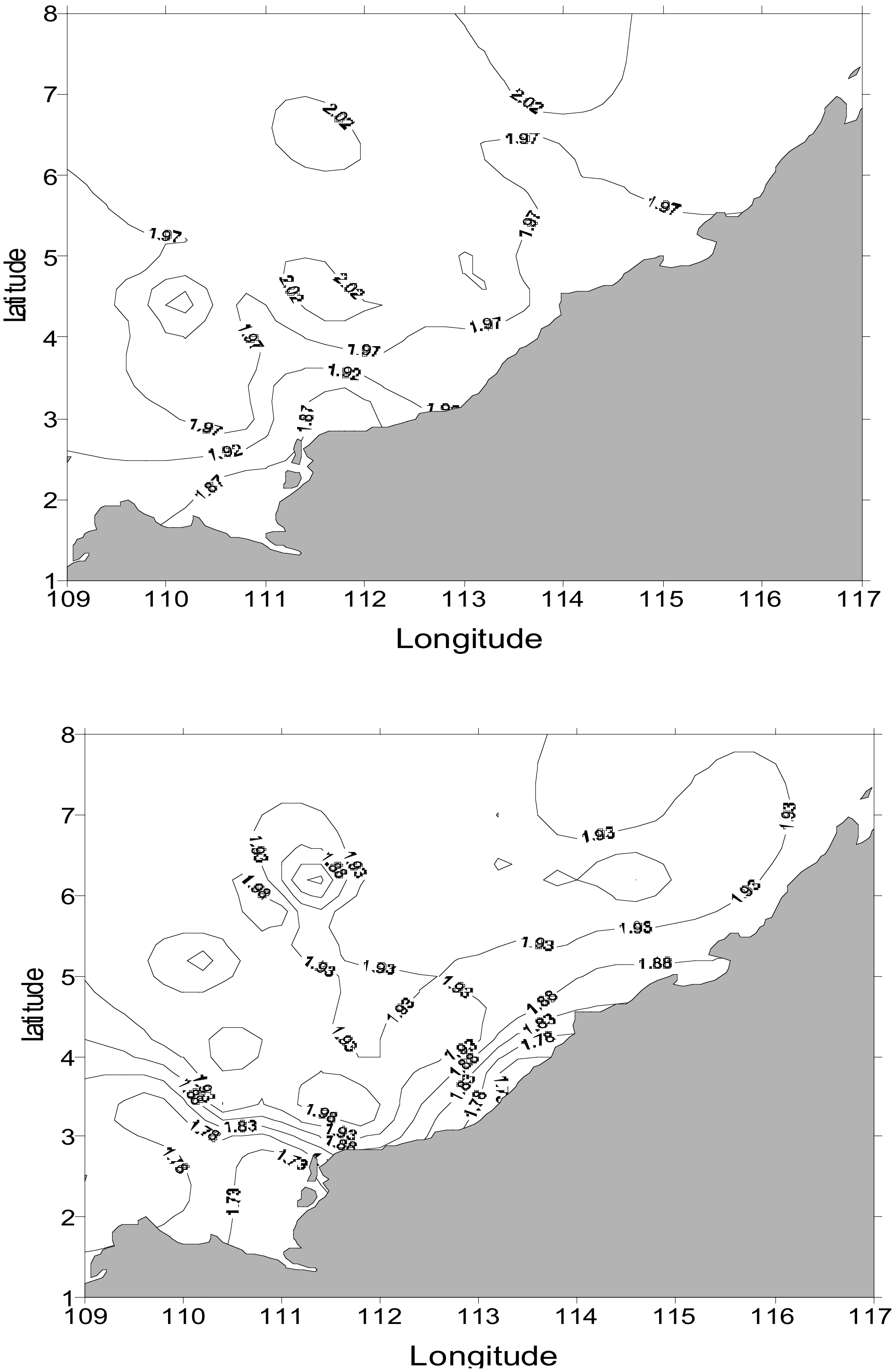


Fig. 8A Total dissolved inorganic carbon at sea surface

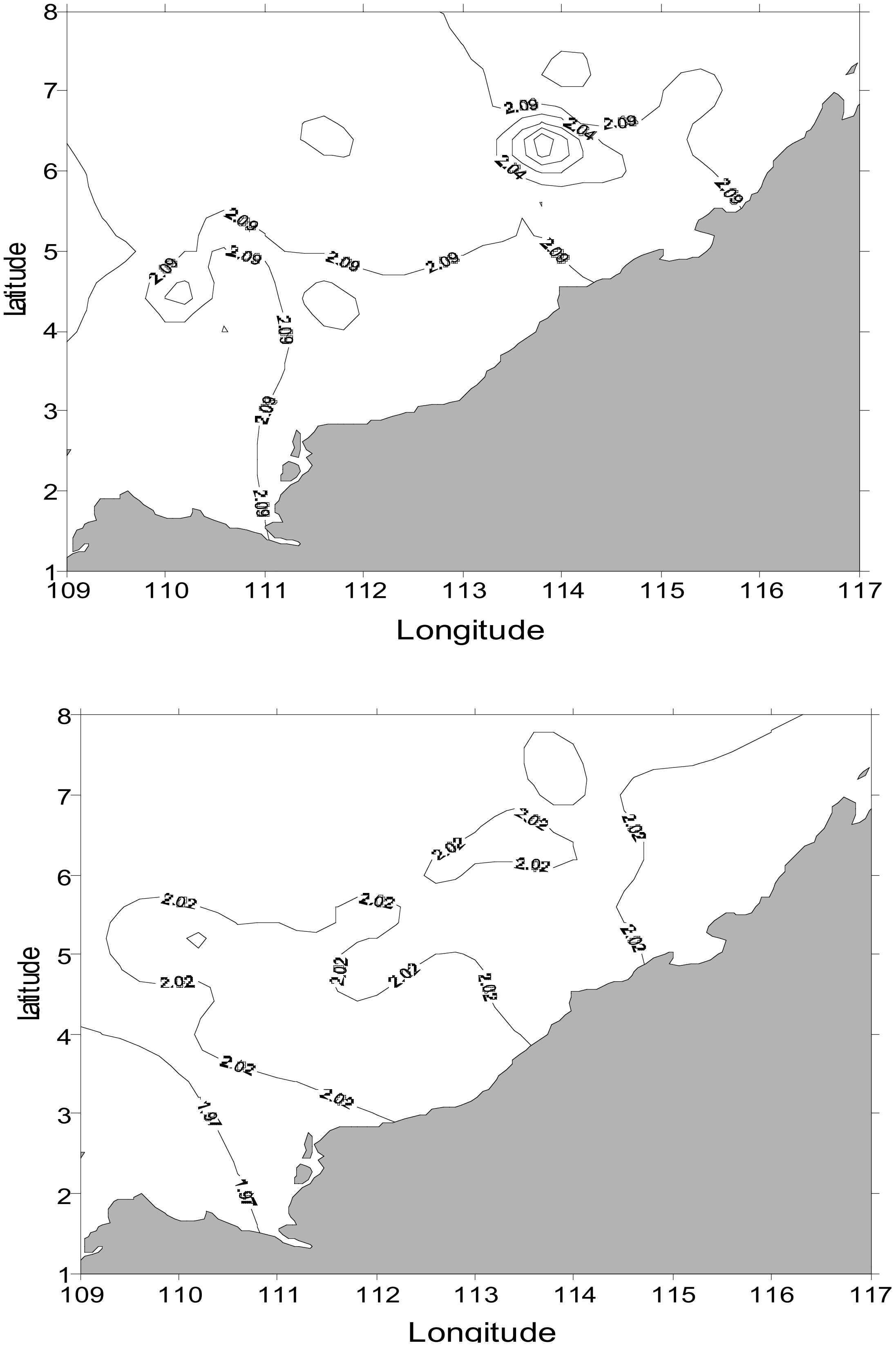


Fig. 8B Total dissolved inorganic carbon on the 23.0 kg/m^3 isopycnal surface

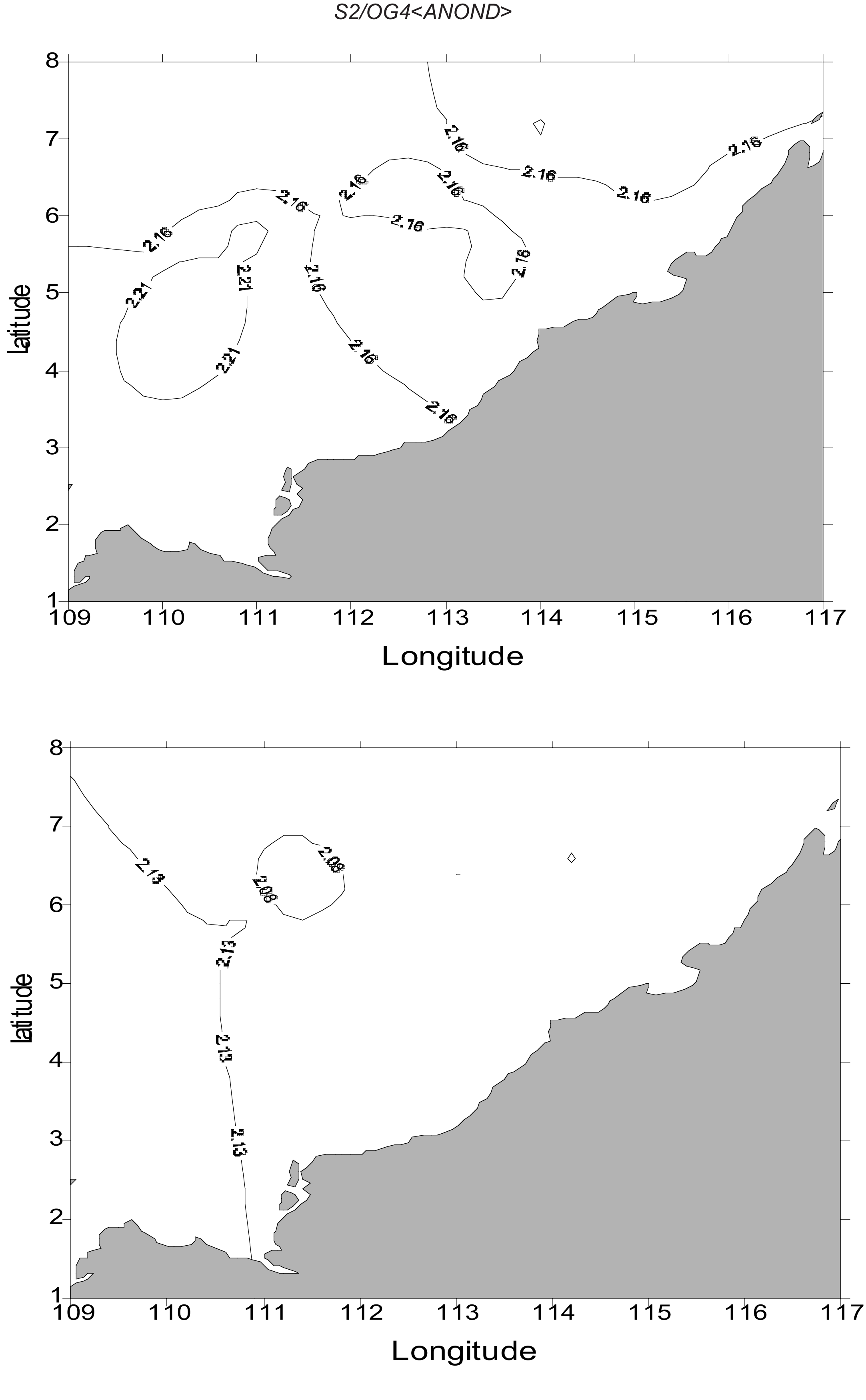


Fig. 8C Total dissolved inorganic carbon on the 27.0 kg/m^3 isopycnal surface

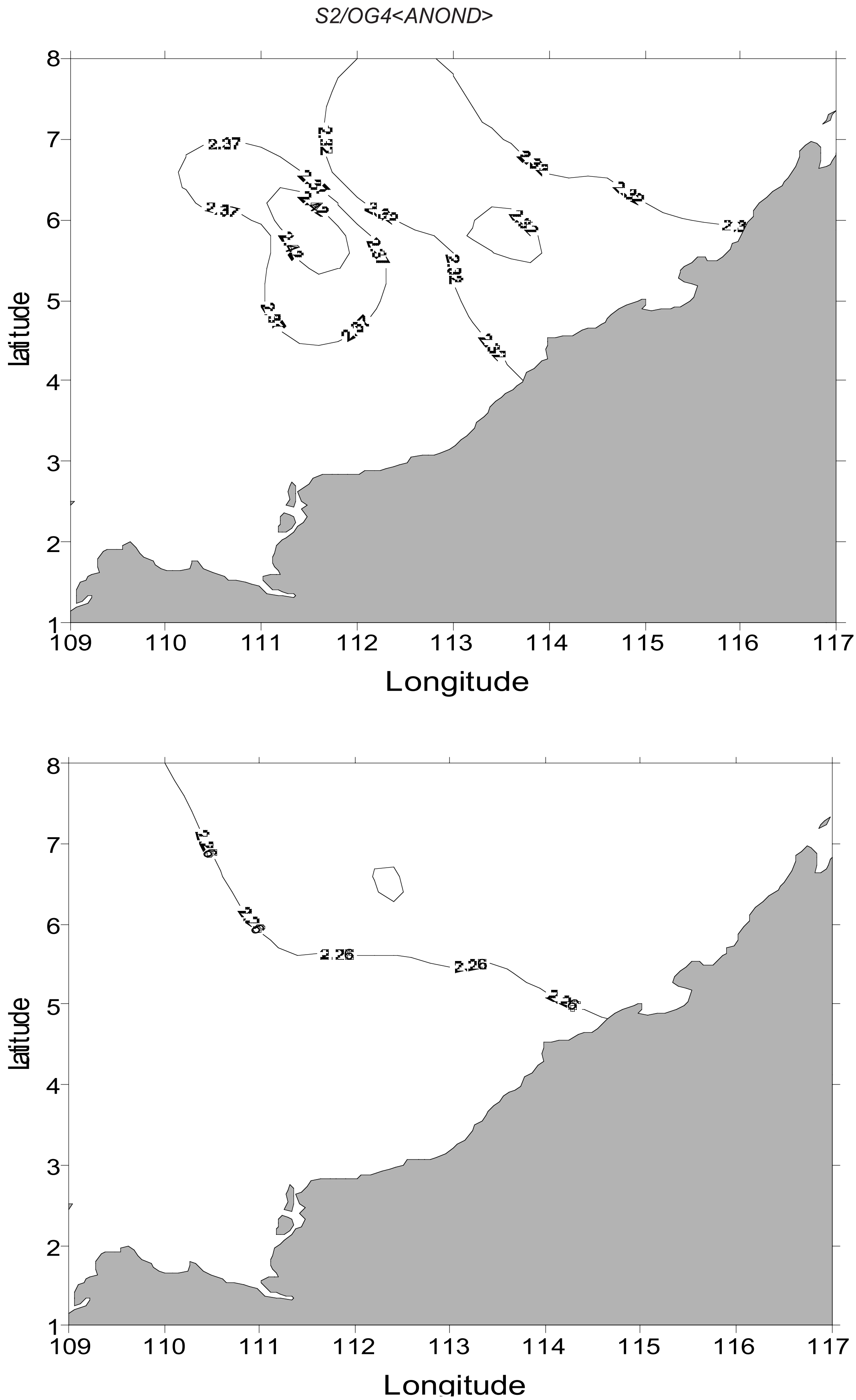


Fig. 8D Total dissolved inorganic carbon on the 27.0 kg/m^3 isopycnal surface

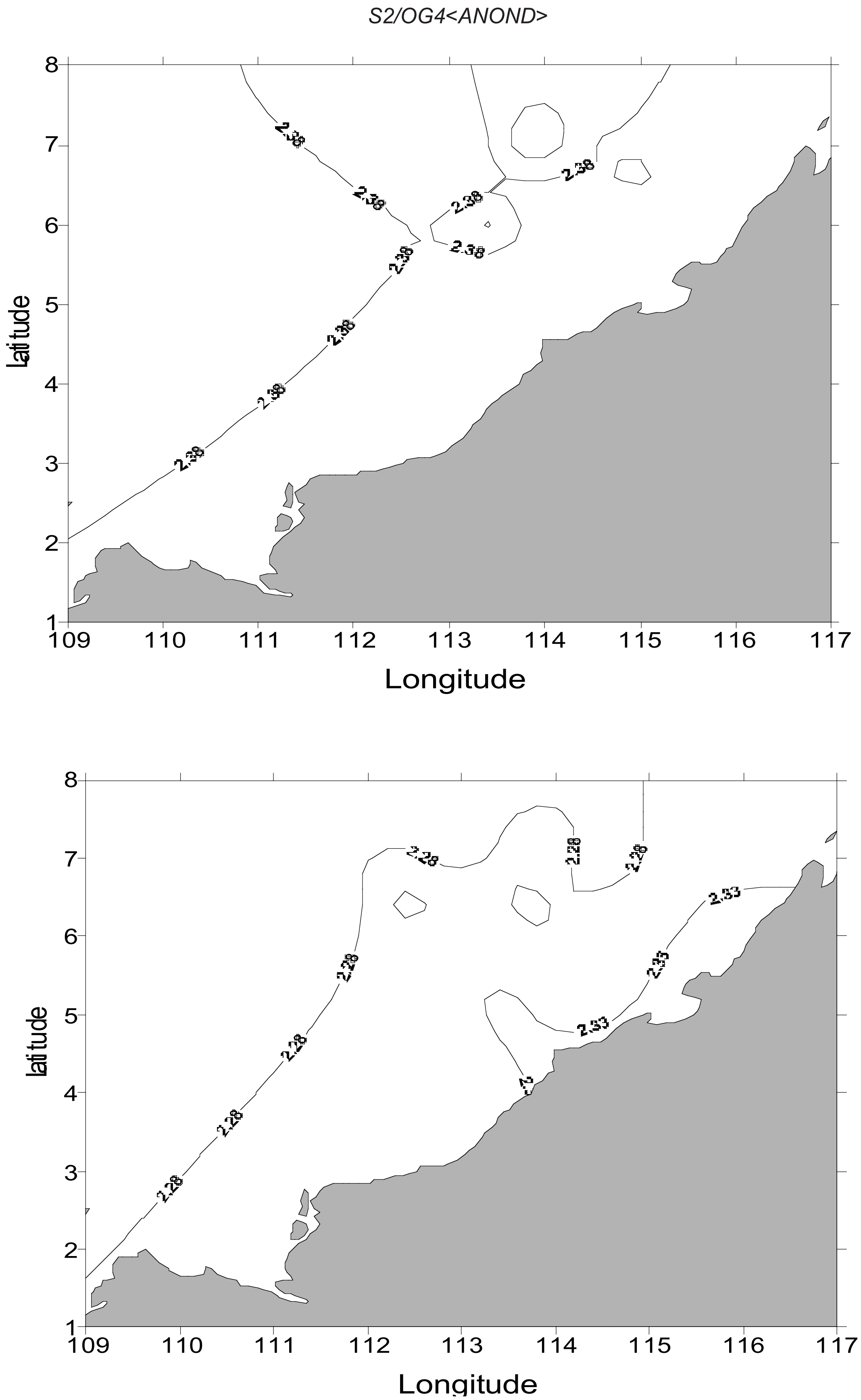


Fig. 8E Total dissolved inorganic carbon on the 27.5 kg/m^3 isopycnal surface

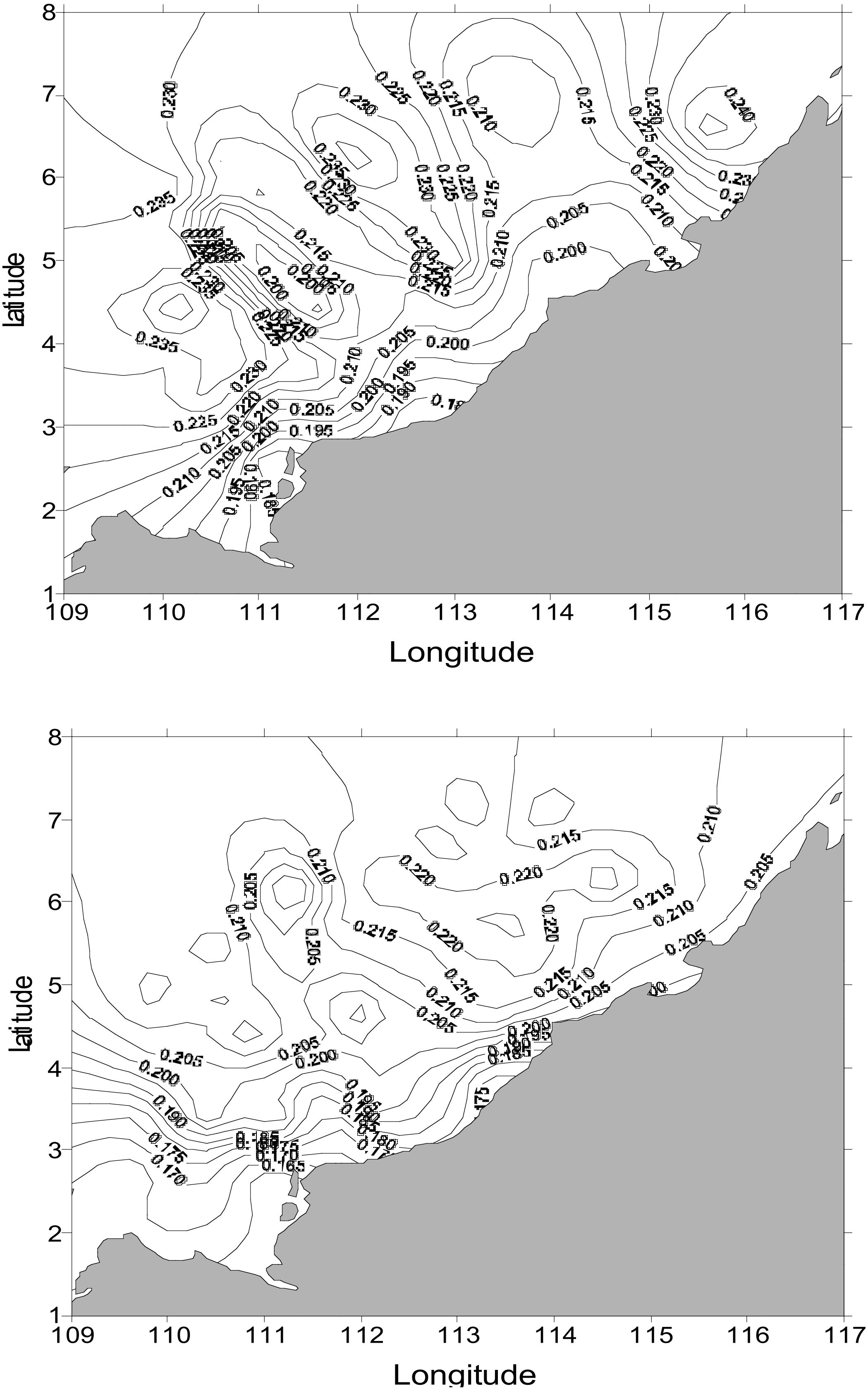


Fig. 9A Dissolved carbonate at sea surface

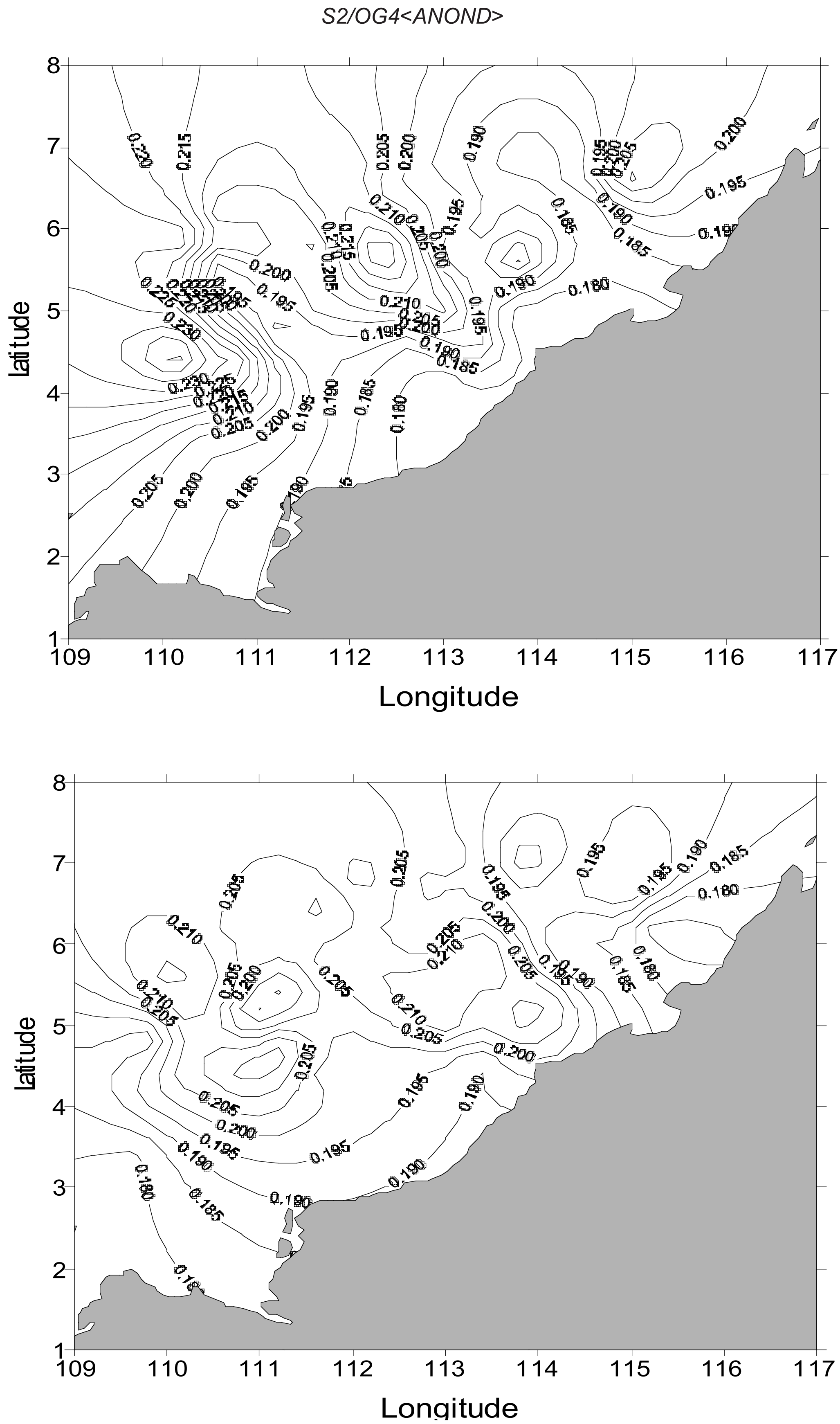


Fig. 9B Dissolved carbonate on the 23.0kg/m^3 isopycnal surface

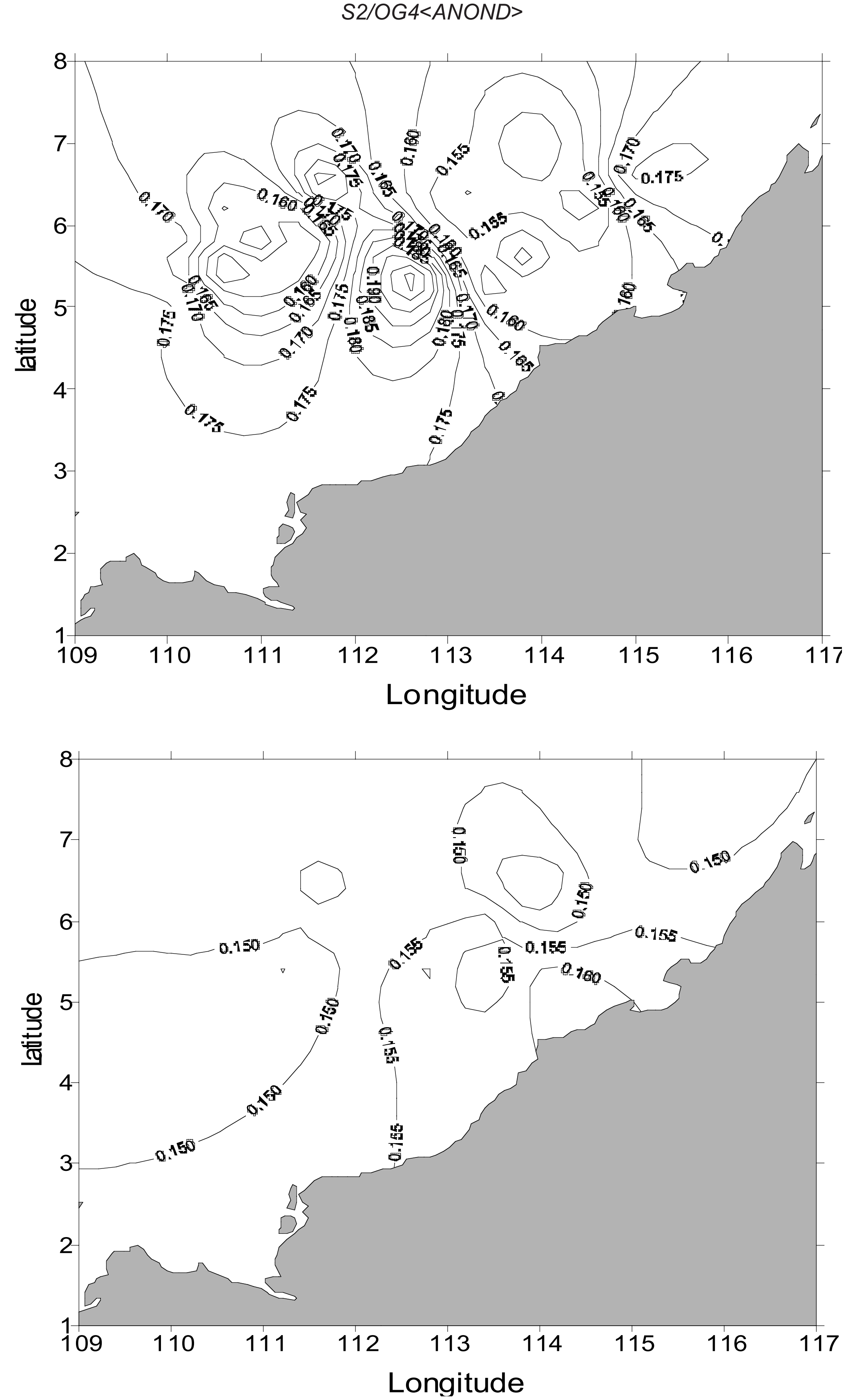


Fig. 9C   Dissolved carbonate on the 25.0kg/m³ isopycnal surface

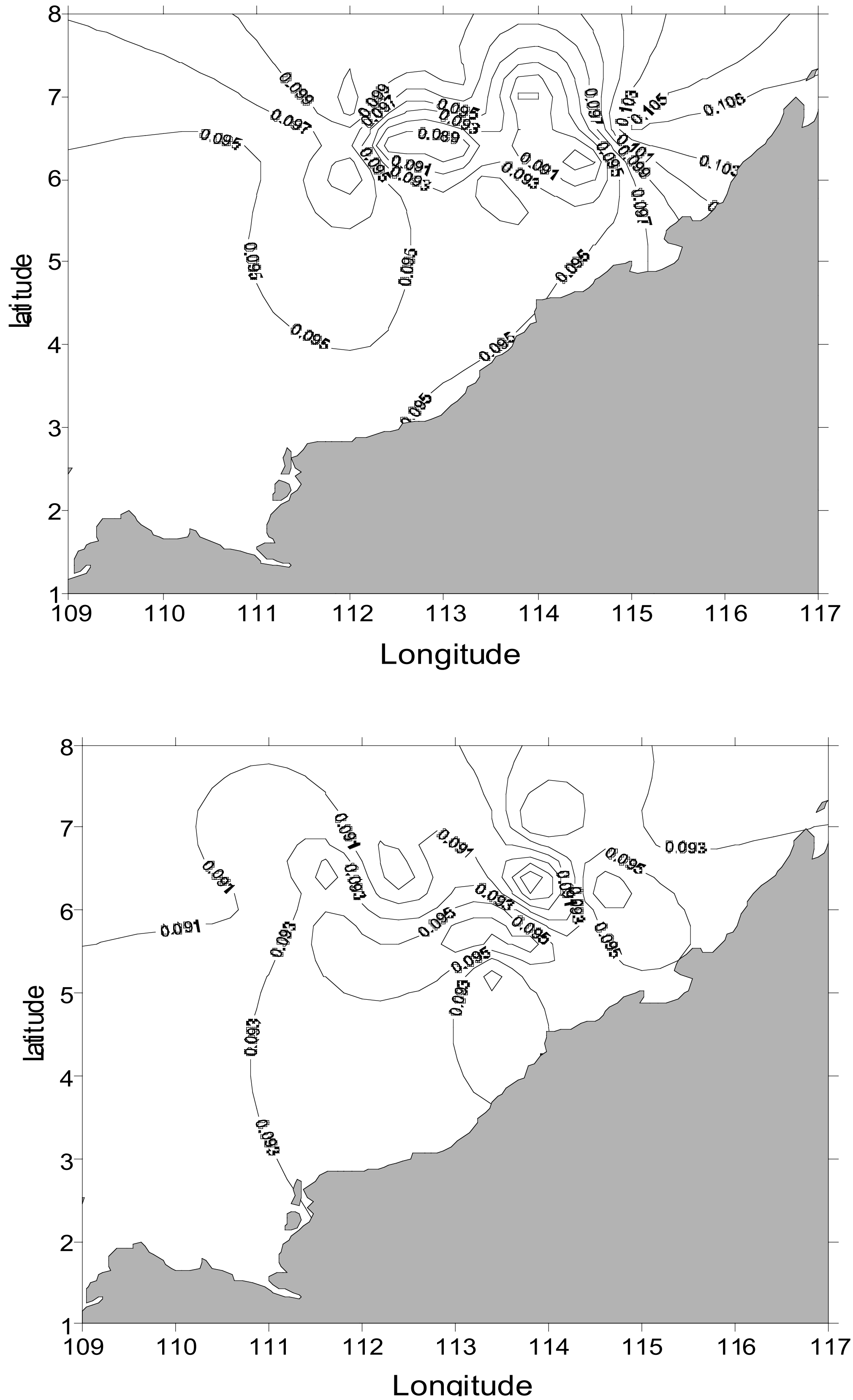


Fig. 9D Dissolved carbonate on the 27.0kg/m³ isopycnal surface

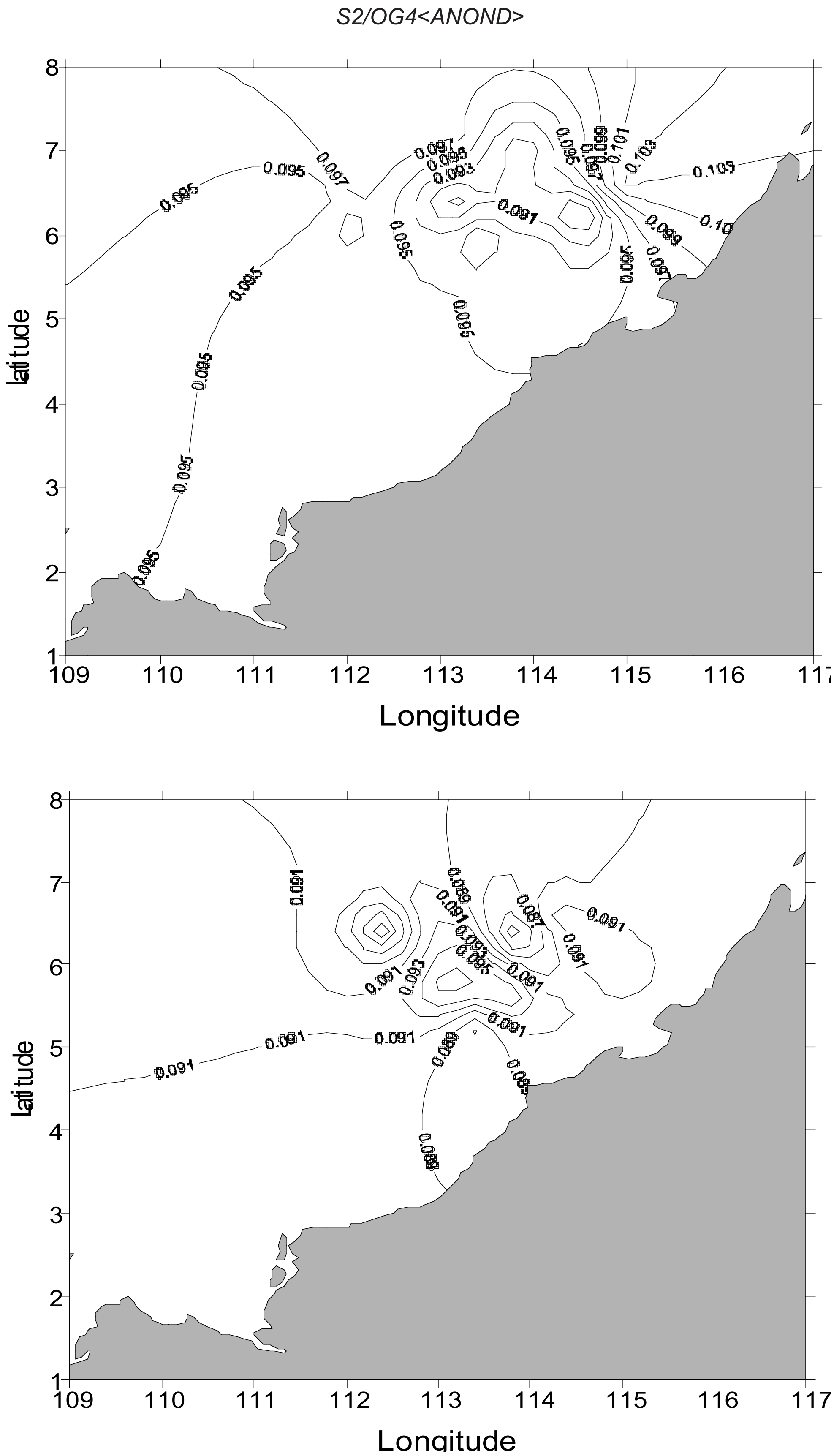


Fig. 9E Dissolved carbonate on the 27.50kg/m^3 isopycnal surface

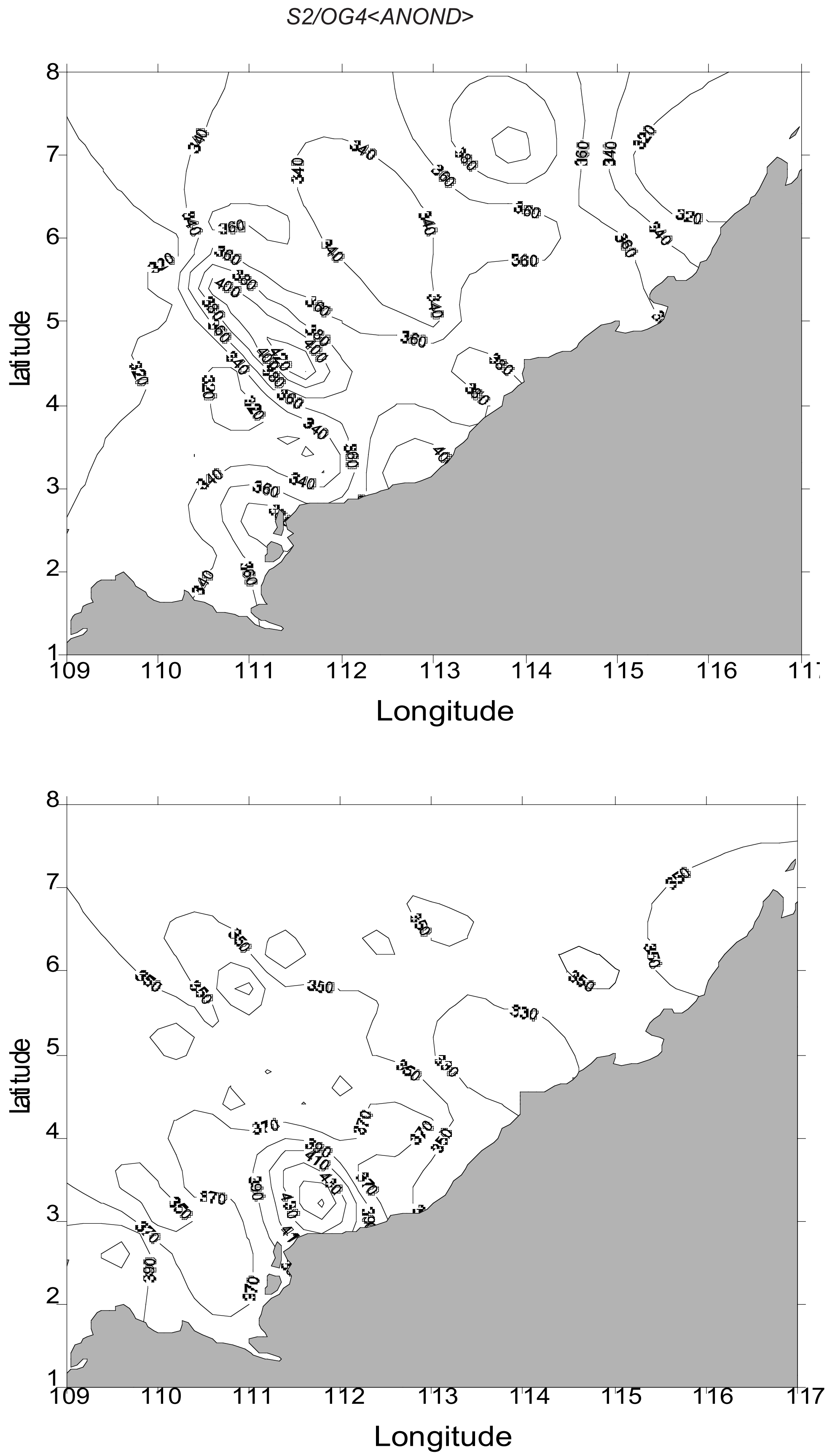


Fig. 10A Carbon dioxide partial pressure (uatm) at the sea

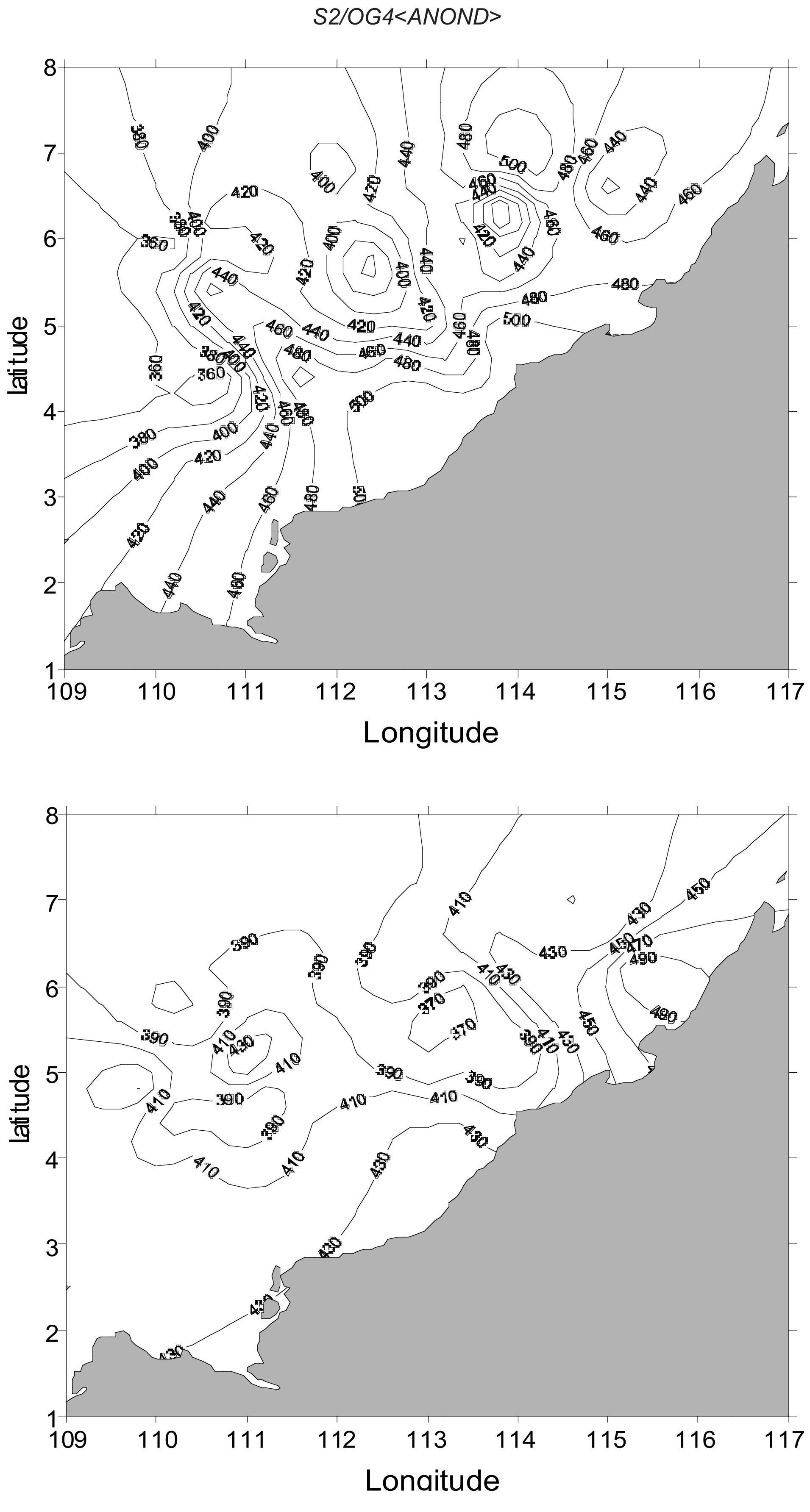


Fig. 10B Carbon dioxide partial pressure (uatm) on the 23.0 kg/m^3 isopycnal surface

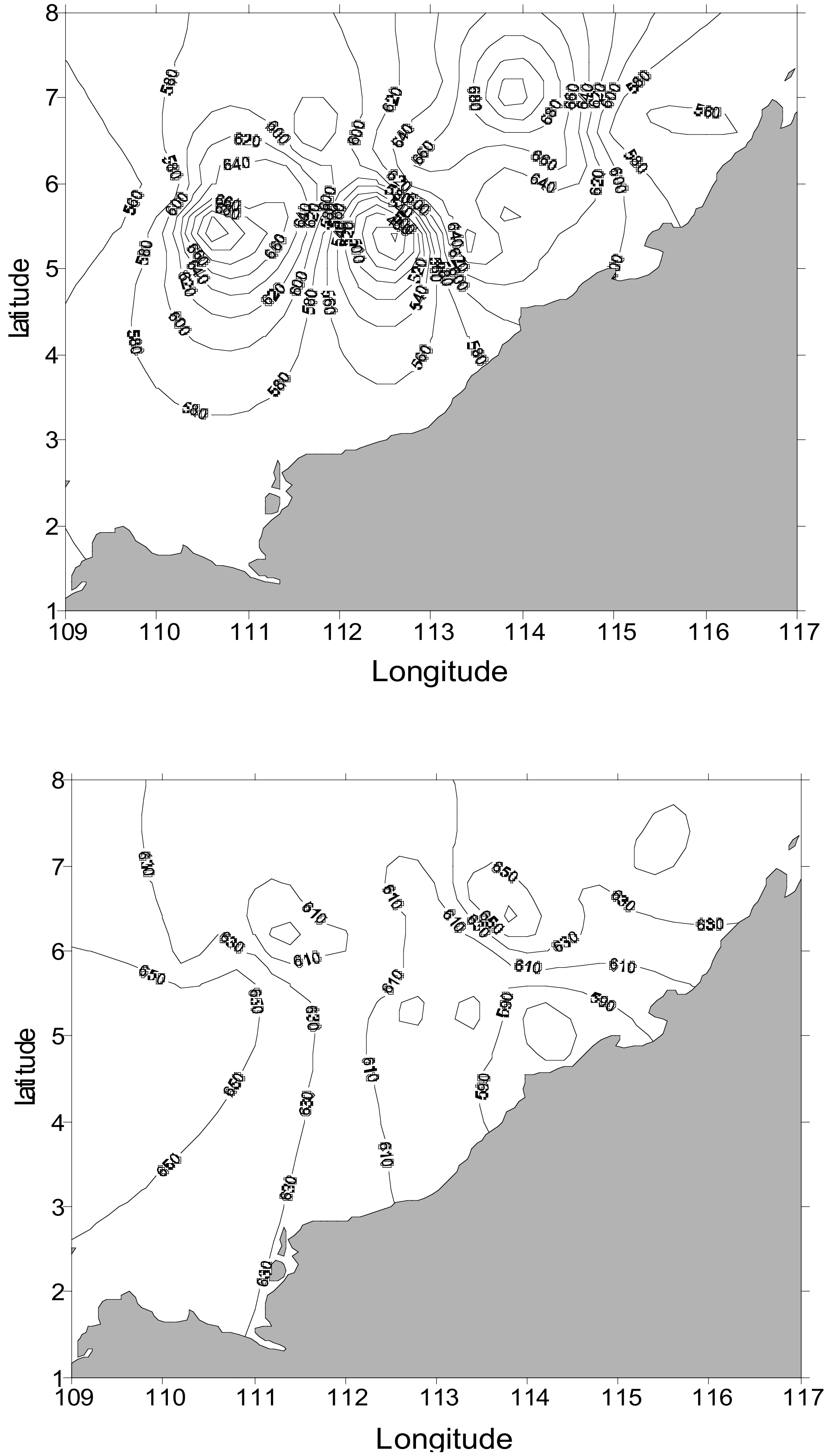


Fig. 10C Carbon dioxide partial pressure (uatm) on the 25.0 kg/m3 isopycnal surface

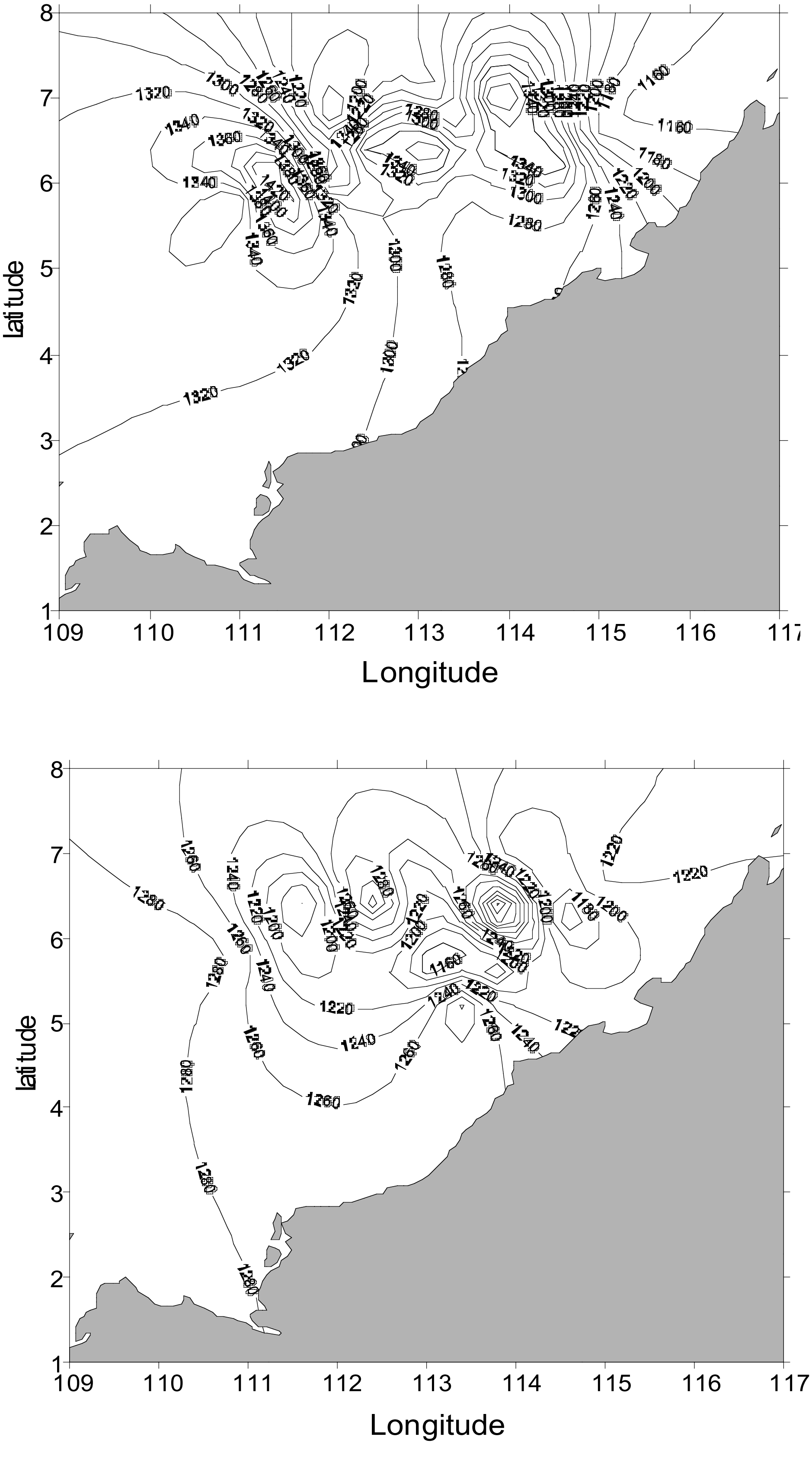
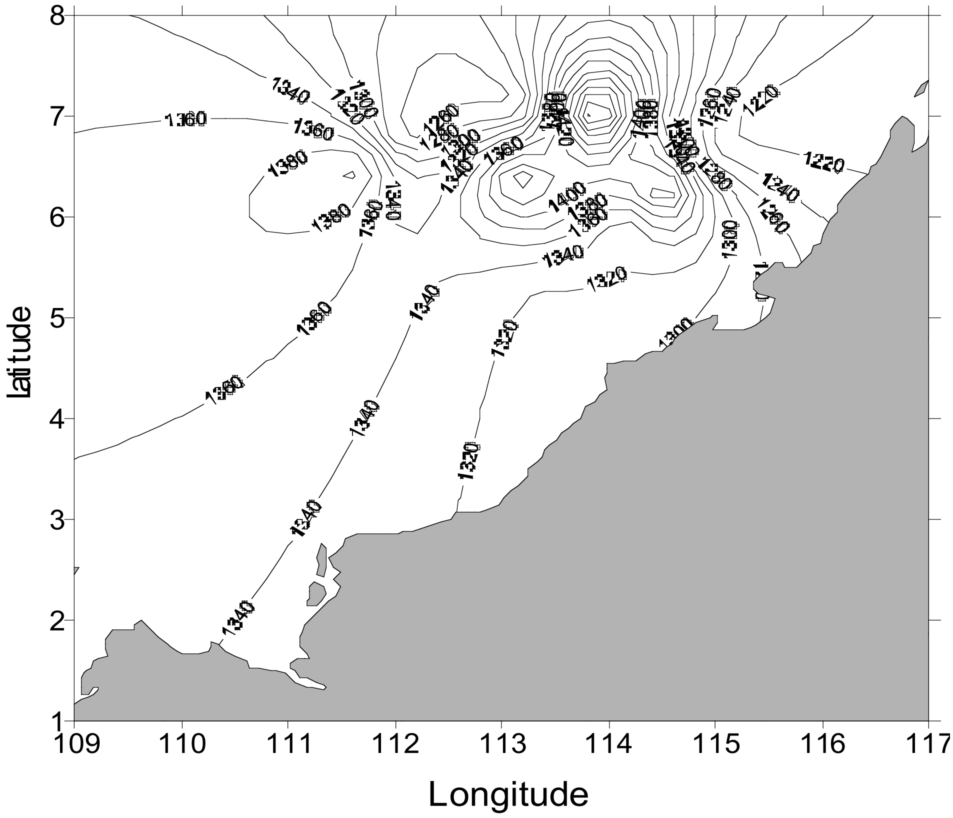


Fig. 10D Carbon dioxide partial pressure (uatm) on the 27.0 kg/m3 isopycnal surface

S2/OG4<ANOND>



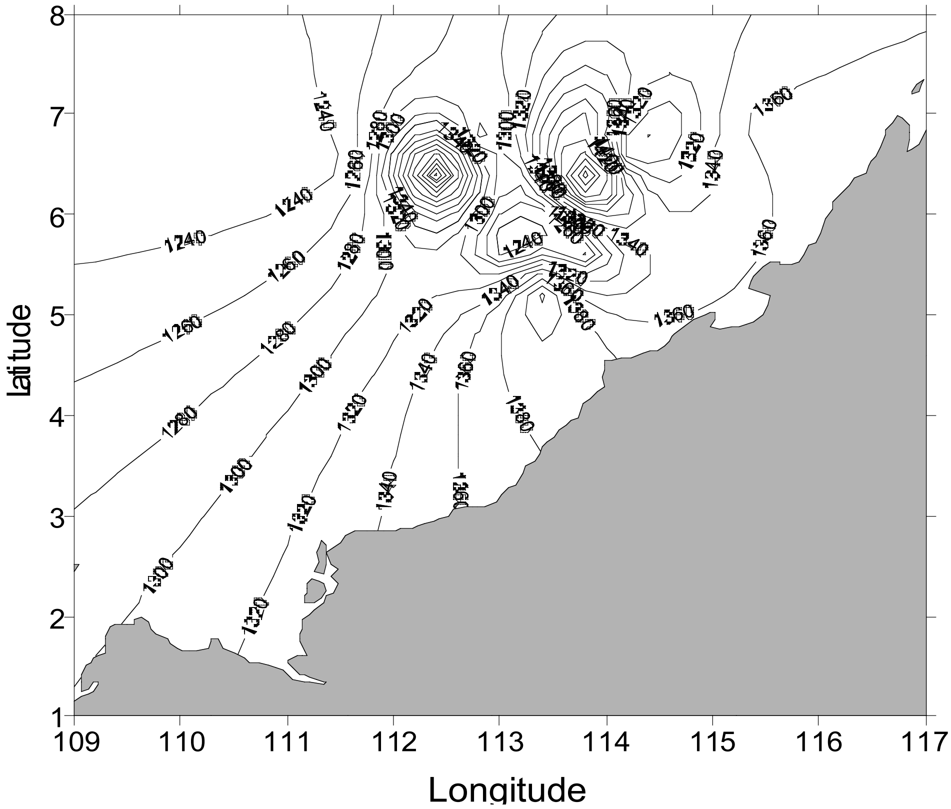


Fig. 10E Carbon dioxide partial pressure (uatm) on the 27.5 kg/m3 isopycnal surface

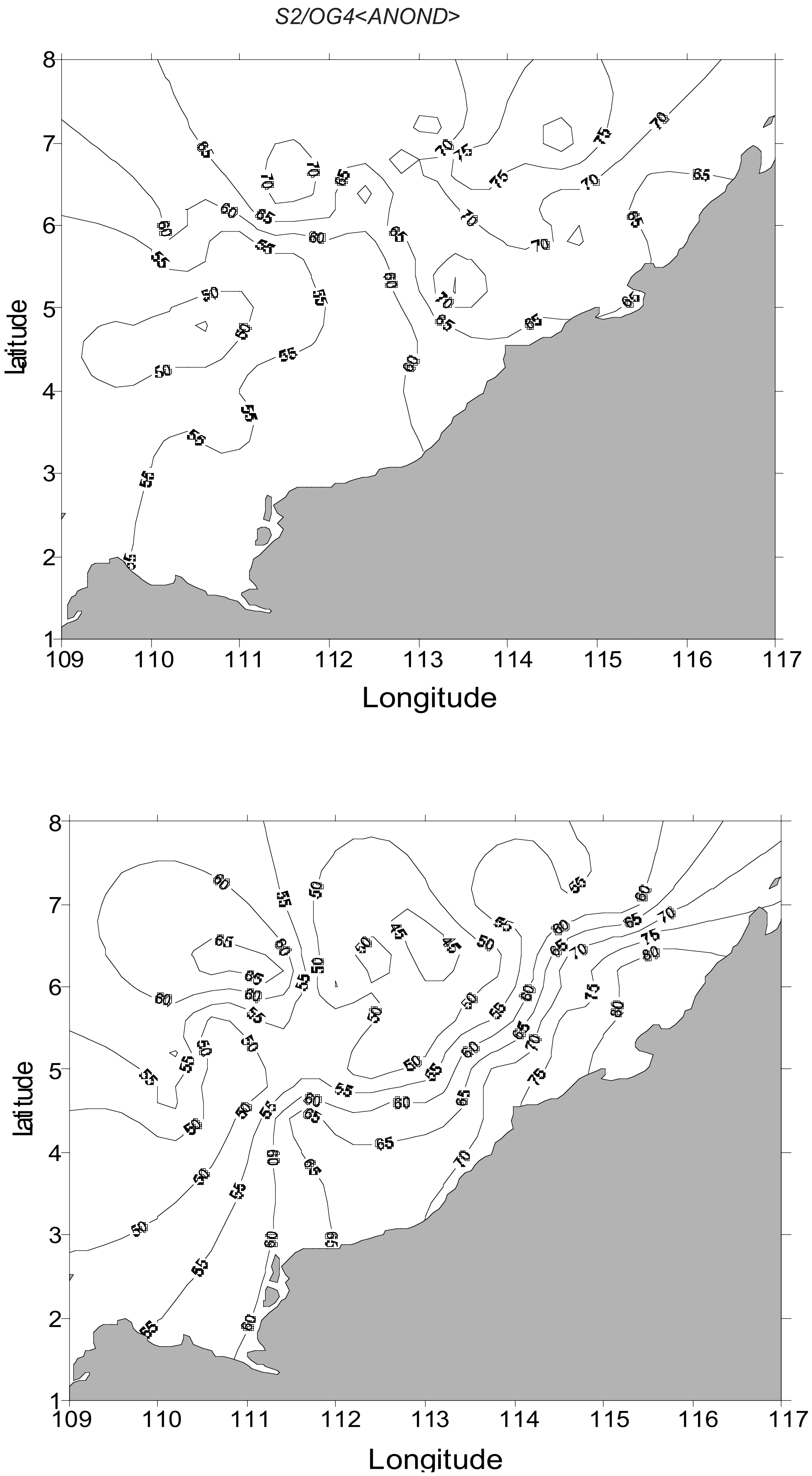
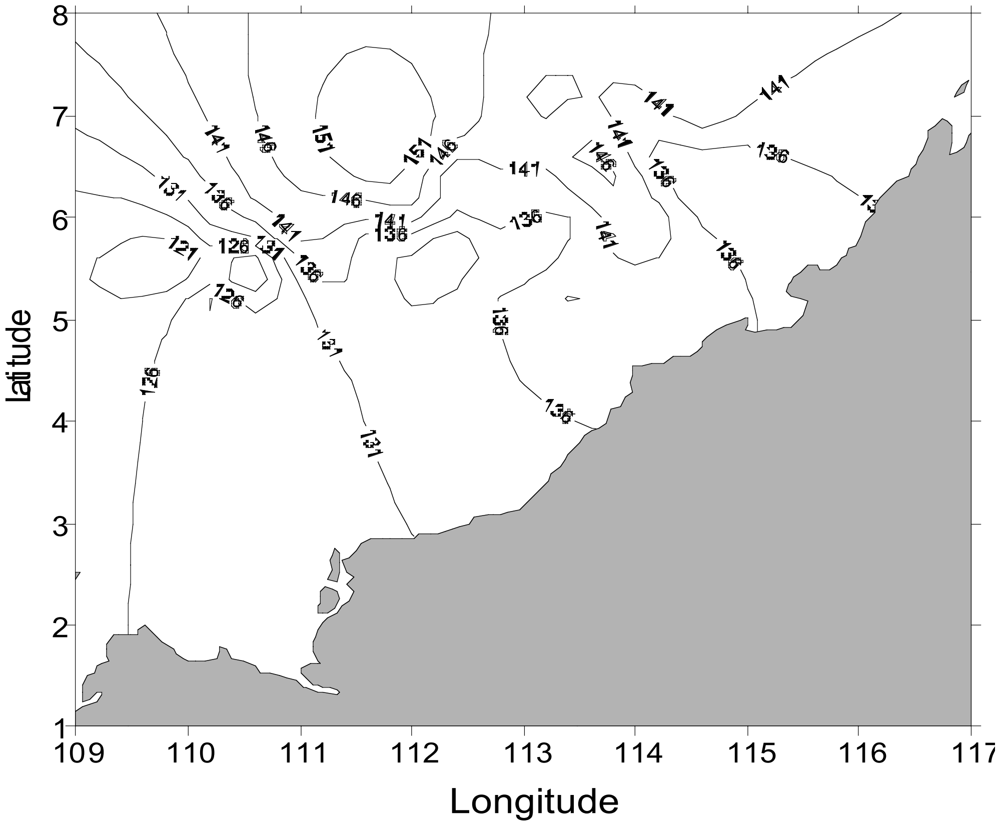


Fig. 11A Depth of 23.0 kg/m3 sigma theta isopycnal surface (m)

S2/OG4<ANOND>



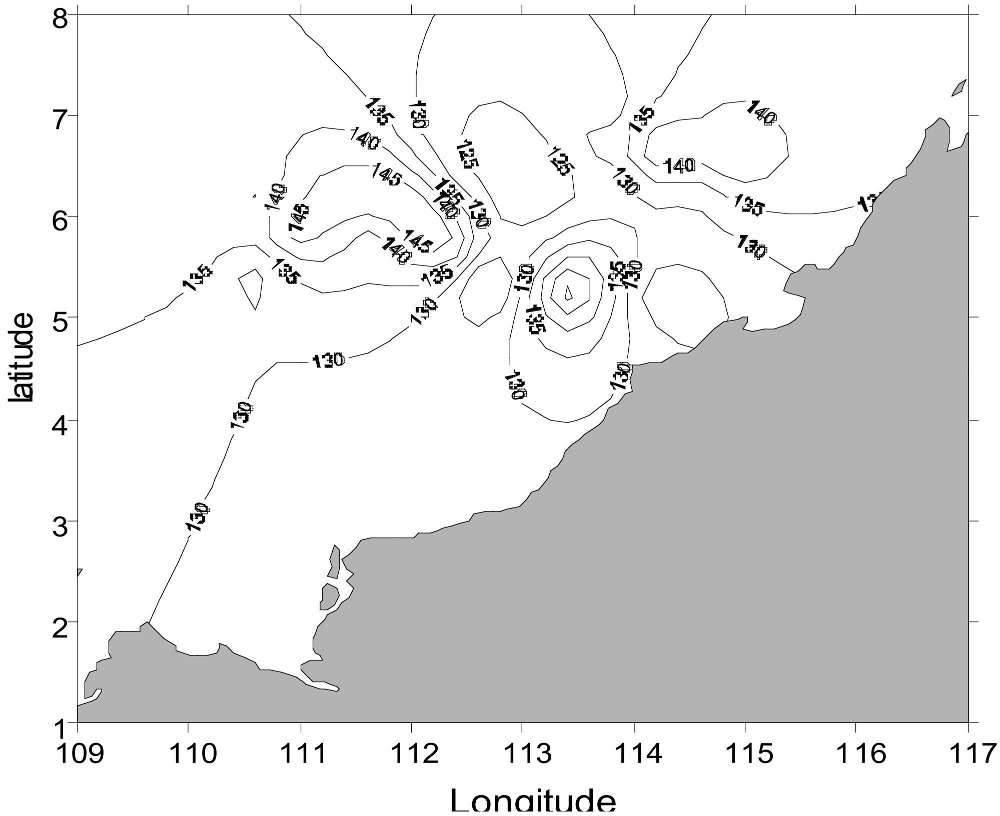


Fig. 11B Depth of 25.0 kg/m3 sigma theta isopycnal surface (m)

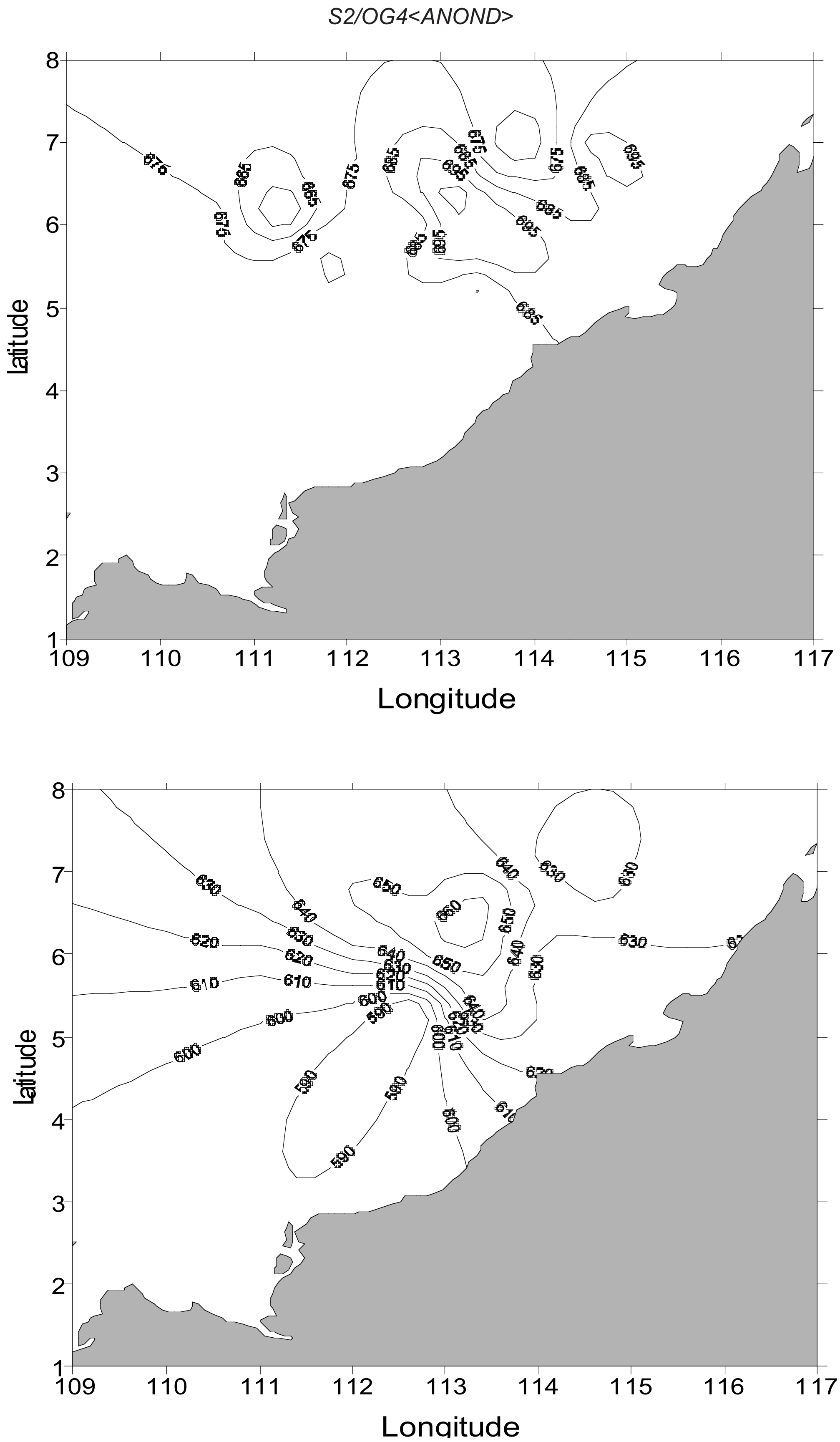


Fig. 11C Depth of 27.0 kg/m3 sigma theta isopycnal surface (m)

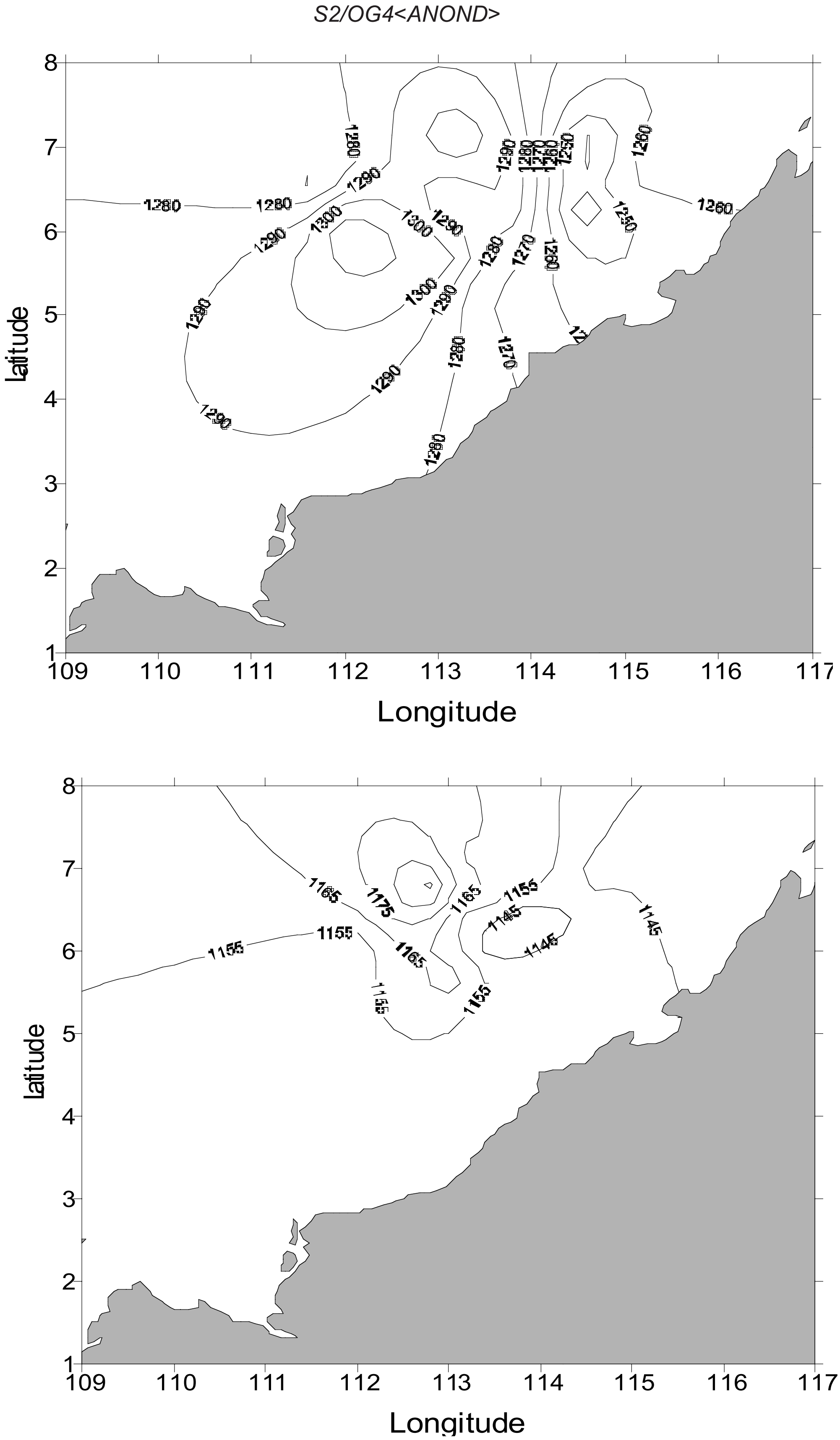


Fig. 11D Depth of 27.5 kg/m^3 sigma theta

Sedimentological Characteristics of sediments of the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters

Mohd-Lokman Husain, Harith, M.R., Rosnan, Y. and Kassim K. K. Y.**

Faculty of Applied Science and Technology, University Putra Malaysia Terengganu (UPMT)
21030 Kuala Terengganu, Malaysia.
** Marine Fishery Resource Development and Management Department
South East Asian Fisheries Development Center
21080 Kuala Terengganu, Malaysia

ABSTRACT

Surficial investigation of bottom sediments was conducted within the waters off the coast of Sabah, Sarawak and Brunei Darussalam. Two sampling of bottom sediments were conducted, one before (September 1996) and one after (April 1997) the Northeast monsoon period, which normally lasts from November to February annually. During the pre-monsoon cruise, fifty-one samples were collected while 52 samples were collected during the post-monsoon exercise. The collected samples were analysed for their sedimentological characteristics of mean, sorting, skewness and kurtosis. Analyses revealed that the post-monsoon sediments are finer, better sorted in arrangement, more symmetrical and less peaked than the pre-monsoon sediments. Deeper water sediment shows the same characteristics as described above when compared to shallow water sediments. In general, the near-shore sediments are coarsest, more poorly sorted, more positively skewed and most peaked in characteristics when compared to the mid-shore and off-shore sediments.

Introduction

South China Sea (SCS) covers a vast area of approximately 959,160 nm^2. It contains a variety of living and non-living marine resources, which are of interest to the littoral states bordering it. Nevertheless, research concerning the characteristics of the SCS is very much lacking although very much more is needed to be done if the resources available are to be harvested in a sustainable manner. In addition, the multiple claims for the SCS by the bordering littoral states demand that cooperative effort be made to properly manage and exploit the available resources. To achieve this, more information concerning available resources and characteristics of the SCS are required so that proper harvesting of living and exploitation of non-living resources can be planned in an optimal manner.

Several scientific reports containing extensive data on the South China Sea resources and sediments are those published by University Pertanian Malaysia and Kagoshima University through their previous joint expeditions aboard research vessel-Kagoshima Maru. The expeditions were referred to as Matahari expeditions and were conducted in 1985, 1986, 1987 and 1989. These expeditions, however, cover only small areas of the SCS at one time and were not extensive in coverage even if the different study areas are combined together.

In the early part of 1995, SEAFDEC's Marine Fishery Resource Development and Management Department (MFRDMD) in Malaysia and the Training Department in Thailand in collaboration with the Fishery Departments of Thailand and Malaysia and university researchers from both countries have embarked upon a broad program of information gathering on the South China Sea. The vessel used was a modern vessel-M.V. SEAFDEC. Initially two cruises were carried out during the pre-monsoon (September 1995) and post -monsoon period (April, 1996) periods covering the Gulf of Thailand and the EEZ waters bordering the eastern board of Peninsular Malaysia (area I). Another two expedition covering the areas off the coast of Sabah, Sarawak and Brunei Darussalam (area II) were done in September 1996 and April 1997 to represent pre and post monsoon conditions respectively.

This paper focuses only on the information gathered and data analyzed from the bottom sediment samples collected for the third and fourth cruises covering area II. This paper highlighted mainly the sedimentological characteristics of bottom sediments, since they relate directly and indirectly to living resources productivity and in addition act as indicators to the dominant processes and the evolution of the resources.

Description of Study Area

Study area II lies between longitude 109oE to 117oE and 5oN to 7oN as shown in figure 1A. Compared to area I, this area is deeper since it is not located on the continental shelf. It has an average depth of 94 m. Minimum depth of 20 m was recorded at station 46 while the deepest station with a depth of 528 m was recorded at station 24. Additionally, it is an entirely open area in contrasts to area I, which has a semi-enclosed body of water-the Gulf of Thailand.

Near-shore areas have depths ranging from 0 to 70 m, mid-shore areas are enclosed by depths ranging from 70 to 120 m, while the off-shore areas have depths exceeding 1000 m. However, the maximum depth of the sediment sampling station during the two cruises were only 528 m. This was due to the logistic constraint imposed on each sampling station.

Similar to area I, the current direction in the South China Sea, particularly, is controlled by seasonal winds of the monsoon. The predominant wind is from the north during the Northeast monsoon seasons and from the south during the Northwest monsoon period (Wrytki, 1961).

In order to facilitate the description of study areas, the sampling stations are divided into 3 classifications based on distance from the shoreline and another 2 classifications based on depth. For the first category of classification (distance) the stations were divided into near-shore, mid-shore and off-shore stations. Near-shore stations are stations 1, 2, 4 , 5, 6, 7, 8, 16, 17, 18, 30, 31, 32, 33, 45, 46, 47, 48, 59, 60, 69, 70, 76, 77, and 79. Midshore stations on the other hand are stations 3, 9, 10, 14, 15, 19, 20, 28, 29, 34, 35, 43, 44 and 49. Meanwhile the remaining stations are classified as off-shore stations and they are stations 11, 12, 13, 21, 22, 23, 24, 25, 26, 27, 36, 37, and 42.

The cutoff point for the purpose of station classification into shallow and deep categories is 100 m. Based on this, the deep water stations are stations 11 to 13, 21 to 26, 36 to 43, 49, 60, 70, and 76 while the remaining stations fall under shallow water stations category.

Samples and Sampling Method

Sampling technique

Sediment samples were collected using both a gravity corer and a Smith McIntyre grab. During both the pre and post-monsoon cruises, 51 and 52 stations out of the 79 stations planned were successfully sampled for sediment respectively. Due to some technical problems, the other 24 stations, located in the deeper water, were not sampled for both cruises.

Laboratory Methods

For sedimentological analyses, only the sediment samples recovered using the Smith McIntyre grab was used. Similar to area I, the methodology chosen to analyze the sedimentological characteristics depended upon the amount of coarse (>63 microns) or fine sediments (<63microns) available in each sample. Samples consisting mostly fine sediments with less than 10% coarse sediment were analyzed using a laser diffractometer. However, if the opposite occurs then the sieving method is employed.

When sieving method is used, approximately 100 grams of split sediment samples were passed through a set of ASTM standard sieves with intervals of approximately 0.25 ø. The sediments were

Table 1A : STATISTICAL PARAMETERS OF BOTTOM SEDIMENTOLOGICAL CHARACTERISTICS.

	ALL STATIONS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	4.87	5.25	-0.4	2.03	1.9	0.13	0.39	0.16	0.23	2.94	2.41	0.53
Min	2.34	3.23	-0.9	1.17	1.31	-0.1	-0.5	-0.6	0.07	1.64	1.55	0.09
Max	6.22	6.44	-0.2	2.59	2.49	0.1	3.3	1.8	1.5	15.7	5.09	10.6
Range	3.88	3.21	0.67	1.42	1.18	0.24	3.84	2.41	1.43	14	3.54	10.5

	SHALLOW WATERS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	4.8	5.13	-0.3	2.04	1.98	0.07	0.44	0.2	0.24	3.23	2.42	0.82
Min	2.34	3.23	-0.9	1.17	1.31	-0.1	-0.5	-0.6	0.07	1.64	1.55	0.09
Max	6.22	6.44	-0.2	2.59	2.49	0.1	3.3	1.8	1.5	15.7	5.09	10.6
Range	3.88	3.21	0.67	1.42	1.18	0.24	3.84	2.41	1.43	14	3.54	10.5

	DEEP WATERS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	5.02	5.51	-0.5	1.98	1.74	0.25	0.28	0.07	0.21	2.29	2.41	-0.1
Min	3.76	4.34	-0.6	1.61	1.31	0.3	-0.1	-0.4	0.28	1.94	1.87	0.07
Max	5.84	6.21	-0.4	2.23	2.2	0.03	1.13	0.55	0.58	3.25	3.34	-0.1
Range	2.08	1.87	0.21	0.62	0.89	-0.3	1.21	0.91	0.3	1.31	1.47	-0.2

Table 1B : STATISTICAL PARAMETERS OF BOTTOM SEDIMENT WITH RESPECT TO SHORELINE.

	ALL NEARSHORE STATIONS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	4.72	5.06	-0.3	2	1.99	0.01	0.54	0.24	0.3	3.67	2.52	1.14
Min	2.34	3.23	-0.9	1.17	1.46	-0.3	-0.5	-0.6	0.07	1.64	1.63	0.01
Max	6.22	6.37	-0.2	2.59	2.4	0.19	3.3	1.8	1.5	15.7	5.09	10.6
Range	3.88	3.14	0.74	1.42	0.94	0.48	3.84	2.41	1.43	14	3.46	10.6

	ALL MIDSHORE STATIONS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	5.12	5.4	-0.3	2.1	1.89	0.21	0.17	0.06	0.11	2.13	2.28	-0.2
Min	3.61	4.18	-0.6	1.69	1.31	0.38	-0.3	-0.6	0.25	1.81	1.55	0.26
Max	6.12	6.44	-0.3	2.46	2.49	-0	1.21	0.84	0.37	3.07	2.97	0.1
Range	2.51	2.26	0.25	0.77	1.18	-0.4	1.53	1.41	0.12	1.26	1.42	-0.2

	ALL OFFSHORE STATIONS											
	Mn			S.D			Skew			Kurt		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	4.87	5.44	-0.6	1.99	1.75	0.24	0.35	0.11	0.24	2.36	2.36	-0
Min	3.76	4.34	-0.6	1.61	1.31	0.3	-0.1	-0.4	0.29	1.94	1.75	0.19
Max	5.81	6.21	-0.4	2.31	2.37	-0.1	1.13	0.54	0.59	3.25	2.92	0.33
Range	2.05	1.87	0.18	0.7	1.06	-0.4	1.2	0.9	0.3	1.31	1.17	0.14

Diff - Difference between September 1996 and April 1997
Aug. denote - August 1996 sediment (Pre-monsoon)
April denote - April 1997 sediment (Post-monsoon)

Table 1C : PERCENTAGES OF SAND, SILT AND CLAY.

	ALL STATIONS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	42.68	32.96	9.718	45.93	56.4	-10.5	11.4	10.57	0.827
Min	15.39	3.56	11.83	3.97	11.74	-7.77	1.22	4.8	-3.58
Max	94.79	83.11	11.68	69.67	83.84	-14.2	26.02	22.78	3.24
Range	79.4	79.55	-0.15	65.7	72.1	-6.4	24.8	17.98	6.82

	SHALLOW WATERS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	44.63	37.1	7.528	43.62	51.75	-8.14	11.84	11.05	0.787
Min	15.39	3.56	11.83	3.97	11.74	-7.77	1.22	4.8	-3.58
Max	94.79	83.11	11.68	69.12	82.05	-12.9	26.02	22.78	3.24
Range	79.4	79.55	-0.15	65.15	70.31	-5.16	24.8	17.98	6.82

	DEEP WATERS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	38.42	24.44	13.98	50.99	65.98	-15	10.44	9.582	0.854
Min	16.68	5.68	11	25	35.35	-10.4	3.9	7.06	-3.16
Max	71.09	57.6	13.49	69.67	83.84	-14.2	17.24	14.12	3.12
Range	54.41	51.92	2.49	44.67	48.49	-3.82	13.34	7.06	6.28

Table 1D : PERCENTAGES OF SAND, SILT AND CLAY.

	ALL NEARSHORE STATIONS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	45.9	38.49	7.414	42.34	50.29	-7.95	11.66	11.08	0.576
Min	15.39	7.8	7.59	3.97	11.74	-7.77	1.22	4.8	-3.58
Max	94.79	83.11	11.68	69.12	81.7	-12.6	26.02	22.78	3.24
Range	79.4	75.31	4.09	65.15	69.96	-4.81	24.8	17.98	6.82

	ALL MIDSHORE STATIONS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	38.28	30.9	7.378	49.34	58.03	-8.69	12.6	11.07	1.527
Min	17.45	3.56	13.89	20.58	26.51	-5.93	5.23	8.01	-2.78
Max	73.2	65.49	7.71	69.67	82.05	-12.4	22.18	14.42	7.76
Range	55.75	61.93	-6.18	49.09	55.54	-6.45	16.95	6.41	10.54

	ALL OFFSHORE STATIONS								
	% SAND			% SILT			% CLAY		
	Aug	April	Diff	Aug	April	Diff	Aug	April	Diff
Average	41.1	25.54	15.55	49.44	65.26	-15.8	9.459	9.196	0.263
Min	16.68	5.68	11	24.88	35.35	-10.5	3.9	7.06	-3.16
Max	71.09	57.6	13.49	68.71	83.84	-15.1	14.98	11.73	3.25
Range	54.41	51.92	2.49	43.83	48.49	-4.66	11.08	4.67	6.41

Diff - Difference between September 1996 and April 1997

Aug. denote -August 1996 sediment (Pre-monsoon)

April denote - April 1997 sediment (Post-monsoon)

TABLE 1E : T-test RESULTS FOR PRE-MONSOON (Aug-96) VS. POST-MONSOON (April-97)

PARAMETER	MEAN	SORTING	SKEWNESS	KURTOSIS	% SAND	% SILT	% CLAY
PROBABILITY	< 5 %	< 5 %	< 5 %	> 10 %	< 5 %	< 5 %	> 10 %
CONCLUSION	Significant	Significant	Significant	Not Significant	Significant	Significant	Not Significant
AVERAGE	4.866 < 5.253	2.025 > 1.897	0.393 > 0.157		42.678 > 32.960	45.929 < 56.404	

TABLE 1F : T-test RESULTS FOR DEEP WATER VS. SHALLOW WATER

PARAMETER	MEAN	SORTING	SKEWNESS	KURTOSIS	% SAND	% SILT	% CLAY
PROBABILITY	> 10 %	< 5 %	> 10 %	> 10 %	< 5 %	< 5 %	> 10 %
CONCLUSION	Not Significant	Significant	Not Significant	Not Significant	Significant	Significant	Not Significant
AVERAGE		1.856 < 2.010			31.215 < 40.863	58.712 > 47.684	

TABLE 1G : ANOVA RESULTS FOR DISTANCE FROM SHORE (NEAR : MID : OFFSHORE)

PARAMETER	MEAN	SORTING	SKEWNESS	KURTOSIS	% SAND	% SILT	% CLAY
PROBABILITY	> 10 %	> 10 %	> 10 %	< 10 %	> 10 %	< 5 %	< 10 %
CONCLUSION	Not Significant	Not Significant	Not Significant	Significant	Not Significant	Significant	Significant
AVERAGE				3.107>2.358>2.205		57.96>53.68>46.2	11.84>11.38>9.32

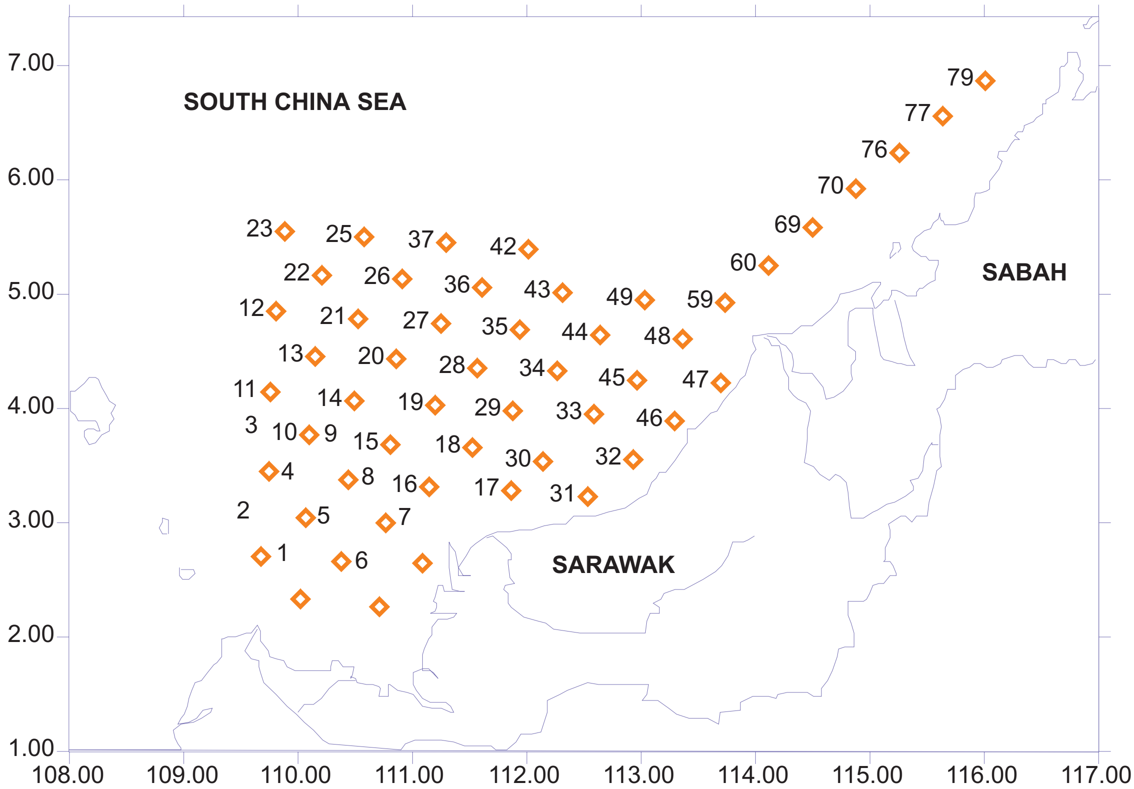


Figure 1A : Pre-monsoon sampling locations within Sabah & Sarawak Sea.

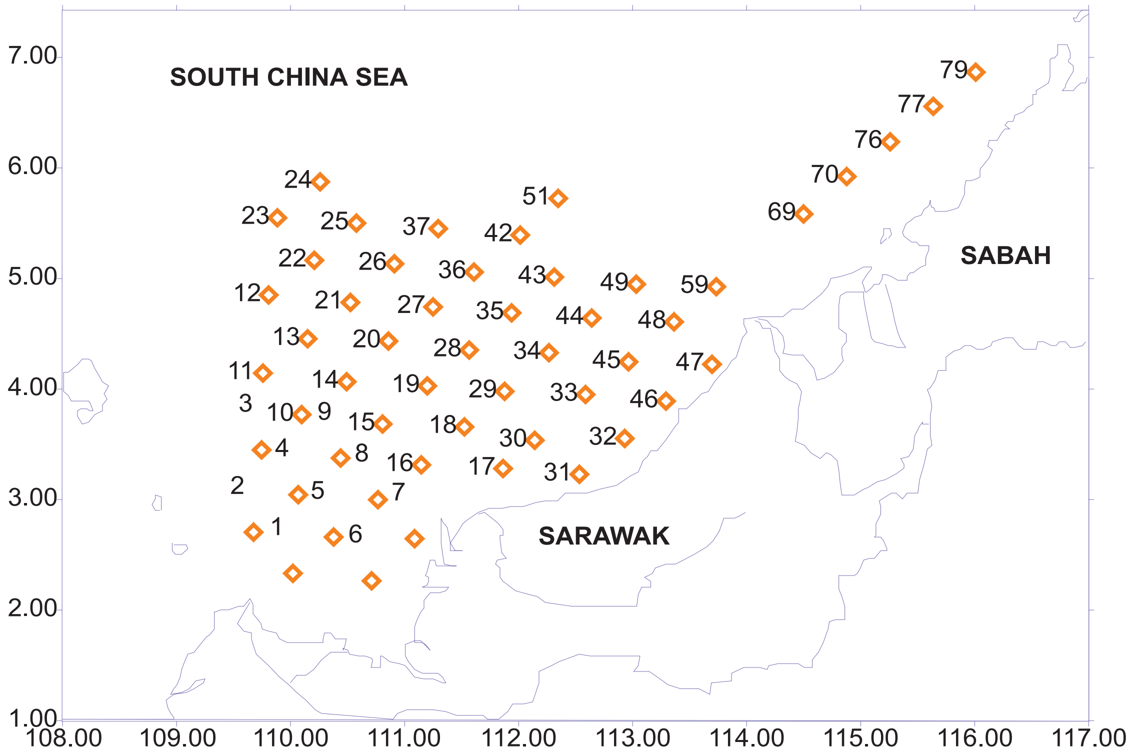


Figure 1B : Post-monsoon sampling locations within Sabah and Sarawak sea.

sieved using a sieve shaker for 15 minutes. The sediments trapped on each sieve were then weighed, recorded and used in the determination of the sedimentological parameters: mean, median and skewness and kurtosis.

The characteristics of the sediments are reported in terms of phi unit following standard convention in the study of sediments. The formula for phi is as given below:

$$\text{Phi } (\varnothing) = -\log_2 D$$

ø = Particle diameter in phi

D = Particle diameter in mm

For laser diffraction analyses, the sediments are first rid off carbonate shell materials and organic matter using hydrochloric acid and hydrogen peroxide solutions respectively. Then a dispersing agent (sodium hexametaphosphate) was added to the sediment solution prior to passing it through the laser diffractometer. The Malvern-E particle size analyzer was used in this study.

Data obtained from both methodologies were calculated for the sedimentological characteristics of mean, sorting, skewness and kurtosis using the method of moments. Further details and formulae about the moment methods are given and discussed by Griffiths (1967), McBride (1971) and Folk (1980) among others.

Results and Discussions

Although study area II is in deeper water, the sedimentological characteristics of the seabed studied during the pre and post-monsoon periods show similarities to seabed of Area I, which is located in the shallower waters of the continental shelf. The post-monsoon sediments, in general, are finer in size when compared to those sampled during the pre-monsoon period. After the monsoon, the finer sediments are widely distributed covering a larger area when compared to the period before the monsoon. (Figures 2A and 2B). The mean size of pre-monsoon sediments was 4.87ø (coarse silt) while the mean size of post-monsoon sediments was 5.25ø (medium silt). The range of mean size for pre and post -monsoon sediments were 6.22ø (fine silt) to 2.34ø (very fine sand) and 6.44ø (fine silt) to 3.23ø (very fine sand), respectively.

On the average the pre-monsoon sediments are very poorly sorted (2.03) and gradually become better-sorted (1.9) during the calm period (after the monsoon season). Figures 3A and 3B show that almost all area of the seabed is covered with better sorted materials after the monsoon. The range between maximum and minimum sorting values is larger for the pre-monsoon sediments (1.42) compared to the post-monsoon sediment (1.18). The smaller range of sorting values for post-monsoon results in better sorting of sediments. As mean sediment size also decreases in values after the monsoon, as discussed above, it can be postulated that the finer sediments are more dominant in suspension and deposition during and immediately after the monsoon season. This may be due to the influence of the monsoon rain, which causes more silt and clay to be eroded and carried to rivers, which then transported the fine materials to the sea and eventually deposited.

Similar to area I, the post-monsoon seabed sediments of Area II also tend to be more negatively skewed (average value 0.16) compared to the pre-monsoon sediments (average value 0.39). This can be attributed to the dominance and addition of more finer materials during the monsoon season thus reducing the gap between the amount of fine and coarse and eventually reducing the positive skew value.

As can be observed from table 1A, although the post-monsoon sediments are less peaked (2.41) than the pre-monsoon sediment (2.94), figures 5A and 5B seem to indicate otherwise. From the figures it seemed that, except for a few stations with very high values, the pre-monsoon sediments are less peaked and have kurtosis values ranging mainly from 1 to 3. The higher kurtosis for the pre-monsoon sediments are due to two stations exhibiting anomalously high kurtosis values: stations eight and seventeen with values of 15.66 and 13.48 respectively. The accuracy of these figures is being ascertained by re-analysing the samples and cross analysing them with other parameters. With-

Mohsin, A. K. M., M. I. Mohamed and M. A. Ambak. 1985. Ekspedisi Matahari '85: A study on the off-shore waters of the Malaysian EEZ. Occassional Publication. No.3. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia.

Mohsin, A. K. M., R. A. Rahman and M. A. Ambak. 1986. Ekspedisi Matahari '86: A study on the off-shore waters of the Malaysian EEZ. Occassional Publication. No.4. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia.

Mohsin, A. K. M., M. Z. M. Said and M. I. Mohamed. 1989. Ekspedisi Matahari '89: A study on the off-shore waters of the Malaysian EEZ. Occassional Publication. No.9. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia.

Wentworth, C.K. 1929. Method of Computing mechanical composition types in sediments. Bull. Geol. Soc. Am. (40): 771-790

Wrytki, K. 1961. Physical oceanography of the Southeast Asian waters. Naga report: Scientific results of marine investigations of the South China Sea and the Gulf of Thailand 1959-1961.

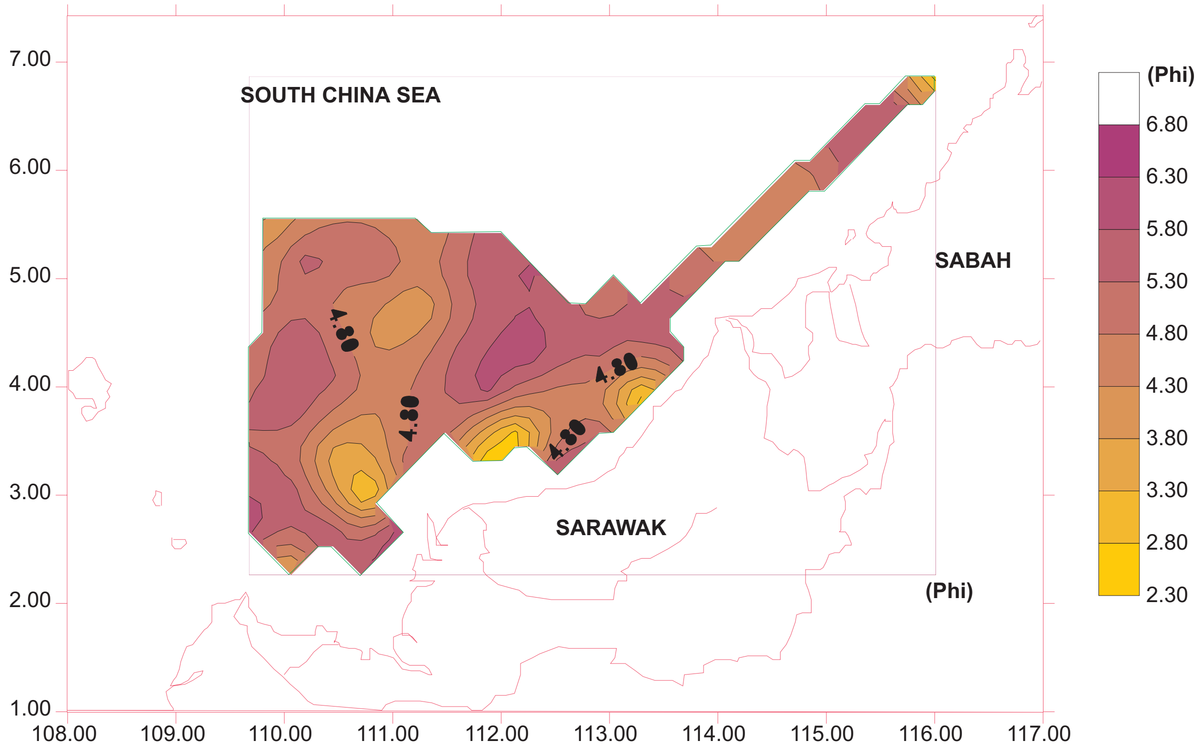


Figure 2A: Pre-monsoon patterns of sediment mean size

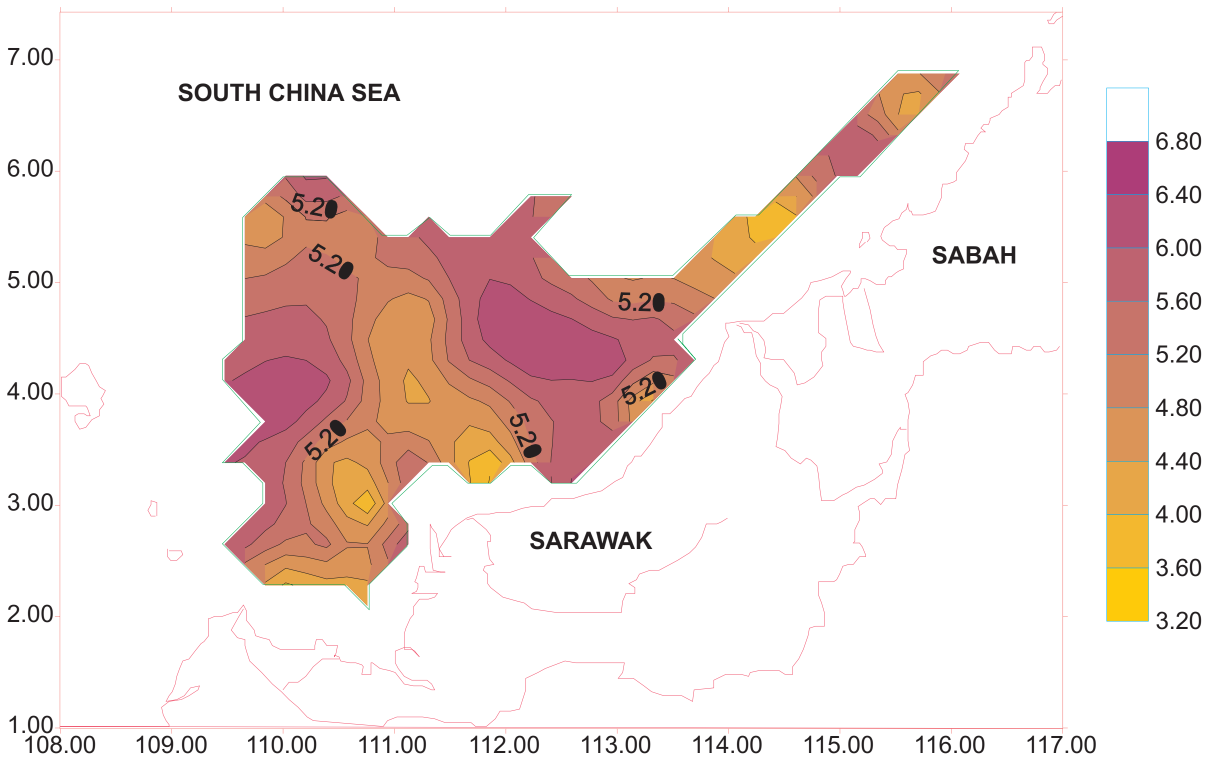


Figure 2B: Post-monsoon patterns of sediment mean size

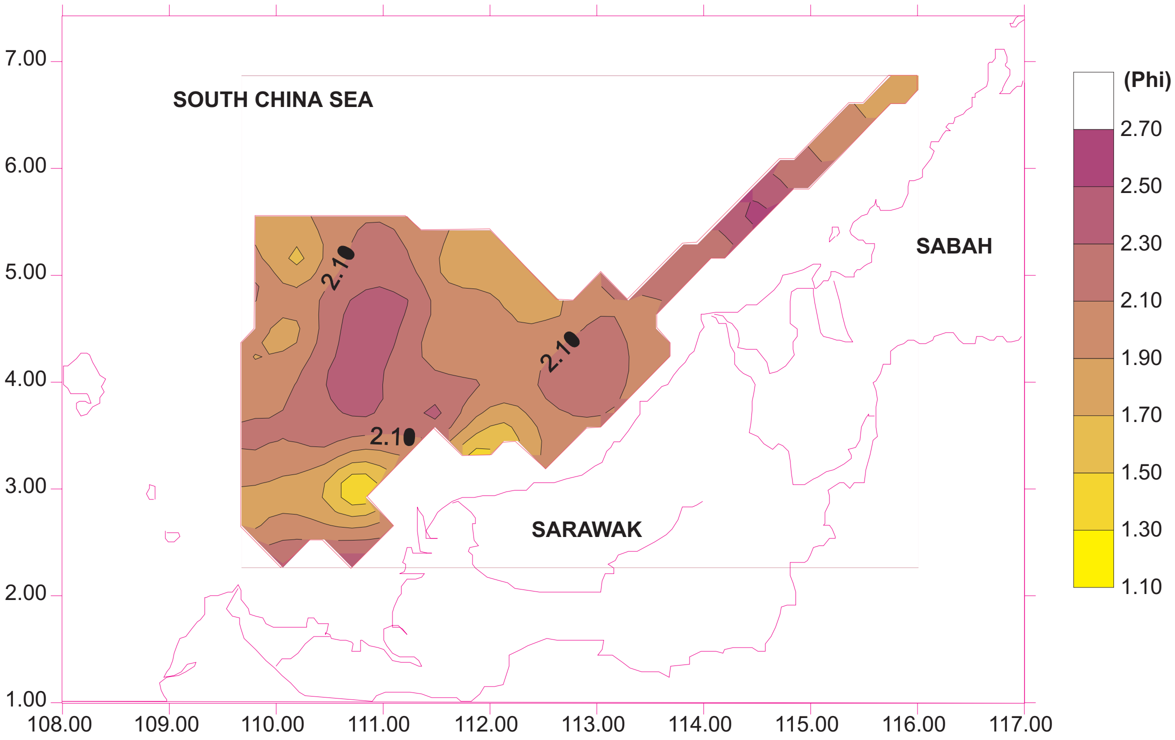


Figure 3A: Pre-monsoon patterns of sediment sorting

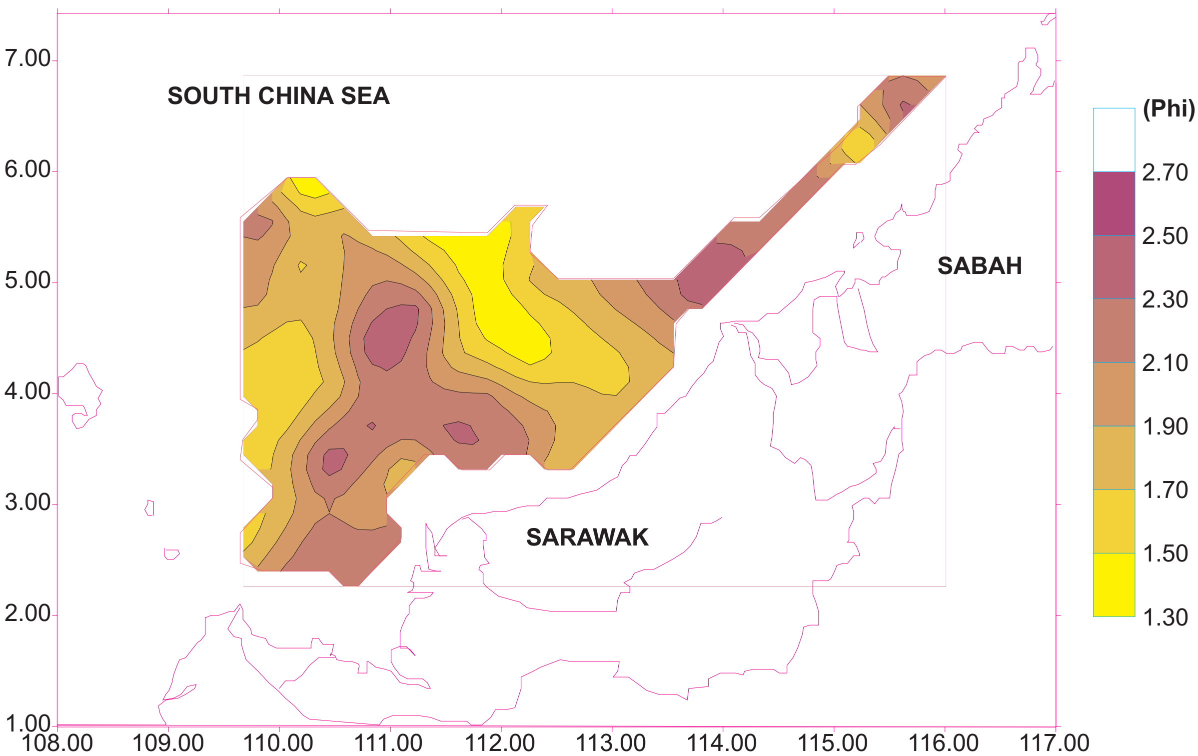


Figure 3B: Post-monsoon patterns of sediment sorting

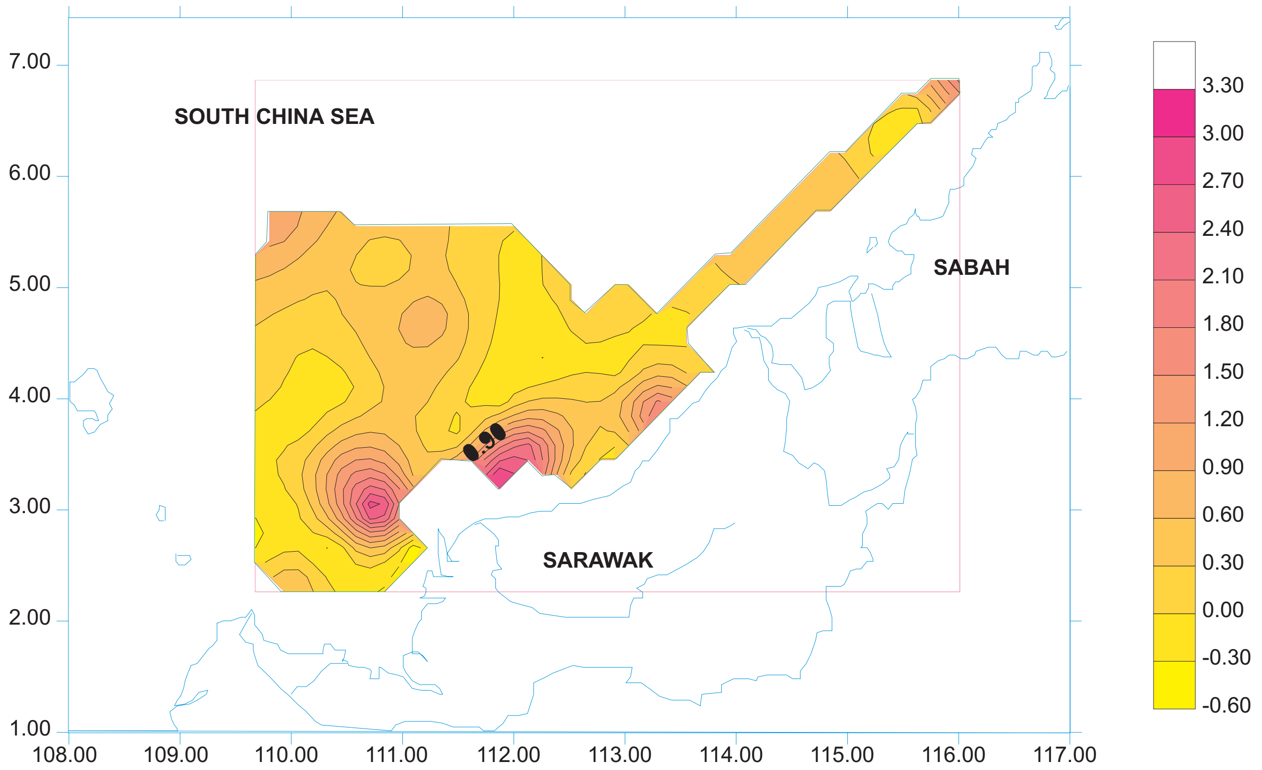


Figure 4A: Pre-monsoon patterns of sediment skewness

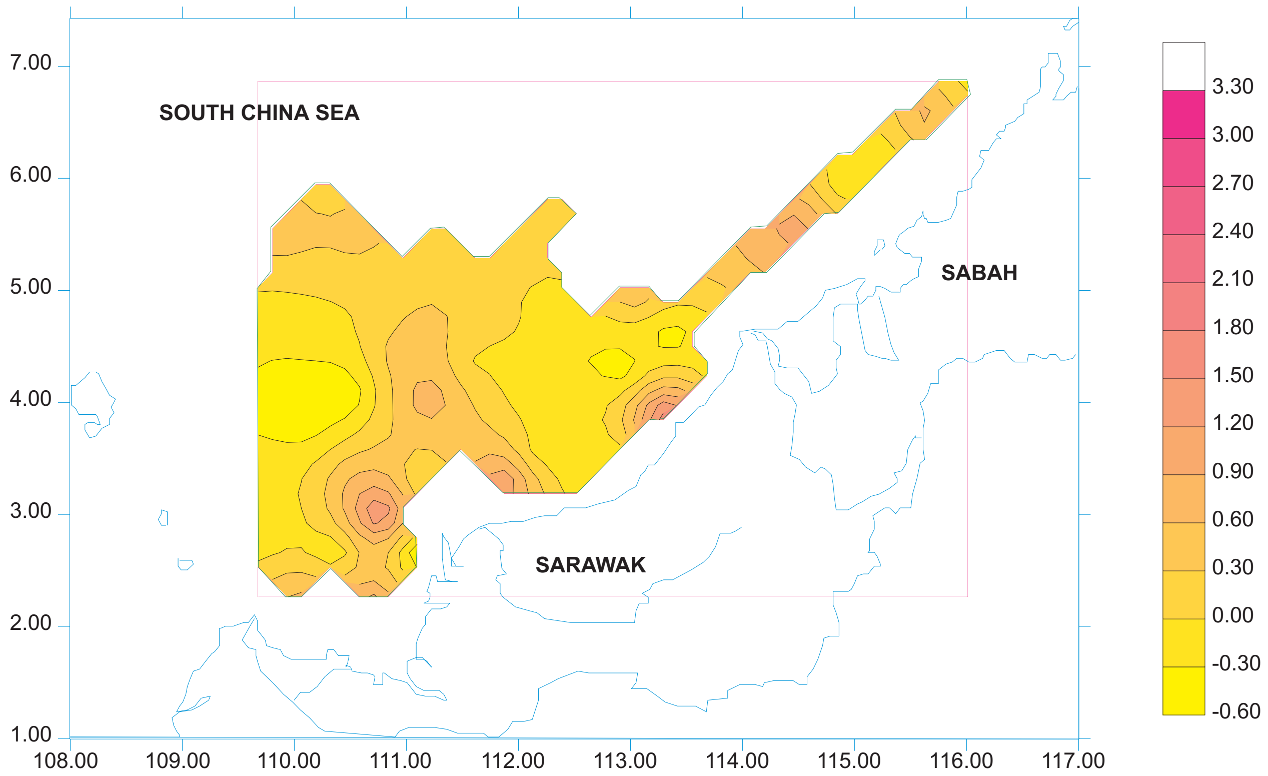


Figure 4B: Post-monsoon patterns of sediment skewness

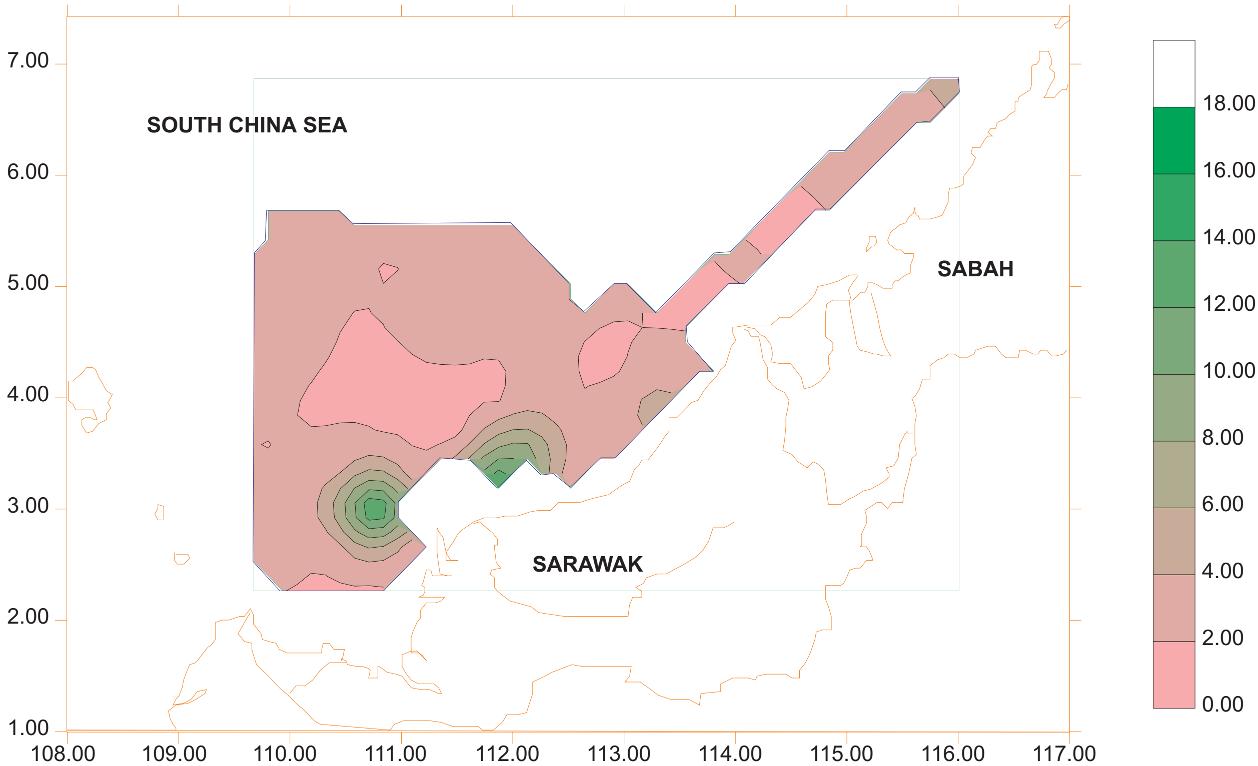


Figure5A: Pre-monsoon patterns of sediment Kurtosis

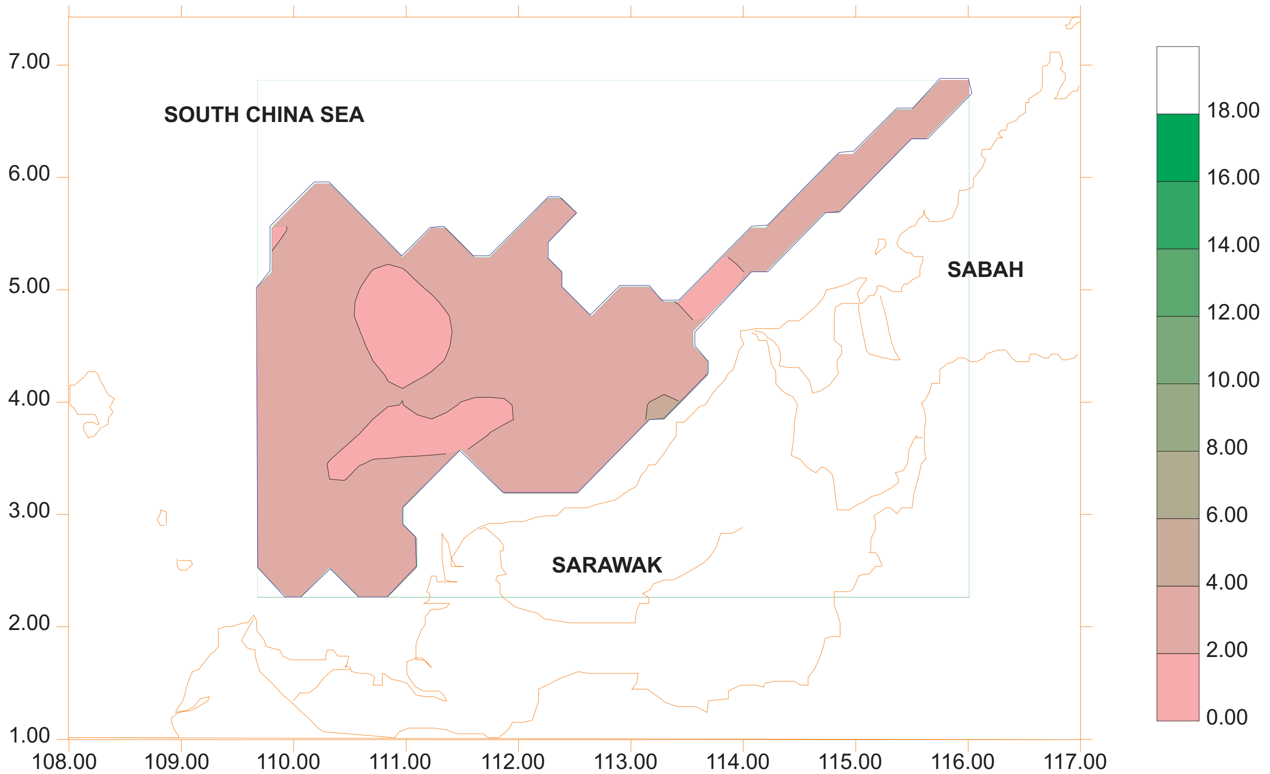


Figure5B: Post-monsoon patterns of sediment Kurtosis

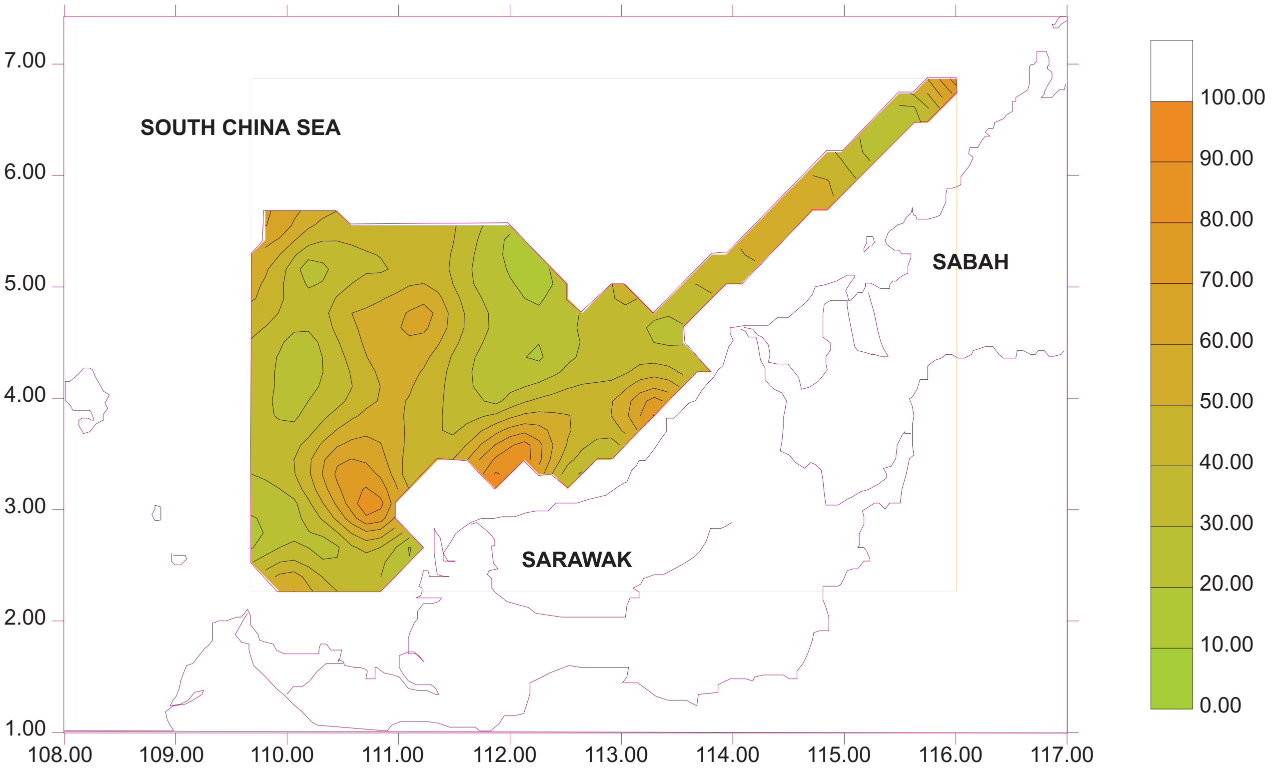


Figure 6A : Pre-monsoon patterns of sand distribution

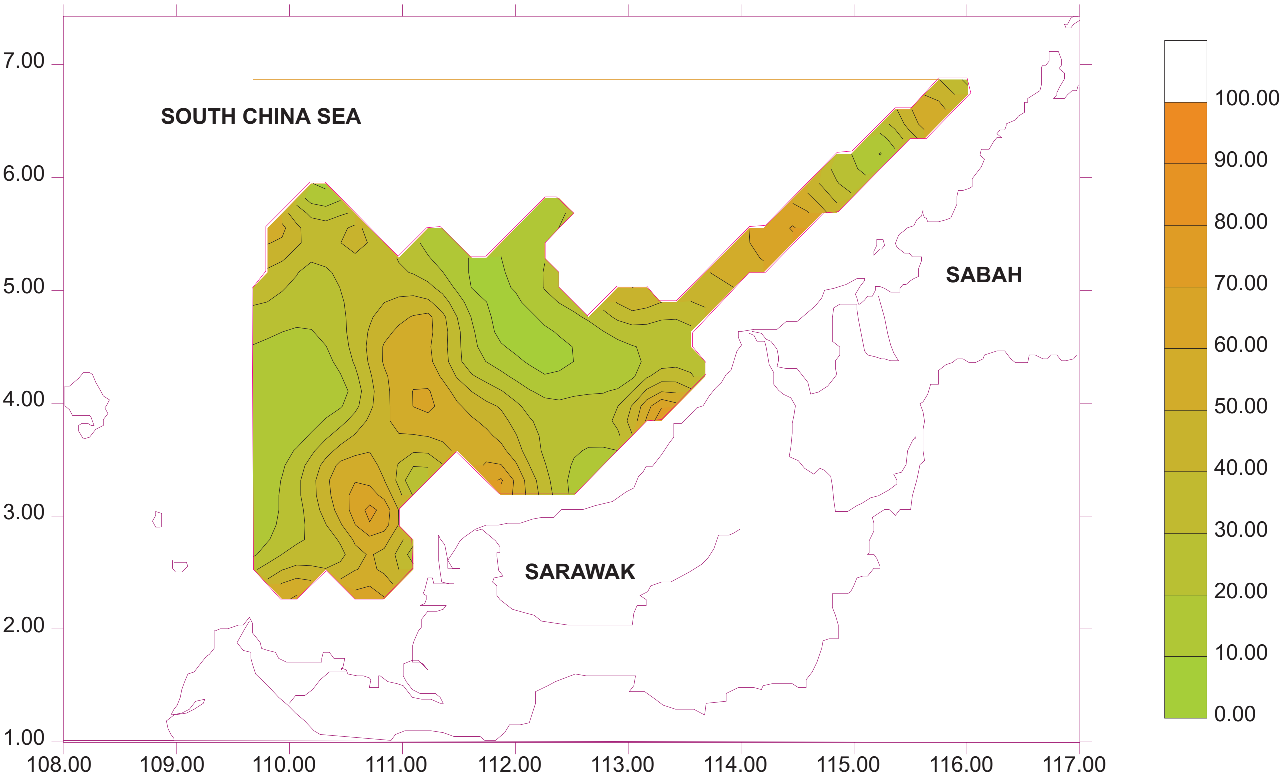


Figure 6B : Post-monsoon patterns of sand distribution

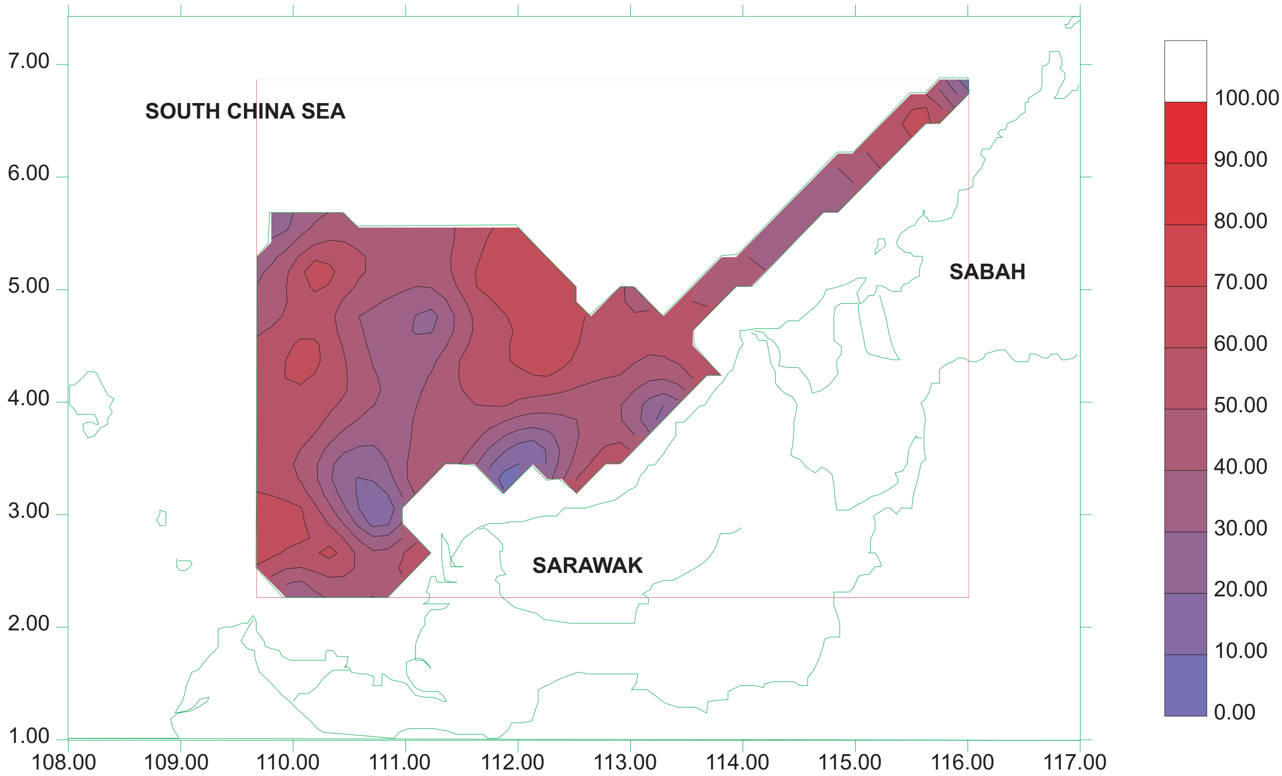


Figure 7A : Pre-monsoon patterns of silt distribution

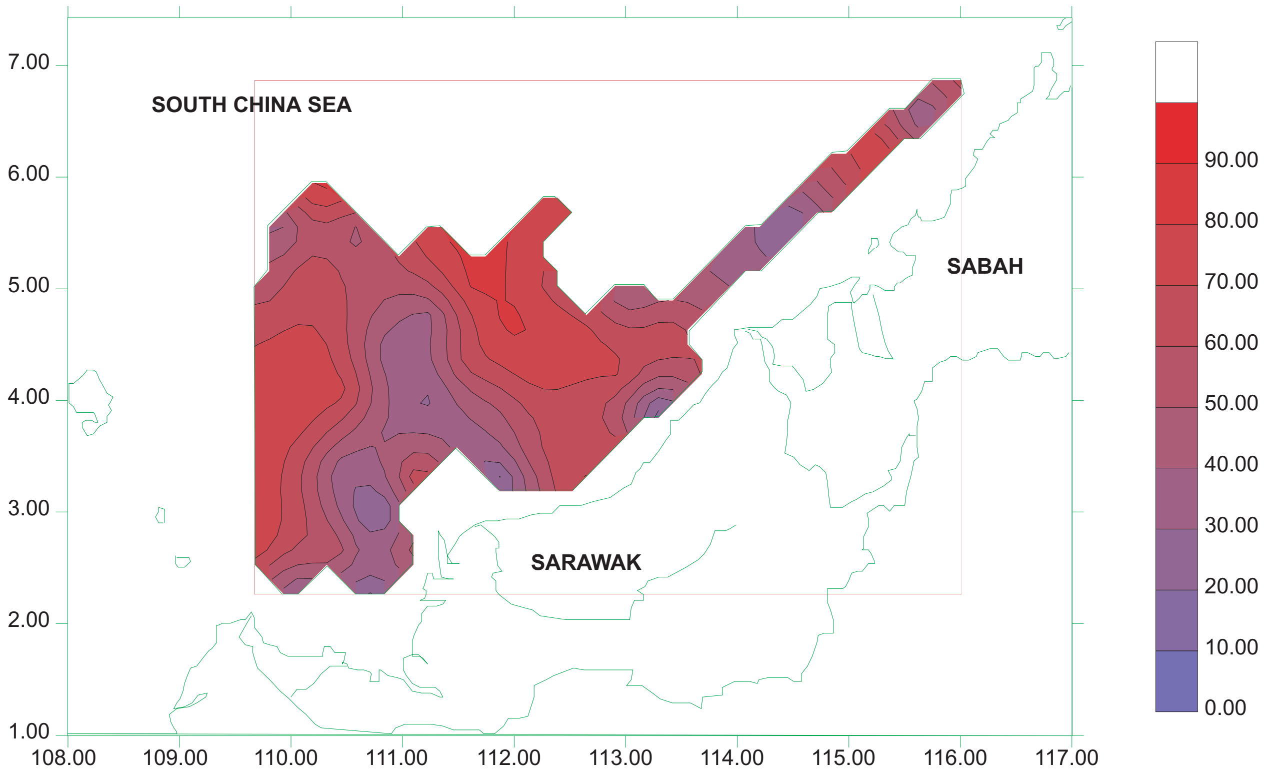


Figure 7A : Post-monsoon patterns of silt distribution

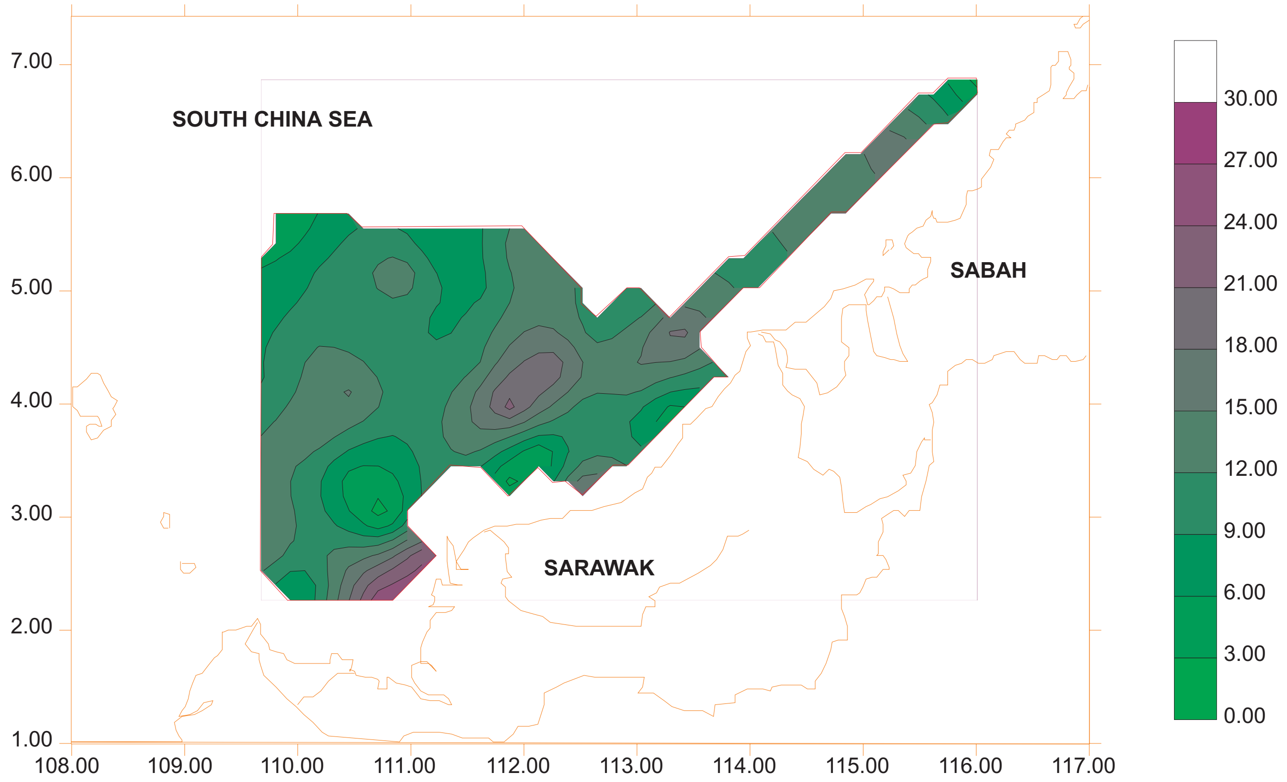


Figure 8A : Pre-monsoon patterns of clay distribution

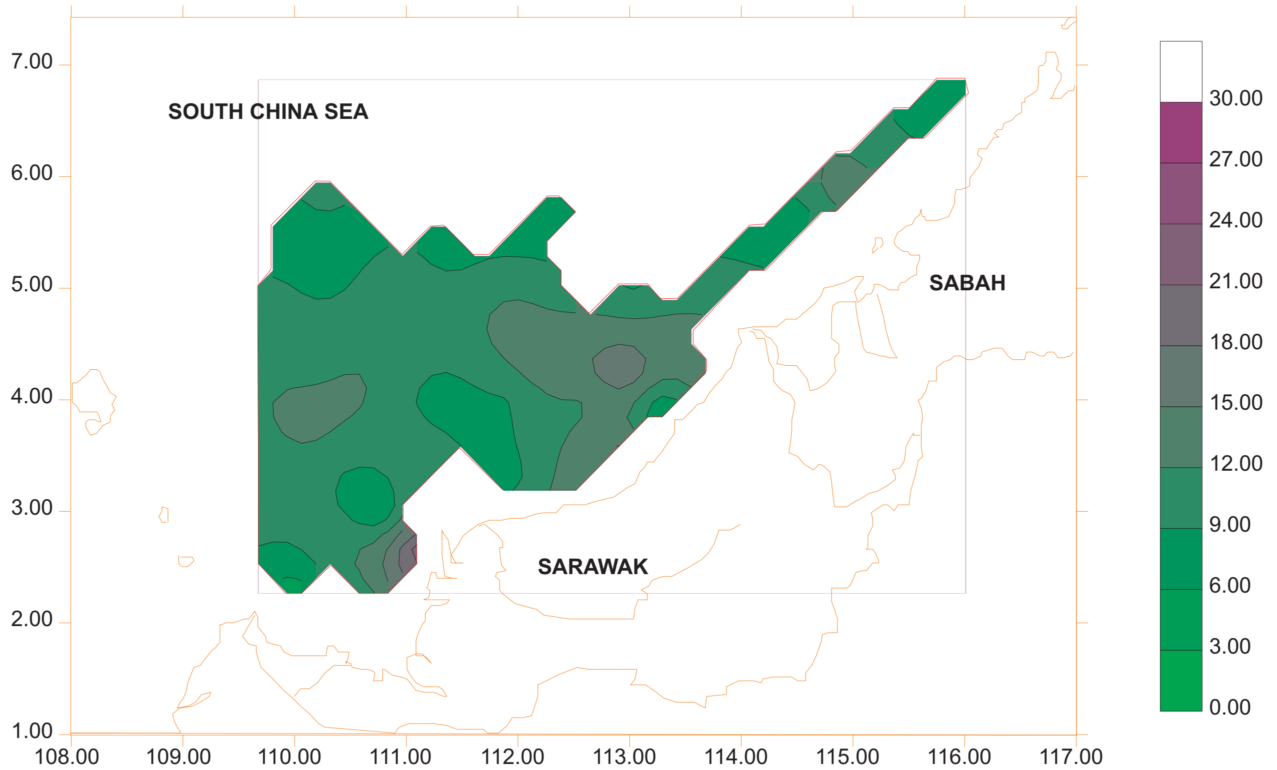


Figure 8A : Post-monsoon patterns of clay distribution

out these two stations the values for the pre-monsoon season will most certainly be below that of the post -monsoon thus making it similar to those described for Area I.

For the sediment samples collected during the pre-monsoon and post-monsoon cruises, the differences in characteristics are statistically quite significant (Tables 1E to 1G). Except for percentage of clay, all other sedimentological parameters show that the differences between the pre and post-monsoon sediments are statistically different.

On a cross-shore basis the general trend of decreasing in size from pre to post-monsoon sediments are similar to those described for Area I. The mean size of near-shore, mid-shore and off-shore sediments are finer for post-monsoon sediments as compared to the pre-monsoon sediments. During both seasons, the coarsest sediment are those for the near-shore stations.

Although the study Area II is located further away from study Area I, both are comparatively close to the shore and therefore strongly influenced by terrestrial input by discharging rivers. The differences between the pre and post-monsoon sediments can most probably be attributed to the weather conditions prevailing during both seasons. The site conditions during and before the sampling period are vastly different. The large outflow of fine sediments to the ocean environment during the monsoon season may have contributed to a considerable volume of fine sediments being deposited on the sea bottom. This has contributed to the sedimentological characteristics of the post-monsoon sediments into finer, better sorted and less negatively skewed as compared to the pre-monsoon sediments. The differences on the cross-shore sediment are strongly attributed to the near-shore region being most affected by wave, which naturally act as a siever, removing the finer materials, and eventually allowing only coarser materials to settle. This has given rise to the smaller range of size and better sorting values.

Conclusion

The monsoonal factor which causes terrestrial erosion of fine particles to be transported by the rivers into the adjacent ocean environment is the primary reason for the significant differences in the sedimentological characteristics of seabed materials sampled during the pre and post monsoon periods. In addition, the forces generated within the near-shore region of the area have induced the sorting mechanism on the sediments that resulted in the nearshore region covered with coarser materials.

Acknowledgement

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References.

Folk, R. L. 1980. Petrology of sedimentary rocks. Austin, Hemphill Publishing Company.

Folk, R.L. 1966. A review of grain size parameters. Sedimentology. (6): 73-93

Griffiths, J. C. 1967. Scientific method in analysis of sediments. New York, McGraw Hill Inc.

Krumbein, W.C. 1937. Sediments and exponential curves. Jour. Geol. (45): 577-601

Krumbein, W.C. 1938. Size frequency distributions and the normal phi curves. Jour. Sed. Petrol. (8): 49-90

Mc Bride, F. E. 1971. Mathematical Treatment of Size Distribution data. In: T. E. Carver (Ed.). Procedures in sedimentary Petrology. Toronto, Wiley Interscience. 109-128

Mohsin, A. K. M. and M. I. Mohamed. 1987. Ekspedisi Matahari '87: A study on the off-shore waters of the Malaysian EEZ. Occassional Publication. No.8. Faculty of Fisheries and Marine Science, Universiti Pertanian Malaysia.

Nutrient Diagenesis in Sediments of the South China Sea, Area II: Sabah, Sarawak, and Brunei Darussalam waters

Charumas Chareonpanich[a] , Siriporn Seurungreong[b] and Shettapong Meksumpun[a]

[a]Faculty of Fisheries, Kasetsart University, Chatuchak, Bangkok 10900, Thailand
[b]Southeast Asian Fisheries Development Center, Training Department, Phrasamutchedi, Samut Prakan 10290, Thailand

ABSTRACT

Study on nutrient diagenesis and physico-chemical characteristics of bottom sediments of the Sabah, Sarawak and Brunei Darussalum waters had been carried out under the ongoing SEAFDEC Collaborative Research Project. The results indicated that organically enriched offshore sediments consisted high levels of pore water nitrate and phosphate concentrations. For the whole study area, the levels of nitrate and phopsphate concentrations in pore water were in the ranges of 0.05 to 77.12 µg at NO_3^--N/L and 0.07 to 13.13 µg at PO_4^{3-}-P/L, respectively. Upward diffusive fluxes of pore water nitrate widely changed in stations. At the nearshore area, the fluxes of pore water nitrate had an average of 26.5 mg at NO_3^--N/m^2/d and were about one order of magnitude higher than those of phopsphate. However, phosphate upward fluxes were apparently high at deep areas off Sabah. Pore water ammonium concentrations were commonly very low but tended to be more accumulated at nearshore organically enriched areas. The ammonium concentrations for the whole study area ranged from non-detected level to 81.76 µg at N/L. The nearshore stations showed very high upward fluxes of ammonium, which were nearly 10 times higher than those of nitrate and phosphate. Sedimentary organic levels were comparatively high in two distinct regions; (I) a shallow nearshore region of Sarawak, and (II) a deep offshore region of Sabah amd Brunei Darussalum. The sources of organic materials settled in Regions (I) and (II) were suggested to be derived from different origins. The Northeast monsoon can somewhat enhance organic accumulation in the nearshore region. Overall our results obtained from this study had been used to characterize the bottom sediments into three distinct regions and discussed for further fishery resource development and management.

Key words: sediments, pore water nutrients, upward diffusive fluxes, total organic carbon and nitrogen

Introduction

A knowledge of the properties of the sediment-water interface, as well as of the kinetics of the chemical reactions taking place in the sediments, is essential for describing and understanding the mass transfer processes between sea water and marine deposits (Vanderborght *et al*. 1977*a*). Besides the effluent and the internal production, the release of nutrients from bottom sediments is one of the major causes of production and organic pollution in the sea. Such processes cause great influence to the seawater quality and interact complicatedly each other. The release of nutrients from sediments is important for algal growth (Ryding and Forsberg 1977, Hosper 1984, Søndergaard *et al.* 1990, Meksumpun *et al*. 1998). An indication of the importance of the sediment release is an increase in the phosphate concentration in summer which is far greater than can be explained by external loading (Sas 1989). In the South China Sea, the boundary conditions at the sediment-water interface are often poorly known.

The research study on nutrient diagenesis in sediments of the South China Sea (Area II) is a part of the ongoing project “the Interdepartmental Collaborative Research Project of the South China

Sea" which is supported by the Southeast Asian Fisheries Development Center (SEAFDEC) and aims to collect up-to-date information on the marine fishery resources and the present oceanographic conditions of the South China Sea for further establishment of appropriate scheme of fishery resource development and management. Here we report the results of porewater and bottom sediment analyses. Objectives of this study are listed as the following items.

1) To investigate the levels of biological important nutrients (nitrate, phosphate and ammonium) in sediment pore water and study the nutrient diagenesis characteristics of bottom sediments in the sea area

2) To examine the organic levels (e.g. total organic carbon, total organic nitrogen and total organic contents) of the bottom sediments

3) To study the influence of the Northeast monsoon on the alternation of sediment characteristics

4) To extrapolate the upward diffusive fluxses of biological important nutrients at the sediment-water interface and define the relations among the sedimentary organic levels, diagenesis characteristics and upward diffusive fluxes of nutrients of the bottom sediments

The baseline data obtained can be used not only to characterize the sea bottom in an aspect of a potential contribution to material budget and biological productivity of the water column but also to provide a better understanding of the sediments as potential resources for benthic production development of the sea area.

Materials and Methods

Collection of sediment samples

Sediment samples were collected from 79 stations (**Fig. 1**) at the sea area off Sabah, Sarawak and Brunei Darussalam, in the South China Sea, during 4 July to 9 August 1996 (pre-Northeast monsoon period) and 25 April to 31 May 1997 (post-Northeast monsoon period) by M.V. SEAFDEC. Almost of the sediment samples were collected by gravity corers (see **Table 1**). Sediment grab was applied in stead of the corer at some stations where the bottom deposit was mainly composed of sand and gravels and hence it was unable to retrieve by the corer. Prior to subsampling, measurement of sediment surface temperature was immediately conducted (**Table 1**) and the appearances of the sediment core were recorded. The cores was subsampled as soon as possible after retrieval. After the overlying water was gently taken off, the sediment core was extruded from the liner and cut into 1-cm sections for the upper 10 cm depth, 2-cm sections for the depth between 10 to 20 cm, 3-cm sections for the depth between 20 to 50 cm, and 5-cm sections for the depth greater than 50 cm.

Analyses of sediment samples

After subsampling, a portion of the sediment samples were packed tightly in plastic containers and immediately frozen under -60 °C for further analysis of water content. Remaining part of the sectioned sediment samples were extracted for pore water by centrifugation of the sediment for 5 min at 3,500 rpm. The supernatant was then filtered with Millipore HA (0.45 µm) and immediately frozen until analysis on board of M.V. SEAFDEC. The pore water samples were analyzed for nitrate nitrogen (NO_3^--N), phosphate phosphorus (PO_4^{3-}-P) and ammonium nitrogen (NH_4^+-N) concentrations with an auto nutrient analyzer (TRAACS 800, Bran & Luebbe).

Sediments were dried at 70 °C for 3 days and then ground to powder. Chemical analyses of the sediment samples were carried out at laboratory of the Marine Environment Section, Chugoku Natinal Industrial Research Institute (CNIRI), Japan. The ground samples for organic content analysis were freeze-dried again before being weighed in silver cups. In order to remove inorganic carbon, the sediments in the cups were treated several times with 2M-HCl solution, freeze-dried, and packed in tin cups prior to analysis. The total organic carbon (TOC) and nitrogen (TON) contents were obtained using an elemental analyzer (Carlo Erba, NA-1500). Total organic matter (TOM) contents were determined by measuring the weight loss of dry sediment after ignition in a furnace at 450 °C for 3 hours.

Results and Discussions

Nitrate-N in sediment pore water

Nitrate in sediments is formed from ammonium through nitrification in the aerobic top layer (Smits and Molen 1993). The concentrations of NO_3^--N in the surface sediments of each sampling station are summarized in **Table 1**. The levels of NO_3^--N concentrations in the sampling area range from the minimum value of 0.05 µg at NO_3^-N/L at station 7 (a nearshore station; 32 m depth) to the maximum value of 77.12 µg at NO_3^-N/L at station 65 (an offshore station; 1,457 m depth) and the mean value of 29.09 µg at NO_3^-N/L can be calculated for the whole study area. The levels here were comparatively high when compared to those of the Seto Inland Sea, Japan (Yamamoto *et al*. 1998). Although there has no apparent correlation to the water depth, being considered as a single factor, NO_3^--N concentrations in the surface sediments are generally low in neasrshore stations (e.g. stations 17, 32, and 47) and comparatively high in offshore stations (e.g. stations 24, 40, and 53). The availability of NO_3^--N concentrations in the top layer of the sediments reflects that surface sediments of the study area are rather oxidized. Brown color of oxidized sediment can be observed to be less than 0.5 cm of some nearshore cores but it can extend to more than 4 cm of some deep stations. The thickness of top brownish sediments varies mainly due to the degree of detritus accumulation and oxygen penetration, and the type of deposits. Thus, although NO_3^--N concentrations are somewhat varied in sampling stations, the sediments of nearshore stations are apt to receive more organic loading and have less oxygen penetration than those of the offshore ones.

Below the oxidized layer, nitrate reduction can significantly occur. Typical NO_3^--N profiles can be observed in homogeneous, sandy silt cores of stations 60 and 76 (**Fig. 2**). The NO_3^--N concentrations show a maximum in the upper layer. This maximum can be formed by nitrate production and reduction during diagenesis of organic matter (Kato and Terunuma 1995) and related to the activity of autotrophic bacteria in the bulk of the sediments, which in turn strongly depends on the local redox potential (Vanderborght and Billen 1975). The concentrations are subject to vertical transport and denitrification in the zone just below this layer. Below the peak layers, nitrate apparently decreases.

Irregular vertical distribution pattern of NO_3^--N concentrations can be observed in some cores where the deposits alter considerably (e.g. stations 17 and 32, see **Fig. 2, 3**). At nearshore zone, effect of tidal cycle on the removal of combined nitrogen was studied (Usui *et a*l. 1998). The tidal current was demontrated to have an inhibitory effect on sedimentary denitrification. Nevertheless, coupling role of NO_3^--N concentration in the overlying water has been emphasized. High NO_3^--N concentration in the overlying water should also be a primary source of nitrate in the sediment. Thus, the irregular pattern of NO_3^--N profiles may be explained by physico-chemical functions of inhibition of nitrate reduction and/or stimulation of nitrification in the circumstance.

Phophate-P in sediment pore water

Phosphate can be liberated from organic matter by bacterial activity just like ammonium. Release of phosphate from sediments is known to be important for algal growth (Hosper 1984, Søndergaard *et al.* 1990). In the study area, the levels of PO_4^{3-}-P concentrations in surface sediments range between 0.07 to 13.31 µg at PO_4^{3-}P/L (**Table 1**), with the mean value of 3.73 µg at PO_4^{3-}P/L. Comparatively high PO_4^{3-}-P concentrations can be observed at some offshore stations (e.g. stations 39 and 41) and at some deep nearshore stations (e.g stations 77 and 78), while very low PO_4^{3-}-P concentrations are commonly found. Such occurrences are considered to be due to the differences in types, organic levels and oxidized condition of the deposits. Since phosphate adsorbs strongly to several components of the sediments, the hydroxides of iron (III) and aluminium in particular, and the adsorptions are stronger in the oxidized layer than in the reduced layer (Berner 1974, Lijklema 1980, Van Raaphorst *et al*. 1988), low PO_4^{3-}-P concentrations (e.g. at station 47, **Fig. 2**) may imply comparatively reduced condition of the sediments. Correspondingly, the core of station 47 has revealed only thin layer of oxidized zone (**Fig. 3**). The vertical profiles of pore water PO_4^{3-}-P concentrations remain relatively constant in most cores, which should be caused by the buffering capacity of the adsoption and precipitation processes (Horie and Hosokawa 1985, Smits and Molen 1993).

Ammonium-N in sediment pore water

Ammonium is released from the degradation of detritus and nitrified by bacteria under aerobic conditions (Berner 1974, Vanderborght *et al*. 1977*b*). It has been demonstrated that ammonium is taken up by phytoplankton more rapidly than nitrate (Dugdale and Goering 1967). The levels of NH_4^+-N concentrations of surface sediments in the sampling area range from non-detected level to the maximum value of 81.76 µg at NH_4^+-N/L at station 59 (**Table 1**) and the mean value of 15.58 µg at NH_4^+-N/L can be calculated for the whole study area. Such levels of NH_4^+-N concentrations are generally low when compared to other eutrophic sea areas (cf. Yamamoto *et al*. 1998). About one third of the surveyed stations, the surface sediments show no accumulation of NH_4^+-N and thus the sediments here are well oxidized and, consequently, nitrification process should be significantly enhanced. In the sediments, NH_4^+-N concentrations increase with depth (**Fig. 2**). Especially their concentration gradients in the nitrate reduction zone are somewhat greater (see the profiles of stations 60 and 76). In those cores, sharp discontinuities of the nitrate concentration gradients occur at a depth of about 4 cm and 2 cm, respectively. Those depth are well corresponding to the oxidized depths of each core (**Fig. 3**).

In sediment of a long core obtained from station 78, pore water NH_4^+-N concentrations, as contrast with nitrate, show a sharp increase in the upper 10 cm layer (**Fig. 4**). The observed concentrations gradually increase and seem to be constant in the deep layer of *ca* 70 cm. Vertical distribution pattern of all nutrients imply a rather constant depositional process of the deposits. The remaining of nitrate in deep layer, moreover, has revealed the oxidized characteristics of sediment and water overlying in deep region of the surveyed area.

Total organic carbon, total organic nitrogen and C:N ratio of the sediments

Organic carbon content in the sediment is important for understanding the productivity of the ocean. Amount of organic matter deposited in the sediment can reflect bio-productivity of water column, input of organic matter, and sedimentation rate (Kennet 1982). In the study area, the bottom topography changes from a shallow shelf to a deeper zone with increasing distance from the coast of Sarawak (**Fig. 1**). The water depth rapidly changes and a deep valley is situated just off the coast of Sabah, the east part of the survayed area. Such bottom topography, together with the influence of local current, should play a major role controlling the depositional characteristics of the organic matter there. Bottom sediments in the sea off Sabah was studied by Yaacob and Higashikawa (1990). The nearshore sediment ranged from sand to silty loam and were mostly yellowish-grey sandy mud. The grain size changed from fine-grained sand to silt as depth increases. In this study, we defined the sediment types by the water content of the samples (sandy and sitly sediment defined by a water content less and more than 35 % by weight, respectively). The sandy sediments can be observed commonly at nearshore areas of Sarawak (e.g. at stations 1, 8, 9, 15, 17, 18, 30, and 46) and at nearshore stations (stations 77 and 79) of Sabah. In offshore area, only one distinct sandy station was noticed (station 23). The other stations in the survey area almost consist with silty deposits.

Such differences in types of deposits are positively correlated with the levels of organic contents of the sediments. Horizontal distributions of organic contents of carbon and nitrogen of surface sediment showed similar pattern. Low total organic carbon (TOC) content of sediments occurred in neasrshore areas and high TOC content can be found in offshore area of Sabah where the water depth dramatically increases (**Fig. 5**). Very low organic carbon contents (lower than 1.00 mg/g) were found in the sandy zones around station 1, stations 8 and 9, and stations 18 and 30.Å@ The maximum TOC content (17.39 mg/g) was found in silty clay sediment of station 78 (water depth 1,515 m). Average

TOC content for the whole study area is 5.91 mg/g. It is in the same range of the former report by Yaacob (1990) for the Sabah waters (3-13 mg/g). Organic nitrogen (TON) contents in the sediment showed almost the same pattern as that of organic carbon contents (**Fig. 6**). The lowest TON contents of the sediments (less than 0.20 mg/g) were found in the same area as those of TOC. The highest TON contents of the sediments were found around station 78 at the values higher than 2.00 mg/g. Average TON content for the whole study area is 0.97 mg/g.

Horizontal distribution pattern of TOC and TON contents of the sediment in nearshore area may imply a degree of terrestrial impact to the marine environment. **Figures 5** and **6** show increasing organic contents in the area adjacent to riverine sources, e.g. at stations 7 and 17. Sediment particles from the rivers are likely to be settled there. In those stations, nevertheless, such accumulation patterns of TOC and TON may be complicate since the location there should receive more physical effect from water mass distribution and currents. For the whole study area, because the surface current velocity and direction are remarkably influenced by the monsoon, the accumulation patterns of organic carbon and nitrogen were considered to be directly correlated with the bottom topography and the local monsoon. Although the highest organic contents of carbon and nitrogen of surface sediments in some parts of the study area were as high as the high production areas e.g. in the Osaka Bay, Japan (12-22 mg/g for TOC and 1.8-2.4 mg/g for TON) (Montani *et al*. 1991, Mishima *et al*. 1996), the mean values of the organic carbon and nitrogen contents of the whole area were comparatively low. Such low concentrations of benthic organic materials may be one of the causes of comparatively low fishery production in this area.

The atomic ratios of carbon to nitrogen (C:N) have been employed as source indicators of sedimentary particulate organic matter by numerous workers (e.g. Rashid and Reinson 1979, Prahl *et al*. 1980). Generally, high values of C:N ratios (>10) of sediments from mid-latitude areas have been interpreted to be a large effect of terrigenous materials input (Thornton and McManus 1994, Mishima *et al.* 1996). The C:N ratio of the mixed diatoms (50% *Skeletonema costatum*, 20% *Nitzchia seriata* and 20% mixed *Cheatoceros* spp.) in June at Dabob Bay, Washington, have been reported to be 5.4 (Hedges *et al*. 1988). Additionally, the ratios of sediment in the East China Sea, which contain a dominant contribution of marine organic carbon, lie in the range 6.2 to 8.8 (Tan *et al*. 1991). In this study area, the C:N ratios were almost in the range of 6-8 (**Fig. 7**), indicating the marine source. At some nearshore stations (e.g. stations 7 and 17), apparently high C:N ratios (more than 10) can well reflect the impact of terestrial runoff. However, high C:N ratios can also be observed in some offshore stations in the deep waters off Sabah. Such occurrence may suggest high decomposition rate of carbon and/or nitrogen in the surface sediments.

Influence of the Northeast monsoon on bottom sediments

The major circulation in the South China Sea is driven by the monsoon winds (Wyrtki 1961). Winds prior to September are dominated by the Southwest monsoon. The Northeast monsson expands southwards against the diminish of the Southwest monsoon in October, reaching its maximum strenght and covering the entire South China Sea in December. Numerical simulation of the sea level variation indicated that the monsoon winds are the main driving force affecting the sea level around west Malaysia (Azmy *et al*. 1991). The monsoon, therefore, should have more or less effect to the bottom sediments. Numerical simulation of the flow fields at 50 m depth indicated the intrusion current entering the Luzon Strait accelerates along the boundaries of the basin in response to the Northeast monsoon (Chao *et al*. 1995). The southward current off the coast of Vietnam turns cyclonically as it impinges onto the Sundra shelf. Then, a two-layer circulation develop in the shallow Gulf of Thailand; water flowing out of the Gulf at 50 m, to the west part off Borneo, is replinished by a surface inflow (Chao *et al*. 1995). Such a trend of water movement into the west part of the study area may somewhat contribute to the alternation of the bottom deposits.

Evaluation on the influence of the Northeast monsoon on bottom sediments has been carried out by analysis of the change in total organic content (TOM) of the surface (0-1 cm) sediments after monsoon season (some deep stations off Sabah were omited since the loss of corring apparatus during the post-monsoon survey). The levels of TOM in the surface sediments there ranged between 0.60 to 7.51 % and are significant correlated with those of TOC ($r^2 = 0.76$) and TON ($r^2 = 0.66$) (**Fig. 8**). Such levels were comparatively lower than those usually found in organically enriched area of closed bay. After the Northeast monsoon passes, sedimentary TOM varies from stations to stations. Percentage of changes in TOM (**Fig. 9**) indicate dramatical increases (more than 50 to 160 % of initial TOM) at some nearshore stations that previously consisting with high TOC and TON contents (e.g. station 7) and that previously consisting with low TOC and TON contents (e.g. stations 9, 18, 30 and 69). Such increases should be due to greater discharge of terestrial organic sources enhanced by the monsoon wind. Except for those above stations, other nearshore stations commonly show the decreases of TOM after the monsoon season since those areas receive comparatively strong wind wave effect. In addition, some offshore stations (e.g. stations 12, 13, 22, 23, and 24) demonstrate the increase of TOM (13-24 %). The sources of such increases cannot be clarified yet. Either subsurface outflow circulation from the Gulf of Thailand or resuspension and setlement mechanisms of comparatively high organic matterials can possibly enhance such phenomena. Since suspended matter supplied from rivers or marine productions are transported by the residual flow in the long term, sinks doward and settles at some point of the sea bottom, the sedimentary preocess of the sea area should be more clearly illustrated by further application of 3-dimentional numerical model that can reflect the important role of residual flow characteritics of this sea area.

Estimation of upward diffusive fluxes of nutrients at the sediment-water interface

In water quality management, the estimation of nutrient upward fluxes is often beneficial in description of the water system and prediction of the effects of changes such as enahanced nutrient loadings to the productivity of overlying water column. Generally, the properties of surface sediment layer differ considerably from those of deeper layers, and may strongly affect the mass transport across the water-sediment interface. Degree of compaction in the surface layer is low, especially for muddy sediments. The high porosity also favors an increased flux in the pore water of this layer. Thus, the silty sediments of the study area are considered to be most important for the sediment-water interactions. Eighteen silty stations are focused (stations 7, 11, 16, 17, 24, 31, 32, 33, 38, 39, 42, 43, 47, 60, 71, 75, 76 and 78) and the characteristics of the sediments and the chemical properites of pore water of those stations are used for estimation of upward nutrient fluxes of the biological important nutrients.

For flux estimation, assumption of steady state is allowed for these substances, because the changes of their concentrations in the overlying water is slow compared to the mass fluxed of the diffusion and oxidation processes near the sediment-water interface. Dependency on bio-irrigation and pH are ignored since the lack of information. All the rates of conversion processes are temperature dependents. Dispersion in the pore water is set as the result of molecular diffusion. The concentration of dissolved constituents at the sediment-water interface cause the diffusional transport. Thus, nitrate, phospate and ammonium diffuse from the sediments into the seawater because their surficial pore water concentrations are higher than those in the overlying seawater. Based upon Fick's first law and Yamamoto et al. (1998), we estimated the upward diffusive fluxes of thess nutrients by

$$F = -\phi D_{sed} \frac{\Delta C}{\Delta Z} \qquad (1)$$

where, F = flux (µg at N or P/cm^2/s), ϕ = sediment porosity, D_{sed} = diffusion coefficient in sediment (cm^2/s), C = pore water nutrient concentration (µg at N or P/L), and Z = depth in sediment (cm). The sediment porosity (ϕ) was calculated by its interrelation to the density, water content and temperature of the sediment, and the density and salinity of porewater as the following equation:

$$\phi = (A/\rho_i)/\{(A/\rho_i)+[(1-A)/\rho_m]\} \qquad (2)$$

where, ρ_i = density of pore water (g/cm^3), ρ_m = density of sediment (g/cm^3) and the factor A was determined by

$$A = (\omega/100)/[1-(S/1000)] \qquad (3)$$

where, ω = water content of the sediment (%) and S = salinity of the porewater (psu). The diffusion coefficient in sediment (D_{sed}) was calculated according to Nakashima and Nishimura (1986; cited in Yamamoto *et al*. 1998) through the following equations:

$$D_{sed} = (1/F.\phi).D_0^t \qquad (4)$$

where, F = formation factor and D_0^t = diffusion coefficient at t °C. F was approximated by

$$F = \phi^{-n} \qquad (5)$$

For marine sediment, the facor n is commonly 2 ~ 4 in which it is about 2 in sandy sediment and becomes greater to 2.5 ~ 3.5 in the muddy deposits (Masuzawa 1985; cited in Yamamoto *et al*. 1998). In this study, we decided n to be 3. In the temperature range of 0 ~ 25°C, the factor D_0^t can be approximated according to Lerman (1979) as the following equation:

$$D_0^t = D_0^0(1+\alpha t) \qquad (6)$$

where, D_0^0 = diffusion coefficient at 0 °C and α = ion coefficient. According to Li and Gregory (1974), the D_0^0 of nitrate, phosphate, and ammonium are 0.978x10^{-5}, 6.1x10^{-6} and 0.98x10^{-5} cm^2/s, respectively. The coefficient α for cation and anion are 0.048 and 0.040, respectively (Lerman 1979). By substituting equations (5) and (6) into equation (4), the following equation can be obtained.

$$D_{sed} = D_0^0(1+\alpha t).\phi^2 \qquad (4)'$$

Using equations (1), (2), and (4)′ and the concentration gradients at the interface obtained from the regression curve of C as the function of Z, we can calculate the upward diffusive fluxes as F (*SE* ±8%).

The results together with parameters used in the estimations are summarized in **Table 2**. The depths (Z) of sediment layer for upward flux estimation were determined based upon the vertical distribution pattern of each nutrient and depended on stations. The upward diffusive fluxes of NO_3^--N widely change with the average of 26.5 mg at N/m^2/d for the nearshore stations. The offshore stations (stations 11 and 39) in which comparatively low and high organic levels show correspondingly low and high values of NO_3^--N fluxes of 5.6 and 88.4 mg at N/m^2/d, respectively. The upward diffusive fluxes of PO_4^{3-}-P are slightly lower than those of NO_3^--N. Average PO_4^{3-}-P upward fluxes at the nearshore stations is 2.8 mg at P/m^2/d. The values were in similar range to those of the offshore stations in which the sedimentary organic content are low. However, distinguishably high PO_4^{3-}-P upward fluxes are found in the offshore sediment with comapratively high organic content (e.g. stations 71 and 75). High rate of organic decomposition under comparatively oxidized conditions of the sediment may be the possible cause of such phenomena.

The nutrient fluxes, NO_3^--N in particular, at the sediment-water interface of many stations show a negative trend (see remarks "down-*F*" in **Table 2**). In those cores, the uppermost layers of the sediments have highest levels of the nutrient concentration with a gradual decrease as the sediment depth increase. To estimate the relaease fluxes of such deposits, the method of Yamamoto *et al.* (1998), which evaluated the upward flux from the concentration gradient between the surface sediment and the overlying water, could be further attempted. However, since NO_3^--N fluxes are often negative, the overlying water might be a possible source of nitrogen to denitrification process in the

Table 1 Sampling date and apparatus, depth of obtained cores, and concentrations of nitrate-N, phophate-P, and ammonium-N in pore water of surface (0-1 cm) sediments (nd = no data)

Date	Station	Apparatus	Core depth (cm)	Nitrate-N (_g at NO_3^--N/L)	Phosphate-P (_g at PO_4^{3-}-P/L)	Ammonium-N (_g at NH_4^+-N/L)
10-Jul-96	1	grab	3	nd	nd	nd
	2	gravity core	19	2.64	1.39	10.22
	3	gravity core	19	13.72	1.55	3.37
	4	gravity core	16	5.25	2.16	34.87
11-Jul-96	5	gravity core	12	2.62	1.98	21.63
	6	gravity core	19	2.75	1.84	21.93
	7	gravity core	18	0.05	0.64	35.79
	8	gravity core	18	nd	nd	nd
12-Jul-96	9	gravity core	7	63.22	2.41	nd
	10	gravity core	14	8.41	1.26	0.00
	11	gravity core	16	0.44	0.81	23.28
	12	gravity core	40	16.13	2.08	0.00
13-Jul-96	13	gravity core	34	11.25	1.87	0.00
	14	gravity core	38	31.05	1.95	0.00
	15	gravity core	38	5.15	1.45	24.08
	16	gravity core	29	3.38	1.66	0.00
14-Jul-96	17	gravity core	18	1.22	1.24	41.30
	18	grab	6	nd	nd	nd
	19	gravity core	20	24.26	1.00	47.88
	20	gravity core	16	7.27	1.28	33.43
15-Jul-96	21	gravity core	70	44.05	2.74	1.67
	22	gravity core	41	45.20	3.90	0.00
	23	grab	8	nd	nd	nd
	24	gravity core	41	66.29	8.70	0.00
16-Jul-96	25	gravity core	25	27.24	3.36	0.00
	26	gravity core	47	16.16	3.52	0.00
	27	gravity core	32	30.80	2.59	0.00
	28	gravity core	38	61.52	3.05	0.00
17-Jul-96	29	gravity core	23	8.43	4.75	0.00
	30	grab	6	nd	nd	nd
18-Jul-96	31	gravity core	18	22.71	2.60	19.48
19-Jul-96	32	gravity core	32	2.09	3.37	43.54
	33	gravity core	85	12.48	6.25	4.81
	34	gravity core	41	73.51	0.07	0.00
	35	gravity core	75	25.99	0.93	0.00
20-Jul-96	36	gravity core	60	30.85	0.60	5.15
	37	gravity core	38	38.51	2.21	10.76
	38	gravity core	70	65.71	2.25	0.00
	39	gravity core	70	18.12	13.31	16.99
21-Jul-96	40	gravity core	14	69.73	0.45	3.41
	41	gravity core	60	16.16	11.55	0.00
	42	gravity core	70	7.07	4.46	19.32
	43	gravity core	90	39.02	4.38	14.48
22-Jul-96	44	gravity core	85	37.24	1.33	0.00
	45	gravity core	29	72.98	1.18	24.99
	46	grab	5	nd	nd	nd
	47	gravity core	35	3.09	0.66	0.00
24-Jul-96	48	gravity core	31	24.37	2.65	0.00
	49	gravity core	20	43.11	2.64	0.00
	50	gravity core	38	17.06	7.08	0.00
25-Jul-96	51	gravity core	26	27.01	3.10	0.00
	52	gravity core	68	25.61	7.03	0.00
	53	gravity core	32	69.28	5.57	1.40
	54	gravity core	26	41.79	7.04	0.02
26-Jul-96	55	gravity core	70	39.70	5.98	11.16
	56	gravity core	60	42.10	6.84	12.62
	57	gravity core	26	57.65	3.82	3.00
	58	gravity core	75	22.62	6.00	10.99
27-Jul-96	59	gravity core	32	2.99	3.08	81.76
	60	gravity core	50	12.13	2.90	7.70
	61	gravity core	50	49.00	4.38	6.03
	62	gravity core	85	56.00	3.50	14.95
28-Jul-96	63	gravity core	35	39.93	4.30	8.32
	64	gravity core	55	35.81	4.81	11.34
	65	gravity core	26	77.12	3.99	11.13
	66	gravity core	29	70.17	4.19	17.35
29-Jul-96	67	gravity core	95	33.84	3.29	20.78
	68	gravity core	65	28.59	3.92	57.27
	69	gravity core	32	26.88	5.01	76.59
	70	gravity core	29	14.63	3.60	69.03
31-Jul-96	71	gravity core	32	25.99	4.39	8.50
	72	gravity core	55	45.50	5.17	22.05
	73	gravity core	26	40.44	4.11	8.69
1-Aug-96	74	gravity core	75	26.82	3.99	8.67
	75	gravity core	75	28.68	5.10	26.58
	76	gravity core	29	10.08	4.02	51.10
2-Aug-96	77	gravity core	26	5.73	8.72	53.76
	78	gravity core	70	21.99	9.04	16.42
	79	gravity core	12	27.54	8.58	41.92

Table 2 Parameters used and the results on estimations of the upward diffusive fluxes at the sediment-water interface of some stations in the study area

Surveyed	Sediment	Nitrate upward fluxes			Phosphate upward fluxes			Ammonium upward fluxes		
stations	temp (_C)	*Z*	_C/ _Z	*F*	*Z*	_C/ _Z	*F*	*Z*	_C/ _Z	*F*
7	30.0	2	2.21	32.43	3	0.23	2.13	3	2.47	40.34
11	23.3	2	0.58	5.64	3	0.48	2.89	3	2.64	28.00
16	24.9	down-*F*	-	-	3	0.43	3.29	3	0.00	0.00
17	28.5	2	3.38	32.03	down-*F*	-	-	3	10.11	106.27
24	16.4	down-*F*	-	-	down-*F*	-	-	3	0.00	0.00
31	29.8	down-*F*	-	-	4	0.29	2.64	4	23.89	388.02
32	29.6	2	1.38	20.15	3	0.76	6.86	3	2.15	34.71
33	26.5	down-*F*	-	-	down-*F*	-	-	3	10.52	159.96
38	4.9	down-*F*	-	-	3	0.94	5.05	3	0.00	0.00
39	4.0	2	10.55	88.40	2	3.83	20.02	3	18.47	159.39
42	18.0	down-*F*	-	-	down-*F*	-	-	3	4.26	53.10
43	20.0	down-*F*	-	-	down-*F*	-	-	3	11.51	151.08
47	29.5	down-*F*	-	-	2	0.28	2.53	3	21.41	345.60
60	15.2	2	1.99	21.36	3	0.27	1.83	6	4.30	49.79
71	5.1	down-*F*	-	-	3	2.58	13.99	3	5.05	45.46
75	3.2	down-*F*	-	-	3	2.17	10.21	3	9.72	74.99
76	19.6	down-*F*	-	-	down-*F*	-	-	3	18.55	240.90
78	3.2	down-*F*	-	-	down-*F*	-	-	3	4.29	33.09

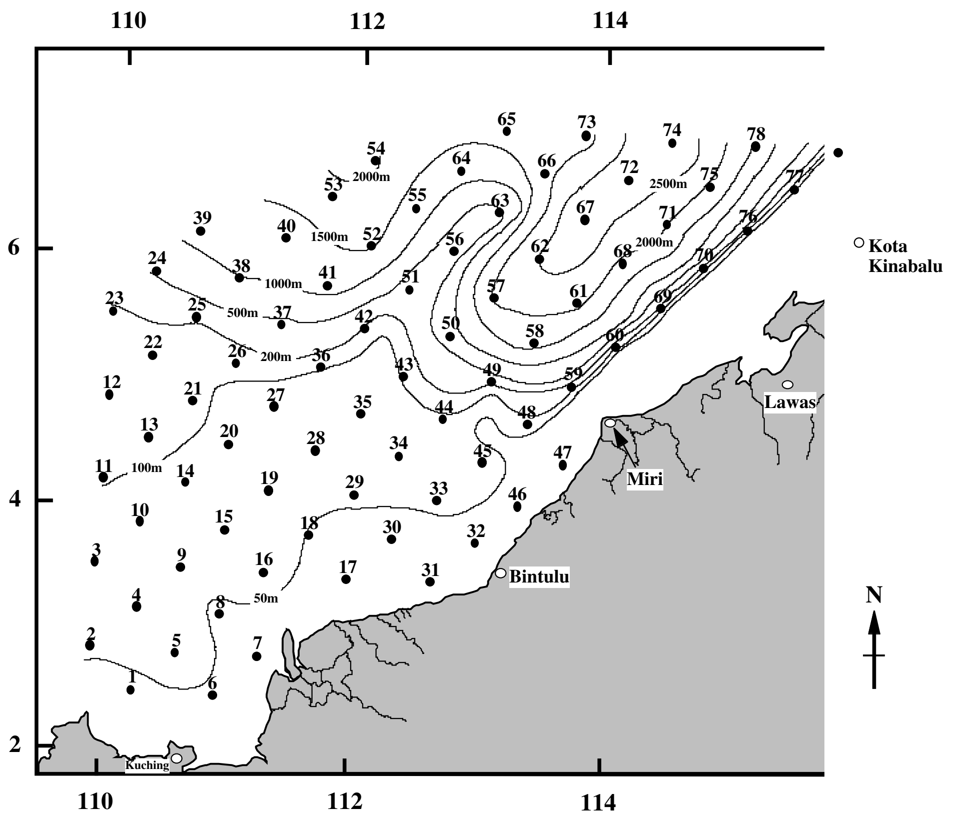

Fig. 1 Sampling stations in Sabah, Sarawak and Brunei Darussalam waters

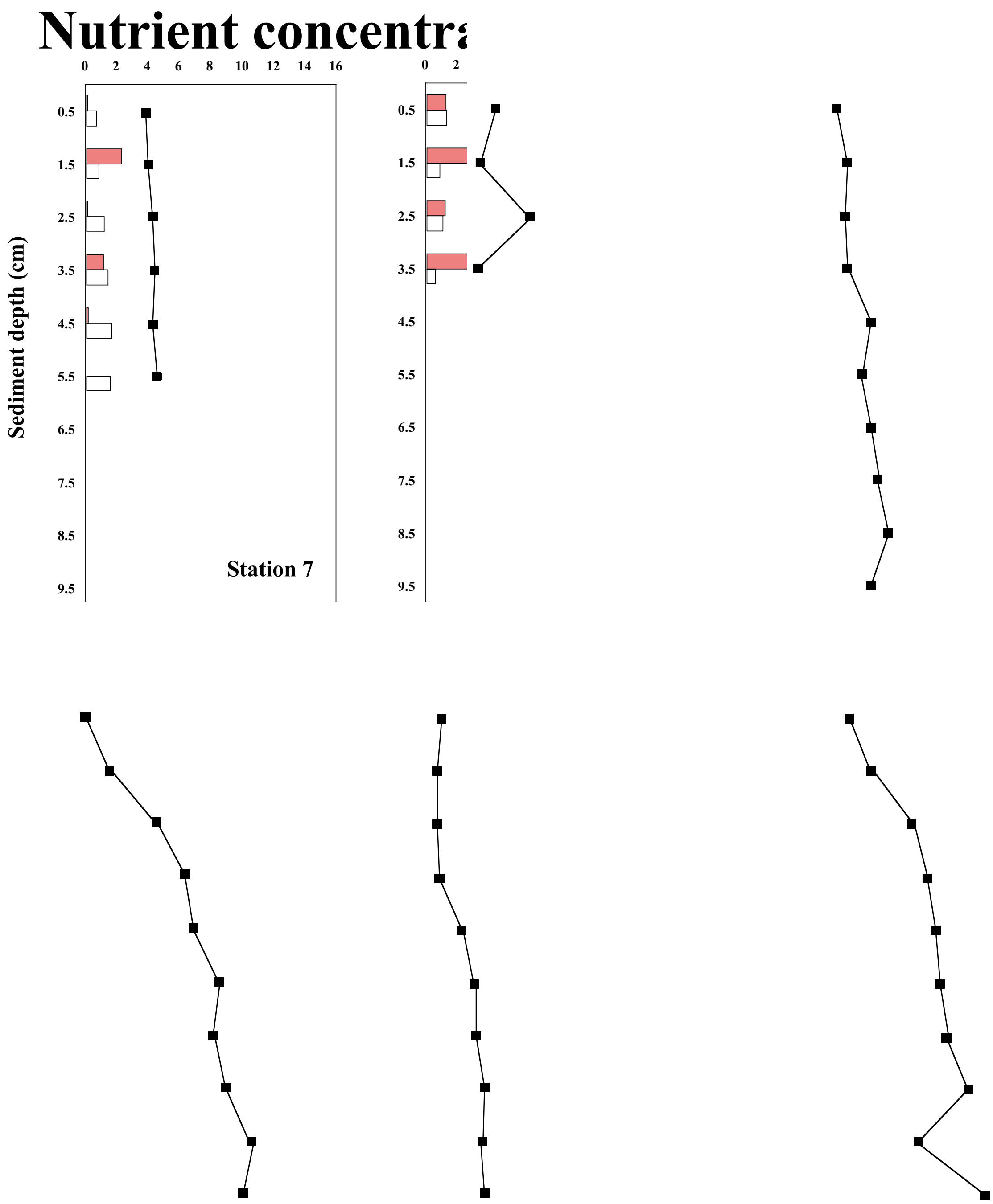

Fig. 2. Vertical profiles of pore water nitrate, phosphate and ammonium concentrations of the sediments.

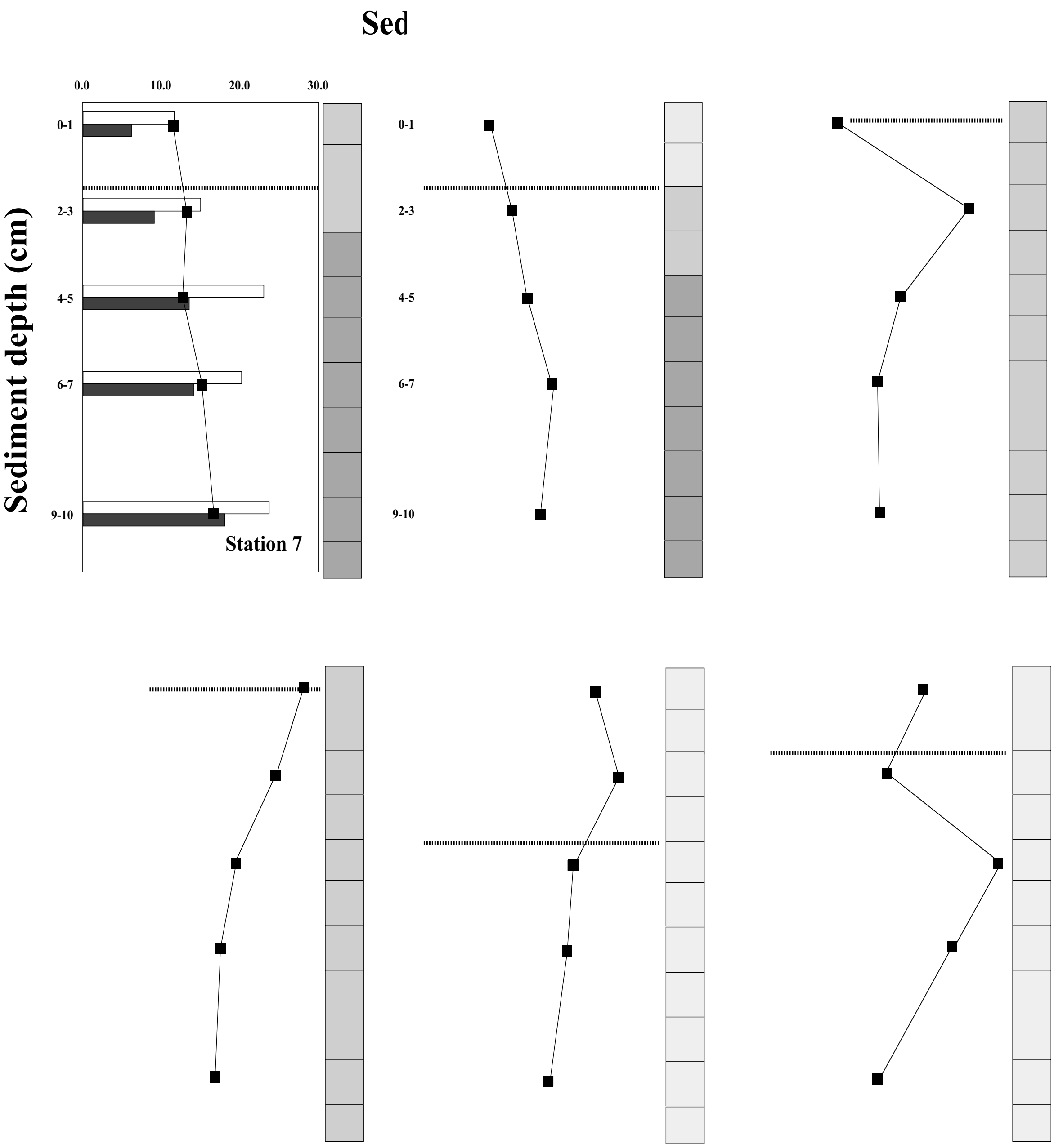

Fig. 3. Vertical profiles of total organic carbon (TOC), total organic nitrogen (TON) and C:N ratio of the sediments (dot lines indicating oxidized depth and core logging for each station are illustrated

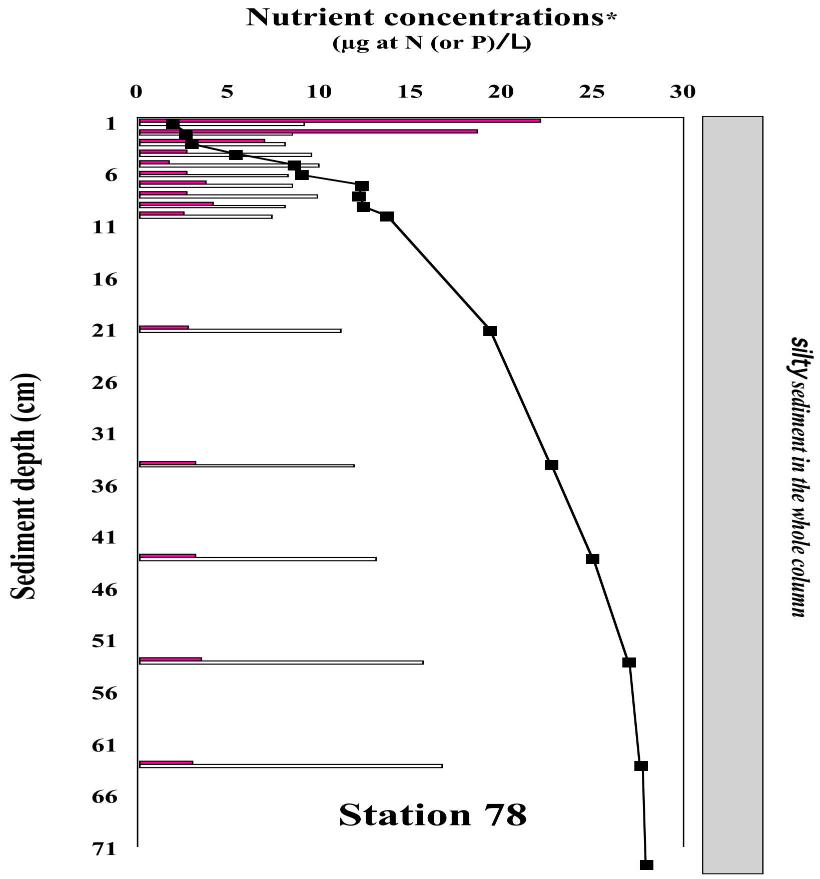

Fig. 4. Vertical profiles of total organic carbon (TOC), total organic nitrogen (TON) and C:N ratio of long sedimental core of station No. 78 (Core logging is comparatively illustrated).

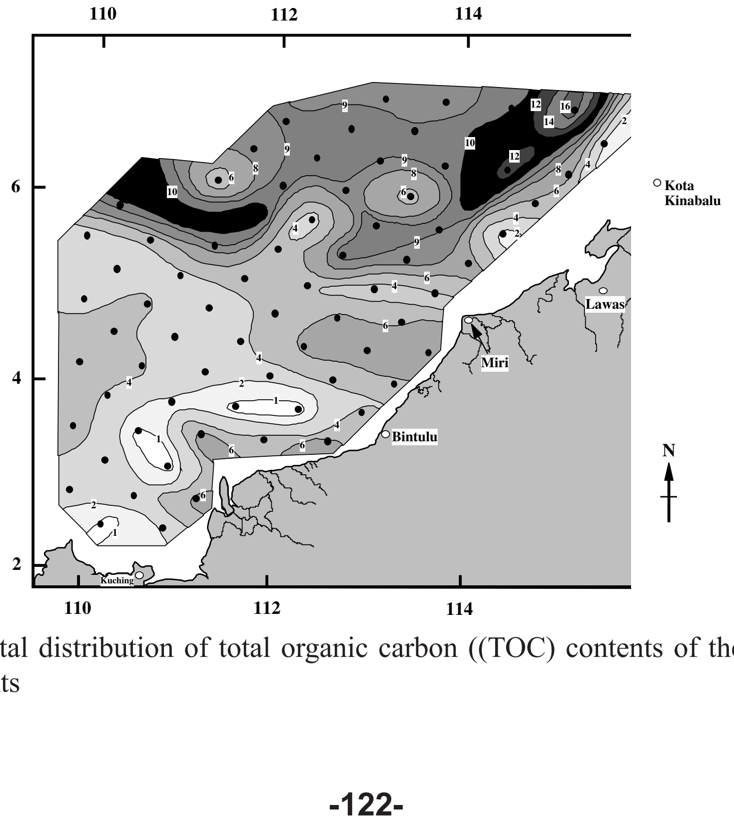

Fig. 5. Horizontal distribution of total organic carbon ((TOC) contents of the surface (0-1 cm) sediments

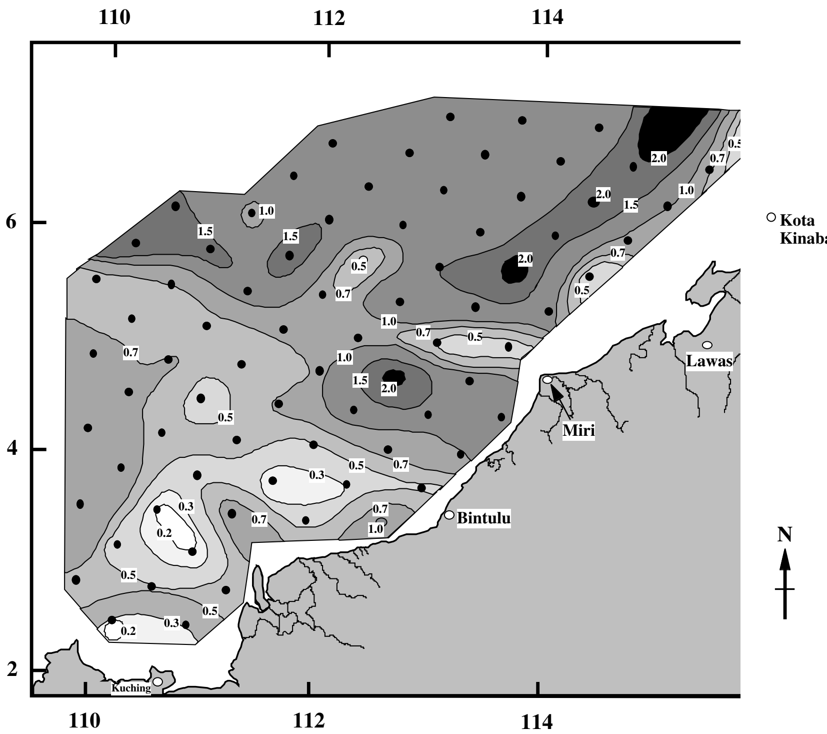

Fig. 6. Horizontal distribution of total organic nitrogen ((TON) contents of the surface (0-1 cm) sediments

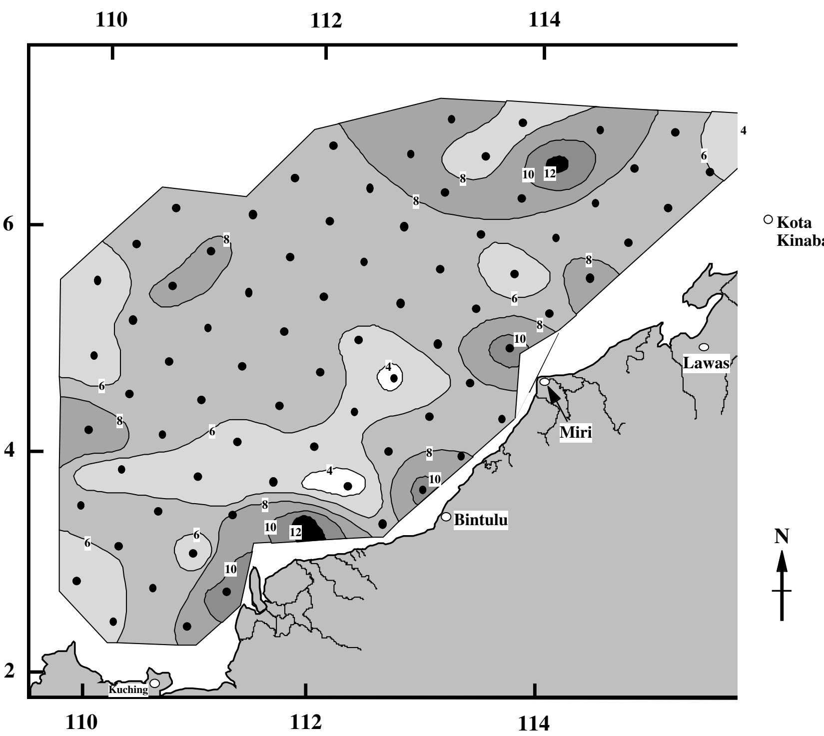

Fig. 7. Horizontal distribution of C:N ratios of the surface (0-1 cm) sediments

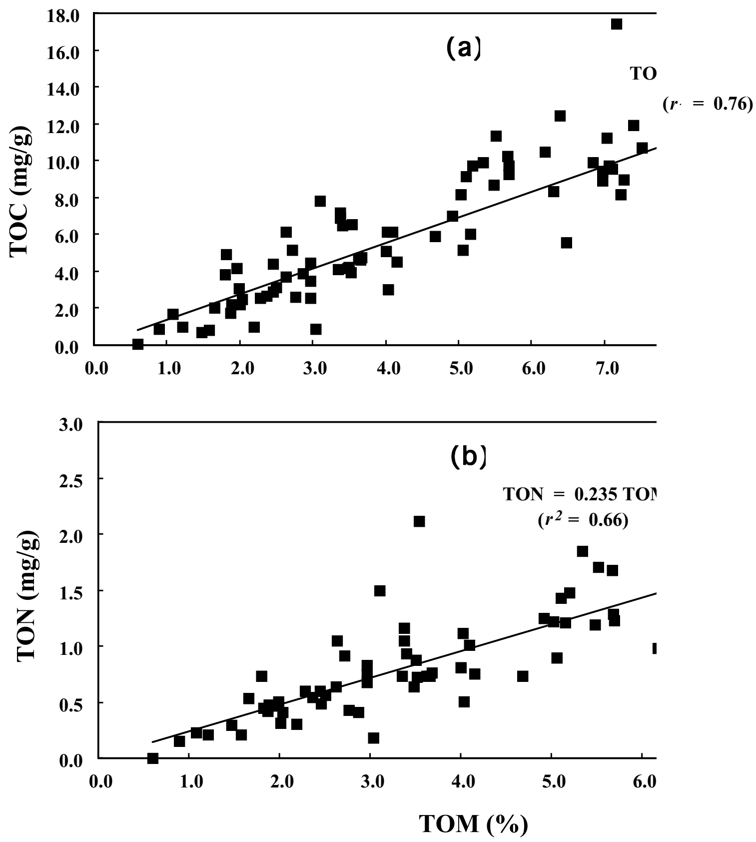

Fig. 8. Relationships between the levels of total organic contents (TOM) and total organic carbon (TOC) contents; a) and total organic nitrogent (TOC); b) of the sediments obtained from the whole study area.

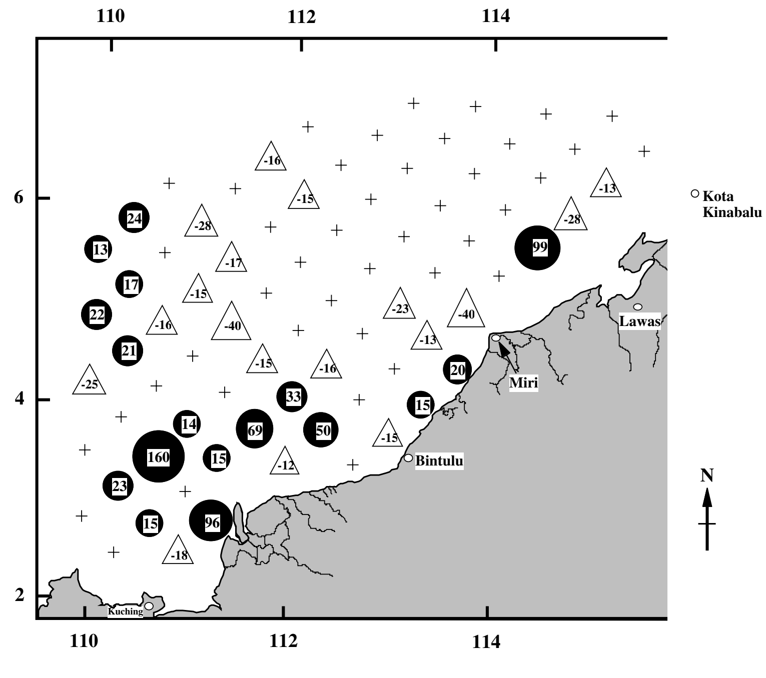

Fig. 9. Percentage of increases (dull circles) or decreases (open triangles) in the levels of total organic contents (TOM) of the surface (0-1cm) sediments after the northeast monsoon period

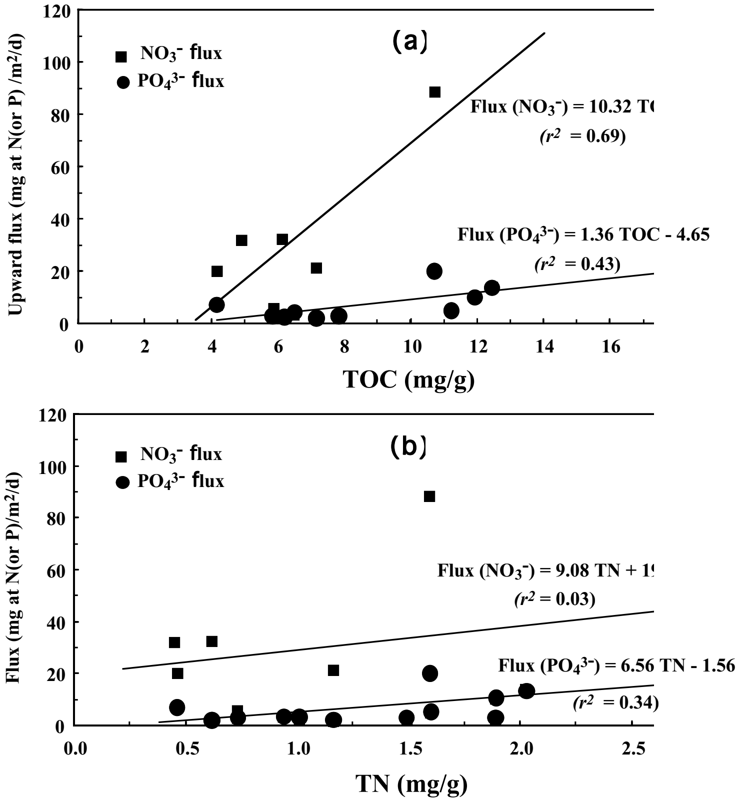

Fig. 10 Relationships between the calculated rates of upward diffusive fluxes of pore water nutrients and the levels of total organic carbon (TOC) contents; (a) and total organic nitrogen (TON) contents; (b) of the surface (0-1cm) sediments.

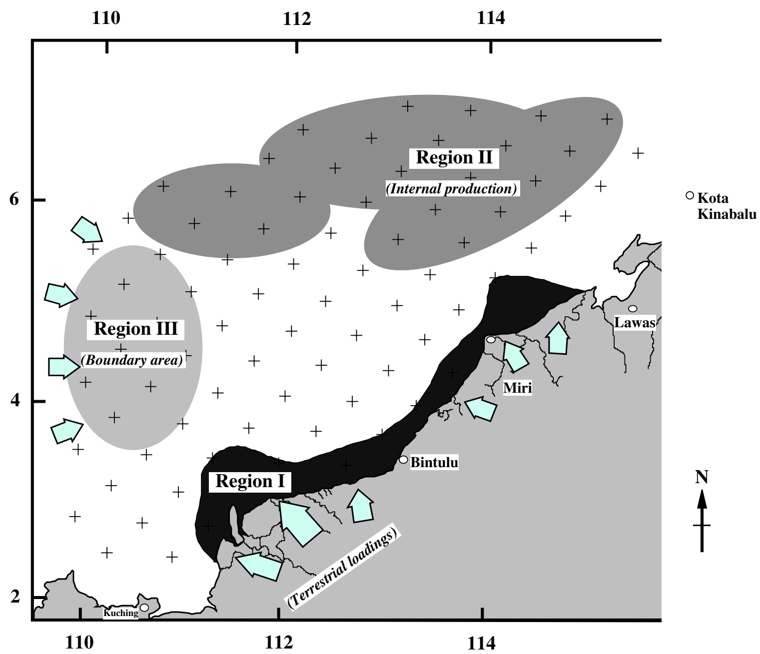

Fig. 11 Schematic zoning of the bottom sediments in the Sabah, Sarawak and Brunei Darussalam waters for fishery resource development and management purpose.

surface sediment. In the case of NH_4^+-N, the upwad fluxes range widely from 0 to 388.0 mg at N/m^2/d. Very high NH_4^+-N upwad fluxes are about one order of magnitude higher than those of NO_3^--N and PO_4^{3-}-P, and generally observed in nearshore stations with high organic content (e.g. stations 31, 47, and 76). However, such values fluctuated greatly in stations and thus may reflect the variations in macrofaunal activity, detrital inputs to the sediment-water interface, and the oxygen content of the bottom water.

In this study area, fairly high rates of nutrient upward fluxes have been demonstrated. They are comparable to the estimated benthic flux at very high productivity areas (e.g upwelling area of Chile; Farias *et al*. (1996) and organically enriched area of the Seto Inland Sea; Yamamoto *et al*. (1998)). The sediment here should thus be able to provide an important nutrient sources for phytoplankton in the water column with respect to other sources, such as inputs from salt marshes and rivers. Release flux from the sediment is known to be affected by sediment property, temperature, dissolved oxygen, deposited substances supplied from seawater, etc. (Kato and Terunuma 1995) Examination on the relations between the rates of nutrient upward fluxes and sedimentary organic levels (TOC and TON) by linear regression method (**Fig. 10**) indicates remarkable correlations of NO_3^--N and PO_4^{3-}-P upwad flux rates to TOC (r^2 = 0.69 and 0.43, respectively) but less correlations to TON (r^2 = 0.03 and 0.34, respectively). These correlations indicate that the accumulated organic matter tends to be biogenically metabolized and thus enhance the exchange between the sediment-water interface of the water region.

General consideration

Organically enriched bottom sediment is important either as habitats and direct food sources for benthic production or as potential nutrient source for biological productivity of the water column. For further fishery resource development and management of the sea areas of Sabah, Sarawak and Brunei Darussalum, the overall information obtained from this study have been used to characterize the bottom sediments into three distinct regions (**Fig. 11**):

(I) a shallow, nearshore organically enriched region, in which the high organic materials accumulated are mostly land-derived sources,

(II) a deep, offshore organically enriched region, in which the high organic materials accumulated are marine-derived sources and,

(III) a boundary-offshore region, with moderate organic levels, receiving more affect of outside water mass movement.

These three regions are different in diagenesis characteristics of the sediment and related pore water nutrient constituents. Region (I) should be the most appropriate area for benthic production development. However, since this region is temporal impacted from terrestrial organic loadings and apt to be organically polluted, monitoring of both magnitude and direction of the organic loadings may be of future importance. Correspondingly high upward diffusive flux of NH_4^+-N at the sediment-water interface is also a distinct characteristic of this region. At Region (II), highest sedimentary organic contents are observed. This region is an important "sink" area of internal production in adjacent waters and thus could provide a potential source of nutrient, PO_4^{3-}-P in particular, into overlying seawater. Here, possibility of upward movement of bottom water should deserve more in depth study since it may occasionally enhance primary production in the water column. Region (III) is the conjunction zone which can receive more influence of the whole water circulation regime of the South China Sea. This area directly faces comparatively strong current and thus future attempt in clarifying depositional characteristics of the bottom sediment may provide a better understanding of precise current pattern of the sea area.

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References

Azmy, A. R., Isoda, Y. and Yanagi, T. 1991. Sea level variation due to wind around West Malaysia. Scientific report of Ehime University, Japan, **12(2)**: 148-161.

Berner, R. A. 1974. Kinetic model for the early diagenesis of nitrogen, sulfur, phosphorus and silicon in anoxic marine sediments. *In* The Sea (E. D. Goldberg, ed.). Wiley, pp. 427-449.

Chao, S., Shaw, P. and Wang, J. 1995. Wind relaxation as a possible cause of the South China Sea warm current. *Journal of Oceanography*, **51**: 111-132.

Dugdale, R. C. and Goering, J. J. 1967. Uptake of new and regenerated forms of nitrogen in primary productivity. *Limnology and Oceanography*, **12**: 196-206.

Farias, L., Chuecas, L. A. and Salamanca, M. A. 1996. Effect of coastal upwelling on nitrogen regenerationfrom sediments and ammonium supply on the water column in Concepcion Bay, Chile. *Estuarine and Coastal Marine Science*, **43**: 137-155.

Hedges, J. I., Clark, W. A. and Cowie, G. L. 1988. Organic matter sources to the water column and surficial sediments of a marine bay. *Limnology and Oceanography*, **33(5)**: 1116-1136.

Horie, T. and Hosokawa, Y. 1985. Mathematical model for prediction of phosphorus release. *Report of the Port and Habour Research Institute*, **24(1)**: 43-68.

Hosper, S. H. 1984. Restoration of Lake Veluwe, The Netherland, by reduction of phosphorus loading and flushing. *Water Science Technology,* **17**: 757-768.

Kato, Y. and Terunuma, Y. 1995. Recycling of biogenic materials in sediments from the East China Sea: Results of MASFLEX pore water study. *In* Proceedings of the 1994 Sapporo IGBP Symposium, 14-17 November 1994, Sapporo, Japan. pp. 238-245.

Kennet, J. 1982. Marine Geology. Prentice-Hall, Inc. Englewood Cliffs, N. J., 486 pp.

Lerman, A. 1979. Geochemical processes: Water sediment environments. John Wiley & sons, 481 pp.

Li, Y. H. and Gregory, S. 1974. Diffusion of ions in sea water and in deep-sea sediments. *Geochimica et Cosmochiica. Acta*, **38**: 703-714.

Lijklema, L. 1980. Interaction of orthophosphate with iron (III) and aluminum hydroxides. *Evironmental Science Technology*, **14**: 537-541.

Meksumpun, S., Meksumpun, C., Hoshika, A., Mishima, Y. and Tanimoto, T. 1998. Stable isotope technique for evaluation of organic matter movement and coastal environment status. *In* Applied Sciences and the Environment. (D. Almorza and H. M. Ramos, eds.), WITpress, Southampton, UK, pp. 189-204.

Mishima, Y., Hoshika, A. and Tanimoto, T. 1996. Movement of terrestrial organic matter in the Osaka Bay, Japan. *In* Proceedings of the third International Symposium of ETERNET-APR: Conservation of the Hydrospheric Environment, 3-4 December 1996, pp. VI-20-25, Bangkok.

Montani, S., Mishima, Y. and Okaichi, T. 1991. Scavenging processes of marine particles in Osaka Bay. *Marine Pollution Bulletin EMECS'90*, **23**: 107-111.

Prahl, F. G., Bennett, J. T. and Carpenter, R. 1980. The early diagenesis aliphatic hydrocarbons and organic matter in sedimentary particulates from Dabob Bay, Washington. *Geochemica et Cosmochimica Acta*, **44**: 1967-1976.

Rashid, M. A. and Reinson, G. E. 1979. Organic matter in surficial sediments of the Miramichi Estuary, New Brunswick, Canada. *Estuarine and Coastal Marine Science*, **8**: 23-36.

Ryding, S. O. and Forsberg, C. 1977. Sediments as a nutrient source in shallow polluted lakes. *In* Interaction between sediment and freshwater (H. L. Golterman, ed.). Dr. W. Junk Publishers. pp. 227-234.

Sas, H. (ed.) 1989. Lake restoration by reduction of nutrient loading: expectations, experiences, extrapolations. Academia Verl. Richarz.

Smits, J. G. C. and van der Molen, D. T. 1993. Application of SWICTH, a model for sediment-water exchange of nutrients, to Lake Veluwe in The Natherlands. *Hydrobiologia*, **253**: 281-300.

Søndergaard, M., Jeppesen, E., Kristensen, P. and Sortkjaer, O. 1990. Interaction between sediments and water in the shallow and hypertrophic lake: a study on phytoplankton collapses in Lake Søbygard, Denmark. *In* Trophic Relationships in Inland Waters (P. Biro and J. F. Talling, eds.). Kluwer Academic Publinshers, Dordrecht, pp. 247-258.

Tan, F. C., Cai, D. L. and Edmond, J. M. 1991. Carbon isotope Geochemistry of the Changjiang Estuary. *Estuarine, Coastal and Shelf Science*, **32**: 395-403.

Thornton, S. F. and McManus, J. 1994. Application of organic carbon and nitrogen stable isotope and C/N ratios as source indicators of organic matter provenance in estuarine systems: Evidence from the Tay Estuary, Scotland. *Estuarine, Coastal and Shelf Science*, **38**: 219-233.

Usui, T. Koike, I. and Ogura, N. 1998. Tidal effect on dynamics of pore water nitrate in intertidal sediment of a eutrophic estuary. *Journal of Oceanography*, **54**: 205-216.

Vanderborght, J. and Billen, G. 1975. Vertical distribution of nitrate concentration in interstitial water of marine sediments with nitrification and denitrification. *Limnology and Oceanography*, **20**: 953-961.

Vanderborght, J., Wollast, R. and Billen, G. 1977*a*. Kinetic models of diagenesis in disturbed sediments. Part 1. Mass transfer properties and silica diagenesis. *Limnology and Oceanography*, **22(5)**: 794-803.

Vanderborght, J., Wollast, R. and Billen, G. 1977*b*. Kinetic models of diagenesis in disturbed sediments. Part 2. Nitrogen diagenesis. *Limnology and Oceanography*, **22(5)**: 787-793.

Van Raaphorst, W., Ruardij, P. and Brinkman, A. G. 1988. The essessment of benthic phosphorus regeneration in an estuarine ecosystem model. *Netherland Journal of Sea Research.*, **22**: 23-36.

Wyrtki, K. 1961. Physical oceanography of the Southeast Asian waters, NAGA Report Vol. 2, Scientific Results of Marine Investigations of the South China Sea and the Gulf of Thailand, Scripps Onstitution of Oceanography, La Jolla, California, 195 pp.

Yaacob, R. 1990. The organic carbon content of sediment in the South China Sea off Sabah. Occasional Publication of UPM, Malaysia. **9:** 87-90.

Yaacob, R. and Higashikawa, S. 1990. Bottom sediment in the South China Sea off Sabah. Occasional Publication of UPM, Malaysia. **9**: 91-96.

Yamamoto, T., Matsuda, O., Hashimoto, T., Imose, H. and Kitamura, T. 1998. Estimation of benthic fluxes of disolved inorganic nitrogen and phosphorus from sediments of the Seto Inland Sea. Umino Kenkyuu, **7(3)**: 151-158. (in Japanese with English abstract)

Trace Metals Concentrations and Distributions in Sea Water of the South China Sea, Area II :Sabah, Sarawak and Brunei Darussalam

Wilaiwan Utoomprurkporn, and Anond Snidvongs

Department of Marine Science, Chulalongkorn University, Bangkok10330, Thailand

ABSTRACT

Water samples off Sabah, Sarawak and Brunei Darussalam were collected during July–August 1996 and May 1997 and analyzed for dissolved and particulate cadmium, copper, iron, lead and nickel. Dissolved metals were coprecipitated with cobalt-APDC while particulate metals were digested with aqua regia and hydrofluoric acid. The concentrations of metals were measured using graphite furnace atomic absorption spectrophotometer. Concentrations of cadmium, copper, lead and nickel were in the same concentration ranges of unpolluted coastal water elsewhere except for some high concentrations of cadmium at some stations offshore. Iron concentrations were much higher than other regions, and the concentrations were about twenty times those found in the Gulf of Thailand and east coast of Malay Peninsula. High concentrations of these five metals in the offshore area in the July-August sampling possibly came from the Indonesian water flowing northward due to the influence of the wind from the south.

Key words: trace metal, South China sea, Sabah, Sarawak, Brunei Darussalam

Introduction

As part of the SEAFDEC Cooperative Programme on the study of Fisheries Oceanography of the South China Sea, a study on trace metal contamination was made. Trace metals are the natural components in seawater. Prior to the period of human disturbance of the environment, trace metals in the water were derived from continental rocks by weathering and partly from sediment due to leaching, desorption, dissolution, cation exchange, and other processes. For some elements, such as lead, anthropogenic atmospheric input may also be important. As the natural system is at equilibrium, the input must be equal to the output where these dissolved trace metals in the water are removed back to solid phase, i.e. sediments, by a suite of geochemical reactions such as adsorption, precipitation and cation exchange. Some metals, mercury for example, can be volatile and removed from seawater via the atmosphere. These physical and chemical processes involving trace metals are strongly controlled by environmental factors, for instances, temperature, salinity (ionic strength), pH and redox potential [Drever (1982)]

In this report, the metals; cadmium, copper, nickel, lead and iron in water collected off Sabah, Sarawak and Brunei Darussalam were studied in the dissolved and particulate forms. Concentration and distribution of these trace metals can provide some details on sources, cycling and removal processes. It is also an indicator of human impact and imprint on the environment and on the quality of its living resources.

Methods

Dissolved trace metals in water samples were coprecipitated with cobalt-APDC [Boyle and Edmond (1977)] modified by [Huizenga (1981)]. Precipitates were collected by hand vacuum filtration on Nuclepore 0.4 µm membranes. The precipitates were further dissolved in HNO_3 and diluted with Milli-Q water. The final solutions were measured for cadmium, copper, iron, lead and nickel

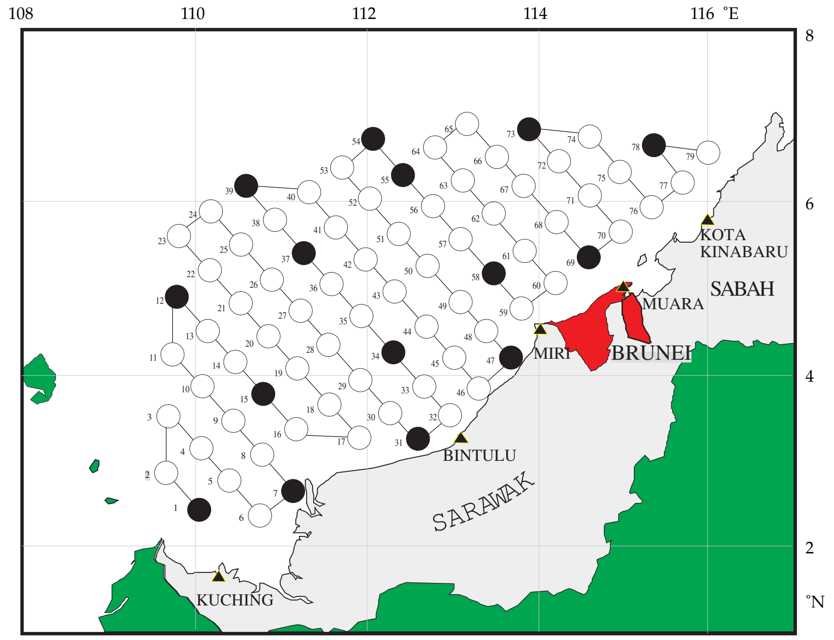


Fig. 1. Sampling stations (in dark circles)

using a Perkin Elmer Zeeman Graphite Furnace 4100ZL atomic absorption spectrophotometer. Merck standard solutions diluted by Milli-Q water was used as standards. Certified Reference Seawater CASS-2 of the Institute for Environmental Chemistry, Canada, was included in sample preparation and analysis as quality control samples to ensure the accuracy of the results. The percentage recovery of cadmium was 115.8%, copper was 94.5%, iron was 105.0%, nickel was 95.0% and lead was 110.5%. All bottles, filter membranes and labwares that would be in contact with samples were carefully pre-washed with nitric acid and Milli-Q water.

Particulates retained on the membrane filter were digested in a teflon decomposition vessel (Lorran, capacity 40 ml.) with aqua regia and HF. The teflon bomb was placed inside a plastic pressure cooker which was then placed inside an ordinary household microwave oven, with the power turned on full for 1 minute. Very pure boric acid was then added to the digested liquid and the liquid quantitatively transferred into a clean 10 ml. polyethylene tube with screw cap [Loring and Rantala (1990)]. Metal concentrations were determined with flameless graphite furnace atomic absorption spectrophotometry. Standard Reference Material used in quality control is MAG-1 by which the percentage recovery of cadmium was 93.2 %, copper was 101.0 %, iron 109.9%, nickel 85.2 % and lead 112.3 %.

Results and Discussion

The results showed that concentrations of dissolved cadmium, copper, nickel and lead in the samples were very low and well within the range found in unpolluted coastal water elsewhere (Table 1). Some high concentrations of cadmium (higher than 1 nM) were observed at station 39, 54, 73 and 78 which were located offshore (Fig 2 -5). Dissolved iron concentrations were 47- 1,672 nM in July-Aug 1996 and 92-2,020 nM in May 1997 which were higher than other regions. Further investigation on the sources of metals especially iron in this area should be carried out. Concentrations of dissolved and particulate metals at each station are shown in Appendix 1-4. Comparison of dissolved and particulate Cd, Cu, Fe, Pb and Ni at different areas in the South China Sea (Table 2) indicated that concentrations of copper, lead and nickel in the three areas i.e. off the Mekong Delta [Hungspreugs *et al*. (1998)], the Gulf of Thailand and east coast of Malay Peninsula [Utoomprurkporn *et al.* (1998)]

Table 1 Comparison of the concentrations of dissolved Cd, Cu, Fe, Ni and Pb off Sabah, Sarawak and Brunei Darussalam with others areas of the world (nM)

Trace metals	Cd	Cu	Fe	Ni	Pb
South African Coast[a]	0.3-1.4	4.7-23.6	12.5-39.4	10.2-66.4	-
Sea of Japan[a]	0.98	4.72	16.12	17.03	-
China Sea[a]	0.4-1.1	6.3-36.2	17.9-25.1	11.9-85.2	-
San Francisco Bay[b]	0.07-1.47	8.5-73.0	2.5-906	3.7-31.5	-
St. Lawrence Estuary[c]	0.53	17.15	537.18	13.8	-
Off the Mekong Delta[d]	0.05-0.17	3.2-9.7	-	2.92-12.40	0.06-0.85
Gulf of Thailand[e]	0.01-0.17	1.5-9.0	1.9-54.3	0.5-9.0	0.03-1.00
ocean margin[f]	0.18	6.3	7.2	10.2	0.12
This study	0.01-1.37	2.9-20.5	47-2020	1.3-14.1	0.02-1.50

a (Chester and Stoner, 1974) b (Flegal et al. 1991) C(Yeats and Loring, 1991)
d (Hungspreugs et al. 1998) e (Utoomprurkporn et al. 1998) f (Martin and Windom, 1991)

Table 2 Comparison of dissolved and particulate Cd, Cu, Fe, Pb and Ni in the South China Sea : off Sabah, Sarawak and Brunei Darussalam, the Gulf of Thailand and off the Mekong Delta (nM)

metal	off Sabah, Sarawak and Brunei		Gulf of Thailand[a]		off the Mekong Delta[b]	
	April-May 97	July-Aug 96	April-May 96	Sept-Oct 95	Mar-97	Oct-97
Cd_D	0.01-1.31	0.01-1.37	0.02-0.13	0.01-0.29	0.05-0.40	0.05-0.20
Cd_P	0.001-0.011	0.001-0.029	0.001-0.090	0.04-0.13	0.048-0.435	0.002-0.596
Cu_D	2.95-20.5	3.81-19.65	1.03-8.87	1.09-22.90	1.30-11.20	4.27-16.50
Cu_P	0.72-2.31	0.92-1.88	0.27-5.65	0.78-20.47	0.26-66.23	0.20-50.07
Fe_D	92-2020	47-1672	4.38-59.80	6.72-87.71	-	-
Fe_P	71-1911	255-1850	21.63-417.65	-	-	-
Ni_D	3.3-14.1	1.3-13.4	1.66-8.71	1.86-17.17	1.93-8.77	3.74-20.48
Ni_P	0.17-0.76	0.17-0.90	0.16-1.96	1.19-6.81	2.59-78.94	0.50-41.73
Pb_D	0.02-0.32	0.02-1.50	0.06-0.93	0.04-1.74	0.06-0.33	0.03-0.34
Pb_P	<0.02	<0.02	0.02-0.65	0.09-0.72	0.97-22.35	0.11-15.63

a (Hungspreugs and Utoomprurkporn, 1997)and (Rattanachongkiat, 1998)
b (Hungspreugs et al. 1998)
D = dissolved metal
P = particulate metal

Table 3. Percentage of dissolved Cd, Cu, Fe, Pb and Ni off Sabah, Sarawak and Brunei Darussalam

Sampling time	%Cd	%Cu	% Fe	% Pb	%Ni
July-Aug 96	58-100	75-94	Nov-95	> 99	67-97
April-May 97	65-100	60-95	18-88	> 99	84-98

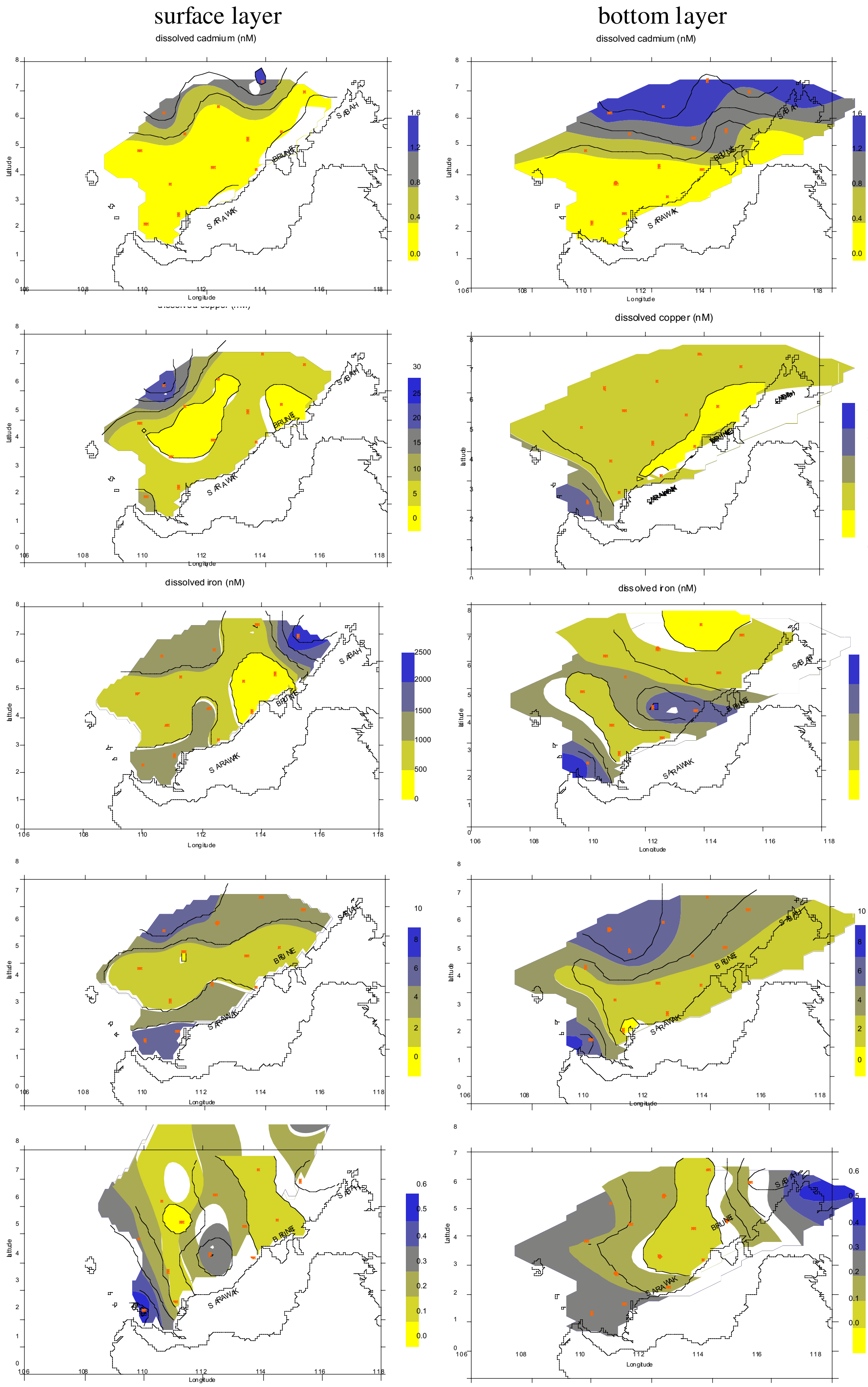


Fig. 2. Distribution of dissolved cadmium, copper, iron, nickel and lead (July-August 1996)

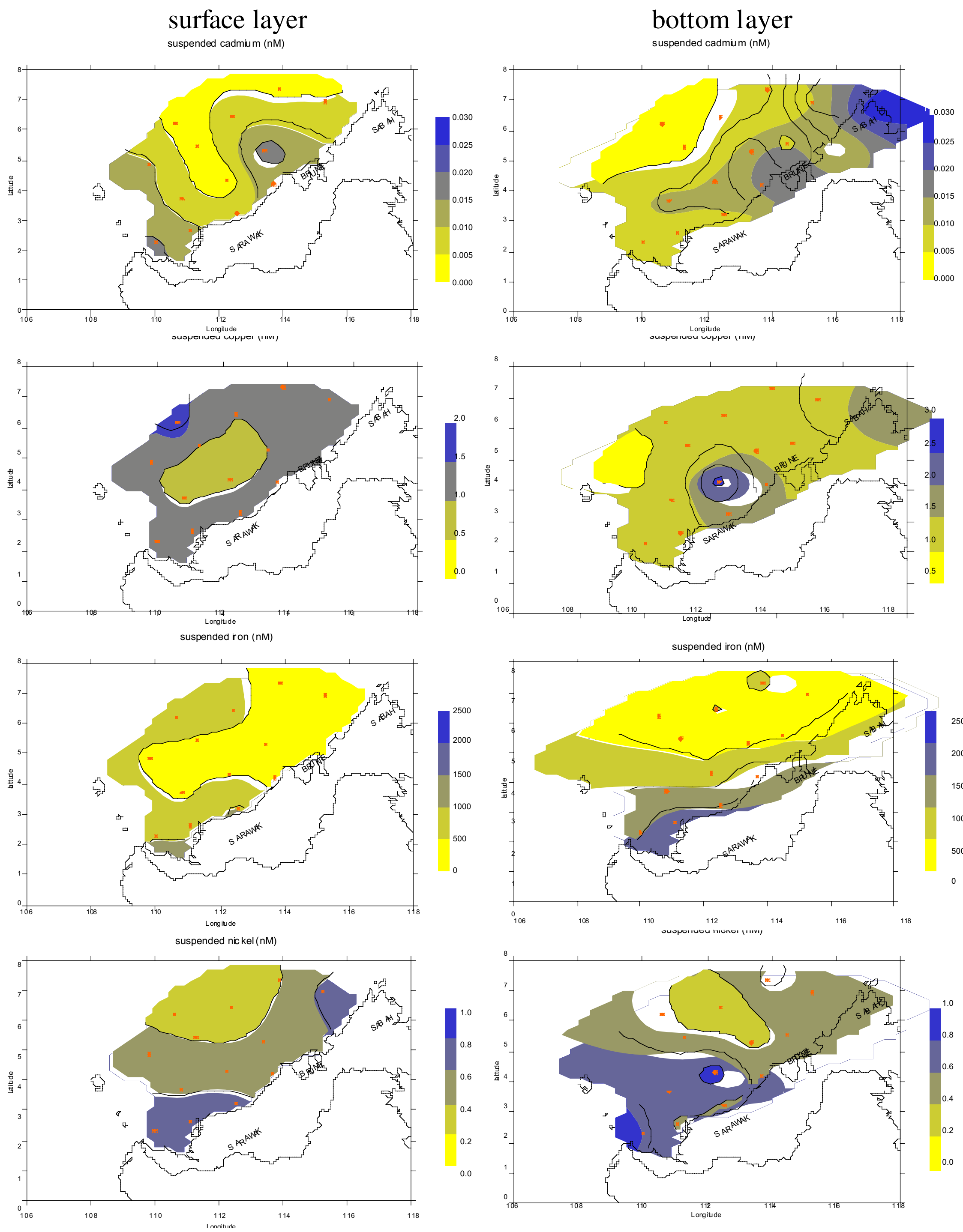


Fig.3. Distribution of suspended cadmium, copper, iron and nickel (July-August 1996)

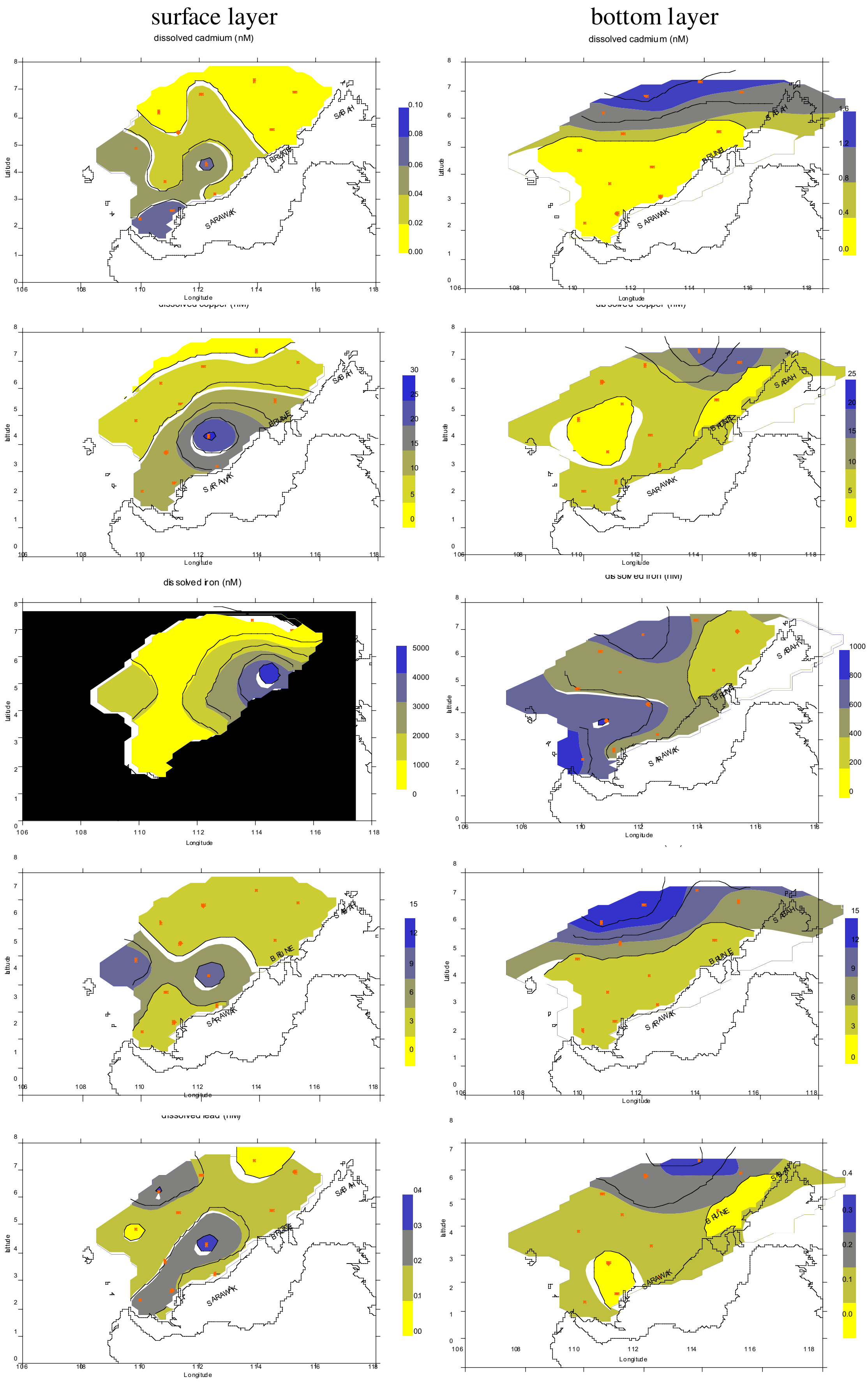


Fig. 4. Distribution of dissolved cadmium, copper, iron, nickel and lead (May 1997)

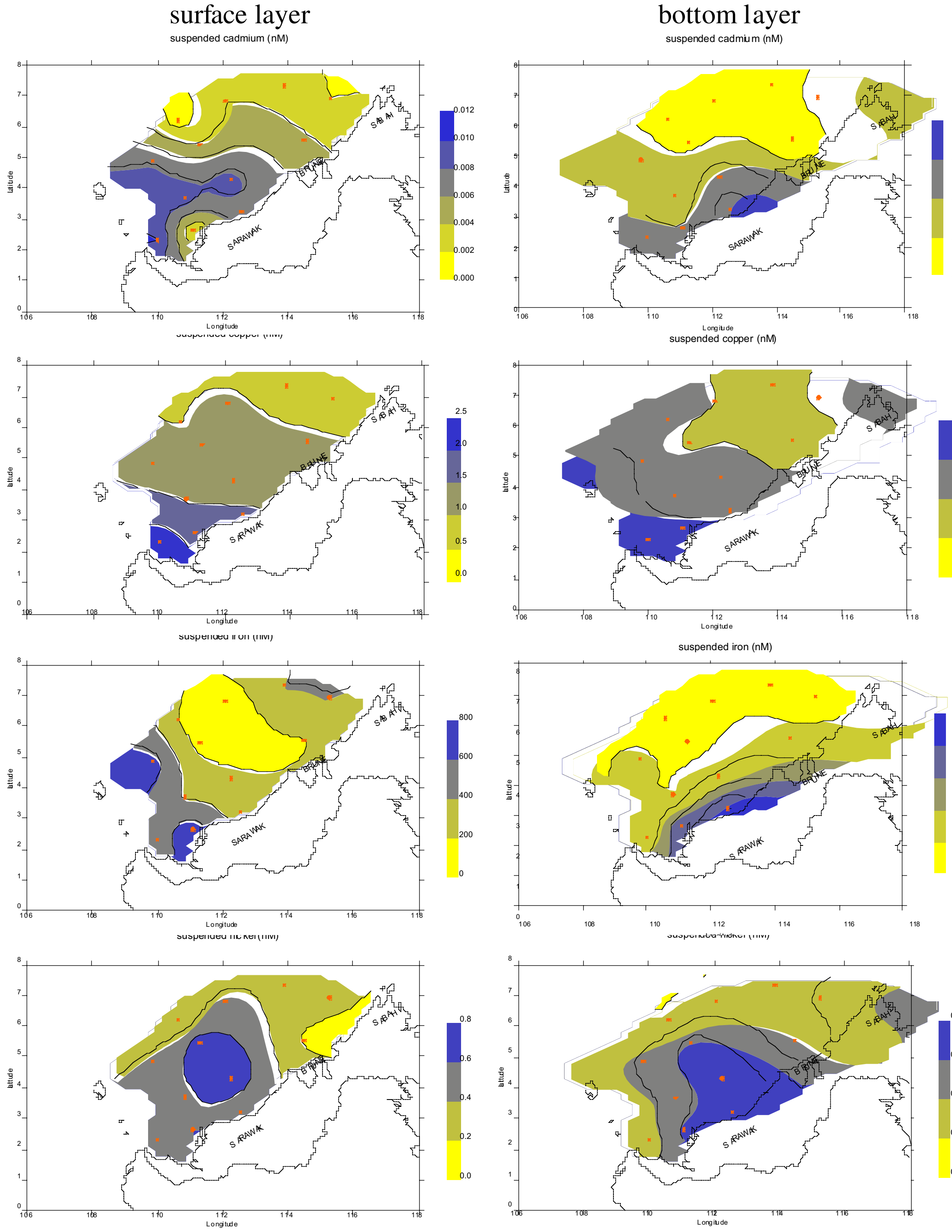


Fig. 5. Distribution of suspended cadmium, copper, iron, and nickel (May 1997)

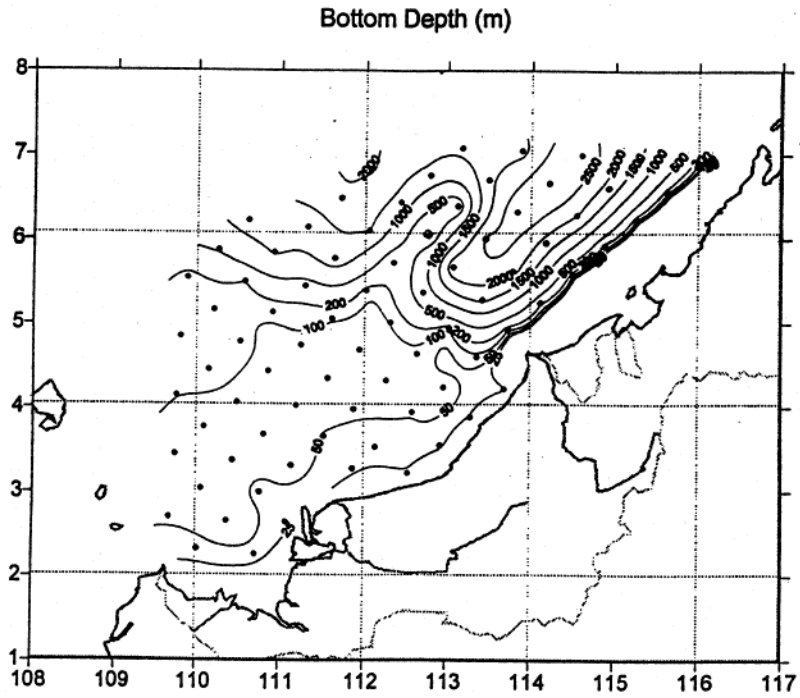


Fig.6. Botom topography off Sabah, Sarawak and Brunei Darussalam [from Snidvongs, *et al*, (1997)]

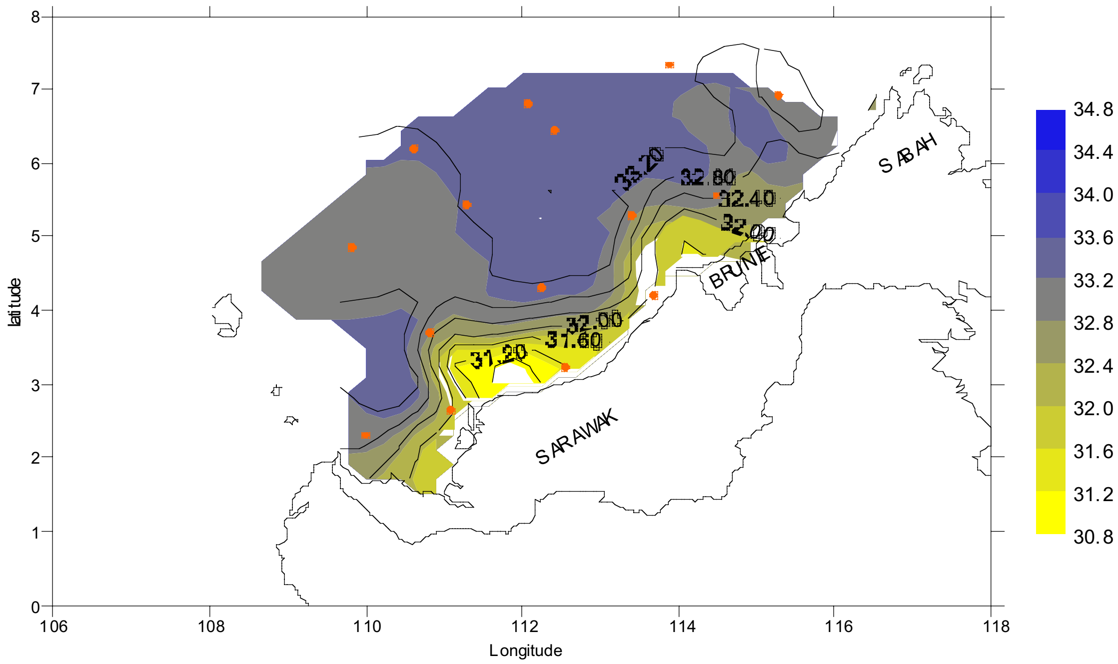
and the area in this study were in the same concentration range. However, cadmium concentrations at some stations offshore in this study area were higher than other two areas. Iron concentrations off Sabah, Sarawak and Brunei Darussalam were about twenty times higher than in the Gulf of Thailand and east coast of Malay Peninsula, but there were no data of iron in the Mekong Delta water.

Cadmium, copper, lead and nickel were mostly present in dissolved form (Table 3) while iron which is geochemically-controlled element [Martin and Windom (1991)] was in particulate form at most stations (low percentage of dissolved iron). However, high percentage of dissolved iron was found at some stations where high concentrations of iron were observed.

Bottom topography off Sarawak (Fig. 6) [Snidvongs, Siriraksophon and Rojana-anawat (1997)] was much shallower than off Brunei and Sabah. The surface mixed layer depths in this area were less than 50 meters. The extent of the influence of freshwater from the Rajang River and the Baram River is shown in Fig. 7. Higher freshwater input was observed in July – August 1996 than in May 1997. The contours of surface distribution of copper, iron lead and nickel reflected some effect of the river input especially in May 1997, but not for cadmium where higher concentrations were observed at stations offshore and extend down to the bottom layer (Fig. 2-5). High concentrations of copper, iron, lead and nickel were also found at stations offshore indicating other sources of these metals.

Surface circulation patterns during the two sampling periods indicated that the circulation appeared to be in the opposite direction (Fig. 8) [Soegiarto (1981)]. In August when the Southwest Monsoon prevails, the water flows from Java Sea up north to the Phillippines. The high concentration of these metals offshore in this season possibly came from the contamination in the Indonesian water. In May 1997, high concentration of metals in the surface layer were found near the coast but in the bottom layer high concentration of metals at stations offshore were still observed (Fig. 4). High metal/Al ratio in suspended particulate also showed the different sources of contamination in the two sampling periods (Fig. 9-10).

July-August 1996



April-May 1997

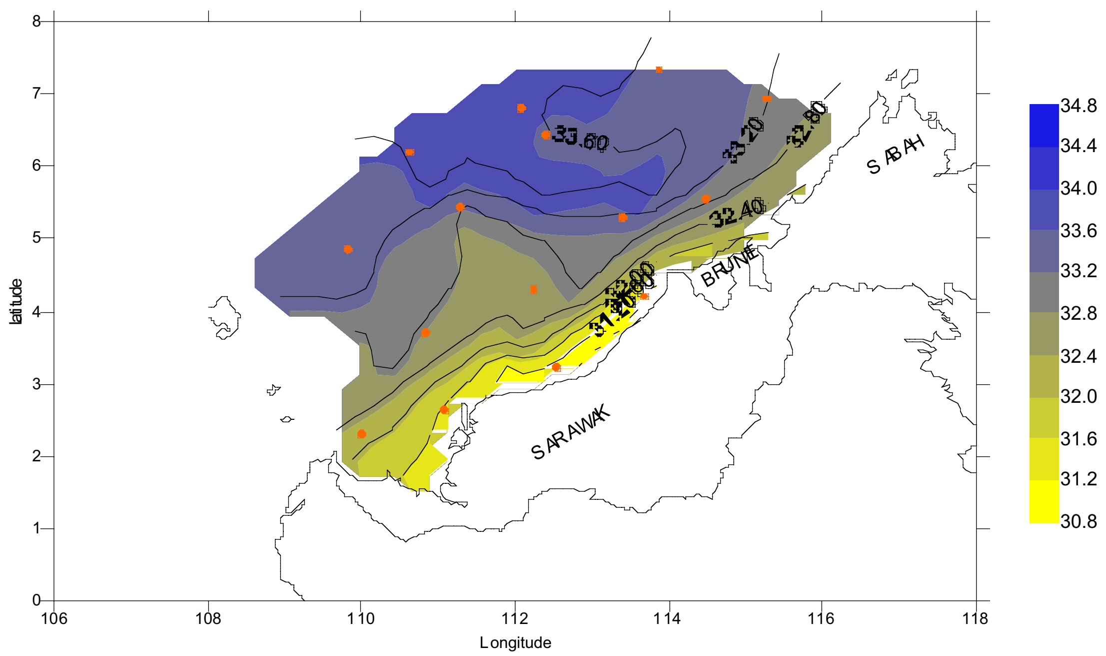
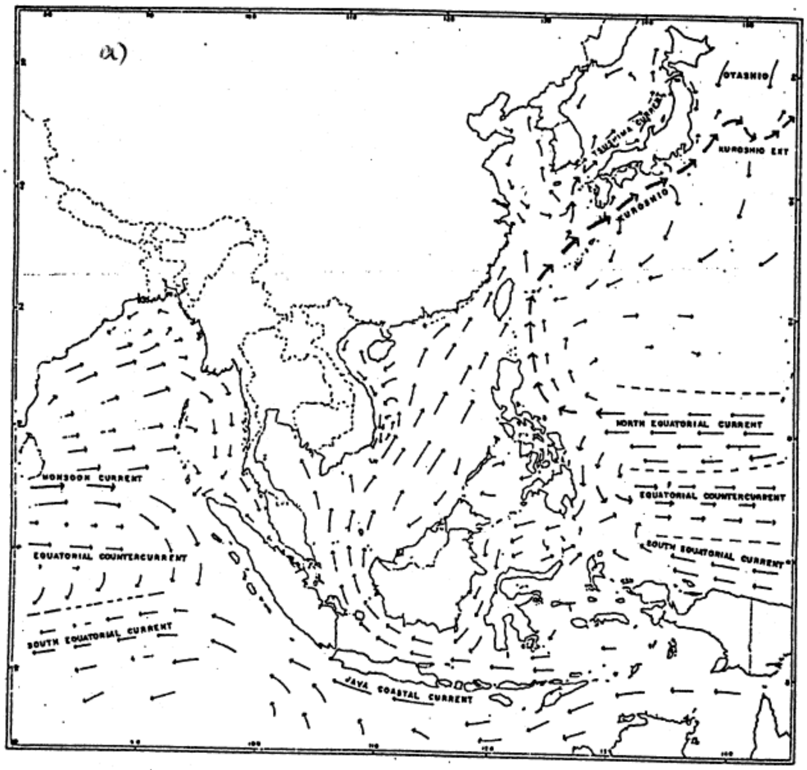


Fig. 7. Surface distribution of salinity



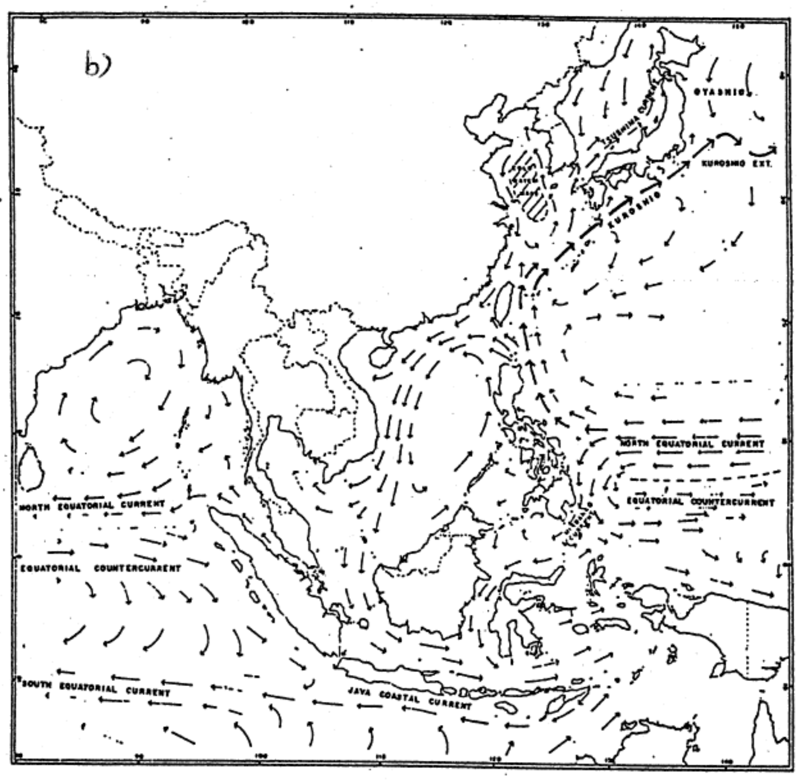


Fig. 8. Surface currents in East Asian Waters [from Soegiarto, (1981)] a. Southwest Monsoon season , b. Northeast Monsoon season

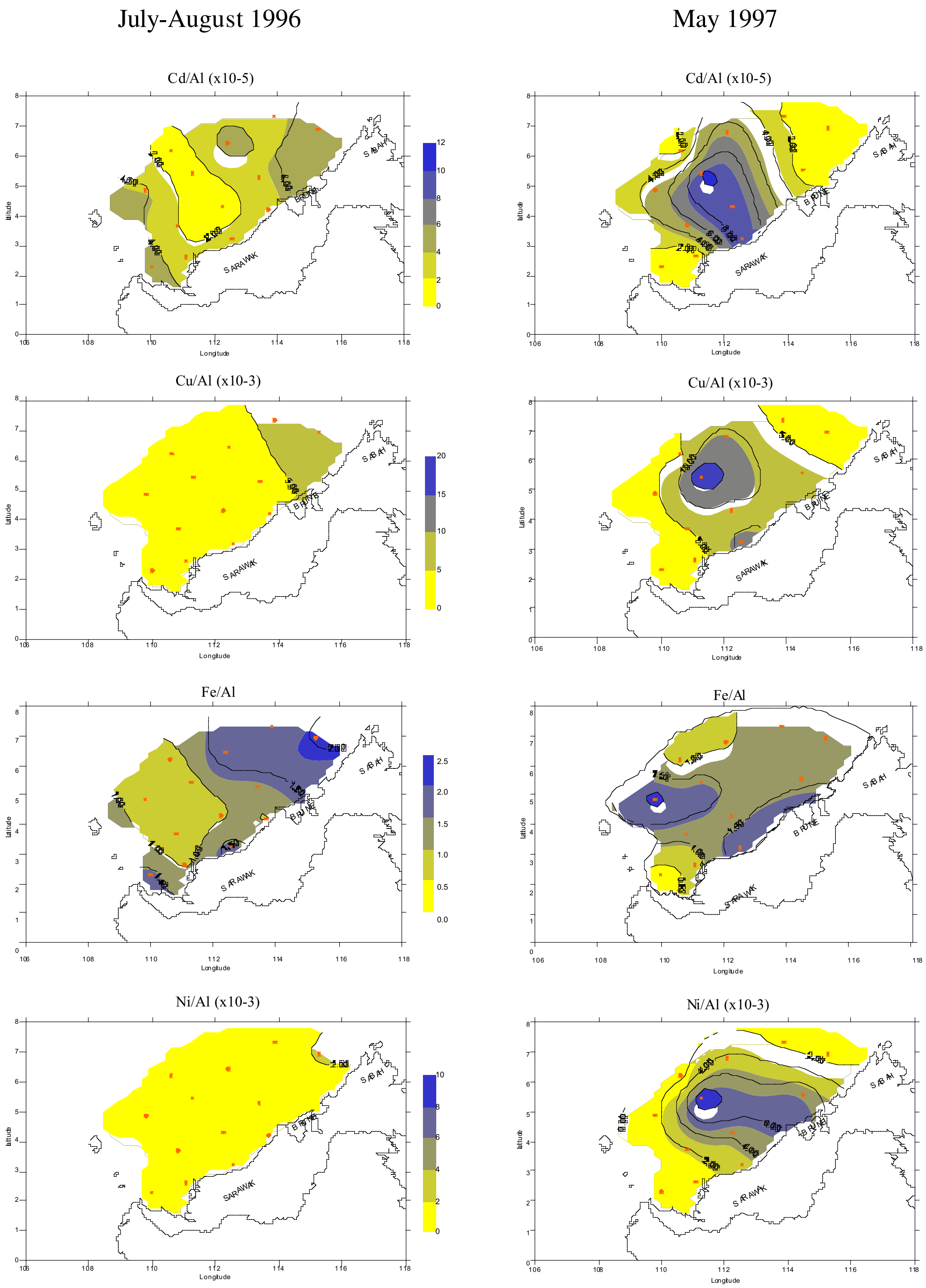


Fig. 9 Ratio of suspended Cd/Al, Cu/Al, Fe/Al and Ni/Al at surface layer

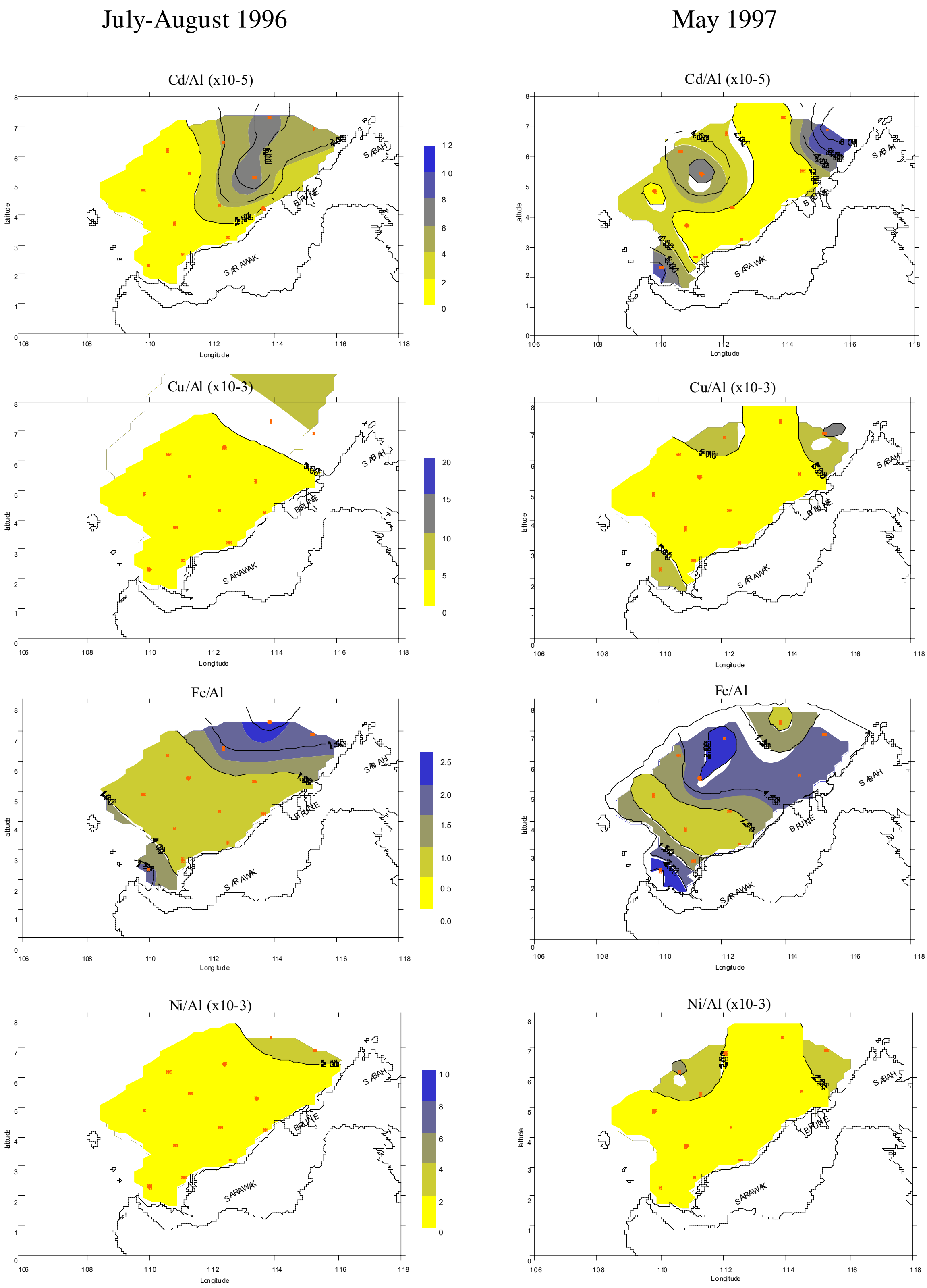


Fig. 10 Ratio of suspended Cd/Al, Cu/Al, Fe/Al and Ni/Al at bottom layer

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Reference

Boyle, E. A. and J. M. Edmond : Determination of Cu, Ni, and Cd in sea water by APDC chelate coprecipitation and flameless atomic absorption spectrophotometry. *Anal.Chim.Acta,* 91, 189-197 (1977).

Chester, R. and J.H. Stoner: The Distribution of Zinc, Nickel, Manganese, Cadmium, Copper and Iron in Some Surface Water from the World Ocean., *Marine Chemistry* 2, 17-32 (1974).

Drever, J.I.: The Geochemistry of Natural Waters. Prentice-Hall., Englewood Cliffs, N.J, 1982

Flegal, A.R., G.L. Smith, G.A. Gill, S. Sanudo-Wilhelmy and L.C.D. Anderson, 1991, Dissolved trace element cycles in the San Francisco Bay estuary, *Marine Chemistry* 36, 329.

Huizenga, D. L.: The cobalt-APDC coprecipitation technique for the preconcentration of trace metal samples. Graduate School of Oceanography, University of Rhode Island. Technical report 81-3, 1981, 93p.

Hungspreugs, M. and W. Utoomprurkporn: Distribution of some trace metals in the Gulf of Thailand. In House Seminar on SEAFDEC Interdepartment Collaborative Research Project. 18-19 February 1997.

Hungspreugs, M., W. Utoomprurkporn., A. Snidvongs, and S. Rattanachongkiat : A Comparative Study of Trace Metal Contamination in the Mekong Delta and the Chao Phraya Estuary . Proceedings of the International Workshop on the Mekong Delta, Feb 23-27, 1998, Chiang Rai, Thailand. pp.150-168.

Loring, D. H. and R.T.T.Rantala : Sediments and suspended particulate matter : Total and partial methods of digestion. International Council for the Exploration of the Sea. Techniques in Marine Environmental Sciences No.9. Copenhagen, Denmark, 1990, 14p.

Martin, J-M. and H. L. Windom : Present and future roles of ocean margins in regulating marine biogeochemical cycles of trace elements, in " Ocean Margin Processes in Global Change" (ed. By R.F.C. Mantoura, J.-M. Martin and R. Wollast) John Wiley, 1991, pp. 45-67.

Rattanachongkiat, S. : Distribution of trace metals in the Gulf of Thailand and east coast of Malay Peninsula. Master thesis, Department of Marine Science, Chulalongkorn University. 1998, 92p.

Snidvongs, A., S. Siriraksophon, and P. Rojana-anawat : Profiles of Oceanographic Data in the South China Sea Area 2: off Sabah, Sarawak and Brunei Darussalam during Post Monsoon Period. TD/RES/42, . Southeast Asian Fisheries Development Center., 1997, 179p.

Soegiarto, A.: The Oceanographic Features of the Southeast Asian Waters, in "Southeast Asian Seas, Frontiers for Development" (ed. by C. L. Sien and C. MacAndrews), McGraw-Hill, 1981, pp. 20 -47.

Utoomprurkporn, W., M. Hungspreugs, S. Rattanachongkiat, and A. Snidvongs : Biogeochemical Implications of Dissolved Trace Metal Concentration and Distribution in the South China Sea. Area I : the Gulf of Thailand and East Coast of Peninsular Malaysia. Seminar on Interdepartmental Collaborative Research Project, Bangkok, Thailand. 1998.

Yeats, P. A and D. H.Loring : Dissolved and Particulate Metal Distributions in the St.Lawrence Estaury. *Canadian Journal of Earth Sciences* 28, 729-742 (1991).

Appendix 1 Dissolved Cd, Cu, fe, Ni and Pd off Sabah, Sarawak and Brunei Darussalam in July-August, 1996

station	Cd (nM)	Cu(nM)	Fe(nM)	Ni(nM)	Pb(nM)
3-1-0 (9)	0.091	10.701	1188.391	7.109	0.545
3-1-35 (2)	0.107	19.652	2404.937	8.666	-2.43
3-7-0 (8)	0.039	7.254	1280.938	7.574	0.147
3-7-29 (2)	0.031	5.218	575.869	1.301	0.354
3-12-0 (11)	0.028	5.015	688.045	2.062	0.279
3-12-117 (1)	0.292	5.645	767.624	3.147	0.299
3-15-0 (9)	0.028	4.985	613.665	2.458	0.17
3-15-63 (2)	0.094	6.853	750.814	3.23	0.306
3-34-0 (10)	0.035	4.995	1254.694	4.259	0.418
3-34-59 (3)	0.074	5.196	2183.484	2.73	0.114
3-37-0 (10)	0.004	3.865	752.469	1.81	0.018
3-37-378 (2)	0.721	6.953	1041.81	7.201	0.305
3-39-0 (12)	1.001	26.032	1396.125	7.321	0.114
3-39-20 (11)	0.027	5.045	2600.907	3.563	0.29
3-39-55 (9)	0.033	4.26	1339.085	2.423	0.241
3-39-100 (7)	0.086	4.038	621.875	1.79	0.053
3-39-150 (6)	0.237	4.115	356.572	5.457	0.281
3-39-200 (5)	0.46	4.835	379.155	4.141	0.336
3-39-300 (4)	0.772	4.734	586.459	4.311	0.298
3-39-500 (3)	0.975	4.924	-4695.32	8.351	0.232
3-39-800 (2)	0.777	10.208	1649.295	5.936	0.139
3-39-1100 (1)	1.212	6.171	1287.949	7.427	0.337
3-47-0 (7)	0.033	5.5	121.423	3.877	0.209
3-47-27 (5)	0.054	4.593	1672.109	2.558	0.145
3-55-0 (10)	0.026	4.309	1260.586	5.73	0.304
3-55-1200 (1)	1.367	5.955	644.115	5.869	0.23
3-58-0 (11)	0.038	7.238	197.499	3.12	0.211
3-58-1500 (1)	1.088	5.968	895.172	3.882	-2.233
3-69-0 (11)	0.011	3.726	47.061	3.031	0.11
3-69-40 (8)	0.009	4.431	1674.015	3.846	0.379
3-69-60 (6)	0.028	5.134	335.452	3.28	0.236
3-69-70 (3)	0.061	3.813	668.46	3.4	0.227
3-73-0 (11)	1.324	6.425	458.23	4.859	0.124
3-73-60 (9)	0.022	5.912	598.235	3.02	0.317
3-73-200 (6)	0.5	5.257	1032.249	3.844	0.111
3-73-1000 (3)	1.209	5.563	265.302	3.961	0.206
3-73-1800 (1)	1.128	7.683	262.159	4.562	0.141
3-78-0 (11)	0.021	7.039	2263.187	4.29	0.338
3-78-1500 (1)	1.363	-95.391	565.048	13.433	0.534

Appendix 2 Susdended Cd, Cu, Fe, Ni and Pd off Sabah, Sarawak and Brunei Darussalam in July-August, 1996

Station	Cd (nM)	Cu(nM)	Fe(nM)	Ni(nM)
3-1-0 (9)	0.016	1.374	994.431	0.659
3-1-35 (2)	0.008	1.31	1453.512	0.873
3-7-0 (8)	0.011	1.436	927.083	0.769
3-7-29 (2)	0.006	1.372	1850.731	0.551
3-12-0 (11)	0.011	1.04	452.927	0.546
3-15-0 (9)	0.007	0.923	396.809	0.564
3-15-63 (2)	0.012	1.011	1082.486	0.784
3-31-0 (7)	0.009	1.285	1068.124	0.659
3-31-20 (1)	0.009	1.58	1511.703	0.561
3-34-10 (10)	0.002	0.916	468.756	0.505
3-34-59 (3)	0.013	-2.764	562.17	0.903
3-37-20 (10)	0.003	0.983	479.761	0.387
3-37-378 (2)	0.002	1.008	417.632	0.438
3-39-0 (12)	0.004	1.667	638.273	0.281
3-39-20 (11)	0.004	1.26	541.022	0.607
3-39-55 (9)	0.002	0.981	474.414	0.493
3-39-100 (7)	0.002	0.989	465.064	0.443
3-39-150 (6)	0.004	-2.478	449.122	0.172
3-39-200 (5)	0.001	1.031	376.542	0.329
3-39-300 (4)	0.009	1.045	269.617	0.442
3-39-500 (3)	0.002	0.956	329.748	0.387
3-39-800 (2)	0.007	1.199	279.776	0.39
3-39-1100 (1)	0	1.07	255.535	0.44
3-47-10 (7)	0	1.103	329.88	0.453
3-47-27 (5)	0.019	1.225	1533.086	0.564
3-55-20 (10)	0.008	0.999	553.294	0.284
3-55-1200 (1)	0.007	1.368	522.181	0.231
3-58-20 (11)	0.018	0.999	430.729	0.448
3-58-1500 (1)	0.02	1.076	397.652	0.344
3-69-40 (8)	0.004	1.068	1482.634	0.439
3-69-60 (6)	0.006	1.129	436.216	0.386
3-69-70 (3)	0.007	1.4	421.303	0.442
3-73-20 (11)	0.003	1.315	425.765	0.381
3-73-60 (9)	0.008	1.604	362.154	0.539
3-73-200 (6)	0.009	1.88	410.106	0.444
3-73-1000 (3)	0.001	1.783	397.4	0.7
3-73-1800 (1)	0.008	1.354	540.191	0.65
3-78-20 (11)	0.005	1.373	383.358	0.645
3-78-1500 (1)	-0.029	1.615	360.3	0.49

Appendix 3 Dissolved Cd, Cu, fe, Ni and Pd off Sabah, Sarawak and Brunei Darussalam in April-May 1997

station	Cd (nM)	Cu(nM)	Fe(nM)	Ni(nM)	Pb (nM)
4-1-0 (10)	0.061	12.007	491.457	5.494	0.209
4-1-33 (2)	0.288	6.389	898.387	4.767	0.17
4-7-0 (10)	0.083	9.841	200.246	5.345	0.214
4-7-33 (2)	0.036	5.794	497.647	3.133	0.049
4-12-0 (11)	0.058	6.176	1976.581	12.053	0.073
4-12-110 (1)	0.136	4.717	592.347	5.141	0.143
4-15-0 (12)	0.021	12.3	259.204	4.511	0.201
4-15-64 (1)	0.045	4.185	829.223	4.335	0.074
4-31-0 (10)	0.026	15.258	838.521	5.285	0.086
4-31-5 (8)	0.034	9.402	1462.957	4.715	0.083
4-31-10 (6)	0.027	14.996	468.835	3.573	0.329
4-31-15 (4)	0.042	6.976	498.913	4.966	0.185
4-31-19 (2)	0.042	6.235	557.978	3.975	0.175
4-34-0 (11)	0.069	27.138	2019.895	11.333	0.368
4-34-71 (1)	0.054	6.499	618.022	4.046	0.133
4-37-0 (12)	0.019	7.808	257.797	3.976	0.077
4-37-409 (1)	0.507	4.192	461.363	7.411	0.166
4-39-0 (12)	0.005	5.756	285.435	3.252	0.315
4-39-20 (11)	0.01	3.35	902.906	3.246	0.195
4-39-40 (10)	0.004	3.412	133.272	3.378	0.041
4-39-60 (9)	0.018	4.739	345.985	5.295	0.127
4-39-80 (8)	0.057	5.134	988.45	4.14	0.018
4-39-100 (7)	0.173	3.318	426.134	4.401	0.106
4-39-150 (6)	0.318	3.953	229.918	4.241	0.143
4-39-200 (5)	0.242	2.985	203.984	5.048	0.127
4-39-300 (4)	0.427	3.626	244.406	6.186	0.073
4-39-500 (3)	0.65	3.658	548.091	6.426	0.097
4-39-700 (2)	0.87	4.599	187.785	8.976	0.108
4-39-1100 (1)	1.034	6.854	530.092	13.029	0.166
4-54-10 (12)	0.028	6.128	445.514	4.209	0.205
4-54-1200 (1)	1.305	8.256	796.723	14.051	0.291
4-69-0 (10)	0.008	12.429	-4586.583	4.266	0.159
4-69-10 (9)	0.021	5.924	269.893	4.03	0.145
4-69-20 (8)	0.02	-138.782	280.78	5.025	0.184
4-69-30 (7)	0.02	12.833	237.068	11.57	0.049
4-69-40 (6)	0.07	6.918	335.902	8.851	0.128
4-69-50 (5)	0.017	5.009	596.171	6.758	0.239
4-69-60 (4)	0.011	4.161	223.567	6.685	0.139
4-69-70 (3)	0.036	5.132	1574.152	12.441	0.318
4-69-80 (2)	0.071	3.915	430.394	5.329	-1.51
4-69-90 (1)	0.095	3.859	233.129	3.826	0.07
4-73-0 (12)	0.001	3.755	124.703	4.664	0.049
4-73-30 (11)	0.011	4.67	185.572	3.058	0.137
4-73-50 (10)	0.005	3.959	162.546	3.711	0.148
4-73-100 (8)	0.235	8.853	725.797	3.963	0.607
4-73-200 (6)	0.319	2.951	329.657	4.297	0.209
4-73-1000 (3)	1.09	6.947	642.186	8.417	0.258
4-73-1750 (1)	1.187	20.546	423.275	8.222	0.315
4-78-0 (12)	0.02	6.874	92.482	3.802	0.123
4-78-1450 (1)	1.033	5.658	372.035	8.76	0.11

Appendix 4 Susdended Cd, Cu, Fe, Ni and Pd off Sabah, Sarawak and Brunei Darussalam in April - May 1997

station	Cd (nM)	Cu(nM)	Fe(nM)	Ni(nM)
4-1-0 (10)	0.01	2.314	529.441	0.496
4-1-33 (2)	0.011	1.839	636.189	0.28
4-7-0 (10)	0.002	1.785	711.886	0.605
4-7-33 (2)	0.008	1.691	1909.43	0.656
4-12-10 (11)	0.008	1.162	705.246	0.441
4-12-110 (1)	0.006	1.482	677.866	0.44
4-15-0 (12)	0.009	1.453	372.094	0.548
4-15-64 (1)	0.005	1.139	522.492	0.444
4-31-0 (10)	0.007	1.569	298.554	0.44
4-31-5 (8)	0.006	2.119	240.938	0.499
4-31-10 (6)	0.006	1.78	562.816	0.226
4-31-15 (4)	0.013	1.992	1911.354	0.551
4-31-19 (2)	0.014	-4.065	-2555.565	0.762
4-34-0 (11)	0.009	1.312	243.958	0.766
4-34-71 (1)	0.011	1.333	1084.62	0.761
4-37-0 (12)	0.004	1.278	131.065	0.71
4-37-409 (1)	0.003	0.927	157.105	0.71
4-39-0 (12)	0.001	0.981	199.391	0.225
4-39-20 (11)	0.001	1.101	1776.062	0.279
4-39-40 (10)	0.001	0.98	109.03	0.439
4-39-60 (9)	0	1.104	135.673	0.226
4-39-80 (8)	0.004	1.274	229.472	0.225
4-39-100 (7)	0	1.194	512.139	0.173
4-39-150 (6)	0.001	1.211	216.705	0.23
4-39-200 (5)	-	1.126	392.336	0.171
4-39-300 (4)	-	1.126	164.832	0.332
4-39-500 (3)	-	1.069	130.636	0.171
4-39-700 (2)	-	1.076	339.119	0.496
4-39-1100 (1)	-	1.133	70.784	0.226
4-54-10 (12)	0.004	1.097	98.791	0.451
4-54-1200 (1)	0.002	1.009	364.186	0.287
4-69-0 (10)	-	1.104	191.843	0.172
4-69-10 (9)	0.004	0.992	360.043	0.498
4-69-20 (8)	0.002	0.837	255.61	0.387
4-69-30 (7)	0.002	0.781	565.898	0.28
4-69-40 (6)	0.003	1.13	368.608	0.279
4-69-50 (5)	0.004	0.779	330.004	0.28
4-69-60 (4)	0.002	0.836	270.899	0.44
4-69-70 (3)	0.001	0.811	444.579	0.334
4-69-80 (2)	0.004	0.72	345.607	0.28
4-69-90 (1)	0.001	0.724	637.729	0.281
4-73-10 (12)	0.003	0.757	400.215	0.337
4-73-30 (11)	0.006	0.839	361.999	0.334
4-73-50 (10)	0.006	1.518	401.53	0.496
4-73-100 (8)	0.003	0.785	403.279	0.444
4-73-200 (6)	0.003	0.785	336.824	0.282
4-73-1000 (3)	0.004	0.812	320.041	0.227
4-73-1750 (1)	0.001	0.798	390.283	0.231
4-78-0 (12)	0.002	0.765	396.583	0.23
4-78-1450 (1)	0.006	1.094	221.148	0.449

Trace Metals in Surface Sediment of the South China Sea, Area II: Sarawak, Sabah and Brunei

**Noor A.M. Shazili, Mohamed Kamil Abd Rashid,
Mohd Lokman Husain and Rosnan Yaakob**

Marine Science Department, Faculty of Applied Science and Technology,
Universiti Putra Malaysia Terengganu, Mengabang Telipot, 21030 Kuala Terengganu, Malaysia.

ABSTRACT

The trace metals composition of surface sediment of the South China Sea off Sarawak, Sabah and Brunei were measured. Total metal concentrations in the 63 µm fraction are reported in this study. For the pre-monsoon cruise, the metal concentrations ranged between 1.01 – 13.0µgg^{-1} Pb, 8.28 – 99.8 µgg^{-1} Cu, 27.8 – 137.0 µgg^{-1} Zn, 10.1 – 75.7 µgg^{-1} Cr, 175 – 1166 µgg^{-1} Mn, 0.83 – 4.57% and Fe 0.16 – 2.25%. The range of metal concentrations measured in the post-monsoon cruise varied between 1.63 – 18.9 µgg^{-1} Pb, 7.52 – 38.0 µgg^{-1} Cu , 14.4 – 105 µgg^{-1} Zn, 19.6 – 87.6 µgg^{-1} Cr, 157 – 1890 µgg^{-1} Mn, 1.37 – 9.83 % Al and 0.51 – 4.47 % Fe.

The distribution of metals in the sediment showed different patterns between the pre-monsoon and the post-monsoon periods. The Rajang River seems to be one of the major factors affecting the distribution of metals in the seabed off Sarawak.

KEY WORDS: South China Sea, Borneo, surface sediments, metals.

Introduction

Malaysia is a maritime nation and surrounded by the Strait of Malacca, South China Sea and the Sulu Sea off Sabah yet few studies on the metal contents of sediments off the Borneo mainland have ever been carried out. In a study on the geochemistry of the surficial sediments of the South China Sea off Sabah and in the Sulu Sea, the distribution of some metals were related to depth of the water column (Calvert et al., 1993) as well as sediment mineralogy.

Similar studies conducted in 1997 (Shazili et al., 1997) in the Gulf of Thailand and the South China Sea off the east coast of Peninsular Malaysia found that Pb:Al ratios exceeded world average continental crust values. Cu:Al ratios were generally higher in the Upper Gulf of Thailand region compared with values for east coast areas of Peninsular Malaysia.

This study, off Borneo, is a continuation of the measurements of metal contents and their distribution in surface sediment of the South China Sea as the sea off Borneo is much deeper and the sedimentary regime may be different. The influence of large rivers flowing into the sea from the Borneo mainland may have effects on the seabed extending far beyond the coast.

Methodology

The methodology for sample collection, preparation and metal analyses adopted in the present study was similar to that used during the previous work in the South China Sea (Shazili et al., 1997) and that of Wood et al. (1997). The method involves the conduct of the following activities:-

3.1 Sample Collection

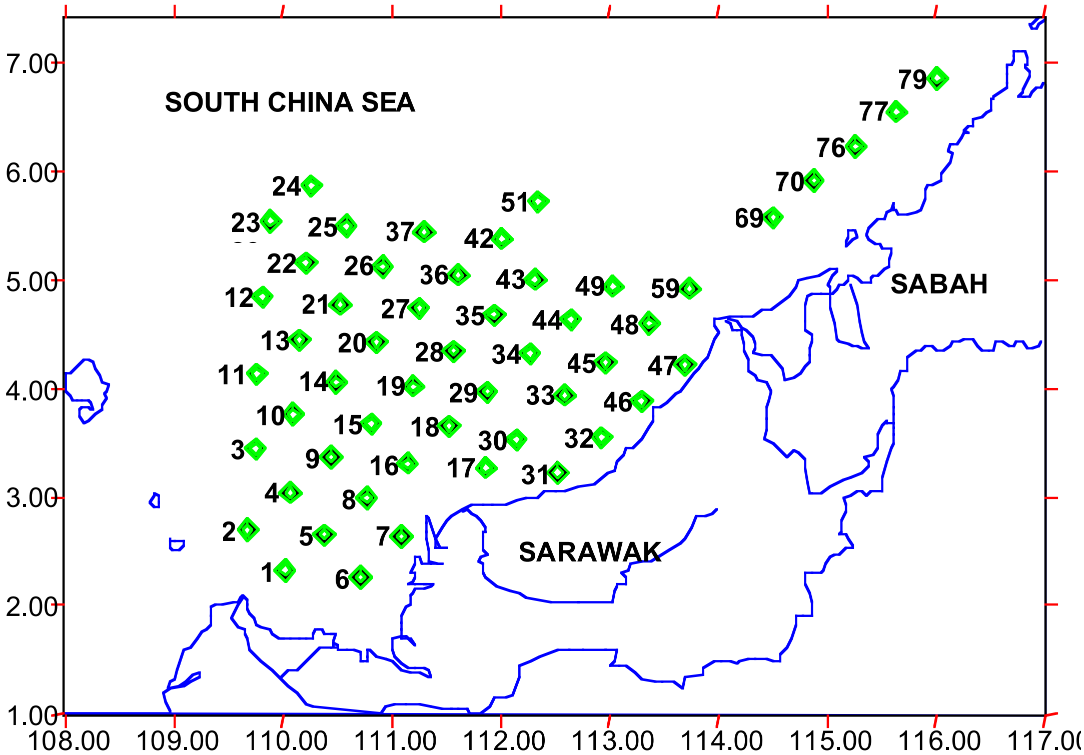

Fig. 1. Location of sampling stations off Sarawak, Sabah and Brunei Darussalam.

Surface sediment samples were collected using a Smith McIntyre grab from 52 sampling locations (Fig. 1). The top 3cm of sediment were carefully collected with a clean plastic spatula, kept in acid-cleaned glass bottles and preserved at –20°C until ready for analysis.

3.2 Sample Preparation

The sediment samples were dried at 95°C then lightly ground to break up the particles. The sediment was sieved through a 63µm mesh and about 1g aliquots of this silt and clay fraction was then totally digested in a mixture of nitric, perchloric, hydrofluoric and hydrochloric acids in open PTFE beakers. The digest was then made up to 50ml with Milli-Q water.

For quality assurance, a standard reference material (1646a Estuarine Sediment) from the National Institute of Standards and Technology was digested as above and analysed for metals.

3.3 Metal Analysis

Metals were analysed using a flame atomic absorption spectrophotometer equipped with Deuterium corrector. Analyses of NBS 1646a Estuarine Sediment (National Bureau of Standards) indicated good recoveries of all metals (Table 1).

Results and Discussion

The total metal contents in surface sediment for the pre-monsoon period and post-monsoon period cruises are shown in Tables 2 and 3 respectively. The measured values for the pre-monsoon cruise ranged between 1.01 – 13.0$\mu g g^{-1}$ for Pb, 8.28 – 99.8 $\mu g g^{-1}$ for Cu, 27.8 – 137.0 $\mu g g^{-1}$ for Zn, 10.1 – 75.7 $\mu g g^{-1}$ for Cr, 175 – 1166 $\mu g g^{-1}$ for Mn, 0.83 – 4.57%for Al and 0.16 – 2.25% for Fe. The range of metal concentrations measured in the post-monsoon cruise varied between 1.63 – 18.9 $\mu g g^{-}$

Table 1. Analysis of certified reference materials (NBS 1646a Estuarine Sediment

	Certified value (μgg^{-1})	Measured value (μgg^{-1})	% Mean Recovery
Aluminium (%)	2.297 0.018	2.356 0.95 %	104.7
Iron (%)	2.008 0.039	2.048 0.12 %	102
Copper	10.01 0.34	10.28 0.64	102.6
Chromium	40.9 1.9	38.7 1.03	94.7
Lead	11.7 1.2	10.6 0.63	90.5
Zinc	48.9 1.6	48.1 1.2	98
Manganese	234.5 2.8	227.5 4.0	97

Table 2. Concentrations of elements surface sediments in mgg^{-1} dry wt. for the pre-monsoon period

Stn	Fe (%)	Al (%)	Cu	Cr	Pb	Zn	Mn
2	1.17	2.75	28.6	47	7.5	75	-
3	0.67	1.48	45.7	40	9	68.1	501
4	0.67	1.38	39	31	6.01	39.1	250
11	0.71	0.78	66	21	3	45.1	250
12	0.67	0.83	99.8	32	2	55.1	301
13	0.8	0.75	60.1	36.1	4.51	75.6	275
14	0.69	1.33	16.5	21.5	9.52	42.1	351
16	0.89	0.88	98.8	29.1	8.03	34.1	477
19	0.67	0.83	55.1	27	4.56	49.1	576
21	1.8	3.63	-	39.5	5.01	92.5	725
22	2	3.85	24.6	42.5	4.5	83.1	801
25	1.42	1.68	-	37.6	13	67.1	551
26	1.98	3.48	36.4	53	4	80.5	850
27	1.39	2.53	30.3	43.6	2	78.2	701
28	2.04	4.23	27.6	42.5	4.5	66	625
31	1.37	2.96	20.4	42.6	8.03	64.7	853
32	1.95	4.56	8.28	72.7	8.53	77.3	778
33	1.63	3.43	28.3	55	3.03	75.2	833
34	1.87	3.53	33.3	53.5	2.02	62.6	581
35	2.25	4.36	35.8	67.1	8.52	113.7	601
36	1.84	4.42	32	59.2	2.01	74.3	878
37	2.17	3.5	43.9	66.8	9.33	97.9	1166
44	0.7	0.53	56.2	28	9.01	50.6	551
45	2.03	4.18	45.1	75.7	10	78.7	952
48	0.81	1.4	38.4	39.1	7.51	61.6	551
49	1.49	1.43	26.4	35.1	9.01	74.1	425
53	1.27	2.37	49.6	76	4	137	175
60	1.8	3.86	56.8	53.6	4.01	109	401
70	1.82	4.57	21.6	65.8	4.52	120	628
77	0.16	1.37	42	10.1	1.01	27.8	329

Table 3. Concentrations of elements surface sediments in mgg-1 dry wt. for the post-monsoon period.

Stn	Fe (%)	Al (%)	Cu	Cr	Pb	Zn	Mn
1	2.66	3.16	14.96	35.74	9.14	30.76	490
2	2.78	5.19	15.52	53.72	5.37	44.77	334
3	3.18	6.4	17.92	67.84	9.6	66.56	538
4	2.74	6.23	16.32	60.73	13.14	59.83	557
5	4.47	7.33	16.09	77.67	18.89	64.37	623
6	2.67	5.89	15.4	64.53	15.4	49.13	279
7	4.07	9.83	18.3	87.62	9.46	69.31	301
8	3.19	1.37	10.42	32.2	13.26	25.57	294
9	2.75	5.53	16.21	54.01	12.15	46.59	358
10	3.31	6.02	18.54	64.55	13.05	57.68	570
11	3.31	6.55	18.01	63.38	11.34	66.05	560
12	2.9	6.27	38.03	59.94	11.6	52.2	432
13	3.08	6.35	18.08	59.05	18.68	59.65	578
14	3.15	6.72	16.13	62.05	17.34	60.81	441
15	2.79	5.59	14.16	57.37	9.92	48.16	354
16	2.75	6.8	14.11	63.84	12.89	46.65	203
17	2.45	3.98	12.44	47.01	9.68	38.03	249
18	2.33	4.51	13.53	46.3	7.84	42.03	235
19	2.46	5.35	12.37	56.43	12.75	51.4	344
20	3.01	6.2	15.85	61.56	6.7	62.16	408
21	2.78	6.21	17.89	57.62	11.92	83.44	550
22	2.63	5.49	16.45	53.15	12.66	83.52	487
23	2.64	4.9	17.96	48.93	10.53	87.34	458
24	3.71	7.51	26.5	74.83	17.89	104.66	364
25	2.54	5.36	15.76	52.73	6.67	66.67	442
26	2.68	5.82	16.13	54.11	10.41	61.4	479
27	2.7	5.02	15.29	53.53	9.56	61.18	465
28	2.9	5.65	17.53	61.36	9.93	68.96	543
29	2.82	6.38	16.07	57.14	12.5	66.67	411
30	1.73	3.07	16.58	33.16	4.88	76.07	244
31	2.78	5.94	15.78	61.87	13.26	77.02	347
32	3.29	8.31	19.83	76.41	12.25	88.66	420
33	2.38	5.37	15.85	51.82	6.71	74.37	329
34	3.09	6.55	18.8	65.52	9.69	85.46	473
35	3.26	6.83	18.39	58.71	7.78	90.54	516
36	2.77	6.01	17.66	52.34	17.03	76.3	498
37	3.41	6.94	24.58	66.81	14.5	93.91	1891
42	2.67	5.26	17.94	53.82	5.52	72.45	462
43	2.74	6.28	17.13	61.08	8.56	70.78	525
44	2.99	6.51	17.25	65.07	7.23	77.91	506
45	3.51	7.85	18.65	75.93	16.65	69.27	440
46	2.28	4.83	21.01	47.67	8.89	41.21	242
47	3.54	8.08	17.96	77.16	8.65	69.18	412
48	3.38	7.27	21.9	73.98	11.25	68.06	426
49	2.07	4.27	15.21	42.31	10.46	46.59	347
51	2.53	5.03	10.81	48.66	6.08	56.1	406
59	2.34	4.54	13.43	41.04	9.7	43.28	261
69	3.33	7.48	11.8	63.97	14.9	69.56	323
70	2.57	5.48	10.72	50.74	14.29	51.45	307
76	2.57	5.01	13.05	44.96	18.85	45.69	703
77	1.94	4.84	12.87	49.22	3.92	42.51	302
79	0.51	1.85	7.52	19.61	1.63	14.38	157

^{1} for Pb, 7.52 – 38.0 μgg^{-1} for Cu , 14.4 – 105 μgg^{-1} for Zn, 19.6 – 87.6 μgg^{-1} for Cr, 157 – 1890 μgg^{-1} for Mn, 1.37 – 9.83 % for Al and 0.51 – 4.47 % for Fe.

4.1 Metal Distribution in the Pre-monsoon period

The distribution of metals in the surface sediments for the pre-monsoon period are shown in Figure 2. The highest levels of Al, Fe, Cr and Pb seeems to be located in the region off Bintulu and extending northwest while Zn levels were generally highest in the region above 4°N. These metals are generally lowest in concentration off the Rajang River Basin. The concentration of Mn generally showed a pattern of increasing concentration with distance towards offshore. Cu concentrations however showed a different distribution pattern, with the highest levels being found directly off the Rajang River Basin and in another region further offshore.

4.2 Metal Distribution in the Post-monsoon period

The results for the post-monsoon period are shown in Figure 3. Concentrations of Al, Fe, Cr, Zn and to a lesser extent Pb were lowest at stations directly off the Rajang River Basin extending northwestward to the deeper stations. Mn showed a clear increase in concentration with depth of water while Zn was highest at the deeper stations and in the region off Bintulu extending northwestward. Copper concentrations (7.52 – 38.03μgg^{-1}) in sediments are lower than the established standard value of 55μgg^{-1} for the Earth crust.

4.3 Normalisation of Metals to Al and Comparison with normal Earth crust values

As some variability was found in the distribution of Zn, Mn, Fe the metal concentrations were normalised against Al (Windom et al., 1984; Windom et al.,1988) in order to elucidate real differences in their distribution patterns for both the pre-monsoon (figure 4) and post-monsoon (figure 5) periods.

Concentrations of Cu normalised to Al gave ratios of between 2 and 8 x10^{-4} with most of samples taken within the study area having ratios of 2 – 4. These values are lower than the standard Cu:Al values of 7.12 x10^{-4} for shale and 8.14 x10^{-4} for continental sands and silts (Hanson et al., 1986). Concentrations of Pb measured in this study are within the average concentration for the Earth's crust (13μgg^{-1}). However most of the samples from the study area have a Pb:Al ratio of <2.0 which is lower than the standard value of 2.91 x10^{-4} in continental shelf sands and silts but is similar to average shale (1.52 x10^{-4}).

Zinc concentrations were between 14.3 and 114 μgg^{-1} and Zn:Al ratios between 8 – 20 x10^{-4} . These ratios are higher than the standard value of 8.6 – 9.15 x10^{-4} for the Earth's crust.

Input of sediment and particulates from the very large Rajang River probably influences the sedimentary characteristics of the seabed which may change between the pre-monsoon and the post-monsoon periods. In the pre-monsoon period, the distribution pattern of all metals (Fig. 4) were somewhat similar, showing highest ratios at 3 locations off Bintulu and the Rajang River Basin. However for the post-monsoon period (Fig. 5), the highest ratios for Fe, Cr and Pb to Pb were located just west off the Rajang River Basin, while Mn:Al ratios were highest off the Rajang River as well as at the deep water regions. Zn:Al was highest off the Rajang river and in a wide region extending off Bintulu northwestwards towards the deepwater stations. For the post-monsoon period the Fe:Al values for almost all of the study area, is much lower than the pre-monsoon period, with very little variation between stations above 3°N as the ratios.

Conclusions

The concentrations of Fe and Pb in this region are similar to natural values (Table 4) for conti-

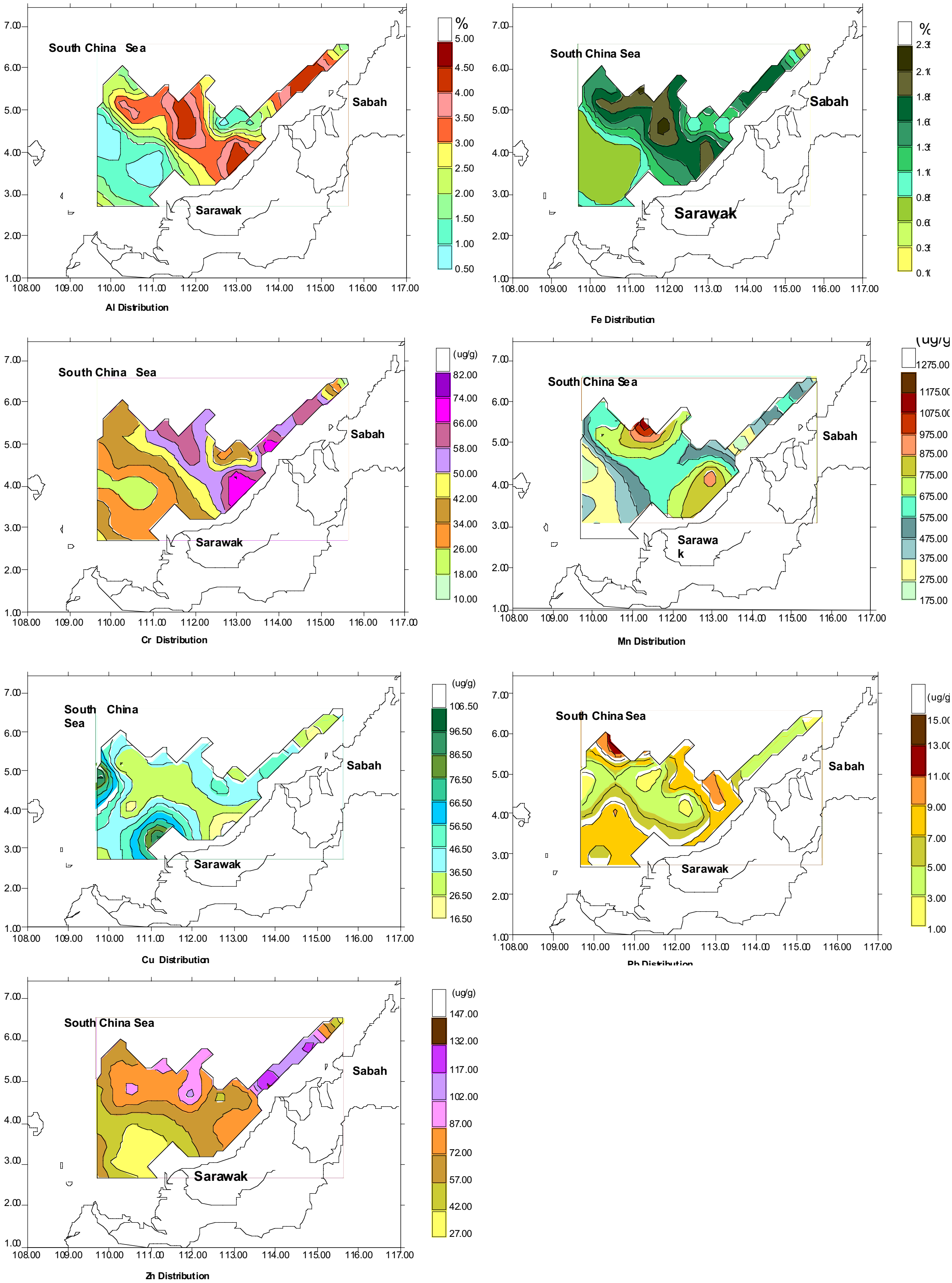

Fig. 2. The pattern of metal distribution in sediment in the pre-monsoon period.

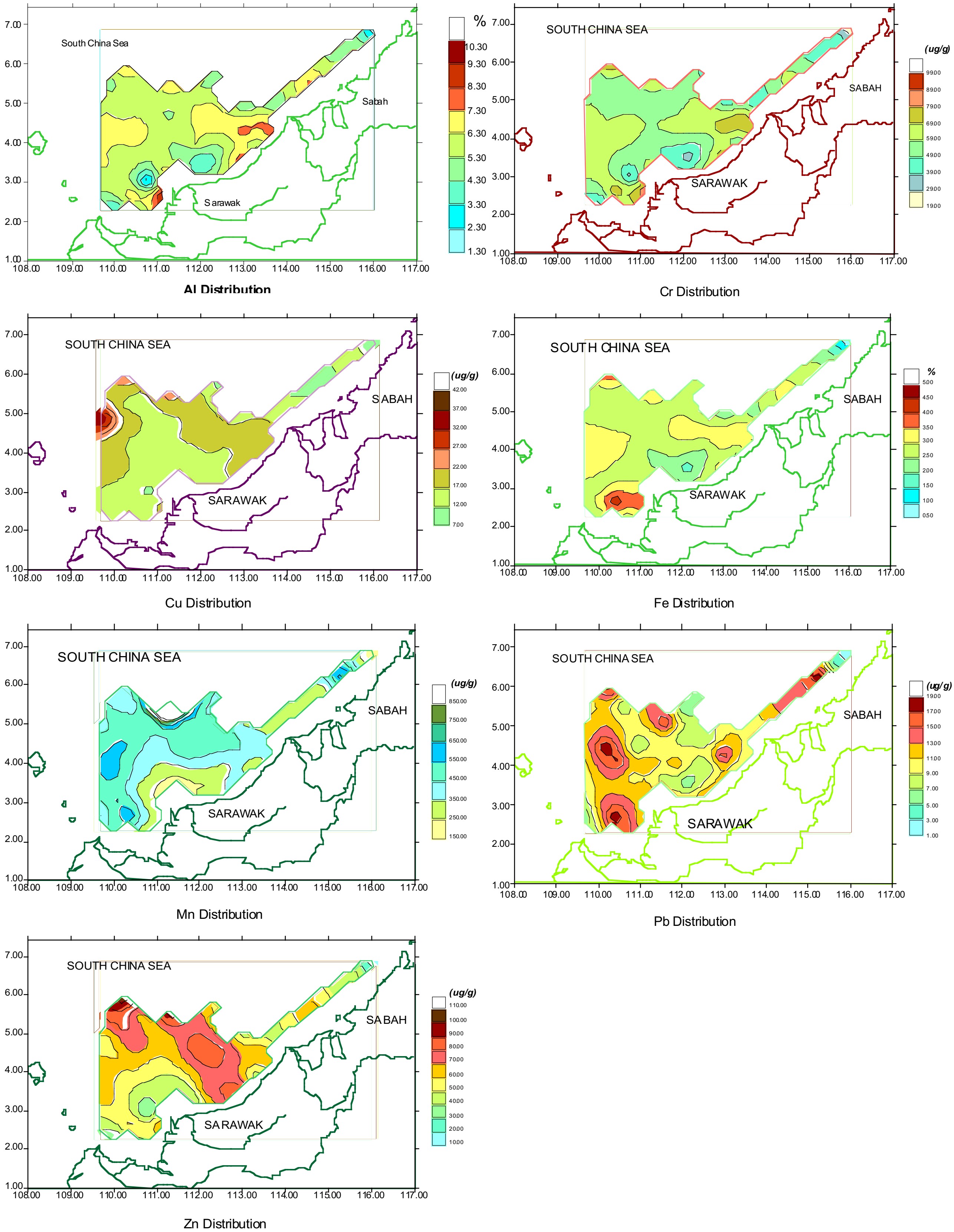

Fig. 3. The distribution pattern of trace metals in sediment in the post-monsoon period

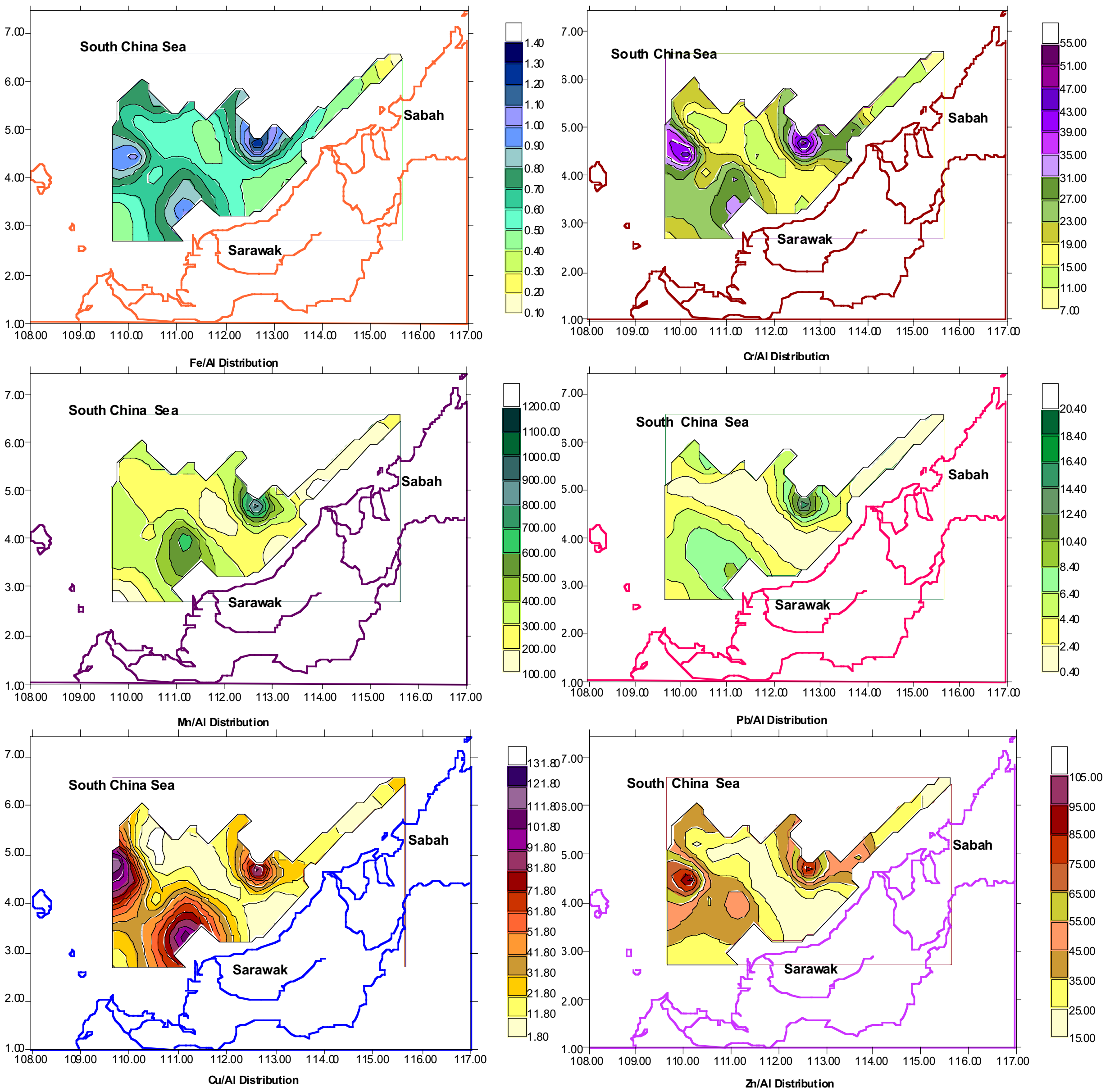

Fig. 4 The pattern of metal:Al ratios in sediment in the pre-monsoon period.

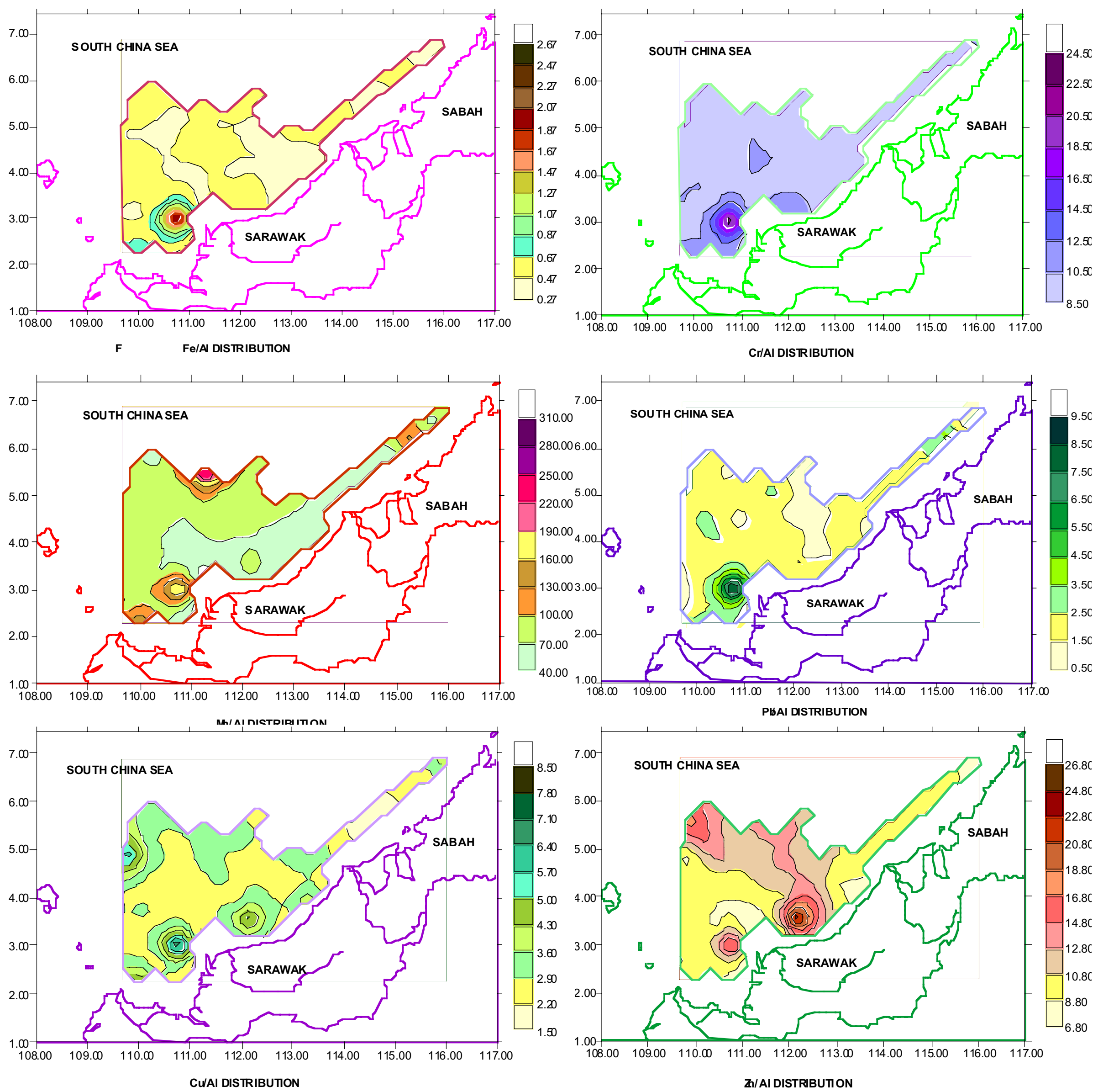

Fig.5. The pattern of metal:Al ratios in sediment in the post-monsoon period

Table 4 Comparisons of normalised data (element:Al ratios) to natural values.

	Element:Alx10^{-4}	Continental shelf values Element:Alx10^{-4} (Hanson et al,1986)	Nearshore sand and mud values Element:Alx10^{-4} (Hanson et al,1986)
Cu			
Johor Strait (Khalik Wood et al, 1997)	3.7		9.78
This study (Borneo)		8.14	
Cr		55	17.9
Johor Strait (Khalik Wood et al, 1997)	5.5		
This study (Borneo)		2.91	
Pb			13.6
Johor Strait (Khalik Wood et al, 1997)	5.1		
This study (Borneo)	1.1 - 3	117	
Zn		9.15 mean earth crust	
Johor Strait (Khalik Wood et al, 1997)	16 - 22.6	value (from Bowen, 1979)	
This study (Borneo)	7 – 25		
Mn			
This study (Borneo)	30 – 272		
Sulu Sea (Calvert et al., 1993)	100 - 6000		

nental shelf sands and silts and for Earth crust materials, as indicated by similar element:Al ratios (Hanson et al., 1986; Bowen, 1979). The ratios of Pb, Cu, Cr, Ni and to a lesser extent Mn, to Al, however indicate that values in this region are lower than natural values (Table 4) by up to two times.

The ratios of Zn:Al for much of the study area are different from all the other metals, as the values are higher than the value of 8.6 – 9.15 x10^{-4} for mean Earth crust materials (Mason and Moore, 1982 and Bowen, 1979). Differences in sediment particle size, organic content and mineralogy may account for this difference.

The Zn:Al ratios found in this study is similar to that found for sediments in the Johor Strait (Wood et al., 1997) and the deep areas of the South China and Sulu Seas of Sabah (Calvert et al., 1993).

Rerefences

Bowen, H.J.M. (1979). *Environmental Chemistry of Elements*. Academic Press, London, 333p.

Calvert, S.E., Pedersen, T.F. and Thunell, R.C. (1993). Geochemistry of the surface sediments of the Sulu and South China Seas. Marine Geology, 114, 207-231.

Hanson, P.J., Wells, J.A. and Newman, M.W. (1986). Preliminary results of the 1984-85 National Benthic Surveillance Project:Southeast Atlantic and Gulf of Mexico coasts. IEEE Oceans ’86 Conference Proceedings, Washington, D.C.,572-577.

Shazili,N.A.M., Mohamed,C.A.R. and Yaakob,R. (1989). Heavy metals in sediments of the South China Sea. Proc. 12th. Annual Seminar of the Malaysian Society of Marine Sciences, 99-106.

Windom, H.L., Silpipat,S., Chanpongsang,A., Smith,R.G. and Hungspreugs, M. (1984). Trace metal composition of and accumulation rates of sediments in the upper Gulf of Thailand. Estuarine, Coastal and Shelf Science,19,133-142.

Windom, H.L., Schropp, S.J., Calder, F.D., Ryan, J.D., Smith, R.G., Burney, L.C., Lewis, F.G. and Rawlinson, C.H. (1989). Natural trace metal concentrations in estuarine and coastal marine sediments of the Southeastern United States. Environmental Science & Technology, 23,314-318.

Primary Production Determination in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam Waters

Waleerat Musikasung[1]
Mohd Shuki Bin Yusoff[2]
Solahuddin Bin Abdul Razak[2]
Anond Snidvongs[3]

[1]Southern Marine Fisheries Development Center, Department of Fisheries, Thailand
[2]SEAFDEC/MFRDMD, Kuala Trengganu, Malaysia
[3]Department of Marine Science, Chulalongkorn University

ABSTRACT

Primary production in the South China Sea, off Sabah, Sarawak and Brunei Darussalam was determined from *in situ* fluorescence, light intensity and the uptake of radioactive carbon incubation on the MV.SEAFDEC cruise in July-August, 1996. Depth integrated primary production varies between 0.13–0.88 gC/m^2/day in the coastal zone and 0.23–0.89 gC/m^2/day in the open sea. The magnitude was high along the north off Brunei Darussalam and Sabah and gradually decreased with depth. The elevated daily primary production was generally found at the sea surface mixed layer and subpycnocline chlorophyll maximum. The decreasing virtual light intensity was tending to restrict the vertical distribution in daily primary production with accompanied by the chlorophyll-a concentration.

Key words: primary production, South China Sea

Introduction

A broad picture of primary production over most regions of the world's ocean is now available, due largely to the widespread use of the radiocarbon method for estimating production, first introduced by Steemann Nielsen (Raymont, 1980). The regional photosynthetic pigment variations and temporal change in the rate of primary production that are of importance through the marine ecosystem. For many reservoirs phytoplankton production is limited by light attenuation (Lind *et al.*, 1992). Variations in primary production must be accompanied by an overall view of the hourly light intensity profile in the water column, the relative importance of light decrease with depth and chlorophyll concentration (Berman *et al.*, 1995).

The study area is observed along the north off Sabah, Sarawak and Brunei Darussalam, a part of the South China Sea. It is approximately rectangular with depth between 30-2,893 m (from sounding depth). In this area considering that the maximal of daily primary production was strongly influenced by light attenuation and/or biomass of chlorophyll-a. This experiment was examined the magnitude and vertical pattern of primary production. Because of spatial and temporal problems, direct measurements of daily primary production in the same time over the whole area were impossible; these results demonstrated a high spatial and temporal variability of primary production.

Sites and methods

The location of the stations (57 stations) was shown in Fig. 1. Seawater samples were collected from several levels of depth (from sea surface to deep water however, only surface to mid water column were analyzed for primary production) by the Rosette sampler during cruise off-Sabar, Sarawak

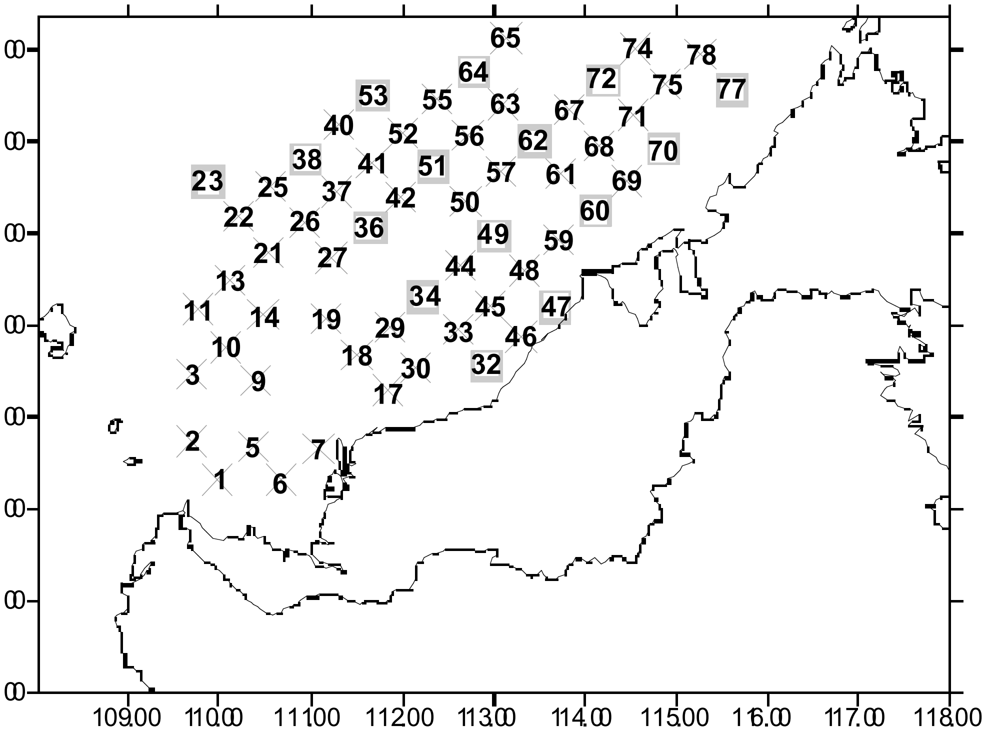

Fig. 1 Location of srvey stations to previous study. square represents stations for carbon-14 incubation

and Brunei Darussalam, on MV SEAFDEC in July-August 1996. Data of water depth and pH were determined with a CTD profiling on cruise. Table 1 was shown the sounding depth, obtained depth of daily primary production and deployment times of the primary production experiment.

Light intensity in water was measured in $\mu E/m^2/s$ by a quantummeter. *In situ* fluorescence was recorded every one meter depth in volt by Sea Tech submersible fluorometer. The chlorophyll-a values discussed in this study was converted from *in situ* fluorescence by correlated linearly with the actual chlorophyll concentration and determined on cruise with spectrophotometer (Parson *et al.*, 1984).

Total alkalinity analyses was performed by 50-ml of filtered seawater mixed with 10-ml of 0.015N HCl and shaking vigorously. The final pH of the solution was measured by pH-meter, Fisher Scientific model 1002. Total alkalinity value was computed by Parson *et al.* (1984), and then the carbonate alkalinity and total carbon dioxid were calculated (carbonate alkalinity (meq/l) = total alkalinity-0.05, total carbon dioxide (meq/l) = 0.96*carbonate alkalinity).

Seawater samples for primary production were taken for incubation using ^{14}C technique (Parson *et al.*, 1984). Each sample was transferred into 300-ml glass bottles (3 bottles of clear glass and 1 bottle of dark glass for each level of depth). Each bottle was inoculated with 1.66 μCi of ^{14}C and incubated immediately in the incubator with setting the temperature in ranges 20-25 C^o. After incubation for 3 hours, samples were took away from sunlight and filtered by syring filtration with GF/F membranes. Membranes were kept frozen in scintillation vials until analyzing. In the laboratory, each vial was filled with 5-ml of scintillation fluid. Allow standing overnight after shaking the sealed vials. Counted the vials in a β-scintillation counter, model GC-9A, Shimadzu.

The method for primary production calculations was described here only briefly. It was based on radioactive carbon technique by Parson *et al.* (1984). Thus,

$$\text{Primary production in mgC/m}^3\text{/hr} = (R_S-R_B)*W/R*N, \qquad \mathbf{(1)}$$

Where R = total activity of 1.66 μCi of ^{14}C solution (dpm),
N = number of hours of sample incubation (hr),
R_S = the light bottle count (dpm),
R_B = the dark bottle count (dpm),
$W_{(\text{the concentration of total carbon dioxide in mgC/m}^3)}$ = 12,000*TC,
TC = total carbon dioxide (meq/l).

Light-Time curve — Light-time equation was made from the time series of light at sea surface and regressed the equation for daily primary production (Fig.2, 3) and the relationship was:

Equation for time between 6 A.M.-12 Noon

$$\text{Light} = 1.7964\ e^{0.5489\text{time}} \quad r^2 = 0.8494,$$

Equation for time between 12 Noon–6 P.M.

$$\text{Light} = 2E{+}09e^{-0.9434\text{time}} \quad r^2 = 0.8001, \quad \textbf{(2)}$$

where unit of light intensity = μE/m^2/s.

Light-Depth curve — Data of light (μE/m^2/s) and depth (m) were combined and correlated linearly then made for the light-depth relationship (Fig. 4):

The overall equation for the light-depth curve

$$L = 542.28\ e^{0.0698D} \quad r^2 = 0.6724, \quad \textbf{(3)}$$

where L = light intensity (μE/m^2/s) in water column, D = depth (m).

Primary production–Light intensity curve — Primary production and light intensity (P–I curve) was made by plotting primary production normalized to chl-a (as *in situ* fluorescense) against light intensity and used for P/Chl-a: light intensity relationship (Fig. 5):

The overall equation for the P–I curve

$$P = 2.3714\ \text{Ln}(L) - 1.8141 \quad r^2 = 0.5228, \quad \textbf{(4)}$$

where P = primary production (mgC/m^3/hr), L = light intensity (μE/m^2/s) in the incubator.

Estimation of daily primary production — Photosynthetic rate in the incubated bottles was calculated for primary production rate in mgC/m^3/hr using equation- (1). Assuming surface intensity to be 100% and integrated daily primary production over 6 A.M. to 6 P.M. by equation- (2). Then extrapolated primary production over the water column to obtain the rate per sq.m using the *in situ* biomass and light intensity (hourly light intensity profile) by equation- (3), and (4).

Result

The wide range of depth integrated primary production in the site analyzed was 0.13–0.89 gC/m^2/day (Table 1) which resulted between 0.13–0.88 gC/m^2/day for the coastal zone and 0.23–0.89 gC/m^2/day in the open sea, the trend became high along the north off Brunei Darussalam and Sabah (Fig. 6). This lowest value was noted at station 32 and highest at station 61.

The patterns of relation declined with depth between light intensity, concentration of chl-a and daily primary production were given in Fig. 7-11. At the shallow stations that total depth approximately 80-m daily primary production would be found through water column (Fig. 7). It was high in surface, decrease with depth and increase again in subpycnocline chlorophyll maximum. At stations which no light penetrated to mid layer (at morning or evening), any primary production also (Fig. 8).

For the stations, which total depth more than 150 m (Fig. 9-11), the result of primary production was somewhat similar distribution to the shallow water. It was common to find maximum of

Table 1 Date, time, sounding depth (m) and primary production (p-depth)

Station	Date	Time	Sounding depth	P-depth
1	10-Jul-96	6.3	38	36
2	10-Jul-96	10.2	54.5	52
3	10-Jul-96	16.2	79.8	77
5	11-Jul-96	7	79.5	57
6	11-Jul-96	10.2	43.5	40
7	11-Jul-96	15	32.5	28
9	12-Jul-96	6.3	68.5	52
10	12-Jul-96	10.2	86	84
11	12-Jul-96	14.3	100	95
13	13-Jul-96	7	115.5	84
14	13-Jul-96	10	93.5	91
17	14-Jul-96	6.55	33	25
18	14-Jul-96	11.3	49.5	45
19	14-Jul-96	16	70	65
21	15-Jul-96	6.3	119	42
22	15-Jul-96	9.5	146	58
23	15-Jul-96	14.1	145	75
25	16-Jul-96	6.3	200	28
26	16-Jul-96	10.1	123	86
27	16-Jul-96	14.3	95.5	89
29	17-Jul-96	7	56	40
30	17-Jul-96	10.2	32	29
32	19-Jul-96	6.3	34	13
33	19-Jul-96	10.2	49	46
34	19-Jul-96	14.3	71	66
36	20-Jul-96	6.3	108	34
37	20-Jul-96	10.2	384	84
38	20-Jul-96	15.1	1031	63
40	21-Jul-96	6.3	1018	55
41	21-Jul-96	10.3	1207	94
42	21-Jul-96	15.2	134	82
44	22-Jul-96	6.3	89	46
45	22-Jul-96	10	66	63
46	22-Jul-96	14.1	20	18
48	24-Jul-96	9	78	71
49	24-Jul-96	13.1	105	100
50	24-Jul-96	17.3	425	70
51	25-Jul-96	7	192	58
52	25-Jul-96	10.2	1650	110
53	25-Jul-96	16	1924	91
55	26-Jul-96	6.3	1316	85
56	26-Jul-96	10.5	1148	120
57	26-Jul-96	15.5	2340	117
59	27-Jul-96	6.3	1619	73
60	27-Jul-96	10	178	106
61	27-Jul-96	15	2148	120
63	28-Jul-96	7	1628	76
64	28-Jul-96	11.15	1242	60
65	28-Jul-96	16	1457	56
67	29-Jul-96	6.3	2814	36
68	29-Jul-96	12	1789	110
69	29-Jul-96	16	97	90
71	31-Jul-96	14	1892	120
74	1-Aug-96	9.5	2893	117
75	1-Aug-96	15	1782	116
77	2-Aug-96	6.3	96.5	90
78	2-Aug-96	10.5	1515	120

Table 2 Depth integrated primary production (gC/m^2/day)at different stations

Station	P(gC/m^2/day)	Station	P(gC/m^2/day)
1	0.3	40	0.39
2	0.39	41	0.61
3	0.62	42	0.59
5	0.46	44	0.33
6	0.34	45	0.44
7	0.34	46	0.17
9	0.37	48	0.52
10	0.58	49	0.69
11	0.68	50	0.54
13	0.63	51	0.39
14	0.89	52	0.76
17	0.27	53	0.66
18	0.43	55	0.62
19	0.55	56	0.66
21	0.33	57	0.8
22	0.41	59	0.56
23	0.54	60	0.77
25	0.23	61	0.88
26	0.56	63	0.52
27	0.71	64	0.4
29	0.34	65	0.4
30	0.28	67	0.28
32	0.13	68	0.76
33	0.39	69	0.64
34	0.5	71	0.83
36	0.26	74	0.69
37	0.57	75	0.81
38	0.46	77	0.63
		78	0.76

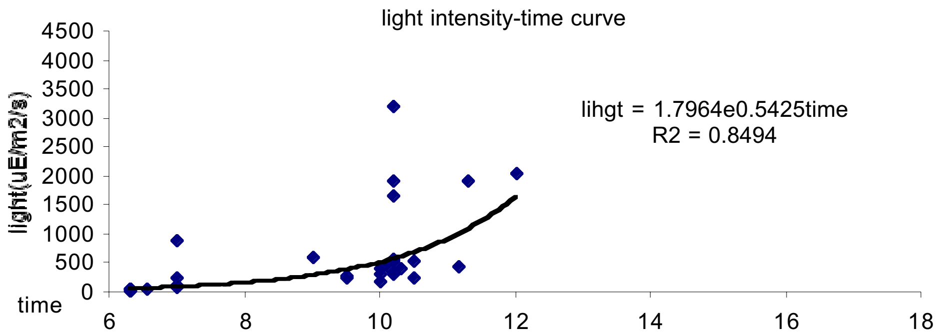

Fig. 2 The light-time relationship between 6 A.M.-12 Noon

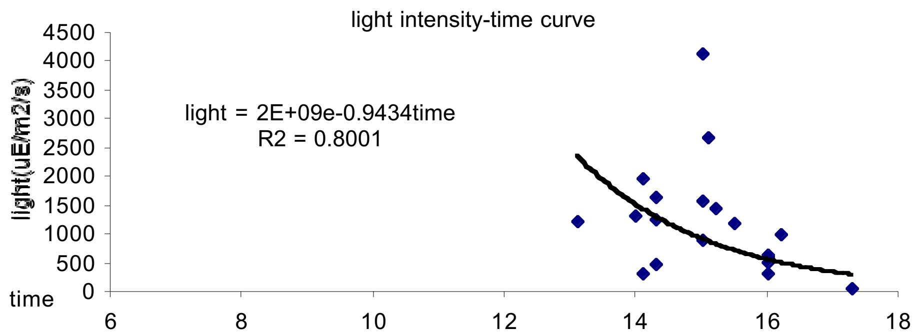

Fig. 3 The light-time relationship between Noon - 6 PM

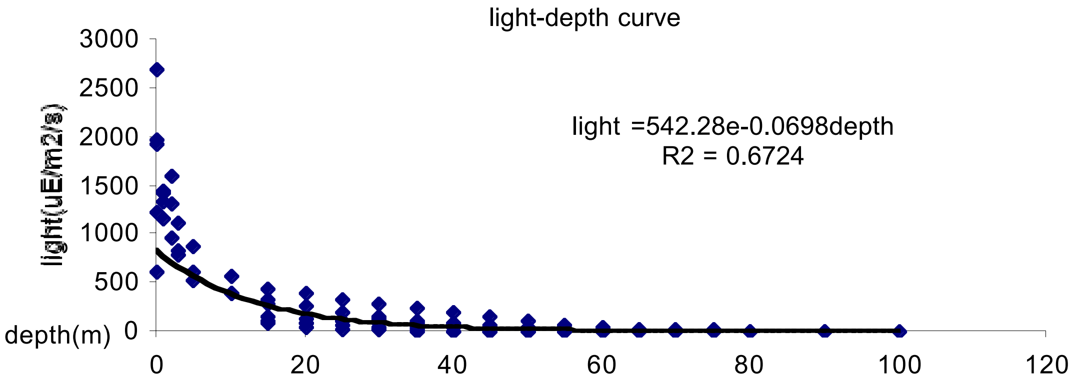

Fig. 4 The relationship of light intensity from 6 A.M.to 6 P.M. and depth of the investigation study area

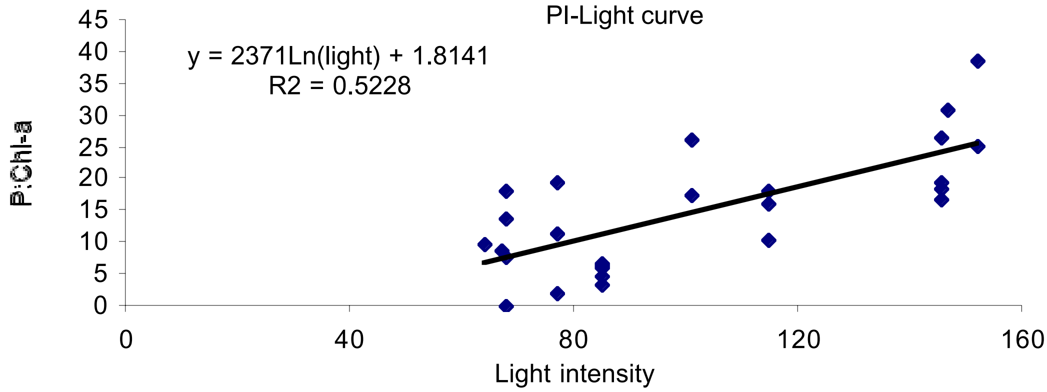

Fig. 5 The relationship between light intensity and daily primary production normalized to phytoplankton biomass

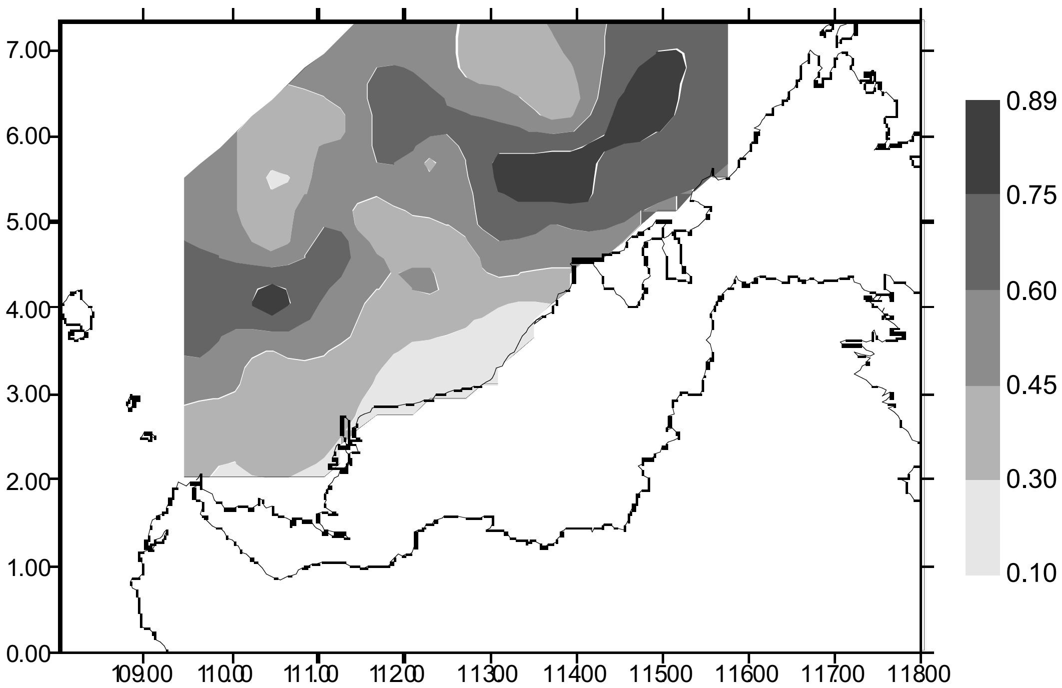

Fig. 6 Demonstration of depth integrated primary production in $gC/m^2/day$

primary production near the surface and subpycnocline chlorophyll maximum: which the generally decrease with depth. In the deep, so reduce light penetration, continuous vertical distribution of chlorophyll-a, most of primary production was usually supported by light attenuation.

The general distribution of daily primary production at different depth was demonstrated in Fig. 12-17.

Discussion

Solar input to the water was saturated for photosynthesis and light factors relating incident solar radiation due to elevate the primary production. As reported previously by Mallin and Paerl, 1992 in shallow water photosynthesis reveal various increasing to alter light intensity and chlorophyll-a. Vertical pattern of primary production due to sea surface daily radiant energy available (Raymont, 1980). In this experiment, it was noteworthy that in surface and subsurface mixed layer, daily primary production was more closely correlated to chlorophyll-a and light intensity. In subpycnocline chlorophyll maximum, daily primary production was tightly linked correlation between photosynthetic pigment and timely light intensity profile.

The depth dependence of the relationship between primary production, light intensity and chlorophyll-a was also examined (Fig. 9-11). The phytoplankton was so concentrated in the subsurface mixed layer and subpycnocline chlorophyll maximum: this depth was found between 10-25 m and 50-70 m respectively. Daily primary production would be important strategy followed by chlorophyll-a concentration in stable stratified water which light was most intense near surface mixed layer. Increased chlorophyll-a content markedly reduced light intensity with depth (Krause-Jensen and Sand-Jensen, 1998). In mid depth chlorophyll maximum, the photosynthetic pigments would like acclimatizing to the low light intensity and might stimulate the daily primary production.

Summary

These results indicated that more realistic assessments of integrated daily primary production in this area could be made by the light- field condition.

Acknowledgement

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References

Berman, T., Stone, L., Yacobi, YZ., Kaplan, B., Schlichter, M., Nishri, A., and Pollingher, U. Primary production and phytoplankton in Lake Kinneret: A long-term record (1972-1993). Limnology and Oceanography, 40(6), 1995, 1064-1076.

Krause-Jensen,D., and Sand-Jensen, K. Light attenuation and photosynthesis of aquation plant communities. Limnology and Oceanography, 43(3), 1998, 396-407.

Lind, O.T., Doyle, R., Vodopich, D.S., and Trotter, B.G. Clay turbidity: Regulation of phytoplankton production in a large, nutrient-rich tropical lake. Limnology and Oceanography, 37(3), 1992, 549-565.

Mallin, M.A., and Paerl, H.W. Effects of variable irrdiance on phytoplankton productivity in shallow estuaries. Limnology and Oceanography, 37(1), 1992, 54-62.

Parsons, T.R., Maita, Y., and Lalli, C.M. A Manual of Chemical and Biological Methods for Seawater

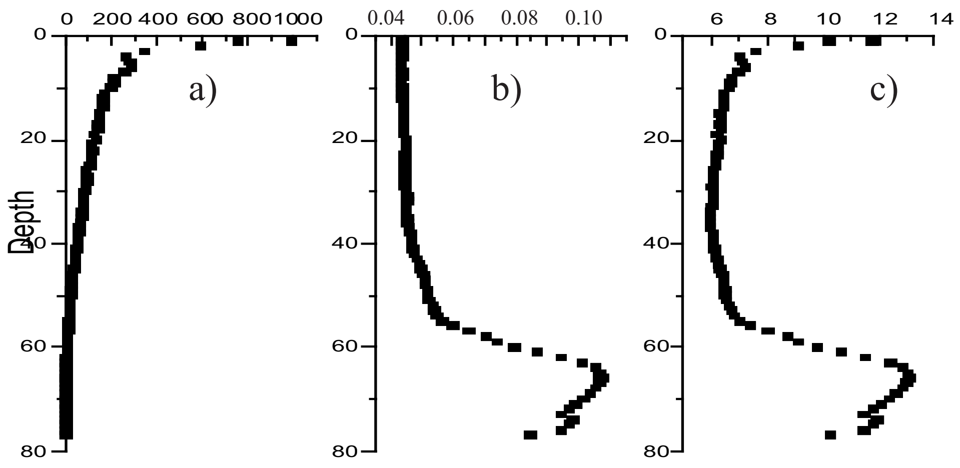

Fig. 7 Light intensity (a), Chl-a (b) and daily primary production (c) from station 3 at time 16.20 P.M.

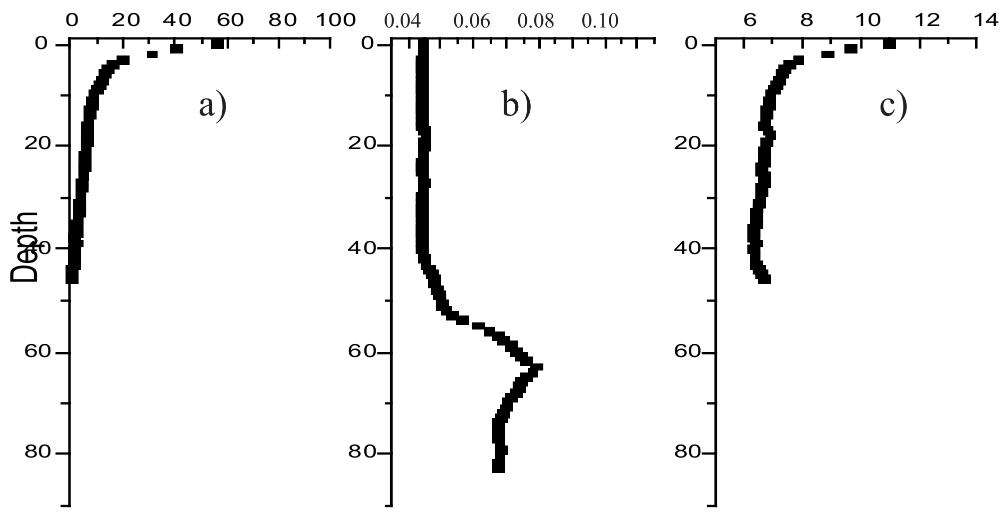

Fig. 8 Light intensity (a), Chl-a (b) and daily primary production (c) from station 44 at time 6.40 A.M.

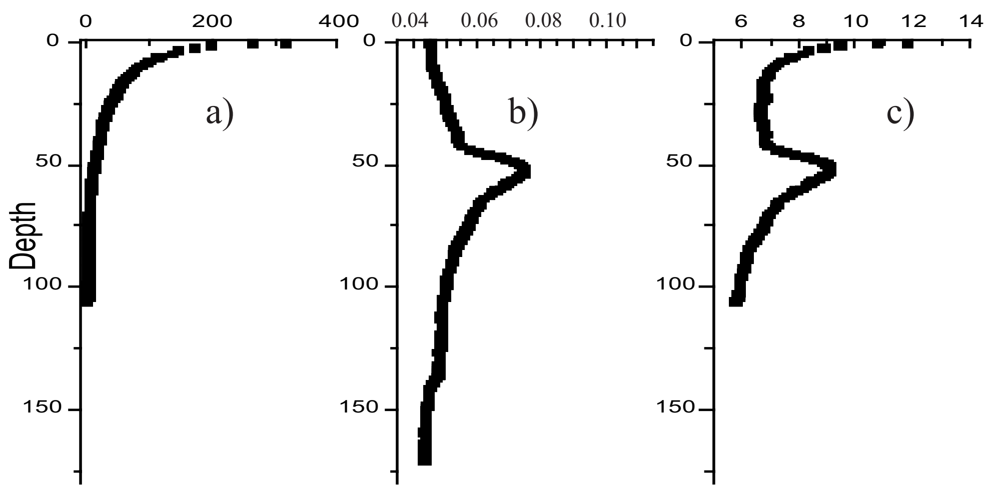

Fig. 9 Light intensity (a), Chl-a (b) and daily primary production (c) from station 60 at time 10 A.M.

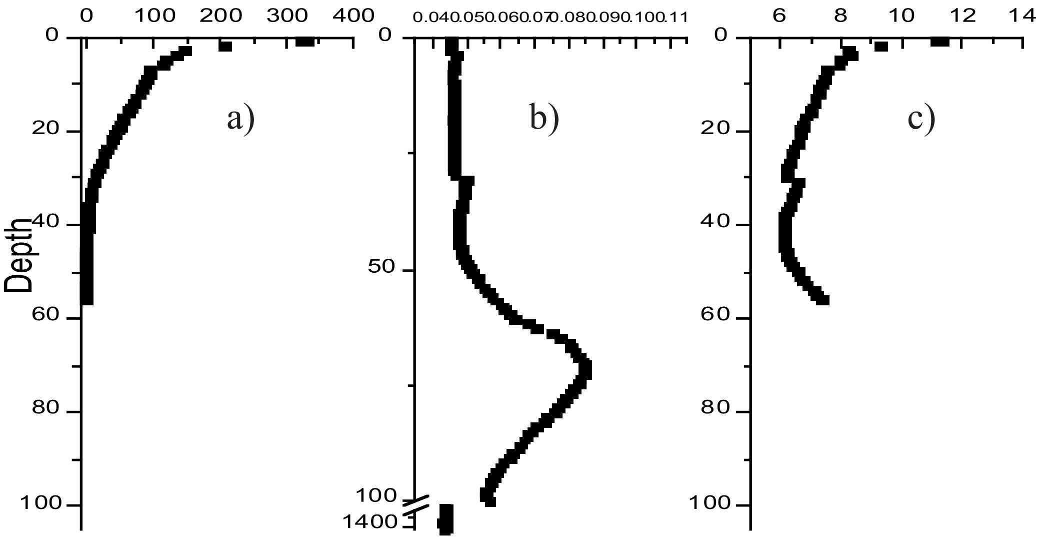

Fig. 10 Light intensity (a), Chl-a (b) and daily primary production (c) from station 65 at time 4PM.

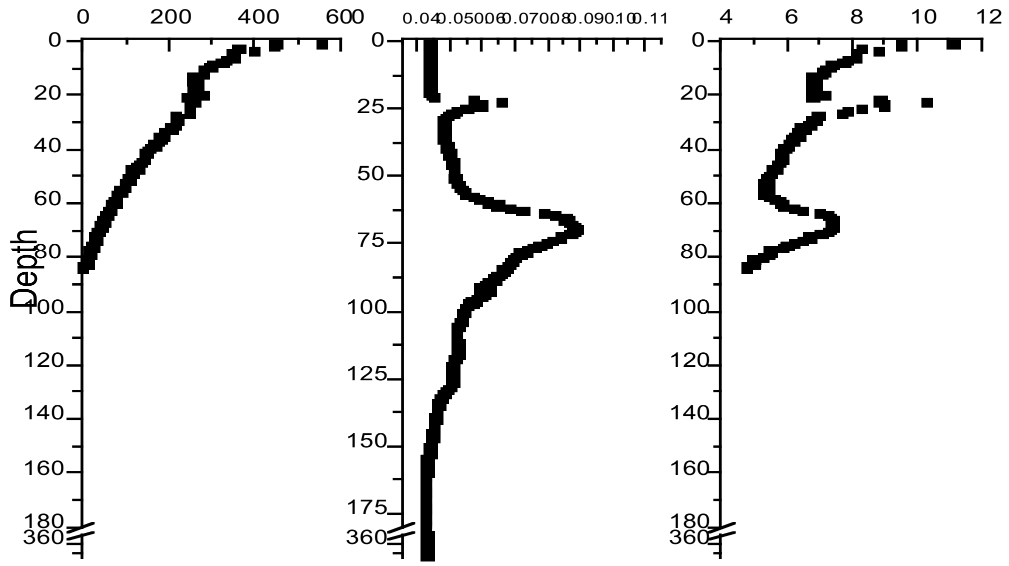

Fig. 11 Light intensity (a), Chl-a (b) and daily primary production (c) from station 37 at time 10:20 AM.

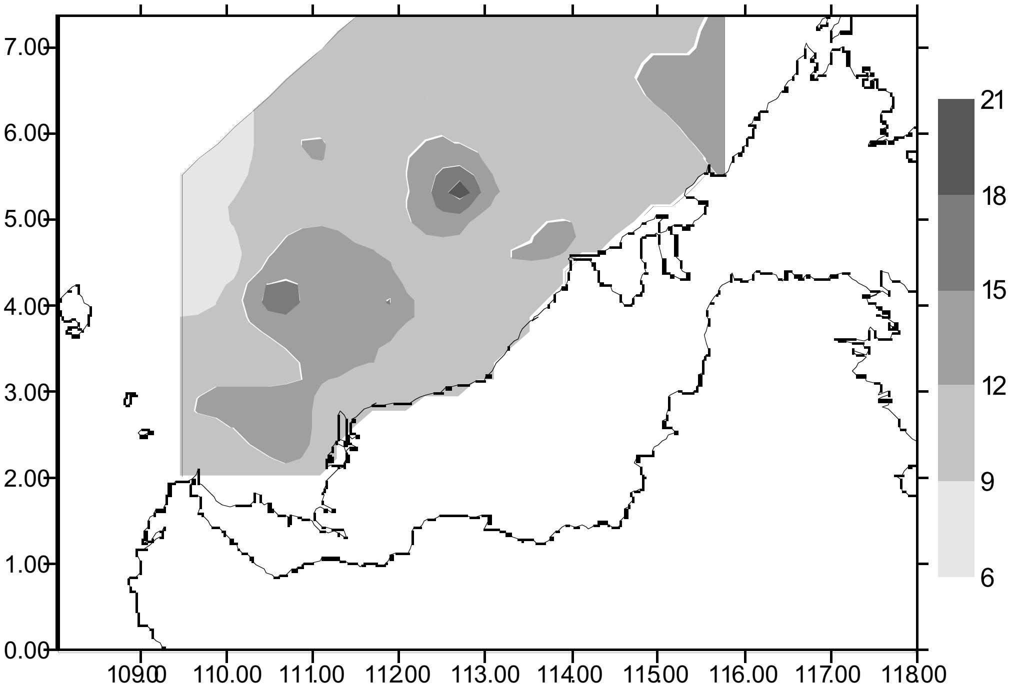

Fig. 12 Investigation dialy primary production of the general surface-water in mgC/m^3/day

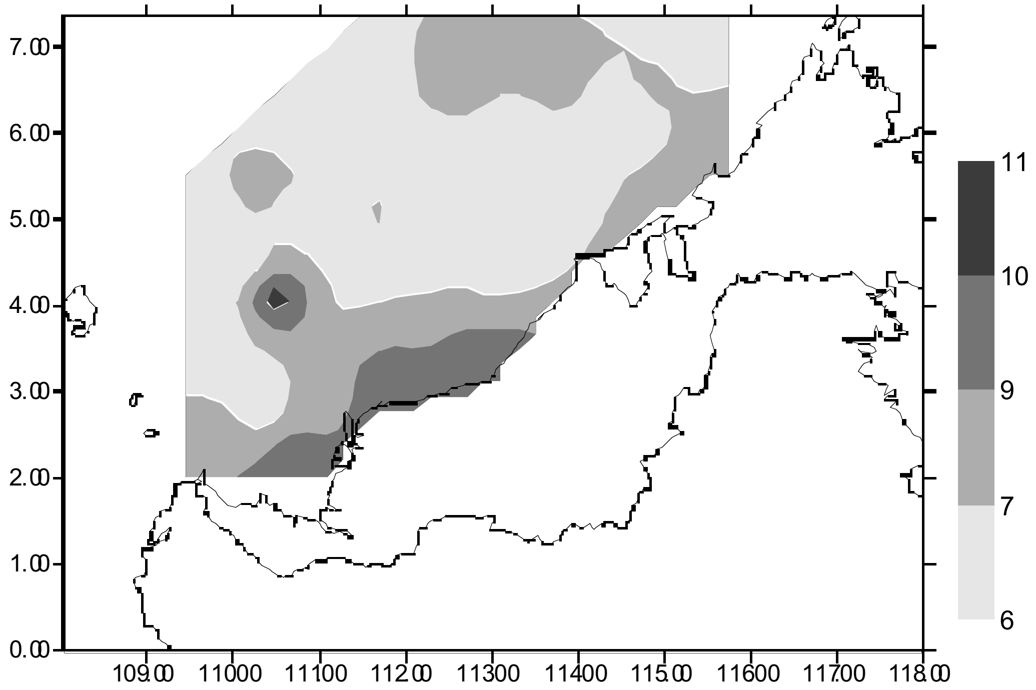

Fig. 13 Investigation dialy primary production of the general 10m water depth in mgC/m^3/day

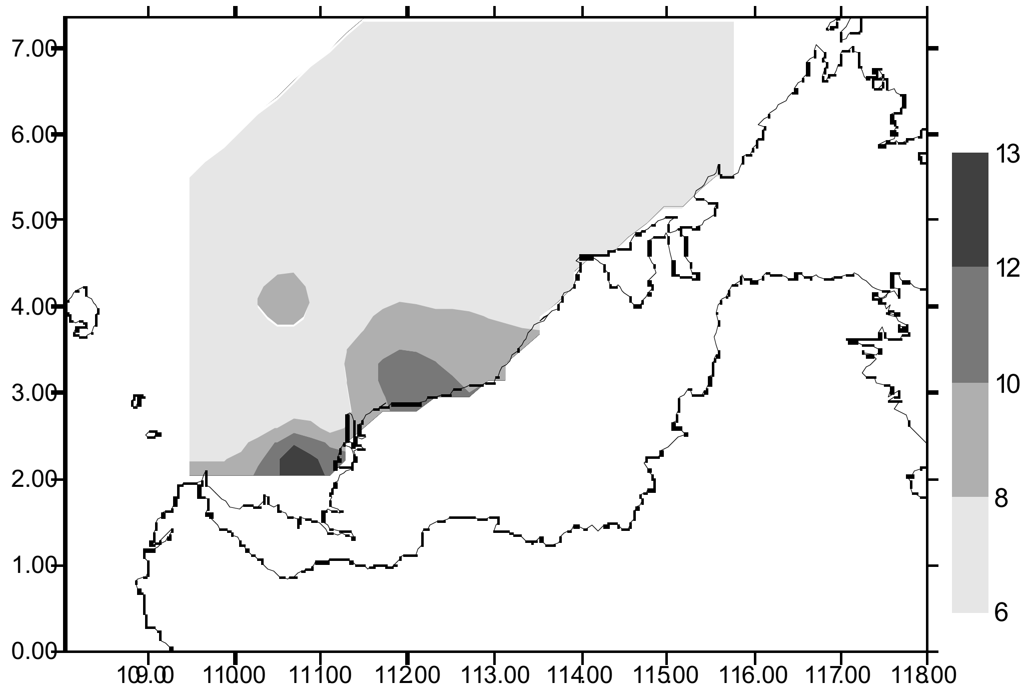

Fig. 14 Investigation dialy primary production of the general 20m water depth in mgC/m^3/day

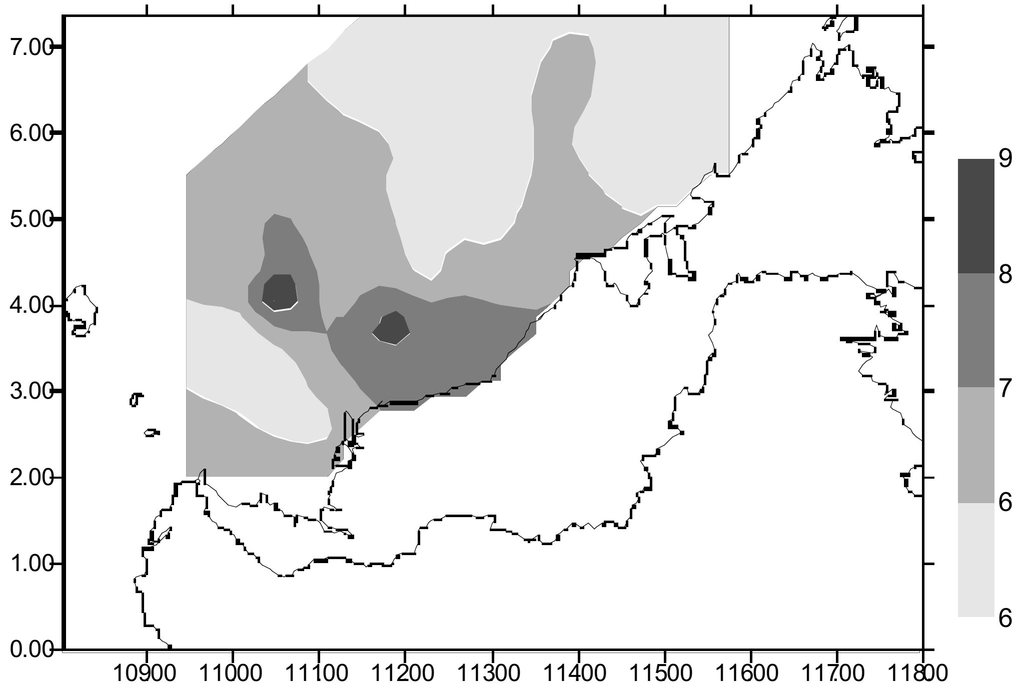

Fig. 15 Investigation dialy primary production of the general 30m water depth in mgC/m^3/day

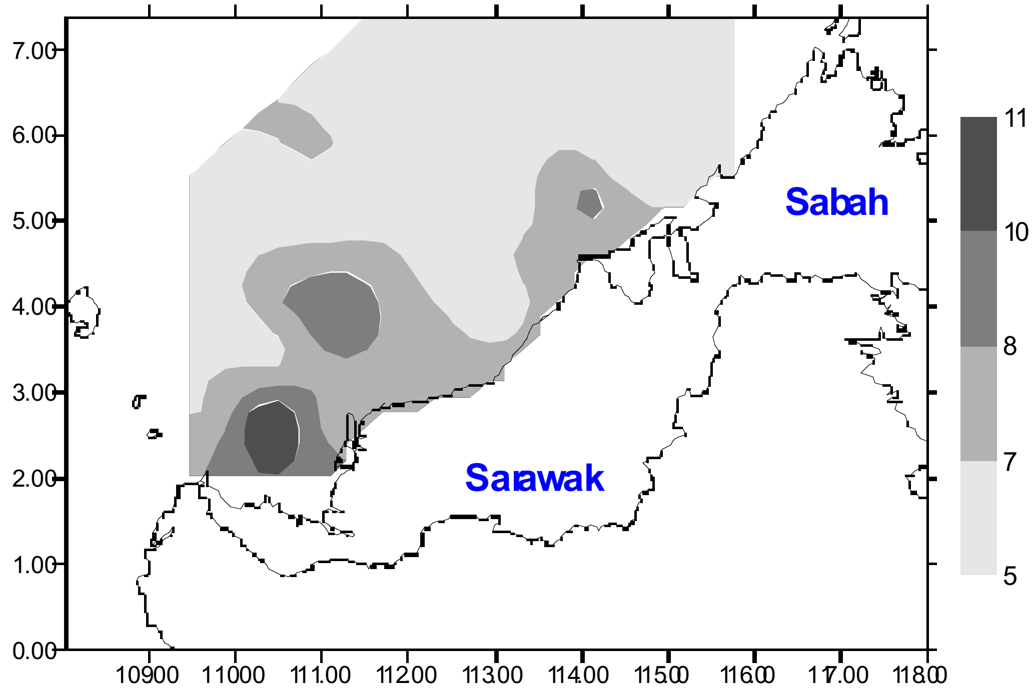

Fig. 16 Investigation dialy primary production of the general 50m water depth in $mgC/m^3/day$

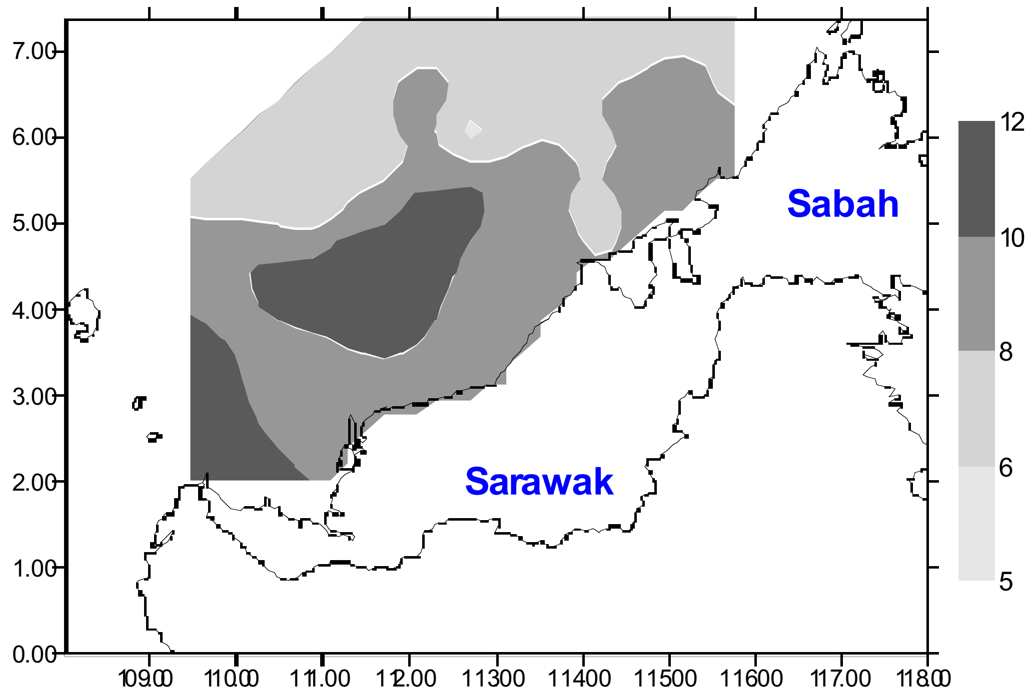

Fig. 17 Investigation dialy primary production of the general 70m water depth in $mgC/m^3/day$

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

Sopana Boonyapiwat

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

Sopana Boonyapiwat

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

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 :

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

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

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

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

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

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 (m)	Sampling level (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*

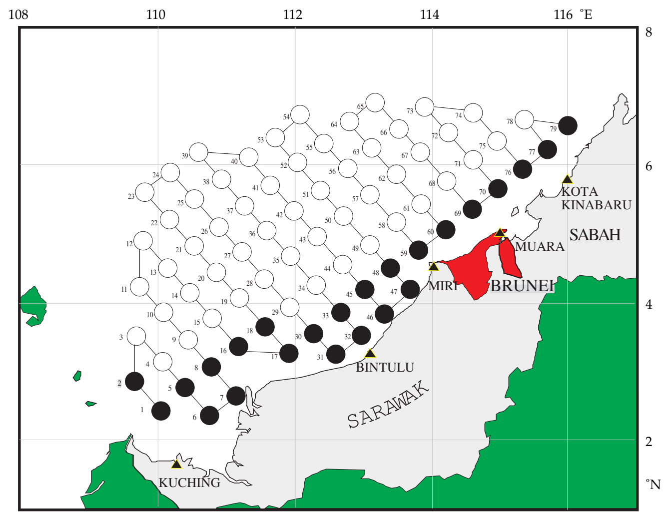


Fig. 1. Location of sampling station.

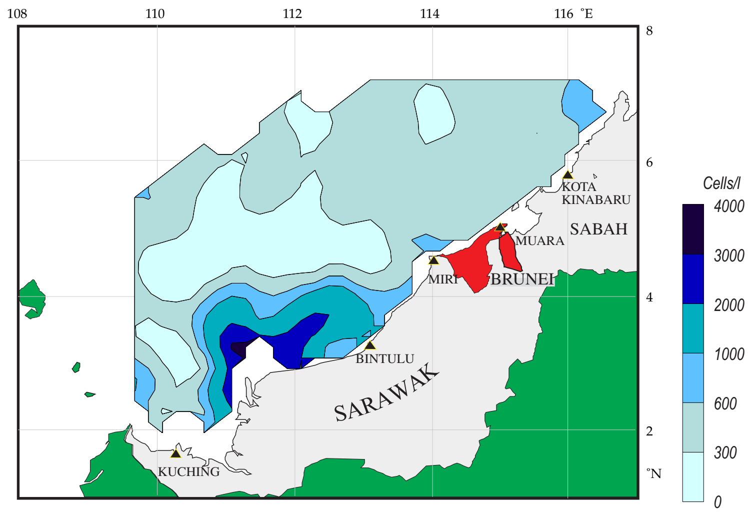


Fig. 2. Phytoplankton density in the surface layer in July 1996.

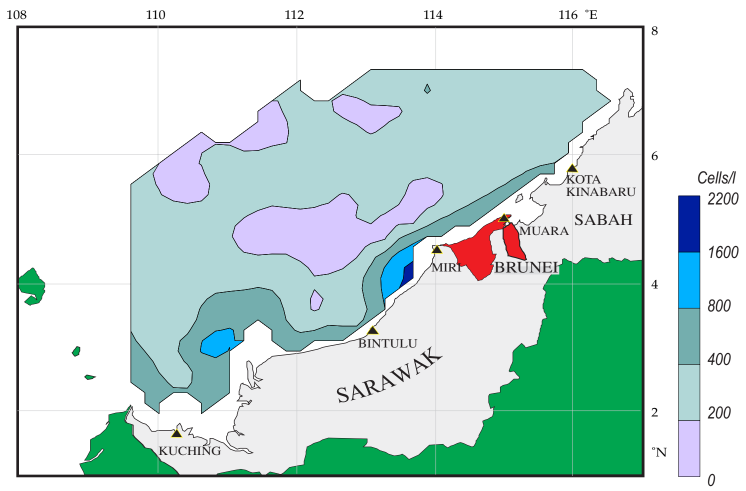


Fig. 3. Phytoplankton density in the surface layer in May 1997.

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

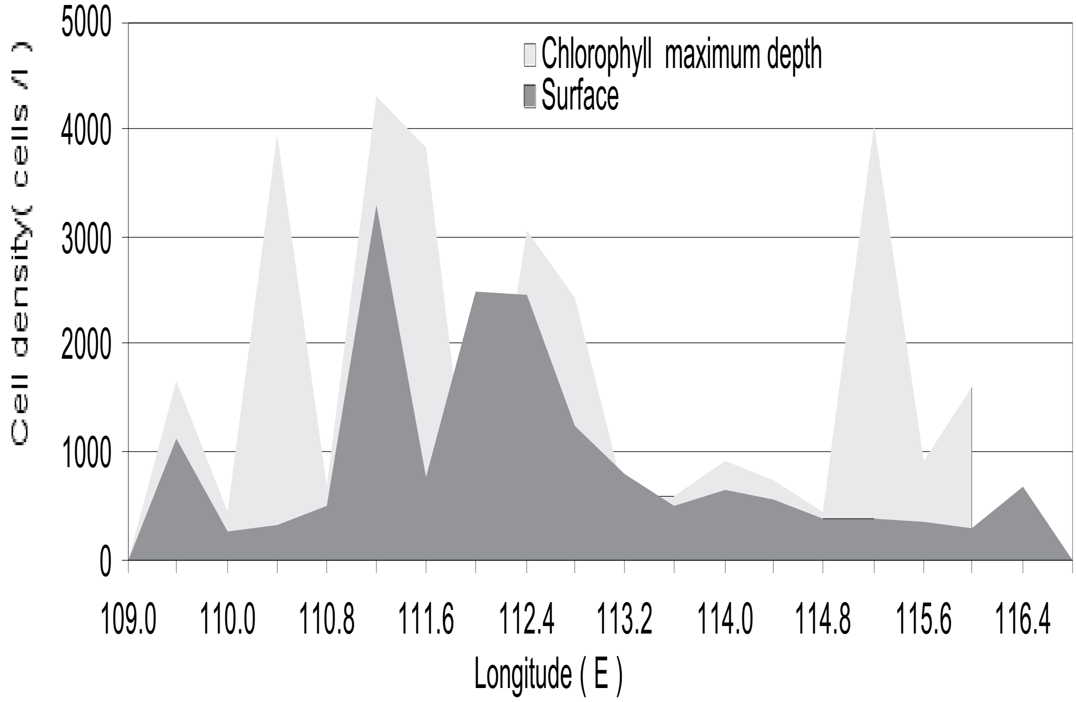


Fig. 4. Phytoplankton abundance in the coastal area of Sabah, Sarawak and Brunei Darussalam in July 1996.

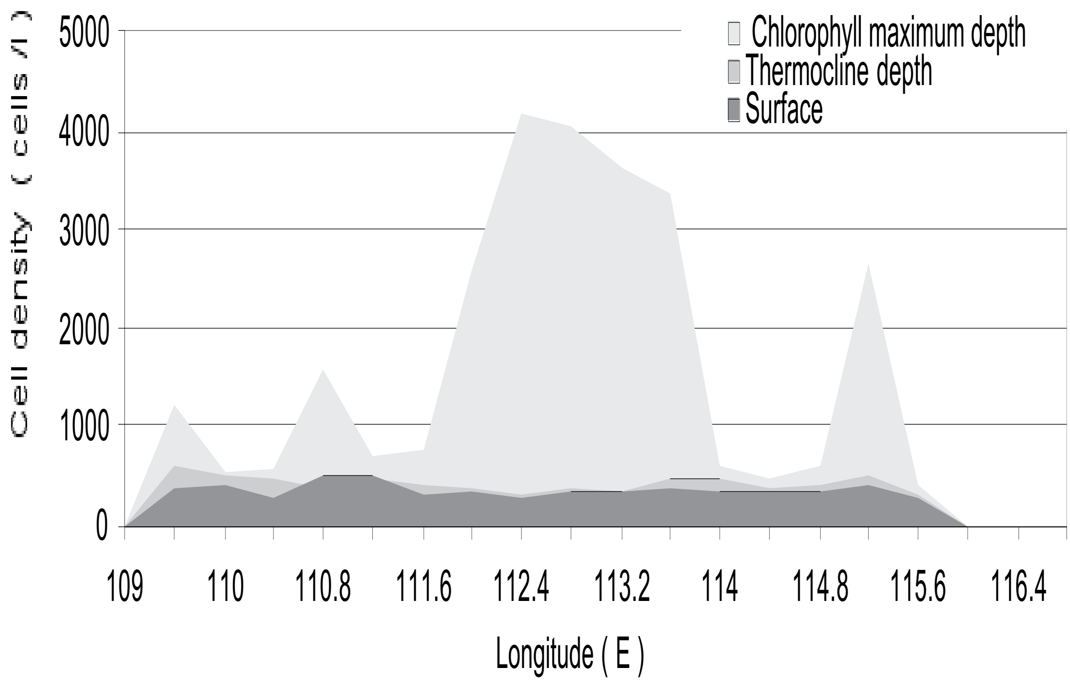


Fig. 5. Phytoplankton abundance in the offshore area of Sabah, Sarawak and Brunei Darussalam in July 1996.

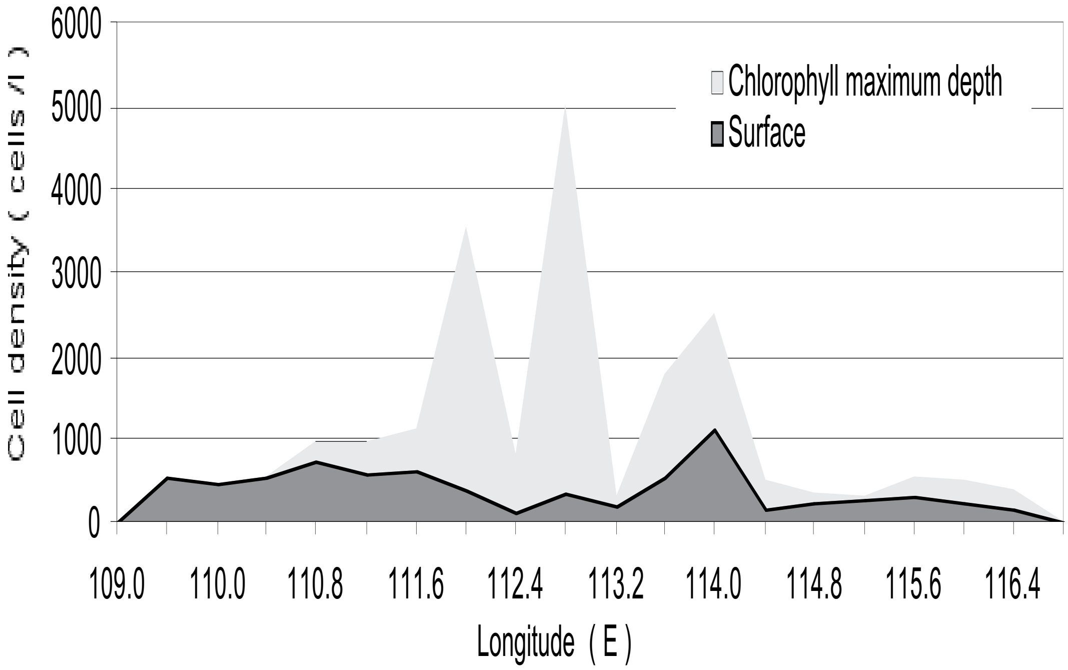


Fig. 6. Phytoplankton abundance in the coastal area of Sabah, Sarawak and Brunei Darussalam in May 1997.

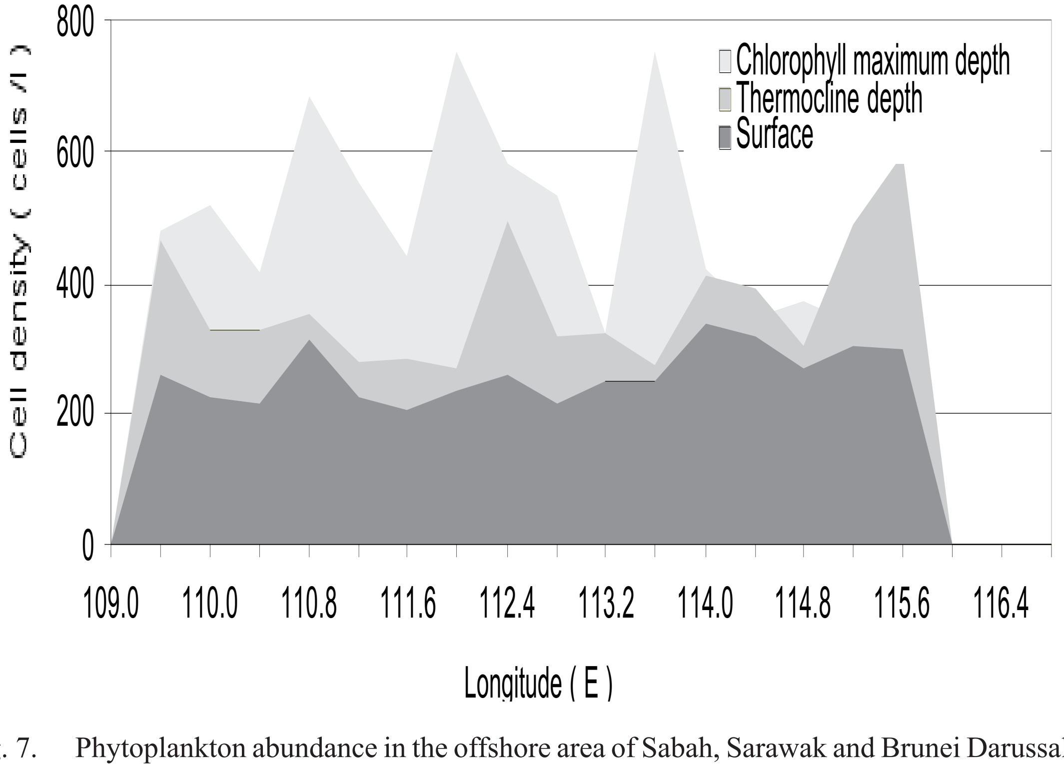


Fig. 7. Phytoplankton abundance in the offshore area of Sabah, Sarawak and Brunei Darussalam in May 1997.

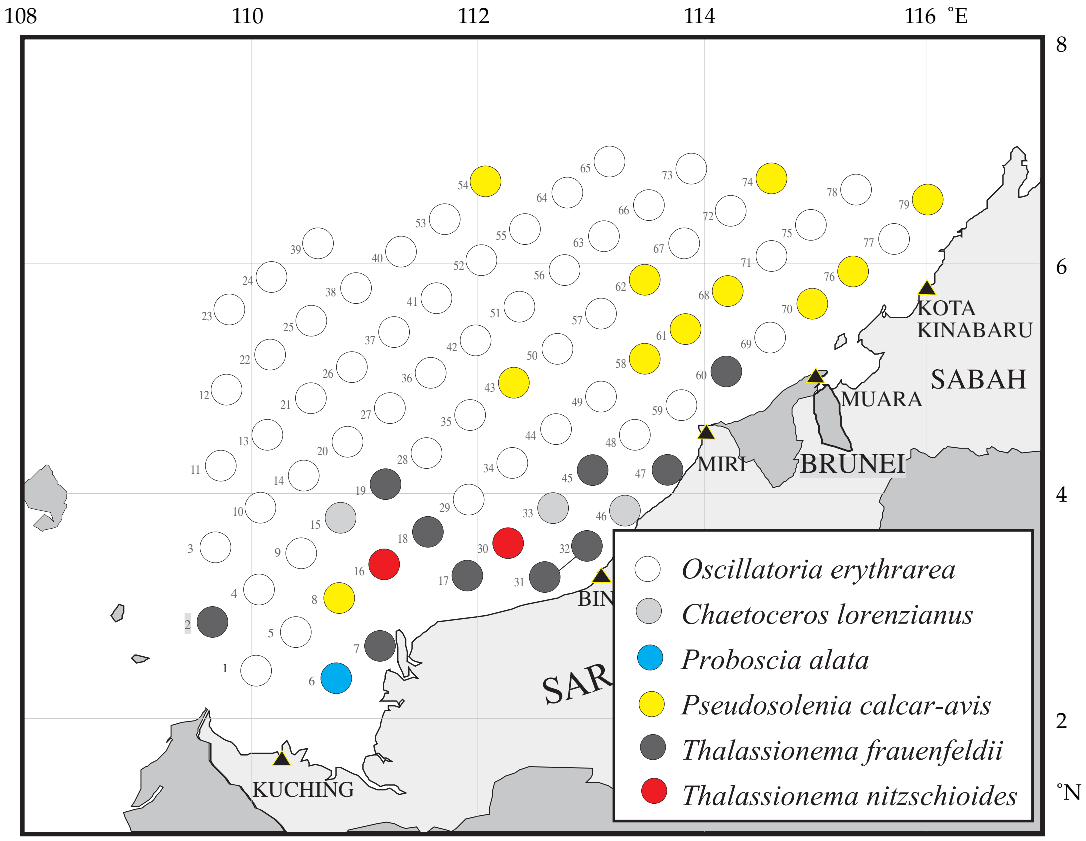


Fig. 8. Occurrence of dominant species in the surface layer in July 1996.

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

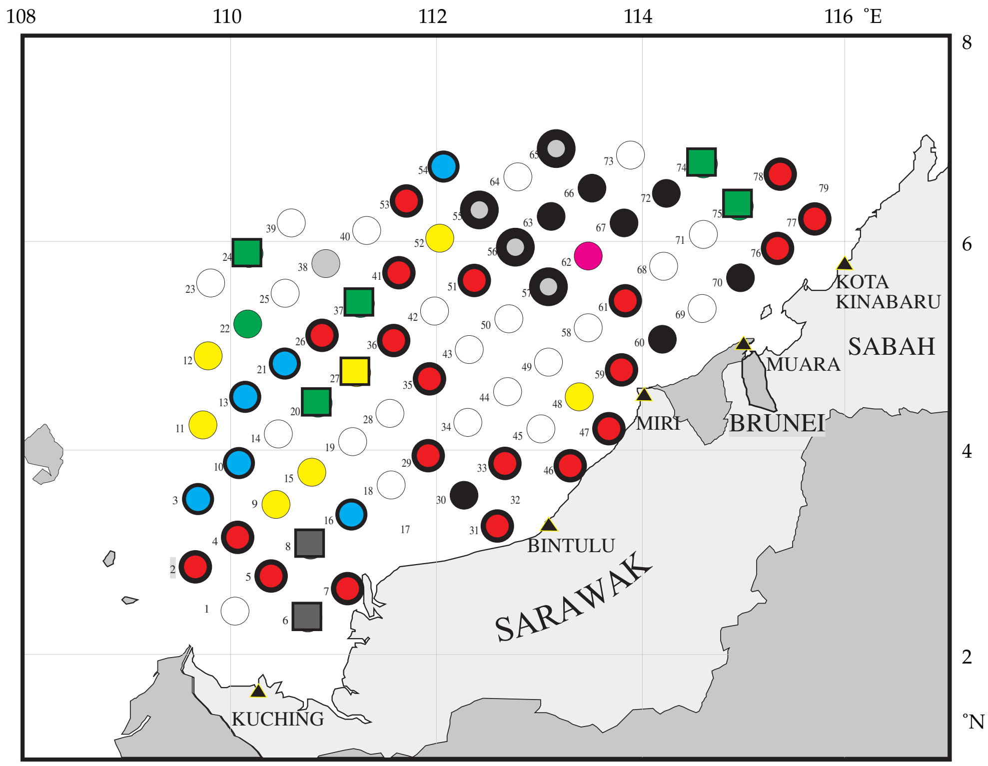
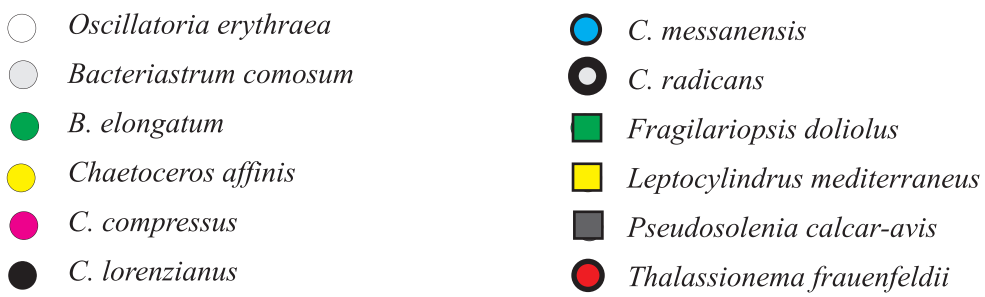


Fig. 9. Occurrence of dominant species in the chlorophyll maximum layer in July 1996.



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.

Acknowledgement

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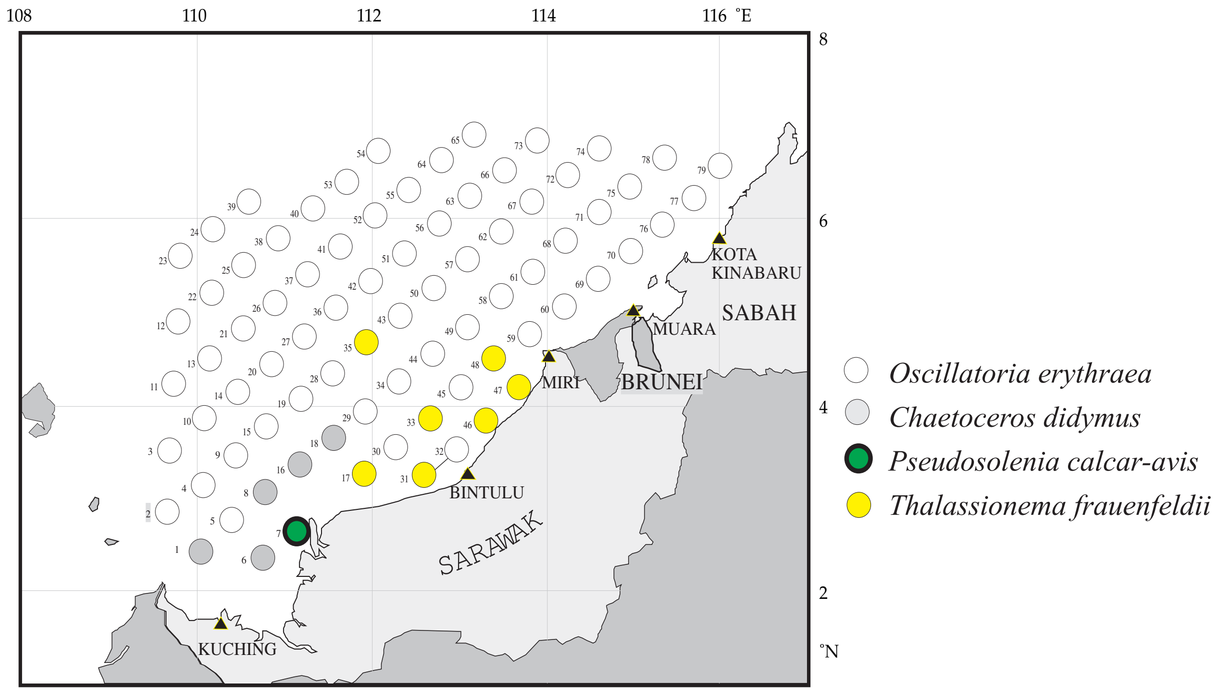


Fig. 10. Occurrence of dominant species in the surface layer in May 1997.

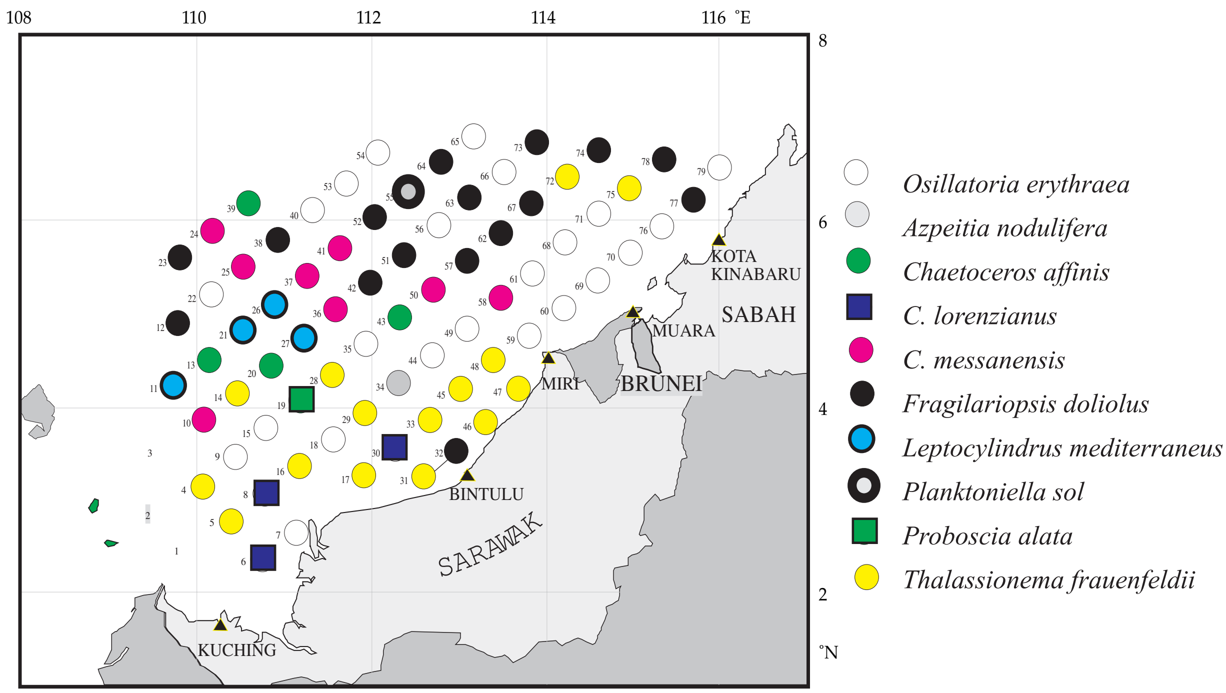


Fig. 11. Occurrence of dominant species in the chlorophyll maximum layer in May 1997.

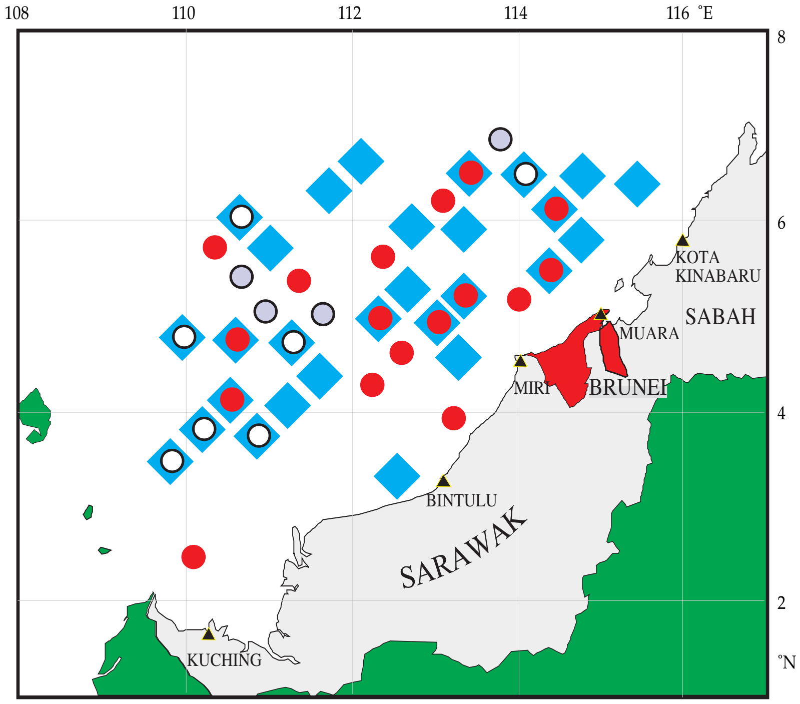


Fig.12. Distribution of *Alexandrium* spp. in July 1996 (1-36 cells/l).

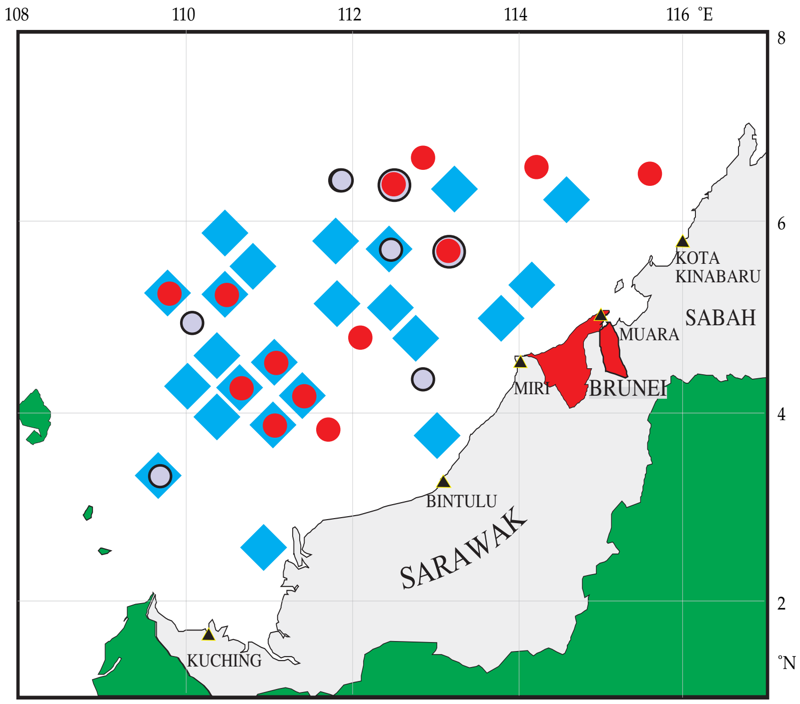
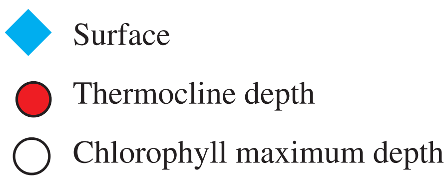


Fig.13. Distribution of *Alexandrium* spp. in May 1997 (1-36 cells/l).



References

Balech, E. : The Genus *Alexandrium* Halim (Dinoflagellatta). Sherkin Island Marine Station, Co Clark, 1995, 15 p.

Boonyapiwat, S. : Distribution, Abundance and Species Composition of Phytoplankton in the South China Sea, Area I : The Gulf of Thailand and the East Coast of Peninsular Malaysia. The 1st Technical Seminar of the Interdepartmental Collaborative Research Program "Report on Marine Fisheries Resource and Environmental Studies in the South China Sea, Area I : the Gulf of Thailand and the East Coast of Peninsular Malaysia" SEAFDEC, Bangkok, 1997, 24 p.

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

Ishimaru, T, and Y. Fujita: Surface chlorophyll maxima in Kuroshio water. *EOS/Trans. Am. Geophys. Union*, 63, 96 (1982).

Jaafar, M.H., M.W.R.N. De Silva and P.H.Y. Sharifuddin : *Pyrodinium* red tide occurrences in Brunei Darussalam.in Biology, Epidenmiology and Management of *Pyrodinium* Red Tides. Proc. of the Management and Training Workshop, Brunei Darussalam. (ed. by G.M. Hallegraeff and J.L. Maclean) ICLARM Contribution No. 585, Manila, 1989, pp. 9 - 17.

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

Ming, T.T. and J.T.S Wong : Summary of red tide and paralytic shelfish Poisoning. in Sabah, Malaysia. in Biology, Epidemiology and Management of *Pyrodinium* Red Tides. Proc. of the Management and Training Workshop, Brunei Darussalam. (ed. by G.M Hallegraeff and J.L. Maclean) ICLARM Contribution No. 585, Manila, 1989, pp. 19 – 26.

Olivieri, E.T : A description of the Hydrography and Phytoplankton communities in the upwelled waters of the Cape Peninsula, South Africa, September 1972 – February 1973. *S. Afr. J. Mar. Sci*. 1 : 199 – 229 (1983).

O'Neil, B.G and C.W. Eason : China Sea Pilot. Vol.II Hydrographer of the Navy, Hydrographic Department, Ministry of Defence, Somerset, England, 1982.

Piyakarnchana, T., S. Wisessang, G. Wattayakorn, S. Boonyapiwat and T. Okaichi : Changes in phytoplankton population in the Chao Phraya Estuary, Thailand, during the eutrophication mechanisms studies. In Proc. 2nd IOC/WESTPAC symp. Sci. Cont. Effact. Manage Mar. Env. In West Pac. Min. Sci. Tech. Env. Malaysia/IOC. 1991. pp.177 – 192.

Sang, J.W.T. and T.T. Ming : Red tide and paralytic shellfish poisoning in Sabah, Malaysia. in Toxic Red Tides and Shellfish Toxicity in Southeast Asia. Proc. of a Consulative Meeting Held in Singapore (ed. by A.W.White, M. Anraku and K.K. Hooi), SEAFDEC, 1984, pp. 35 – 42.

Siripong, A. : Surface circulation in the Gulf of Thailand and South China Sea in 4 seasons from direct measurement. in Proc. 3rd Seminar on the Water Quality and Living Resources in Thai Waters. NRCT, Bangkok, 1984, pp. 140 – 148.

Thorrington – Smith, M. : Some new and little known planktonic diatoms from The west Indain Ocean. *Nova Hedwigia, Beih*., 815 - 835 (1970).

Usup, G, A. Ahmad and H. Ismail : *Pyrodinium bahmense* var. *compressum* red tide studies in Sabah, Malaysia. in Biology, Epidemiology and Management of *Pyrodinium* Red Tides. Proc. of the Management and Training Workshop, Brunei Darussalam. (ed. by G.M. Hallegraeff and J.L. Maclean) ICLAR M Contribution No. 585, Manila, 1989, pp. 97– 110.

Venrick, E. L., J. A. McGowan and A.W. Mantyla.: Deep maximum of photosynthetic chlorophyll in the Pacific Ocean. *Fish. Bull*. 71, 41 – 52 (1972).

Yamaguchi, Y. and S. Ichimura : Subsurface chlorophyll maximum in winter at a station in the western North Pacific Ocean. *La Mer*, 18 , 82 – 88 (1980).

Microplankton on Distribution in the South China sea, Area II: Sarawaw, Sabah and Brunei Darussalam Waters

* Lokman Shamsudin, ** Abdul Hamid Yasin,
**Solahudin Abdul Razak and **Mohd Shukri Yusoff

* Faculty Applied Science and Technology, Universiti Putra Malaysia Terengganu, (UPMT)
21030 Kuala Terengganu, Malaysia
** Marine Fishery Research Development and Management Department SEAFDEC,
Kuala Terengganu.

ABSTRACT

Collaborative cruises in the South China Sea around the coast of Sarawak, Brunei and Sabah were conducted in the premonsoon (October, 1996) and the postmonsoon (June, 1997) periods on board MV SEAFDEC. The microplankton from 79 sampling stations consisted of more than 200 taxa consisting predominantly of blue green algae (3 species), diatoms (> 90 species), dinoflagellates (> 70 species) and microzooplankton (> 20 groups). Among the microplankton collected, three species of blue green (*Trichodesmium erythraeum, T. thiebautii, Richelia* sp.) and numerous diatom species were dominant. The dominant diatom species comprised of *Chaetoceros diversum, C. peruvianum, C. laciniosus, Thalassionema frauenfeldii, Bacteriastrum comosun, Coscinodiscus* sp. and *Rhizosolenia alata*; while those of dinoflagellates consisted of *Ceratium fusus, C. arcuatum, C. teres, Protoperidinium* sp., *Protoceratium* sp., *Ceratocorys* sp. and *Alexandrium* sp. The genera *Chaetoceros, Rhizosolenia, Bacteriastrum* and *Ceratium* were found to contain a wide range of species. The total microplankton densities ranged from 0.74 x 10^6 to 7.94 x 10^6 individuals / m^3 and from 0.16 x 10^6 to 1.25 x 10^6 individuals / m^3 during the premonsoon and postmonsoon periods respectively. The presence of the dinoflagellate species of *Ceratium, Protoperidinium* and *Alexandrium* were detected in considerable amounts at coastal and intermediate middle waters of the South China Sea. Blooms of *Rhizosolenia alata* and *Trichodesmium* sp. occurred during the premonsoon period. The microzooplankton consisted of more than 20 species dominated by copepod nauplii (> 50% of total microzooplankton count), radiolerians, foraminiferas and protozoans; most of the zooplankton species were dominant in nearshore and intermediate middle waters of the South China Sea.

Introduction

Published works on studies of plankton and other related organisms of the Malaysian waters in the South China Sea are scanty. Qualitative studies of plankton in the Malaysian coastal waters, especially the Malacca Straits have been conducted by Sewell (1933), Wickstead (1961) and Pathansali (1968). Primary productivity in the same location had been carried out by Doty *et al.* (1963); however, a detailed study of the species community structure, distribution and abundance of plankton in such waters had been lacking. Studies by Shamsudin (1988) in the South China Sea around coasts of Johore, Terengganu and Kelantan found that majority of the phytoplankton found were diatoms which comprise of numerous species of *Bacteriastrum, Chaetoceros, Rhizosolenia* and *Pleurosigma*. The blue green, *Trichodesmium erythraeum* was found in abundance in tropical waters (Chua & Chong, 1973). Studied on plankton (Shamsudin 1987, Shamsudin & Baker 1987, Shamsudin *et al.* 1987, Chua & Chong 1973) had raised questions about the qualitative and quantitative seasonal availability of these organisms as sources of food for those organisms higher up in the food chain and the relative production of these organisms in various study sectors of the South China Sea.

Studies by Chua and Chong (1973) in the Malacca Straits showed that the distribution and abundance of pelagic species especially the small tuna (*Euthynus affinis*), chub makerel (*Rastrelliger* sp.) and anchovies (*Stolephorus* sp.) were related to the density of phytoplankton. Physico-chemical factors may influence the distribution and abundance of phytoplankton. These factors consisted of temperature, salinity, dissolved oxygen, turbidity, current and nutrient concentration (nitrate, phosphate, ammonium and silicate).

In the present study, the microplankton community structure has been analysed during the pre and postmonsoon periods (October 1996, June 1997) in the Sarawak, Sabah and Brunei waters of the South China Sea. The species community structure patterns, distribution, composition and species abundance at various study sectors of the South China Sea during the two seasons were estimated.

Methods

Study Area

The study area covers an area which extends from the eastern Sarawak waters (Lat. 2^{o} 18.4 E; Long. 109^{o} 35.4'N) to the northern tip of Sabah covering the Sabah waters (7^{o} 9.6'E; 115^{o} 51.9' N) of the South China Sea . The estimated study area is ca 8100 nautical square miles (ca 25100 sq. km) covering the economic exclusive zone (EEZ) of Malaysian sea of the South China Sea. The sea cruise track followed a zig-zag manner starting from the eastern coastal Sarawak waters and ended up at the northern end of Sabah waters covering a total of 79 sampling stations.

Sampling Method & Preparation

The research survey were carried out in October 1996 and June 1997 whereby seventy nine stations were identified during the survey. Vertical plankton net of mesh size 56 µm was hauled at a speed of 1 m/s from 40 m (twice the depth of the 1% surface illumination) to the surface. The net diameter is 45 cm and length 92 cm. Samples at various depths using Van Dorn water sampler (20 litres) were also taken to quantify the microplankton population which also include some of the microzooplankton. This is to compensate the error which might arise from plankton escaping the net plankton. During sampling the plankton also included some zooplankton that might be caught in the water sampler and net plankton at the same time. The net plankton was hauled vertically at very slow speed (to avoid plankton avoidance of the plankton net) at every stations. The samples were preserved in 10% formalin. The microplankton fractions of the samples were examined for species composition and abundance. A quantitative study of the microplankton was carried out using an inverted microscope (Vollenweider *et al.* 1974; Tippett 1970; Shamsudin 1987, 1993, 1994, 1995; Shamsudin & Shazili 1991; Shamsudin & Sleigh 1993, 1995; Shamsudin *et al.* 1987, 1997).

The microplankton cells were routinely examined with a Nikon microscope using a x 10 eyepiece and a x 40 bright field objective. Difficult specimens were examined under a x 100 oil immerson objective. Where it was necessary for a detailed identification, samples were treated by boiling and washing in 10% HCI (Tippett, 1970) to clean diatom frustules in order to show up their ultra fine structure for identification purposes, employing the scanning electron microscope (SEM) technique. The samples which had been fixed and preserved in absolute alcohol, were then mounted on (SEM) stubs with double-sided cellotape. The stubs with adhering samples were then coated with an alloy (gold with pelladium) before being observed under the scanning electron microscope (Barber & Haworth, 1981). Algal were identified with reference to Palmer & Keely (1900), Cleve (1901, 1904), Gran (1912), Pascher (1914, 1915 & 1925), Hustedt (1930), Sewell (1933), Handey (1933, 1964), Fritsch (1935), Cummins & Mulryan (1937), Cupp (1943), Cleve-Euler (1944), Crossby & Wood (1959), Winstead (1961), Banse (1964), Patrick & Reimer (1968), Shirota (1966), Newell & Newell

(1973), Taylor (1976), Taylor & Seliger (1979) and Barber & Haworth (1981).

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

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

n_i = The number of individuals of the i th species

N = The total number of individuals

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

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

Statistical Analysis

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

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

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

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

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

The microplankton can be classified into species assemblages or associations in cluster analysis on species sampled from the nearshore and offshore stations according to their preference on environmental conditions using the unweighted pair group average (UPGA) Pearson correlation index (Pielou, 1984; Ludwig & Reyholds, 1988).

Results and Discussion

The microplankton during the pre and post monsoon survey cruises consisted of more than 200 taxa consisting predominantly of blue green algae (3 species), diatoms (> 90 species) and dinoflagellates (> 70 species) (Tables 1 & 2, see Appendix). Three species of blue greens (*Trichodesmium erythraeum, T. thiebautii, Richelia* sp.) as well as several species of diatoms and dinoflagellates were dominant. The dominant diatom species comprised of *Chaetoceros diversum, C. peruvianum, C. laciniosus, Thalassionema frauenfeldii, Rhizosolenia alata, R. hebatata, R. styliformis, Bacteriastrum comosun, B. varians, B. hyalimum, Coscinodiscus* sp. and *Rhizosolenia alata*; while those of dinoflagellates consisted of *Ceratium fusus, C. teres, C. areuatum, Protoperidinium* sp., *Protoceratium* sp., *Ceratocorys* sp. and *Alexandrium* sp (Tables 2 & 3). The genera *Chaetoceros, Rhizosolenia, Coscinodiscus, Bacteriastrum* and *Ceratium* were found to contain a wide range of species. The total microplankton densities ranged from 0.74 x 10^6 to 7.94 x 10^6 individuals / m^3 and from 0.16 x 10^6 to 1.25 x 10^6 individuals / m^3 during the premonsoon and postmonsoon periods respectively (Fig. 1). There was an increase of about one order of magnitude in the total cell population during the premonsoon as compared to the post monsoon season. The diversity index H values ranged from 1.7 to 4.8 with usually high values in the coastal stations during both seasons (Fig. 2). The J evenness index values were usually directly proportional to the H values.

The maps from Figs. 3.1 a & b show the total cell population density during the pre and post monsoon period during the cruise survey with lesser population density in the latter. Two distinct patches of high cell population density were observed near the Rajang river mouth and offshore waters to the north of Sarawak during the premonsoon. A broad strip of water mass rich in microplankton was observed in the middle Sarawak waters of the South China Sea during the postmonsoon. It is noted that two patches of *Trichodesmium* bloom occurred near the Rajang river mouth and offshore waters to the north of Sarawak (Figs. 3.2 a & b). The dinoflagellate bloom was dense at the Rajang river mouth during the pre monsoon period while it was scattered during the postmonsoon (Figs. 3.3 a & b). An elongated narrow strip of *Thalassionema* bloom was observed along the coast of Sarawak during the premonsoon while two small patches of *Thalassionema* bloom was seen during the postmonsoon (Figs. 3.4 a & b). An isolated *Rhizosolenia* bloom was seen in the middle waters to the north of Brunei during the postmonsoon (Figs. 3.5 a & b). The species of *Trichodesmium* and *Rhizosolenia* were dominant species during the pre and post monsoon periods; numerous small patches of different species of *Chaetoceros, Thalassionema* and *Bacteriastrum* are also found (Figs. 3.6 a & b) during the study period.

Microplankton population at various sectors

Sampling stations can be grouped into at least 5 sectors with respect to their similarities in species composition using cluster analyses on 79 stations by mean of the unweighted pair group average (UPGA) Pearson index analyses (Fig. 4). The identified sectors comprised of a) Sarawak coastal waters (SCW), b) Sarawak middle water (SMW), c) Offshore Sarawak waters (OSW), d) Eastern Sabah waters (ESW) and e) Western Sarawak waters (WSW). The mean population densities at various stations of the 6 sectors (data from various stations from each sector were pooled together) were high during the premonsoon with values ranging from 0.74 x 10^6 to 7.94 x 10^6 /m^3 with Sarawak coastal waters sector having the highest values (Figs. 5 - 9). The trend in the mean densities at the 5 sectors during the post monsoon was similar to that of the premonsoon; however the values were much lower during the postmonsoon, ranging from 0.16 x 10^6 to 1.25 x 10^6 /m^3.

The major microplankton species at the Sarawak middle waters sector during premonsoon comprised of *Rhizosolenia calcar-avis, Chaetoceros lorenzianus, Coscinodiscus* sp., *Trichodesmium erythraceum* and *Ceratium fusus* with values ranging from 794 to 9.7 x 10^5/m^3. The copepod nauplii had a moderate value of 6.31 x 10^4/m^3 (Fig. 5). Microplankton species during the premonsoon were

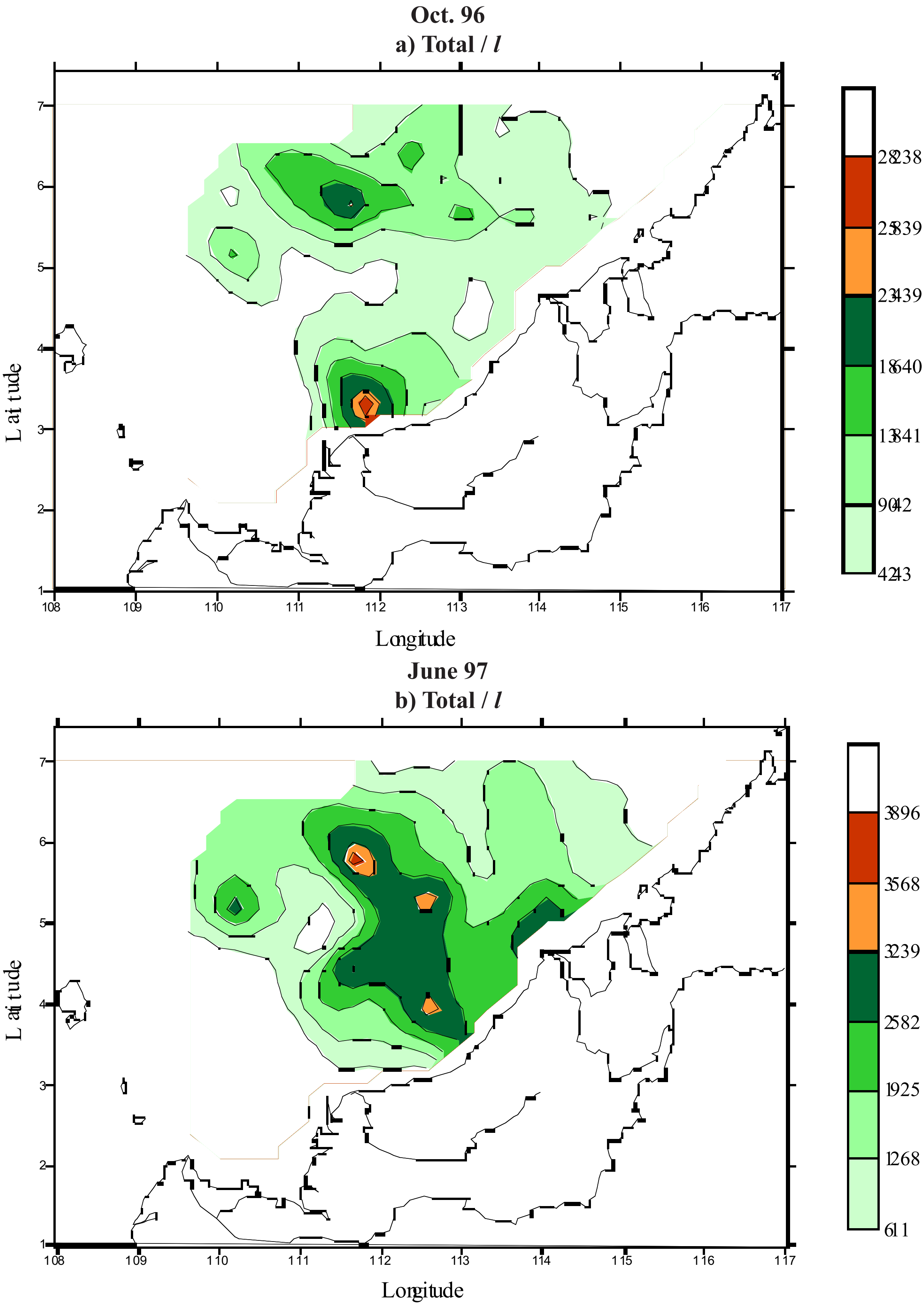


Fig. 3.1 Total cell density (L^{-1}) of microplankton cell population during the (a) pre and (b) post monsoon period of the cruise survey (October 1996 and June 1997).

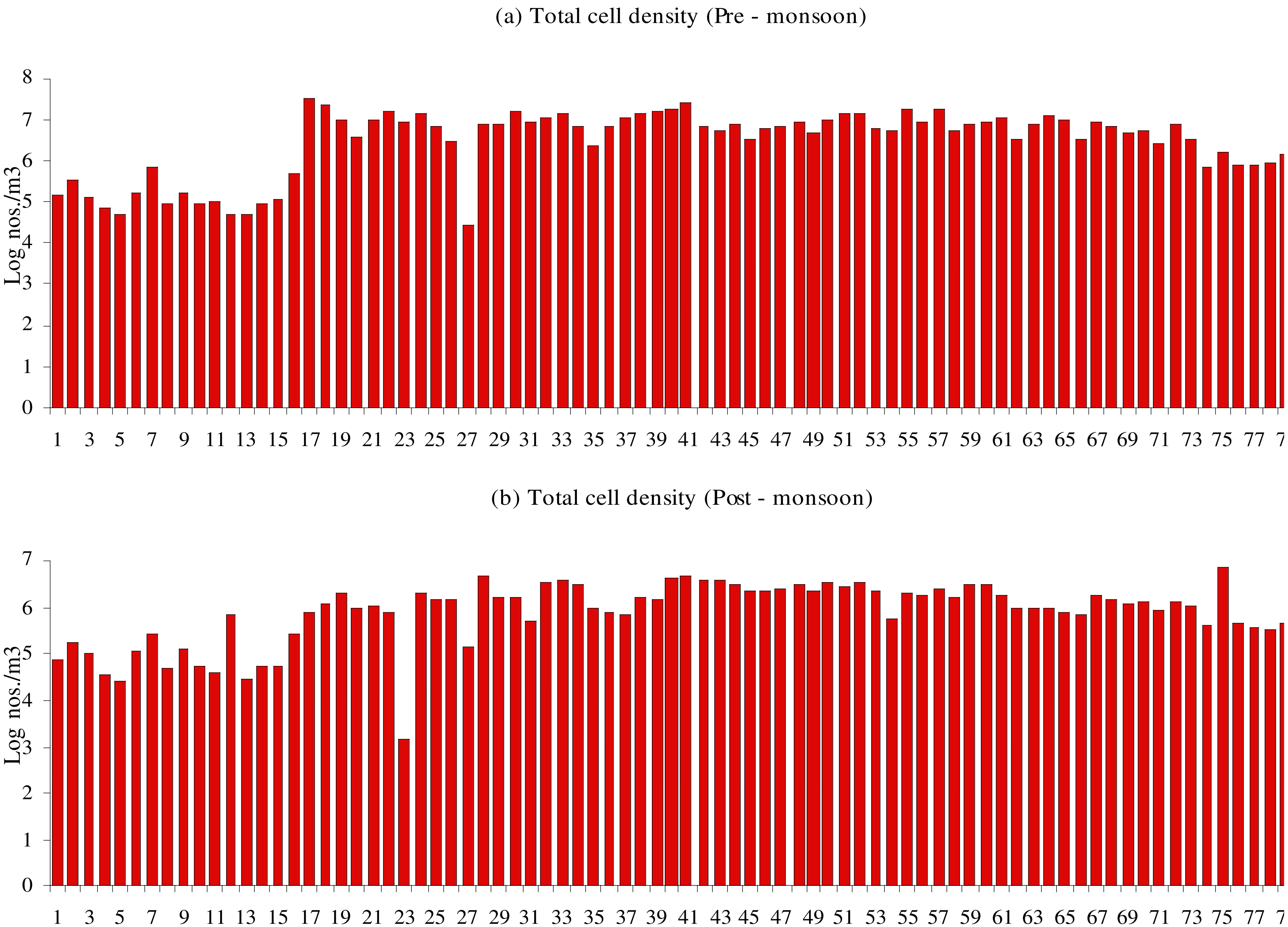


Fig. 1 Total cell densities (log nos./m^3) at different stations during the pre and post - monsoon period (Oct. 1996 / June 1997 respectively) in Sabah - Sarawak waters of the South China Sea.

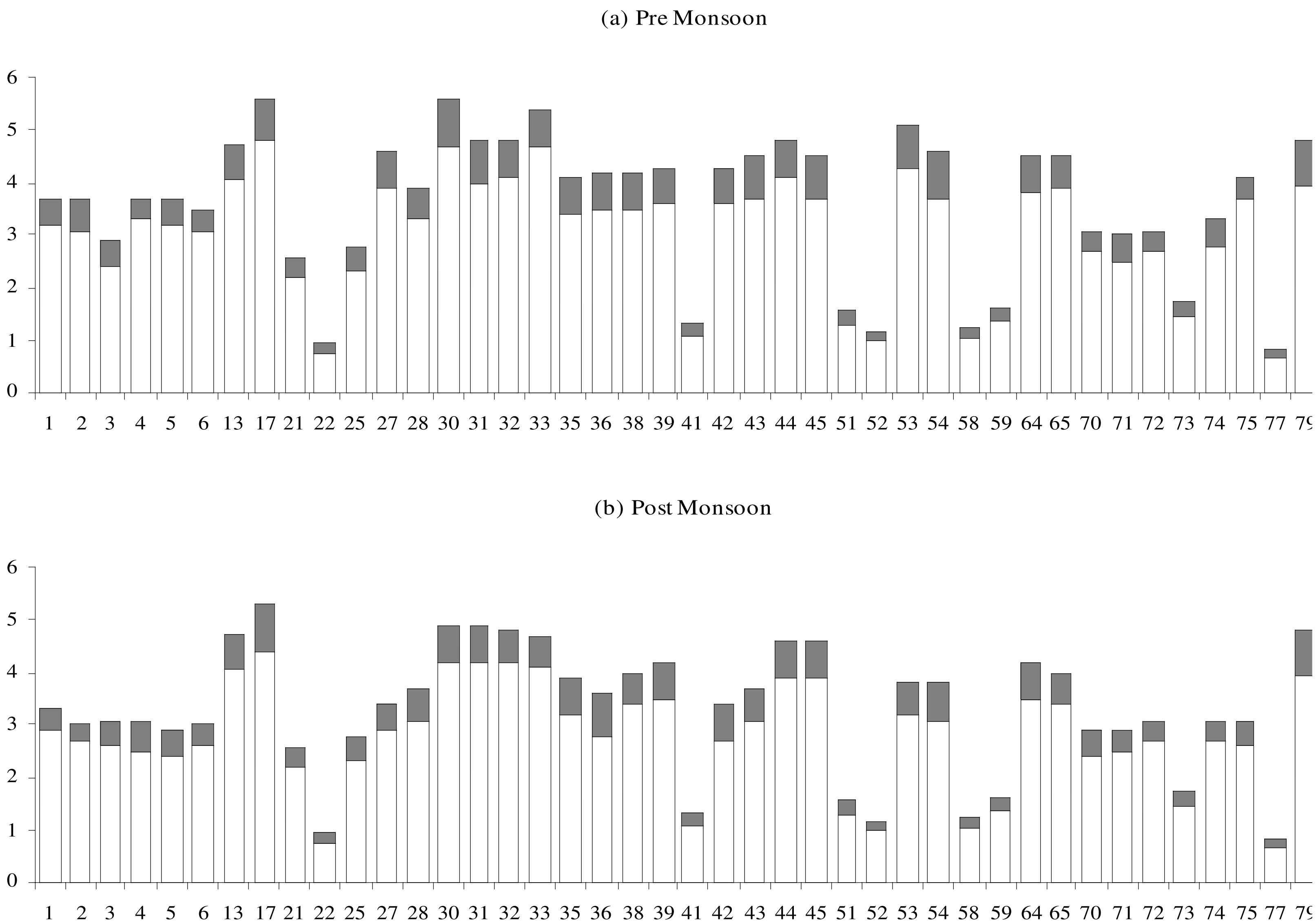


Fig. 2 The diversity (H) and evenness (J) indices of various station in the Sarawak - Sabah waters of the South China Sea during (a) pre monsoon and (b) post monsoon season.

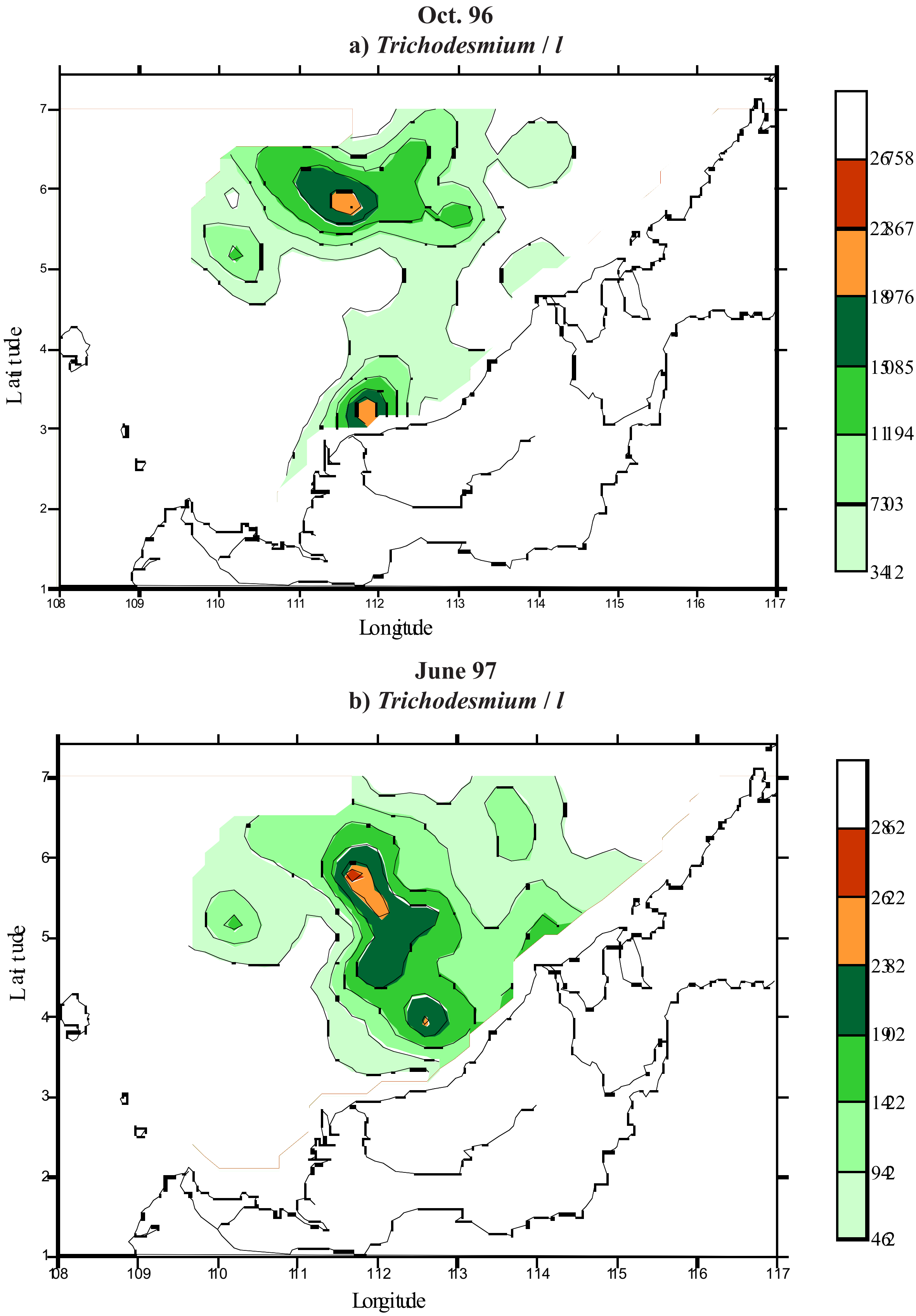
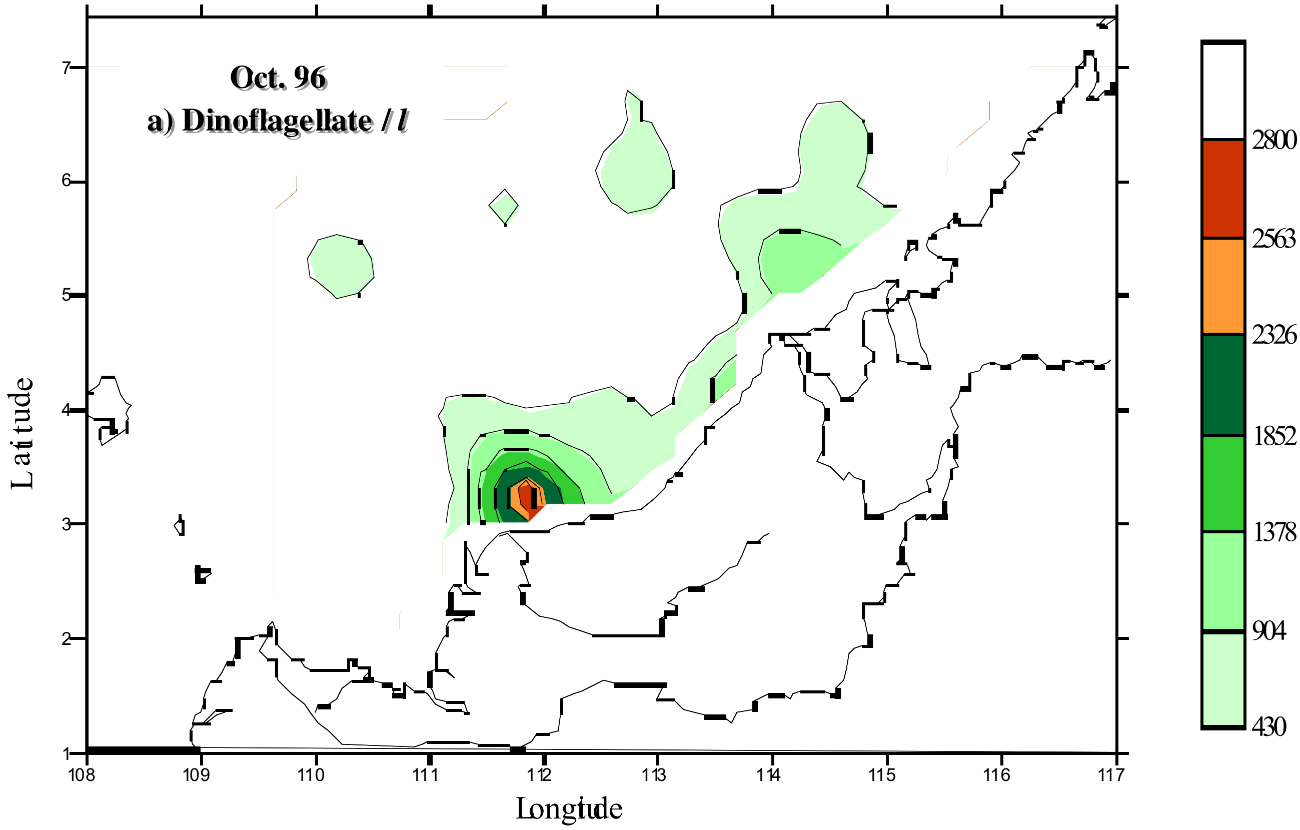


Fig. 3.2 *Trichodesmium* population density (L^{-1}) during the (a) pre and (b) post monsoon period of the cruise survey (October 1996 and June 1997).



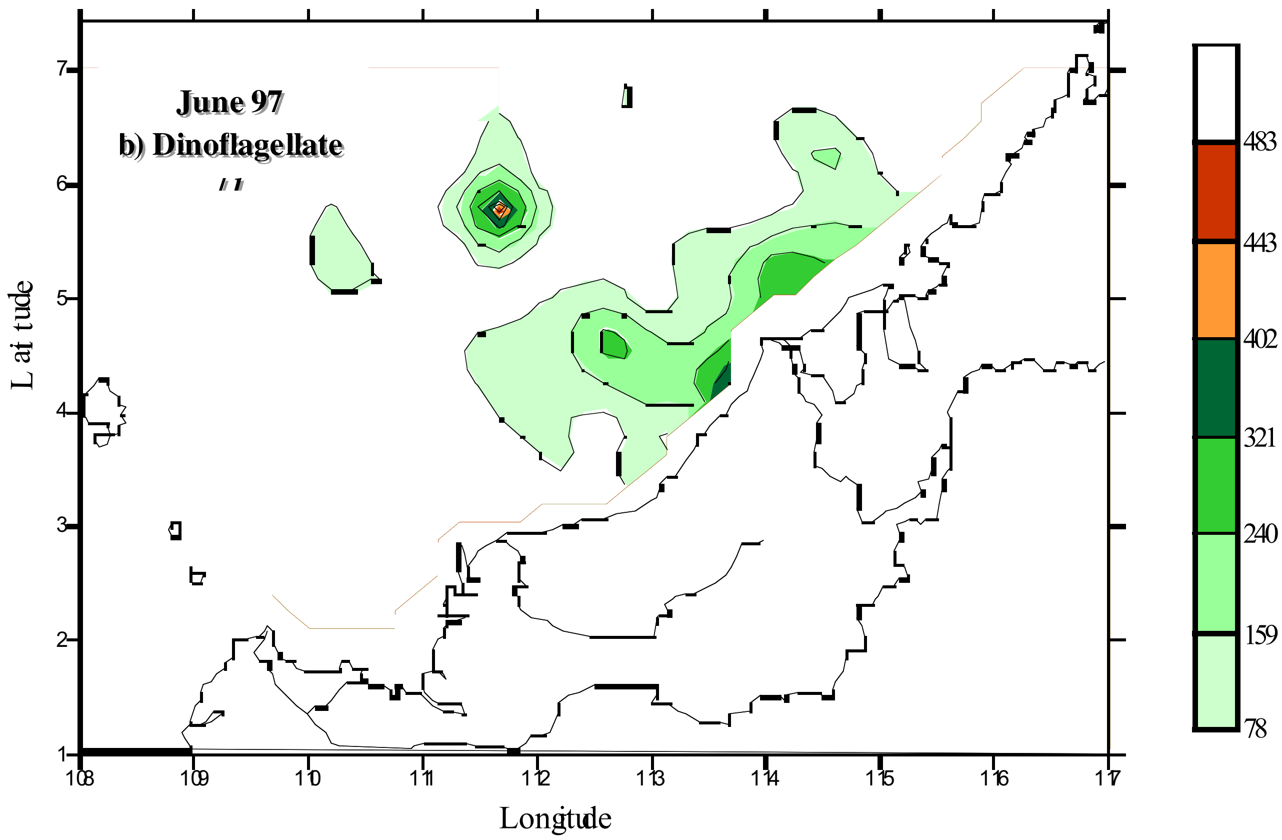


Fig. 3.3 Dinoflagellate population density (L^{-1}) during the (a) pre and (b) post monsoon period of the cruise survey (October 1996 and June 1997).

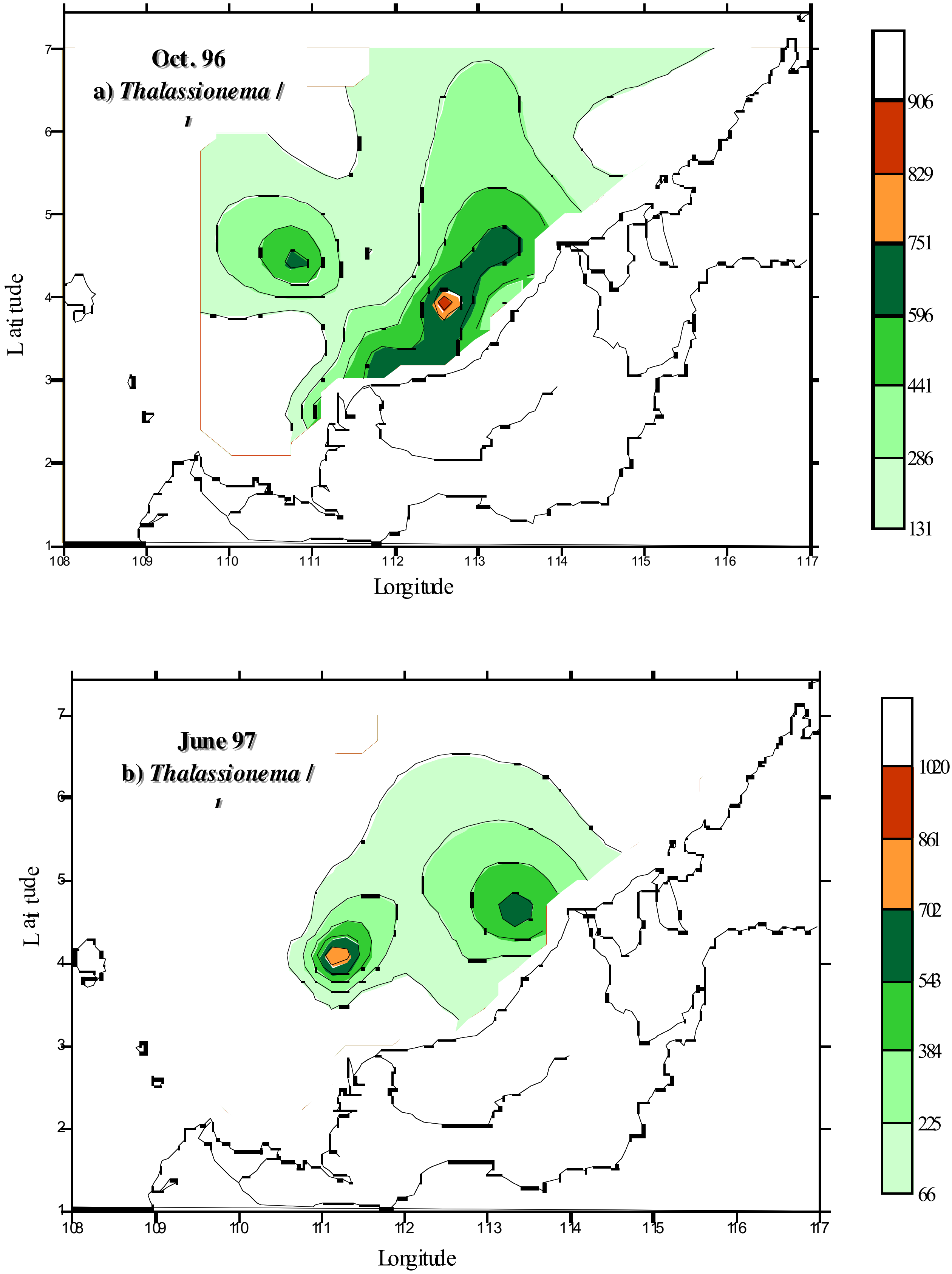


Fig. 3.4 *Thalassionema* population density (L^{-1}) during the (a) pre and (b) post monsoon period of the cruise survey (October 1996 and June 1997).

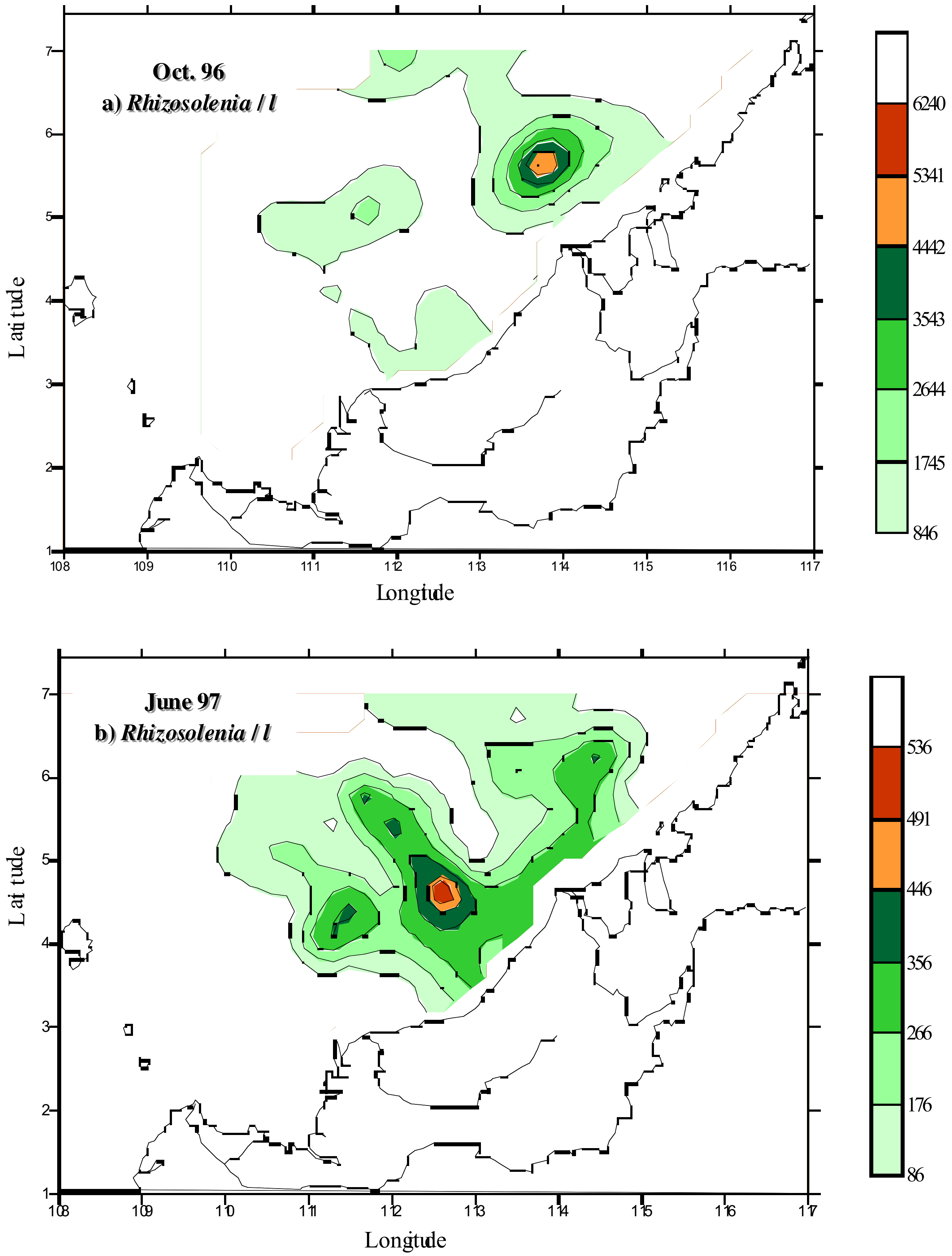


Fig. 3.5 *Rhizosolenia* population density (L^{-1}) during the (a) pre and (b) post monsoon period of the cruise survey (October 1996 and June 1997).

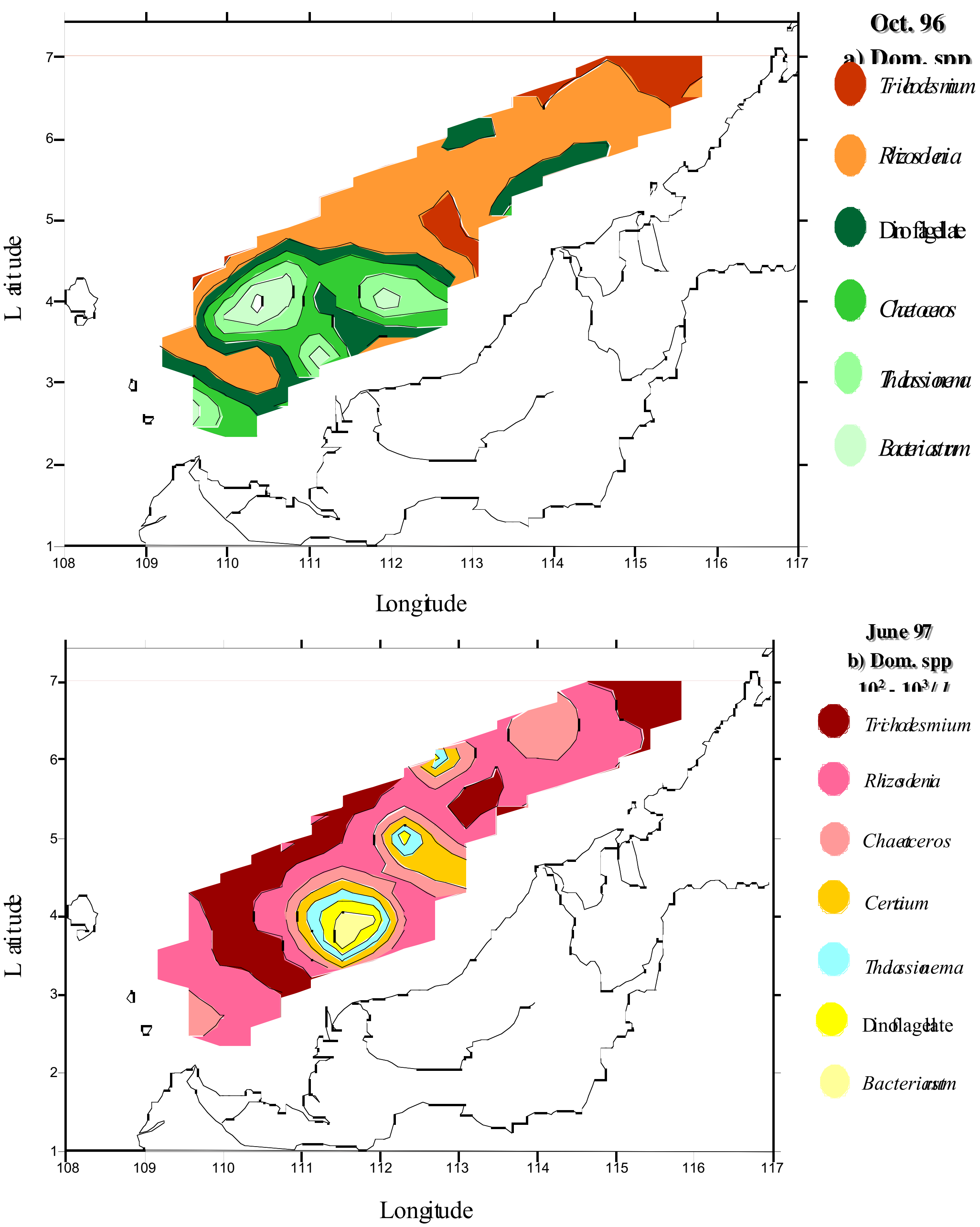


Fig. 3.6 Dominant microplankton species during the (a) pre and (b) post monsoon period of the cruise survey (October 1996 and June 1997).

present in higher concentrations than those during the postmonsoon.

The mean total population densities in the Sarawak middle waters were 5.01 x 10^6 and 7.9 x $10^5/m^3$ during the pre and postmonsoon seasons respectively (Fig. 6). During the premonsoon the blue green, *Trichodesmium erythraeum* reached its peak bloom at concentration of 1.99 x $10^6/m^3$ (> 30% of its total cell density); however, this species was again detected during the postmonsoon with a lower value (6.3 x $10^5/m^3$). *Rhizosolenium hebatata, Bacteriastrum* sp., *Chaetoceros lorenzianum, Thalassionema frauenfeldii* were dominant diatoms present during the premonsoon with values ranging from 1.9 x 10^3 to 2.51 x $10^5/m^3$. *Coscinodiscus* sp. and *Thalassionema frauendeldii* were present only during the premonsoon. Four species or *Rhizosolenia* (*R. alata, R. hebatata, R. styliformis* and *R. calcar - avis*) were also present with values ranging from 3.98 x 10^4 to 5.01 x $10^5/m^3$. *Tintinnopsis* sp. and copepod nauplii were high during the premonsoon.

Trichodesmium bloom (comprising of *T. erythraeum* and *T. thiebautii*) occurred in offshore Sarawak waters with its peak density value of 2.24 x $10^6/m^3$ (>20% of total cell density) (Fig. 7). The bloom occurred during both monsoons. *Rhizosolenia hebatata* was the only dominant diatom present during the premonsoon. Species of *Ornithocerus* and *Peridinium* were present with values ranging from 6.31 x 10^4 to 11.5 x $10^4/m^3$. Fair amounts of *Richelia* sp., *Climacodium* sp., *Ceratium macroceros* and *C. fusus* also occurred during the two seasons. The mean total cell density of the post monsoon was 28% that of the premonsoon.

Chaetoceros macroceros and *Trichodesmium erythraeum* were dominant species in the eastern Sabah waters with mean densities of 1.58 x 10^5 /m^3 and 3.54 x $10^5/m^3$ respectively; however both the species were present in lower concentrations during the postmonsoon (Fig. 8). *Protocentrum* sp., *Dinophysis* sp. and *Thalassionema nitzschoides* were present during the postmonsoon; however *Chaetoceros macroceros, Ceratium furca* and copepod nauplii were found during both seasons. *Protoperidinium* sp. was present in considerable concentration during the post monsoon. The mean total cell densities in this sector were 1.58 x 10^6 and 2.50 x $10^5/m^3$ during the pre and postmonsoon seasons respectively.

The fifth sector was identified for those stations around the western nearshore Sarawak waters. During the premonsoon, the diatoms (*Rhizosolenia alata, Chaetoceros lorenzianum, Bacteriastrum delicatilum*) and the blue greens (*Trichodesmium erythraeum* and *T. thiebautii*) were dominant with values ranging from 2.51 x 10^3 to 1.38 x $10^3/m^3$ (Fig. 9). Copepod nauplii were present during both seasons with values ranging from 150 to 1150/m^3. The mean total cell densities were 1.99 x 10^5 and 1.58 x $10^5/m^3$ during the pre and postmonsoon seasons respectively.

Microplankton assemblages and associations

The results from Fig. 10 illustrate that the microplankton species during the premonsoon comprised of at least seven species assemblages or associations in cluster analysis on 57 species sampled from the nearshore and offshore stations according to their preference on environmental conditions using the unweighted pair group average (UPGA) Pearsons index analyses. The species assemblages consisted of group A (*Chaetoceros coarctatum, Thalassionema fraeufeldii, Bacteriastrum delicatulum*); group B (*Trichodesmium erythraeum, Ceratium arcuatum*); group C (*Thalassionema fraeunfeldii, Chaetoceros lorenzianun*); group D (*Rhizosolenia hebatata, Chaetoceros laciniosus, C. decipiens, Ceratium longissinum*); group E (*Rhizosolenia styliformis, R. robusta, R. bergonii, R. alata*); group F (*Thalassionema thiebautii, Chaetoceros peruvianum, Ceratium teres, C. fusus*)(Table 3).

During the post monsoon period, cluster analysis of 51 species sampled from the 79 stations shows that there was a change in species assemblages or associations. At least 7 species associations according to their preference on environmental conditions (Fig. 11, Table 3). The species assemblages consisted of group A (*Ceratocorys* sp., *Bacteriastrum hyalinum, Nitzshia frigida*); group B (*Thalassionema fraeunfeldii, Nitzschia seriata, Rhizosolenia stolterforthii, Chaetoceros lorenzianum*);

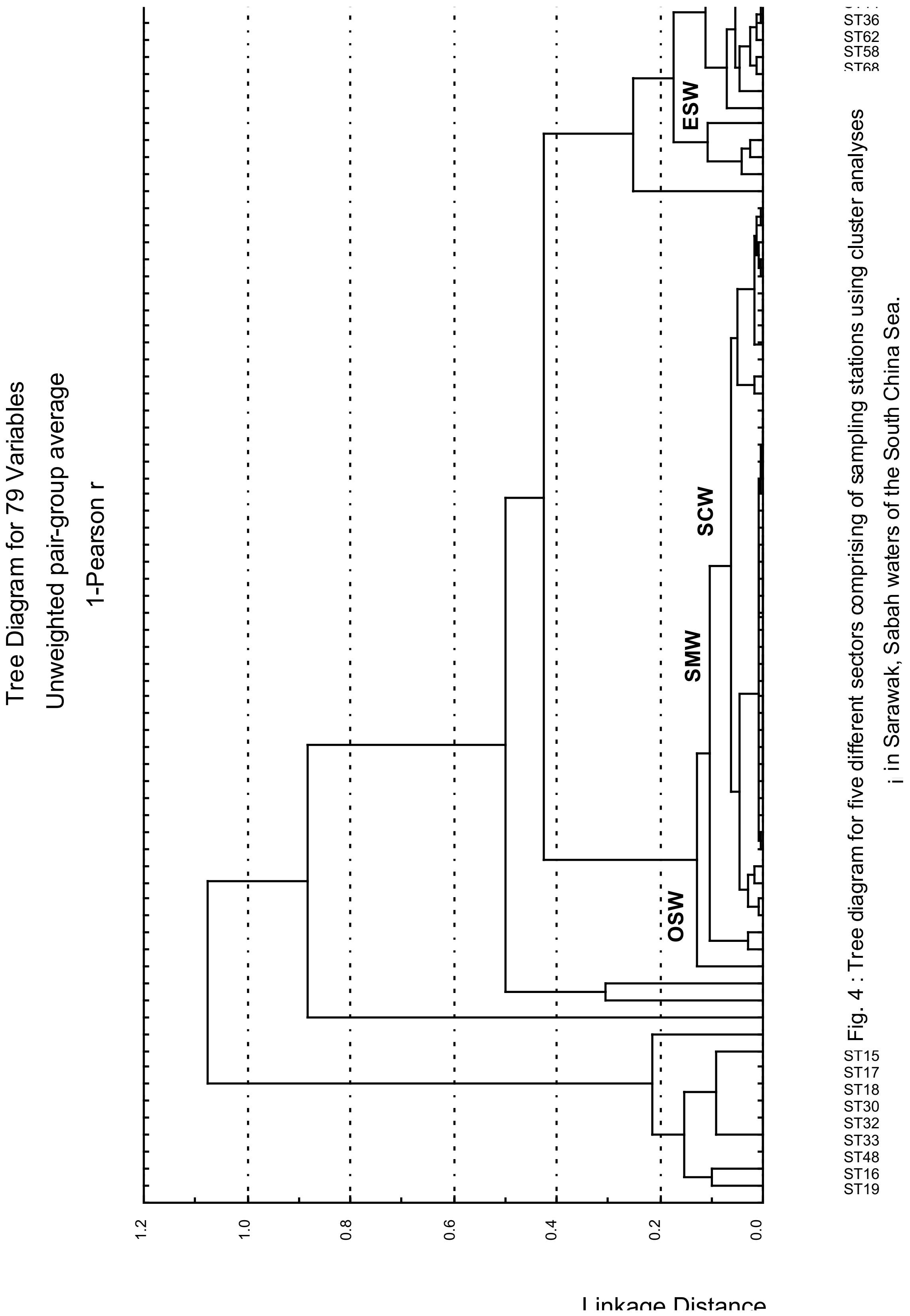


Fig. 4 : Tree diagram for five different sectors comprising of sampling stations using cluster analyses i in Sarawak, Sabah waters of the South China Sea.

Fig 4

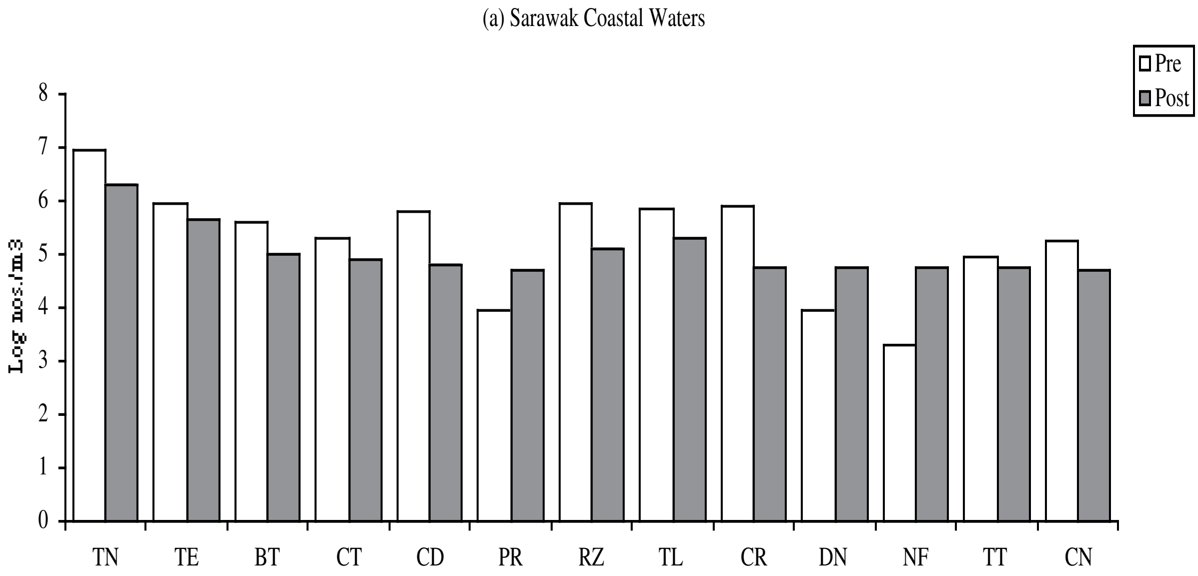


Fig. 5 Cell densities (log nos./m^3) of various microplankton species at stations nearby Sarawak Coastal Waters during pre and post monsoon seasons. (TN-total cell, TE-*Trichodesmium erythraeum*, BT-*Bacteriastrum cosmosum*, CT-*Chaetoceros lorenzianum*, CD-*Coscinodiscus debilis*, PR-*Peridinium* sp., RZ-*Rhizosolenia calcar-avis*, TL-*Thalassionema frauenfeldii*, CR-*Ceratium fusus*, DN-*Dinophysis* sp., NF-*Nitzchia frigida*, TT-*Tintinnopsis* sp., CN-Copepod nauplii).

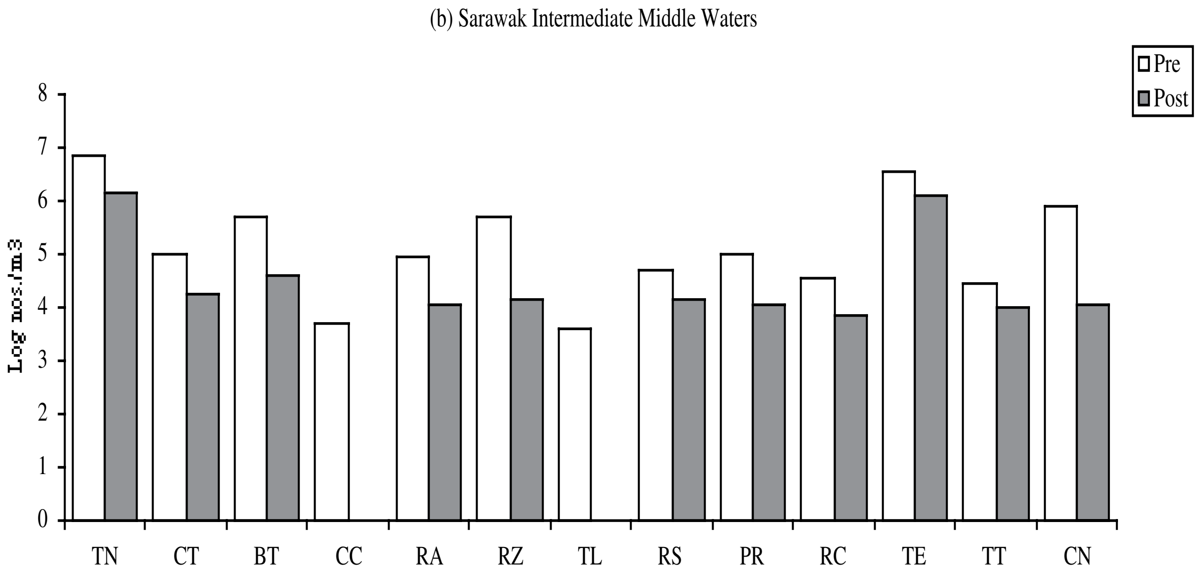


Fig. 6 Cell densities (log nos./m3) of various microplankton species at stations in Sarawak Intermediate Middle Waters of the South China Sea during pre and post monsoon seasons. (TN-total cell, CT-*Chaetoceros lorenzianum*, BT-*Bacteriastrum delicatulum*, CC-*Coscinodiscus* sp., RA-*Rhizosolenia alata*, RZ-*Rhizosolenia hebatata*, TL-*Thalassionema frauenfeldii*, RS-*Rhizosolenia styliformis*, PR-*Peridinium* sp., RC-*Rhizosolenia calcar-avis*, TE-*Trichodesmium erythraeum*, TT-*Tintinnopsis* sp., CN- Copepod nauplii).

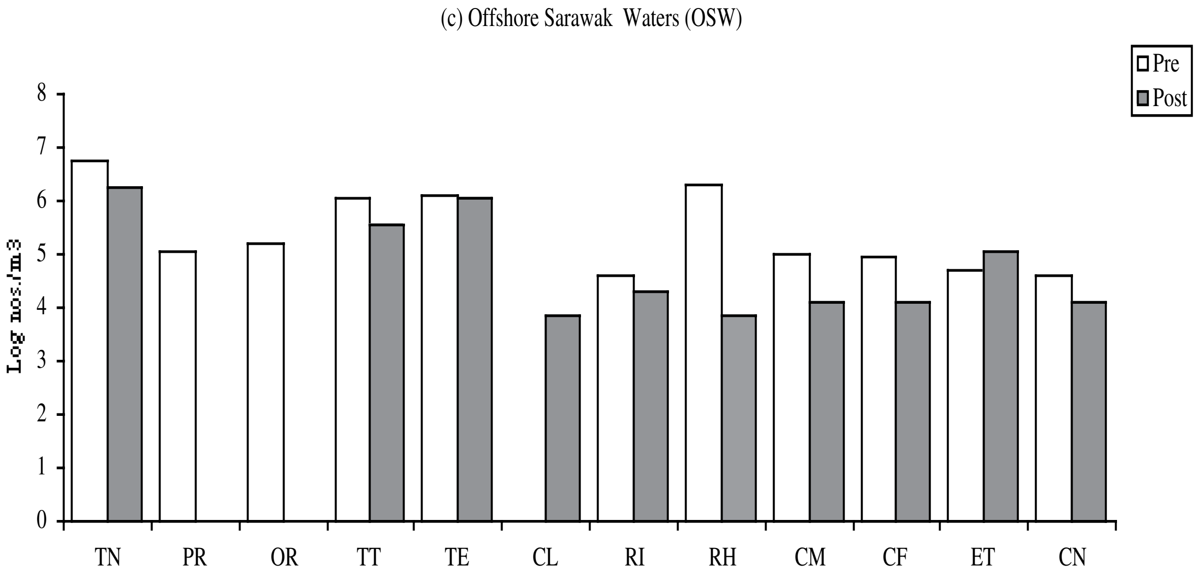


Fig. 7 Cell densities (log nos./m3) of various microplankton species at stations in Offshore Sarawak waters of the South China Sea during pre and post monsoon seasons. (TN. total cell, PR-*Peridinium* sp., OR-*Ornithocerus* sp., TT-*Trichodesmium thiebautii*, TE. *Trichodesmium erythraeum*, CL-*Climacodium* sp., RI-*Richelia* sp., RH-*Rhizosolenia hebatata*, CM-*Ceratium macroceros*, CF. *Ceratium fusus*, ET-*Eutintinus* sp., CN. Copepod nauplii)

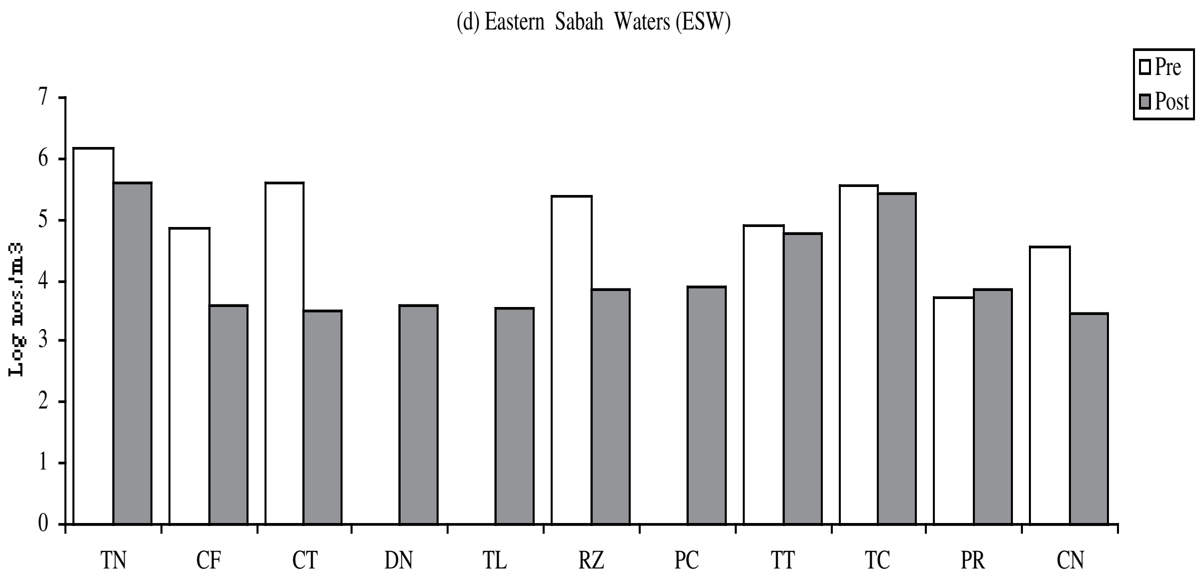


Fig. 8 Cell densities (log nos./m3) of various microplankton species at stations in Eastern Sabah waters of the South China Sea during pre and post monsoon seasons. (TN-total cell, CF-*Ceratium furca*., CT-*Chaetoceros macroceros*, DN-*Dinophysis*, TL-*Thaliassionema nitzschoides*, RZ-*Rhizosolenia*, TT-*T. thiebautii*., TC-*Trichodesmium erythraeum*, PR-*Protoperidinium* sp., CN-Copepod nauplii).

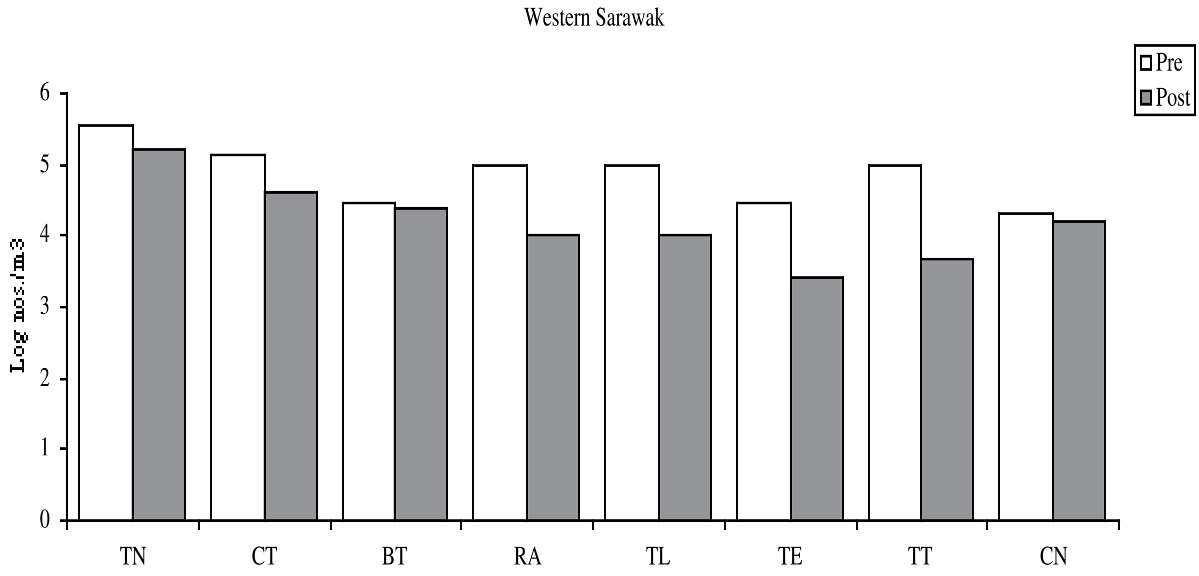
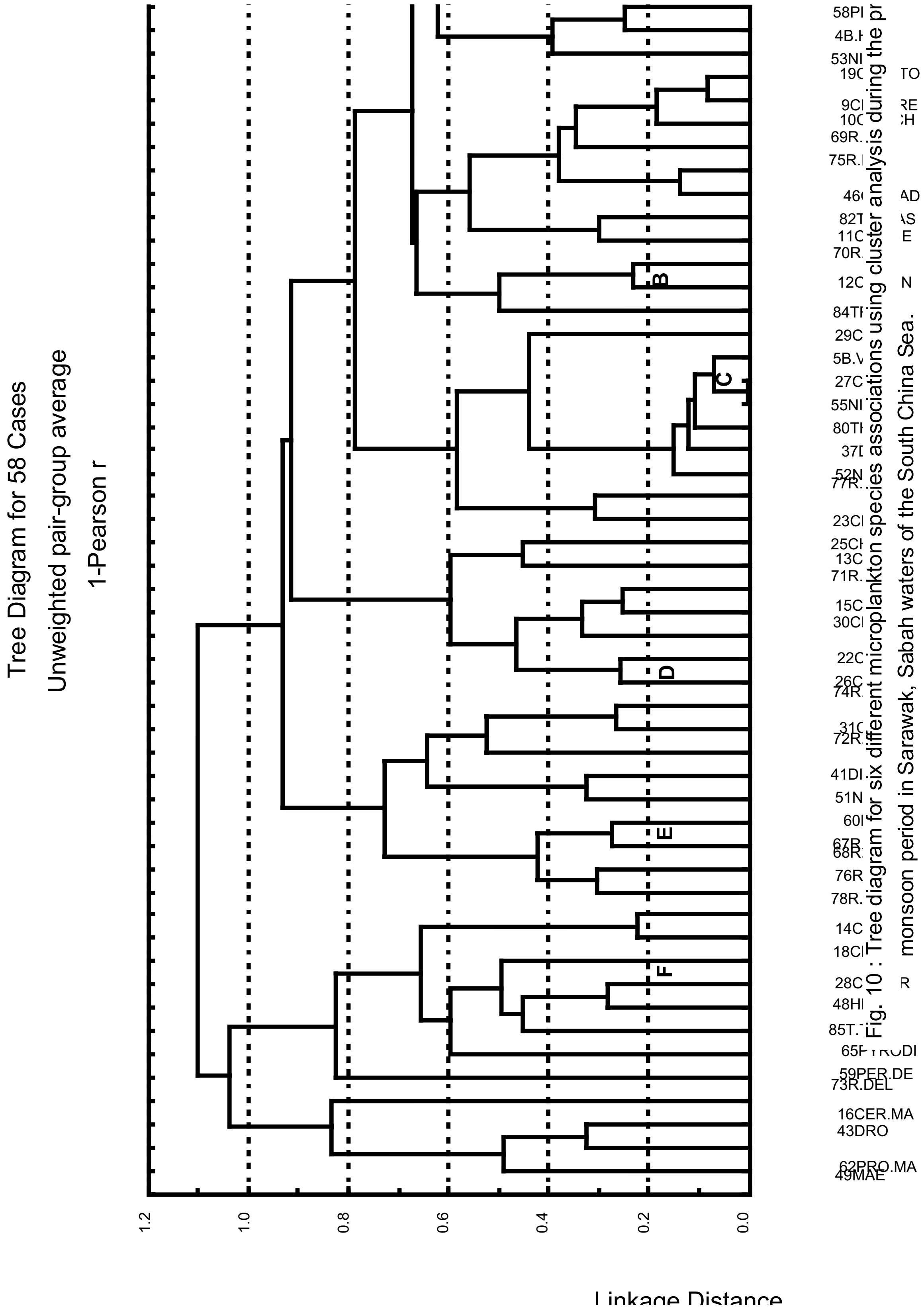


Fig. 9 Population densities (log nos./m^3) of various microplankton species at stations in Western Sarawak Waters of the South China Sea during pre and post monsoon seasons. (TN-total cell, CT-*Chaetoceros lorenzianum*, BT-*Bacteriastrum delicatulum*, RA-*Rhizosolenia alata*, TL-*Thalassionema frauenfeldii*, TE-*Trichodesmium erythraeum*, TT-*T. thiebautii* sp., CN-Copepod nauplii).

group C (*Richelia* sp., *Rhizosolenia clevei, Peridinium* sp*., Pleurosigma* sp., *Climacodium* sp.); group D (*Trichodesmium erythraeum, T. thiebautii, Protoperidinium* sp., *Hemialus* sp.); group E (*Rhizosolenia habatata, Globigerina* sp*., Chaetoceros decipiens*); group F (*Chaetoceros comosum, Ceratium fusus, C. teres*).

Earlier studies by Shamsudin *et al.* 1987 in the Malaysian waters of the South China Sea showed that the microphytoplankton from 16 oceanographic stations consisted predominantly of diatoms and blue green algae. The bulk of the diatom species consisted of *Chaetocerus, Rhizosolenia, Melosira, Thalassiothrix, Dactyliosolen* and *Guinardia*. Another diatom species, *Planktoniella* was present only at stations further offshore from the coast. However, other diatom species which were also present included those species of *Bacteriastrum, Asterionella, Fragilaria, Nitzschia, Skeletonema*, *Coscinodiscus* and *Pleurosigma*. More than 30 major species of diatom have been identified. The genera *Coscinodiscus, Chaetocerus* and *Rhizosolenia* were found to contain a wide range of species. The Cyanophyta comprised of only a few species among which *Trichodesmium thiebautii* and *T. erythraeum* were present in abundant.

Other studies of microplankton in Malaysian waters including the Straits of Malacca had been conducted by Sewell (1933), Winstead (1961), Pathansali (1968), Chua & Chong (1973), Shamsudin (1987, 1993, 1994, 1997) and Shamsudin & Shazali (1991). Most of these studies were carried out at certain predetermined time and location; however, the present study was carried out during the pre and postmonsoon periods. An increase in the diversity value could be due to an increased number of species or even distribution of individuals per species as described by Gray (1981). In reality, such community organisation is constantly acted on by biological and physical factors in many different ways to produce, perhaps a different organisation in the future as a response to such environmental changes. When a bloom occurs, only a few microplankton species will predominate and thus effect or influence the number of species or the even distribution of individual species.


Tree Diagram for 58 Cases
Unweighted pair-group average
1-Pearson r
Linkage Distance
1.2
1.0
0.8
0.6
0.4
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B
C
D
E
F
Fig. 10 : Tree diagram for six different microplankton species associations using cluster analysis during the pr
monsoon period in Sarawak, Sabah waters of the South China Sea.

Fig. 10

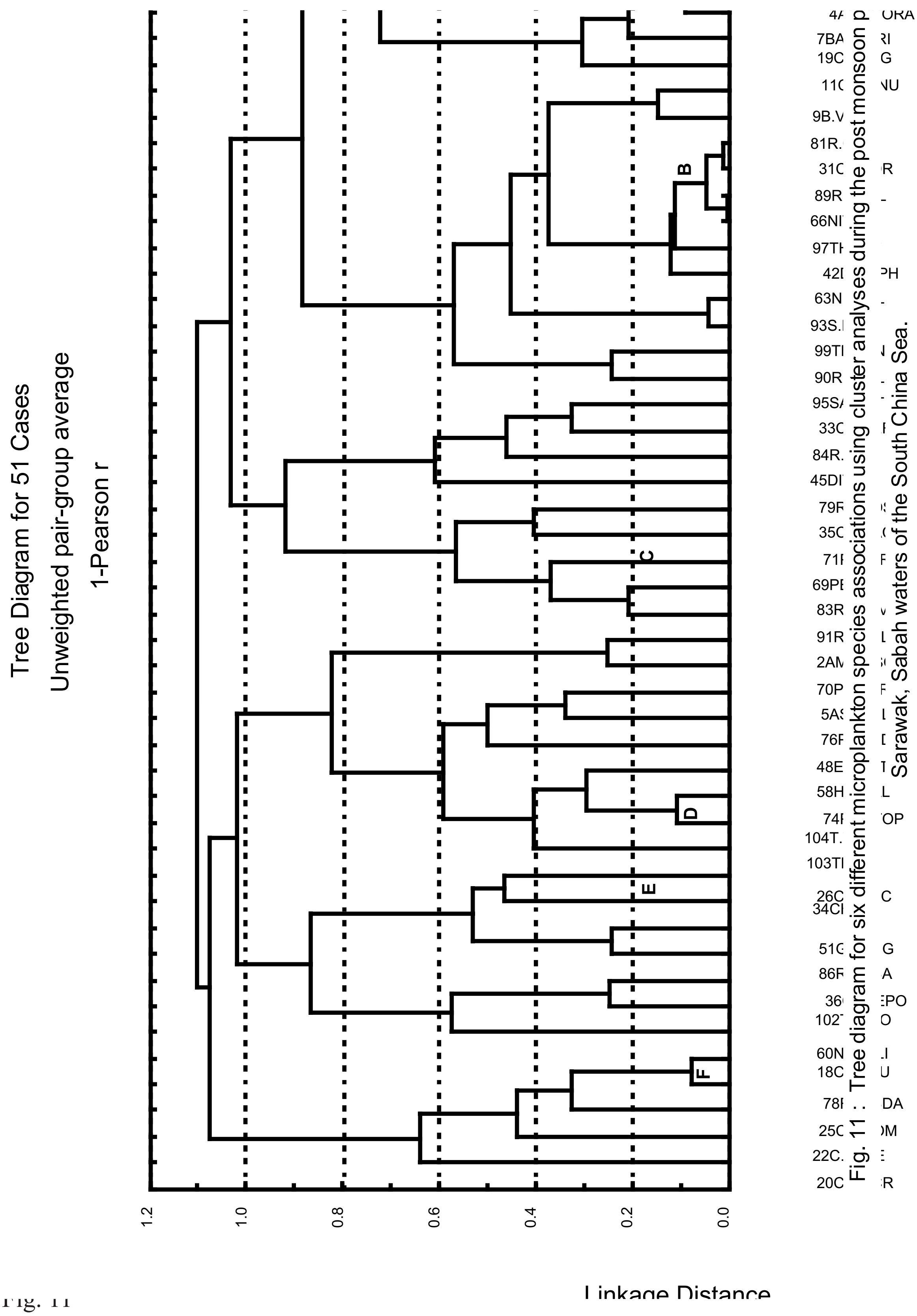

Fig. 11 : Tree diagram for six different microplankton species associations using cluster analyses during the post monsoon p
Sarawak, Sabah waters of the South China Sea.

Fig. 11

Microzooplankton population

Microzooplankton species consisted of more than 20 different groups with several dominant species namely, copepod nauplii (> 50% of the total microzooplankton count); Chaetognatha larvae (5%), Ciliophora (4%) and Foraminifera (2-3%) (see Appendix 2). The Ciliphora consisted of a few genera (*Tintinnopsis, Distephanus, Tintinnus, Favella, Dictyocha, Tomopteris, Xystonella, Xystonellopsis, Codonellopsis*) while Foraminifera consisted of *Globigerina* and *Tretomphalus* species (considered to be indicator tropical species). *Amphisolenia* (Peridinidae) and *Ceratocorys* species were detected in considerable amount in nearshore stations. Namerous *dinoflagellates (Dinophysis favus, D. norvegicas, D. triposolnia, Ornithocercus* sp., *Peridinium brochii, P. depressum, P. subpyriformes, Podolampas* sp., *Prorocentrum* sp., *Pyrocystis fursiformis, P. lunula, Pyrophacus horologium, Rhabdonella* sp.) were found in middle Sarawak waters of the South China Sea.

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REFERENCE

Barber H.G. & Haworth E.Y. (1981). A Guide to the Morphology of the Diatom Frustule. FSA Scient. Publ. no. 44. Ambleside. Freshwater Biological Association, 35 p.

Chua T.E. & Chong B.J. (1973). Plankton Distribution in the Straits of Malacca and Its Adjacent Waters. Special symposium on Marine Science, Dec. 1973, Hong Kong.

Cleve P.T. (1901). Plankon from the Indian Ocean and Malay Archipelago. K. Sv. Vet. Ak. Handl. Vol. 35 No. 5. 57 p.

Cleve P.T. (1904). Plankton of the South African Seas. Marine Inverstigation in South Africa, Vol. III. 45 p.

Cleve-Euler A. (1944). Die diatomeen als quartargeologische Indikatoren. Geologiska Foreningens i Stockholm Forhandlingar, 66(3) : 383-410.

Crosby L.H. & Ferguson Wood (1959). Studies on Australian and New Zealand Diatoms. II. - Normally Euphotic and Benthic Genera. Trans. Roy. Soc. New Zealand Vol. 86, part 1, 58 p.

Cummins A.B. & H. Mulryan (1937). Diatomite, Industrial Minerals and Rocks. Published by the American Institute of Mining and Metallurgical Engineers, pp. 243-260.

Cupp E.E. (1943). Marine Plankton Diatoms of the West Coast of North America, Bykk, Scruoos Ubst. Oceanography, Vol. 5, No. 1, 237 p.

Doty H.S., Soeriaatmadja R.E. & Sogiarto A. (1963). Observations on the Primary Marine Productivity of Northern Indonesian Waters. Marine Research in Indonesian 5; 1-25.

Elliot J.M. (1977). Some Methods for the Statistical Analysis of Benthos Invertebrates. Freshwater Biology Station Science Publication No. 25; 316 p.

Fritsch F.E. (1935). The Structure and Reproduction of the Algae. Vol. I. London and New York, Cambidge University Press, xvii + 791 pp.

Gran H.H. (1912). Pelagic Plant Life. In Depths of the Ocean, J. Murray and J. Hjort. London, Macmillan and Co., Chapter 6, pp. 307-386.

Gray J.S. (1981). The Ecology of Marine Sediments. An introduction to the structure and function of benthic communities. Cambridge University Press 185 p.

Hendey NI. (1964). An Introductory Account of the Smaller Algae of British Coastal Waters. Post V Bacillariophyceae (Diatoms) Fishery Investigation Series IV 317 p.

Hustedt F. (1930). Bacillariophyta (Diatom). In Die Sasswasser-flora Mitteleuropas 10 (Pascher, A., editor), 1-466. Jena. 122 p.

Ludowig J.A. & Reynolds J.F. (1988). Statistical Ecology - Primer on Methods and computing, John Wiley new York 317 p.

Markina N.O. (1972). Special Features of Plankton Distribution Around Northern Coasts of Australia During Different Seasons of 1968-1969, TINRO v. 81, 1-18.

Newell G.E. & Newell R.C. (1973). Marine Plankton. Hutchinson educational Ltd. 244 p.

Palmer T.C. & Keeley F.J. (1900). Structure of the Diatom Girdle. Proceedings of the Academy of Natural Sciences of Philadelphia, 52: 465-479.

Pasher A. (1914). Chlorophyceae 111. In Die Sasswasser-flora Deutschlands, Osterreichs Und Der Schweiz 6. 1-250. Jena. 120 p.

Pasher A. (1915). Einzellige Chlorophyceengattungen Unsicherer Stellung Die Sasswasser-flora Deutschlands, Osterreichs Und Der Schweiz, Heft 5, 206 et seq. 110 p.

Pasher A. (1925). Cyanophyceae. In Sasswasser-flora Deutschlands, Osterreichs Und Der Schweiz 12. 1-481. Jena. 114 p.

Pathansali D. (1968). Some observations on the distribution of Chaetognatha, west of Penang Island. Publications of the Sato Marine biological laboratory Japan 15; 391-397.

Patrick R. & Reimer CIW. (1968). The Diatom of the United States Exlusively of Alaska and Hawaii. Vol. I Philladelphia. 540 p.

Pielou E.C. (1984). The Interpretation of Ecological Data. Wiley NY 125 p.

Semina G.I. (1967). Phytoplankton, Pacific Ocean. Biology of the Pacific Ocean. B.I. plankton, M. pp.

Sewell S.R. (1933). Marine Copepoda from Malay States. Bulletin of the Raffles Museum, Singapore 8; 65 p.

Shannon C.E. & Weaver W. (1949). The Mathematical Theory of Communication. Illinois Press, Urbana, III. 117 p.

Shamsudin L. & Bakar M.G. (1987). The Microzooplankton (including dinoflagellate and Foraminifera) of Sarawak Waters of South China Sea In: Matahari Expedition 1987 (ed.) AKM. Mohsin et al., FPSS, UPM : 109 - 114.

Shamsudin L. (1987). Microplankton Distribution in the Coastal Waters of Port Dickson. In : Proceedings of the 10th Seminar of the Malaysian Society of Marine Science. Sasekumar, A. *et al.* (Eds) University Malaya special publication 23-29.

Shamsudin L. & Shazili N.A.M (1991). Microplankton Bloom in a Brackish Water Lagoon of Terengganu. Environmental Monitoring and Assessment 19: 287-294.

Shamsudin L. (1993). Biochemical Composition and Fatty Acid Content of Zooplankton from Tropical Lagoon for Larval Rearing. Journal Archives Internationales de Physiologie, de Biochemie et de Biophysique, 1993, 101: 1-4.

Shamsudin L. & Sleigh M.A. (1994). Seasonal Changes in Composition and Biomass of Epilithic Algal Floras of a Chalk Stream and a Soft Water Stream with Estimates of Production. Hydrobiologia 273 (3) 131 - 146.

Shamsudin L. (1994). Food Values of Indigenous Zooplankton from the South China Sea on the East Coast of Peninsular Malaysia. Journal of the World Aquaculture Society. 25 (2) 208-231.

Shamsudin L. (1995). Lipid and Fatty Acid Content in Microplankton Bloom from Tropical Fish Ponds. Archives Internationales de Physiologie, Biochemie et Biophysique 103 (5) 21-27.

Shamsudin L. & Sleigh M.A. (1995). Seasonal Changes in Composition and Biomass of Epiphytic Algae on the Macrophyte Ranunculus Penicillatus is a Chalk Stream with Estimates of Production and Observation on the Ephytes of Cladophora Glomerata. Hydrobiologia 306: 85-95.

Shamsudin L., Yusof M., Azis A. & Shukri Y. (1997). The Potential of Certain Indigenous Copepod Species as Live Food for Commercial Fish Larval Rearing. Aquaculture 151: 351-356.

Shamsudin L., Kamal S. & Samo K. (1987). The Microzooplankton of Sarawak Waters of the South

China Sea In : Matahari Expedition 1987 (ed.) AKM Mohsin *et al.*, FPSS, UPM : 99-108.

Southwood, TRE. (1978). Ecological Methods Cambridge 210 p.

Taylor F.J.R. (1976). Dinoflagellates from the International Indian Ocean Expeditions. A report on material collected by the R.V. Anton Brunei 1963-1964. Stuttgant 227 p.

Taylor D.L. & Seliger H.H. (1979). Toxic Dinoflagellate Bloom In: Proceedings of the 2nd International Conference on Toxic. Dinoflagellate Blooms Lewis M. Carrie (Ed.) Key Bicayre Florida 31 Oct. - Nov. 1978, 497 p.

Tippett R. (1970). Artificial Surfaces as a Method of Studying Populations of Benthic Micro-algae in Freshwater. Br. phycol. J. 5, 189-199.

Shirota A. (1966). The Plankton of South Vietnam - Fresh water and Marine Plankton. Oversea Technical Cooperation Agency Japan 464 p.

Vollenweider R.A., Talling J.F. & Westlake D.F. (1974). A Manual on Methods for Measuring Primary Production in Aquatic Environments, IBP Handbook No. 12. Blackwell, Oxford, 2nd. edn. 225 p.

Wickstead J.H. (1961). A Quantitative and Qualitative Study of some Indo-West Pacific Plankton. Colonial Office Fisheries Publication. 16, Her Majesty's Stationery Office, London. 47 p.

Zemova V.U. (1964). Distribution of Phytoplankton in the Tropical Parts of the Western Pacific Ocean. Tr. ION USSK, 4. 65.

Table 1 The number of species in the genera of the microplankton population in Sabah and Sarawak waters of the South China Sea during the study period (* Dominant)

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

Table 2. Dominant microplankton species at various sectors in Sabah and Sarawak waters of the South China Sea during the study period.

Sector	Monsoon	
	Pre	**Post**
Sarawak coastal waters (SCW)	***Trichodesmium erythraeum*** ***Ceratium furca*** *Rhizosolenia stoleterfothii* *Chaetoceros lorenzianus*	***Trichodesmium erythraeum*** ***Thalassionema fraunfeldii*** *Thalassionema nitzschoides* *Rhizosolenia stolterfothii* *Bacteriastrum varians* *Chaetoceros lorenzianum*
Western Sarawak waters (WSW)	***Trichodesmium erythraeum*** ***Rhizosolenia alata*** *Coscinodiscus* sp.	***Trichodesmium thiebautii*** ***Trichodesmium erythraeum*** *Thalassionema nitzschoides* *Thalassionema delicatulum* *Rhizosolenia alata*
Offshore Sarawak waters (ESW)	***Trichodesmium erythraeum*** ***Rhizosolenia alata*** *Coscinodiscus* sp. *Peridinium* sp.	***Trichodesmium erythraeum*** ***Trichodesmium thiebautii*** *Rhizosolenia hebatata* *Bacteriastrum hyalinum* *Chaetoceros didynum*
Eastern Sabah waters (ESW)	***Trichodesmium erythraeum*** ***Rhizosolenia alata***	***Trichodesmium erythraeum*** ***Ceratium furca*** ***Peridinium depressum*** ***Protocentrum* sp.** ***Rhizosolenia alata***
Intermediate Middle Sarawa waters (IMSW)	***Trichodesmium erythraeum*** ***Rhizosolenia alata*** ***Pleurosigma* sp.** ***Chaetoceros lorenzianus***	***Trichodesmium erythraeum*** ***Trichodesmium thiiebautii*** ***Rhizosolenia hebatata*** ***Bacteriastrum hyalium*** ***Bacteriastrum varians***

Table 3. Species association in Sabah and Sarawak waters of the South China Sea during the pre and post monsoon period

Group	Monsoon Pre	Monsoon Post
A	*Chaetoceros coarctatum*	*Ceratocorys* sp.
	Thalassionema fraeufeldii	*Bacteriastrum hyalinum*
	Bacteriastrum delicatulum	*Nitzschia frigida*
B	*Trichodesmium erythraeum*	*Thalassionema fraeunfeldii*
	Ceratium arauatum	*Nitzschia seriata*
		Rhizosolenia stolterforthii
		Chaetoceros lorenzianum
C	*Thalassionema fraeunfeldii*	*Richelia* sp.
	Chaetoceros lorenzianum	*Rhizosolenia clevei*
		Peridinium sp.
		Pleurosigma sp.
		Climacodium sp.
D	*Rhizosolenia hebatata*	*Trichodesmium erythraeum*
	Chaetoceros laciniosus	*Trichodesmium thiebautii*
	Chaetoceros decipiens	*Protoperidinium*
	Ceratium longissinum	*Hemialus* sp.
E	*Rhizosolenia styliformis*	*Rhizosolenia hebatata*
	Rhizosolenia robusta	*Globigerina* sp.
	Rhizosolenia bergonii	*Chaetoceros decipiens*
	Rhizosolenia alata	
F	*Trichodesmium thiebautii*	*Chaetoceros comosum*
	Chaetoceros peruvianum	*Ceratium fusus*
	Ceratium teres	*Ceratium teres*
	Ceratium fusus	

Appendix 1 The taxonomic list of Microzooplankton identified from Sarawak and Sabah watersSouth China Sea (* Dominant)

1 Class, Cyanophyceae; Order Hormogoneae; Family Osciliatoriaceae;
* ***Trichodesmium erytheraeum*** **Ehrenberg**
T. thiebautii Gom.

2 Pylum Bacillariphyceae (Diatom)
Actinophychus undulatus Ralfs
Actinocyclus Ehrenberg
Asterolampra marylandica Ehrenberg
Asteromphalus elegans Greville
A. heptactis Ralfs
A. flabellatus Greville
Bacillaria paxillifera O.F. Muller
Bacteriastrum comossum Pavillard
* *B. delicatulum* Cleve
B. elegans Pavillard
B. elongatum Cleve
* *B. hyalinum* Lauder
B. mediaterraneum Pavillard
B. minus Lauder
* *B. varians* Lauder
Biddulphia dubia Cleve
B. longicrucia Greville
* *B. mobilensis* Bailey
B. regia Ostenfeld
B. sinensis Grevillae
Campylodiscus biangulatus Hantsch
C. daemelianus Grun
C. echeneis Ehrenberg
C. ornatus Grun
C. undulatus Grevillae
Cerataulina Bergonii
C. Compacta Ostenfeld
C. pelagica (Cleve) Hendey
C. coarctatum Lauder
Chaetoceros affinis Lauder
C. brevis Schutt
C. compressum Lauder
C. constrictum Gran
C. costatus Pavillard
* *C. curvisetum* Cleve
C. dadayi Pavillard
C. debile Cleve
* *C. decipiens* Cleve
C. densum Cleve
C. denticulatum Lauder
C. decipiens Cleve
* *C. didymum* Ehrenberg
* *C. distans* Ehrenberg
* *C. diversus* Cleve
C. hispidum Brightwell
C. indicum Koosten
* *C. laciniosus* Schutt
C. latderi Rafts
C. lauderi Reefs
C. leavis Leuduger - Fortimorel
C. messanensis Castracane
C. paradoxum Cleve
C. pendulus Karsten
* *C. peruvianum* Brightwell
* *C. pseudocurvisetum* Mangin
C. setaceum Jorg
C. siamense Ostenfeld
C. sumatranum Karsten
C. tetrastichon Cleve
C. tripos Nitsch
C. weissflogii Schutt
Climacodium biconcavum Cleve
C. frauenfeldianum Grunow
Corethron hystrix Henden
C. pelagicum Brun
Coscinodiscus asteromphalus Ehrenberg
* *C. concinus* W. Smith
* *C. centralis* Grunow
* *C. curvatulus* Grunow
* *C. debilis* Ehrenberg
* *C. gigas* Ehrenberg
C. granii Gough
C. janischii Schmidt
* *C. jonesianus* (Greville) Ostenfeld
C. lineatus Ehrenberg
C. marginatus Ehrenberg
C. nitidus Gregory
C. nobilis Grunow
C. nodulifer Schmidt
C. occulus rividis Ehrenberg
C. perforatus Ehrenberg
C. radiatus Ehrenberg
C. Rothii Grunow
C. stellaris Roper
C. subtilis Ehrenberg
C. weilesii Gran & Angst
Cylindrotheca closterium Ehrenberg
Dactyliosolen blavyanus H. Peragallo
D. fragilissinum (Bergon) Hasle
Detonula pumila (Castracane) Gran
Ditylum brightwelii (West) Grunow
D. sol Grunow
Eucampia cornuta (Cleve) Grunow
E. zodiacus Ehrenberg
Fragilaria interrmedia Grunow
Guinardia cylindrus (Cleve) Hasle
G. flaccida (Castriacane) H. Peragallo
G. striata Stolteriotn Hasle
Gossleriella tropica Schutt
Gyrosigma acuminatum Rabh
G. balticum Cleur
G. Strigile Smith
Halicotheca thamensis Grunow
Hemiaulus hauckii Grunow
H. indicus Karsten
H. membranacea Cleve
H. sinensis Greville
* ***Hemidiscus cuneiformis*** Wallich (Indicator sp.)
H. hardmanianus
Lauderia annulata Gran
L. borealis Gran
Leptocylindrus danicus Cleve
L. mediterraneus (H. Peragallo) Hasle
Lithodesmium undulatum Ehrenberg
Navicula **sp.**
* ***Nitzschia closterium*** W. Smith

Appendix 1 Continue

N. closterium W. Smith
N. hungarica Grun
N. lanceolata W. Smith
N. longissima Gran
N. longissima var. reversa W. Smith
N. paradoxa Gmelin
N. pacifica Cupp
N. plana W. Smith
N. pungens Cleve
N. seriata Cleve
N. sigma W. Smith
N. sigma var intercedens Grun
N. spectavilis Ralfs
N. vitrea Norman
N. bicapitata Cleve
Odontella mobiliensis (Bailey) Grunow
O. sinensis (Greville) Grunow
Planktoniella blanda A. Schmidt
P. sol (Wallich) Schutt
Pleurosigma affine Gran
P. angulatum W. Smith
P. coompactum Grew
* *P. elongatum* W. Smith
P. fasciola W. Smith
P. intermedium W. Smith
P. nicobaricum Gran
P. Normanii Ralfs
P. pelagicum Perag
P. rectum Donkim
P. rigidum Brun
P. salinarum Gran
Pseudoguinardia recta Von Stesen
P. pungens Grunow & Cleve Hasle
*** *Rhizosolenia acuminata*** Gran
* *R. alata* Brightwell
R. bergonii H. Peragallo
R. clevei Ostenfeld
R. castracanei H. Perag
R. curvata Zacharias
* *R. calcar-avis* M. Schutze
R. formosa H. Peragallo
R. cylindrus Cleve
R. hyaline Ostenfeld
R. delicatula Cleve
R. imbricata Brightwell
R. hesetata Gran
R. robusta Norman
R. delicatula Cleve
R. setigara Brightwell
R. styliformis Brightwell
*** *Skeletonema costatum*** (Greville) Cleve
Stephanopyxis palmeriana Greville
***Striatella* sp.**
***Surirella* sp.**
*** *Thalassionema frauenfeldii*** Grunow
T. nitzschioides Grunow
Thalassiosira bingensis Takano
T. dipporocyclus Hasle
T. eccentrica (Ehrenberg) Hasle
T. oestrupii (Ostenfeld) Hasle
* *T. subtilis* (Ostenfeld) Gran
Triceratium favus Ehrenberg

3 Phylum Dinophyceae
(Dinoflagellate)
Family : Peridiniidae
Alexandrium fraterculus (Balech)
A. tamiyavanichi Balech
Amphidoma steini Schill
Amphisolenia bidentata Schroder
A. thrinax Schutt
A. globifera Stein
A. scnauinsianaii Lemmermann
Ceratium axiale Kofoid
C. arietinum Cleve
* *C. breve* Schroder
C. biceps Gourret
C. belone Cleve
C. condillans Jorgensen
C. candelabrium Ehrenberg Stein
C. contortum Gourret
C. carriense Gourret
C. declinatum (Karsten) Jorgensen
* *C. deflexum* (Kofoid) Jorgensen
C. dens Ostenfeld & Schmidt
C. falcatum (Kofoid) Jorgensen
C. furca Ehrenberg
C. fusus Ehrenberg
* *C. gibberum* Gourret
* *C. gravidum* Gourret
C. hexacanthum Gourret
C. horridum (Cleve) Gran
C. inflatum (Kofoid) Jorgenden
C. kofoidii Jorgensen
C. longissinum Gran
C. limulus Gourret
C. lunula (Schimpe) Jorgensen
* *C. macroceros* (Ehrenberg) Vanholf
* *C. massiliense* (Gourret) Karsten
* *C. platycorne* Daday
* *C. pentagonum* Gourret
C. pulchellum Schroder
C. symmetricum Paviilard
* *C. teres* Kofoid
C. trichoceros (Ehrenberg) Kofoid
C. tripos (O.F. Muller) Nitzsen
C. vulture Cleve
Ceratocorys norrida Stein
C. horrida Stein
C. gourreti Paulsen
Corythodinium resseratum Stein
Loebiich Jr. & Loebiien
Dinophysis homunculus Stein
D. caudata Sabille - Kent
D. hastata Stein
D. infundibula Schiller
D. miles Cleve
D. ovum Schutt
D. schuettii Murray & Whitting
D. tripos Gourret
Diplopsalis lenticulata Berg
Goniodoma polyedricum Pouchet
G. spaericum Murr. & Whitt
Gonyaulax digitale (Pouchet) Kofoid
G. gluptorhynchus Murray & Whitting
G. polygramma Stein
G. spinifera Clapareda & Lachmann
***Gynmodinium* sp.**
***Gyrodinium* sp.**
***Kofoidinium* sp.**
Noctiluca scintillans Macartney
Ornithocercus magnificus Stein
O. thumii A. Schmidt
Pxytoxum scolopax Stein
O. milneri Gran

Appendix 1 Continue

O. tesselatum Stein

Phalacroma acutoides Balech

P. doryphorum Stein

P. favus Kofoid & Micherner

P. mitra Schutt

P. parvulum Schutt

P. rapa Stein

P. rudgei Murray & Whitting

Podolampas bipes Stein

P. elegans Schutt

P. palmipes Stein

P. spinifera Okamura

Prorocentrum compressum (Bailey)

P. micans Ehrenberg

P. sigmoides Bohm

* ***Protoceratium spinulosum***

Protoperidinium conicum (Gran)

* *P. brochii* Balech

P. crassipes (Kofoid) Balech

P. depressum (Bsiley) Balech

P. diabolus (Cleve) Balech

P. divergents (Ehrenberg) Balech

P. elegans (Cleve) Balech

P. globulum (Stein) Balech

* *P. grande* (Kofoid) Balech

P. hirobis (Abe') Balech

P. latispinum (Mangin) Balech

P. leonis (Pavillard) Balech

P. murrayi (Kofoid) Balech

* *P. oceanicum* (Vanhoff) Balech

P. okamurai (Abe') Balech

P. ovum (Schiller) Balech

P. pallidum (Ostenfeld) Balech

P. paulseni (Pavillard) Balech

P. Pellucidum Bergn

P. puanerense (Schreaser) Balech

P. spinuiosum (Schiller) Balech

P. stenii (Jorgensen)

P. thorianum (Paulsen) Balech

Pyrophacus horologium Stein

P. stein (J. Schiller) Wall & Dale

Scripsiella trochoidea (Stein) Balech

4 Family : Dictyochaceae

(Phulum Protozoa)

Class : Mastogophora

Order : Chrysomonadina

Dictyocha fibula Ehrenberg

D. fibula var stapedia Heack

D. fibula var major Rampi

Family : Procentridae

Procentrum micans Ehrenberg

Family : Phytodinidae

* ***Pyrocystis elegans*** Murray

(Indicator sp.)

P. fusiformis Murray

P. hamulus var imacqualis Schrober

P. noctulica Murray

Species Composition and Diversity of Fishes in The South china Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters

Dr. Chavalit Vidthayanon

Department of Fisheries, Kaset-Klang, Chatuchak, Bangkok 10900. Thailand

ABSTRACT

The collaborative research on species composition and diversity of fishes in the Sabah and Sarawak waters was carried out by using otter-board trawling, through K.K. Manchong, including taxonomic survey for commercial coastal fishes landed in the markets of Sarikei, Bintulu, Miri, Labuan and Kota Kinabalu. Totally 518 species from 24 orders and 108 families were obtained. Hundred and three economic species were obtained from trawling survey and 106 species from the markets. The station point at St. 33 and 48 is the highest species richness, 69 and 70 species found. The highest CPUE were obtained at St. 44 and 48 (196 and 144 kg). Demersal species form main composition of the catchs with the 9 dominant economic species. This trawling survey obtained few amount of 37 pelagic species. This survey also found the third record of *Hapalogenys analis* and *Pomadasys auritus* from the Southeast Asian waters.
Key words: Species composition, Diversity, Fishes, Sabah and Sarawak waters.

Introduction

This collaborative surveys of fisheries and oceanography in the South China Sea; subject of fish diversity and species compositions in the Sabah and Sarawak waters was conduct during 1996-1997 through the orgasnizing by SEAFDEC/TD, DOF Thailand, and MFRDMD, DOF Malaysia. The objective of these surveys are; to update the status of fish diversity and stock of economic species in the Area II (see Map 1,2).

The fishery resource in the Sabah and Sarawak waters has been investigated since 1968 by Exploratory Fishery Division, DOF, Thailand (Exploratory Fishery Division, 1968, 1969, 1970 and 1972); Bejie & Gambang, (1981) and by Pheng (1985). Since then, this survey is the joint surveys with SEAFDEC, the Department of Fisheries of Thailand and Malaysia launced along the Sarawak and Sabah coast. Previously, several report on fish diversity in many areas of this region and adjacent areas, several ichthyological surveys and fieldguide for species was done by Fisher & Whitehead (1974) for the first FAO Species Identification Sheets; Rau & Rau (1980) for commercial fishes and La Paz & Interior (1979) report some deep sea species of the Philippines; Randall *et al*. (1997) for Ogasawara Islands waters; Chen (1993) for Taiwanese waters, and Kuiter & Debelius (1994), Debelius (1993), Allen (1997) for the Southeast Asian reef fishes; Randall, *et al.* (1997) for species found in the Great Barrier Reef and Coral Sea; and Mohsin & Ambak (1996) and Mansor *et al.*(1998) for the Malaysian waters.

Materials and Methods

<u>Cruising and survey methods</u>.

1. The survey for species diversity of the South China Sea fishes in the Area II, was carried out in the Sabah and Sarawak waters. Two cruises were conducted, during 9 July-5 August, 1996 and 25 April-30 May 1997, by the K.K. Manchong. The modified high opening otter-board bottom trawlnets was applied in these surveys, each station was done 1 hour trawling. Both cruise selected 15 and 18 station points of 79 oceanographic stations for trawling surveys (see Map 1,2).

2. During the Port of Call periods Sarawak River, Sarikei, Bintulu, Labuan and Kota Kinabalu,

additional survey for species that was fished from coastal waters of the Area, through purchasing and collecting from the fishing piers and markets.

3. Hand-lines surveys was done at the Station 35-45 and also dip netting, including sighting observation also applied for some occurrence of large species.

Collecting, recording and specimens handling.

1. Any species that was not obtained in the Area I (Gulf of Thailand and eastern Malay Peninsula) were recorded and collected for species representative. Each species representative was collected covering their sizes, sex and varieties. Some huge and uneffordable specimens was photo recorded or partially collected its important part e.g. shark and ray.

2. The representative species were photographed, by Ektachrome slides. Each specimens was treated in the same methods that applied in the Area I, both photographing and preservation.

3. All representative specimens in these survey have been deposited in the Museum and Aquarium Division, Dept. of Fisheries, Bangkok, Thailand.

Identification and classifications.

The classifications in this systematic account was based on Nelson (1994) for bony fishes and Compagno (1984), Last and Stevens (1994) for elasmobranches. The identifications of each family followed to several updated or previous references indicated in the result.

Results

Catching result

1. In the Cruise I, result of CPUE is ranged from 3.5-196 kg/hr, composed with commercial fishes 31.48-90.11 % (see Tab. 2.1). The Station (St) 44 is the highest CPUE obtained, 196 kg with 61.02 % of commercial fishes but the St 35 is lowest, 3.5 kg with 51.42 % of commercial fish. Although the fishes percentage of St 17 is the highest, but its CPUE is low, 17 kg obtained whereas the St 7 is high CPUE but % of commercial fishes is relatively low, 31.38.

2. In the Cruise II; the St. 48 was obtained the highest amout of commercial fishes, 144 kg but mainly *Ariomma indica* (92 kg). At the St. 16, only 4.7 kg fishes was obtained. At the St. 14 is failed in fish hauling, due to rough sea and net deforming (see Tab. 2.2).

3. The Cruise II, obtained commercial fishes 925.9 kg approximately, including 59 species but any species which was obtained less than 0.5 kg in any Station is omitted in the Table 3.

The first five ranked from this Cruise are *Ariomma indica*, *Priacanthus macracanthhus*, *Saurida undosquamis*, *Upeneus moluccensis* and *P. tayenus* (113.2, 54.8, 49, 48.8 and 38.3 kg, respectively). And the small squid *Loligo duvoucelli* is the dominant shellfish that obtained from every stations, 53.6 kg.

Diversity

1. In the Cruise I trawling survey, we obtained 359 species of 87 families. The highest species diversity was obtained in the St. 33 (69 species) following by St. 34, 44 (60, 56 species respectively). The bigeye *Priacanthus macracanthus* is the most abundant, occured in 14 station points and then *Saurida undosquamis, S. micropectoralis, Parupeneus cinabarinus, Gymnocranius griseus, Fistularia petimba, Pentaprion longimanus, Seriolina nigrofasciata* and *Abalistes stellatus*. The economic species survey in the markets in this cruise found 90 species.

2. The Cruise II, we obtained 454 species of 88 families from trawling survey and 97 species from the markets. The St. 48 is the highest diversity, 70 species found follow by St. 76, 31-32 and 15 (54, 55 and 53 species respectively). Saurida undosquamis is te most abundant, occured in 16 station points and follow by *Abalistes stellatus, Synodus hoshinonis, Fistularia petimba, Pentaprion longimanus, Priacanthus macracanthus, Seriolina nigrofasciata, Parupeneus cinabarinus* and *Nemipterus nemurus*.

At least 24 orders, 108 families and 523 species including 103 economic species were trawled and 160 species were collected in the markets (see checklist below: **m**). There systematic account with brief notice and checklist of all species obtained is provided below (see Appendix 1,2).

Thirty seven species (see checklist below: HL) were obtained by handline fishing around the Station 35-45, off Miri, 7 species are commonly obtained, there are; *Lutjanus malabaricus, Gymnocranius griseus, Cephalopholis miniatus, C. sonnerati, Diagramma pictum, Lethrinus lentjan and Arius bilineatus*. At the Sarawak River, we obtained 4 estuarine species by handlines; catfishes, *Arius maculatus, A. caelatus;* eel *Uropterygius* sp. and puffer, *Xenopterus naritus*.

Mainly coastal and estuarine fishes occured at the markets of Sarikei, Miri and Bintulu, taken by small scale fishing; trawl nets, gill nets and seins. At the Labuan and Kota Kinabalu markets, most of commercial species come from coral reefs through traps, gillnets, handlines and some species from offshore trawlings.

Systematic Account
Elasmobranchs

Twenty eight species of 11 families and 6 orders were obtained. From the Area I, in this survey 13 species were collected previously. References: Compagno (1984 a, b and pers. comm., 1997); Michael (1993) and Last & Stevens (1994). At least 13 orders, 49 families, 240 species known to the South China Sea and adjacent areas, mainly from coastal habitats (Compagno pers. comm., 1997).

Order Orectolobiformes

Family Hemiscyllidae; Two species obtained from trawling survey, *Chiloscyllium griseum* and *C. plagiosum*.

Order Heterodontiformes

Family Heterodontidae; Only one species *Heterodontus zebra* taken from the Stations 7, 14, 19 and 69.

Order Carcharhiniformes

Family Triakidae; Three species were taken from trawling in the deeper areas, *Mustelus griseus* and two species of *Mustelus* sp. and *Hemitrakis* sp. are unknown.

Family Carcharhinidae; Six species found from trawling survey in a few individuals and *Carcharhinus hemiodon* is commonly sold in the markets of Miri to Kota Kinabalu.

Family Sphyrenidae; Four species occur in the Areas, two were taken from trawl survey *Sphyrna mokarran* and *M. leweni.*

Order Torpediniformes

Family Narcinidae; Two species taken, one specimens of *Narcine prodorsalis* was taken from the St. 6, *N. maculata* is very common.

Order Rajiformes

Family Rajidae; two species, an unkhown *Raja* (*Okamejei*) sp. and *O. boesemani* and taken from trawl in lower 70 m depth.

Order Myliobatiformes

Family Dasyatidae; Up to 30 species known from the South China Sea, 6 of them were taken and same as the species taken in the Area I.

Three species from 3 families more were taken from trawling and markets, there are *Aetomyleus nichoffi* (**Myliobatidae**), *Rhinoptera javanica* (**Rhinopteridae**) and *Gymnura poecilura* (**Gymnuridae**). *Mobula taracapana* (**Mobulidae**) was sigthed around the St. 35.

Bony fishes

In this survey, 18 orders, 96 families and 495 species were obtained. The most diverse family found in this survey are Carangidae, 40 species, Serranidae, 30 species and Nemipteridae, 26 species. The families indicated below are selected from the important or noticeable ones. Previously, 45 orders, 228 families and more 2500 species of bony fish known to the South China Sea.

Order Anguilliformes

Family Muraenidae

More than 30 species known from the South China Sea, seven species found including *Uropterygius* sp. taken from handline in the Sarawak River (Kuching).

Family Synaphobranchidae; only *Meadia abyssalis* was taken from the St. 34 (71 m depth); Ref. Masuda *et al*. (1984).

Family Muraenesocidae

Castle (1984) reviewed the species found in Western Indian Ocean, three species found in this survey.

Order Clupeiformes

Mainly inhabit pelagic and coastal, occasionally obtained by trawling but mainly caught by purse sein nets, most species are economic important. References: Whitehead (1985) and Whitehead, *et al.* (1988).

Family Clupeidae; 7 species of 5 genera found, mainly from trawling in small amount. *Tenualosa toli* is commonly found in the Bintulu market.

Family Engraulididae; 11species from 6 genera found. Five species of 2 genera, *Stolephorus* and *Encrasicholina* taken from trawling. Six coastal species were taken from the markets of Sarikei and Bintulu.

Order Ophiiformes

Family Ophiidae; 3 species found from trawling survey including an unknown species of *Sirembo*. References; Gloerfelt-Tarp & Kailola (1984) and Allen (1997).

A single specimens of *Carapus* sp. (**Carapidae**) symbiont with a cardiid bivalve was taken at the St. 31.

Order Siluriformes (Reference: Gomon, 1983; Jayaram, 1983)

Family Ariidae; 4 species of *Arius* found in the coastal area from trawling, the rest 3 species; *A. nella, A. venosus* and *Osteogeneiosus militaris* obtained from the markets of Sarikei and by handlines.

Order Osmeriformes; one species of *Glossanodon* sp. (**Argentinidae**) was taken from St. 35 (85-90 m depth).

Order Zeiformes; *Antigonia capros* (**Caproidae**) found at 87 m depth of the St. 46.

Order Beloniformes

Family Exocoetidae; 3 species of flyingfishes genus *Cypselurus* were taken by dip net and accidentally stranded on the deck of M.V. SEAFDEC.

Order Gasterosteiformes; Known from the South China Sea 8 families, more than 40 genrara and 150 species. This survey obtained 5 families 7 species including; *Solenostomus paradoxus* (**Solenostomidae**) from the St. 1. Three species of the **Centrisidae**, *Centriscus* sp., *C. scutatus* and *Aeoliscus* sp. from the shallow area, a single specimens of *Pegasus laternarius* (**Pegasidae**, Palsson & Pietsch,1989).

Family Fistulariidae; 2 species were commonly taken from trawling survey almost of the station points. *Fistularia petimba* and *F. commersoni* are similar species and always confused in identification. Reference; Fritzsche (1976).

Order Lophiiformes

Three species of *Lophiomus* (**Lophiidae**) taken from the St. 19-48. *Antennarius dorehensis* and *A. striatus* (**Antennaridae**) were obtained from the St. 76, including *Chaunax* sp. (**Chaunacidae**).

The **Ogcocephalidae** was taken 3 species of the genus *Halieutaea* (reference; Gloefelt-Tarp & Kailola, 1984 and Chen, 1993).

Order Scorpaeniformes

Family Scorpaenidae; Over 15 genera and 40 species known in this region, 10 species of 8 genera found from trawling suvey (References; Eschmeyer, et al., 1979a,b; Gloefelt-Tarp & Kailola, 1984; Masuda *et al*., 1984; Randall, 1995; Allen, 1997 and Randall *et al*. 1997).

Family Triglidae; 4 species of 3 genera found from below 5o m depth, *Lepidotrigla spiloptera* is the common species whereas two species of *Pterygotrigla* and *Satyrichthys rieffeli* are rarely found from below 90 m. References; Chen (1993) and Randall (1995).

Family Platycephalidae

More than 60 species of 19 genera known from Indo-Pacific, 9 species of 8 genera found mainly from trawling (references: Wongratana, 1975; Gloefelt-Tarp & Kailola, 1984 and Randall, 1995).

Order Perciformes

Family Priacanthidae; 13 species of 4 genera occur in the Area**,** 4 species found. *Priacanthus macracanthus* is commonly occurs below 50 m depth with uncommon species*, P. sagittarius* and *Pristigenys niphonia.*

Family Callionymidae; 6 species of 5 genera taken from trawling, including *Bathycallionemus* sp. References; Gloefelt-Tarp & Kailola (1984) and Masuda *et al*. (1984).

Family Serranidae; totally 30 species of 7 genera found in this survey, 10 species were trawled, including 11 species from handlines and 13 from the markets of Labuan and Kota Kinabalu. *Pseudanthius marcia* which known only from the western Indian Ocean is previously found at the St. 76 including *Pseudanthius* spp. and *Plectanthius* sp. (references: Masuda *et al*., 1984; Randall & Hoese, 1986; Randall & Heemstra, 1991; Heemstra & Randall, 1993, Randall, 1995 and Randall et al., 1997).

Family Apogonidae; About 100 species from 20 genera known from the South China Sea, 16 species found (references; Gloefelt-Tarp & Kailola, 1984; Masuda *et al*., 1984; Fraser & Lachner, 1985; Kuiter, 1992; Allen & Swainston, 1993 and Randall, 1995).

Family Carangidae; Seventeen genera and about 70 species known from Indo-Pacific, 40species of 14 genera found. Twenty-four species taken by trawling, including 5 from handlines and 11 from the markets of Labuan, Kota Kinabalu. References: Gushiken, 1983; Smith-Vaniz, 1984 and Randall (1995).

Family Leiognathidae; Known only from the Indo-Pacific region; 3 genera and about 24 species, 14 species found mostly from trawling (references: Kulmorgan-Hille, 1968; Premcharoen, 1993 and Randall, 1995).

Family Lutjanidae; At least 30 species, 8 genera known in the Indo-Pacific (Allen, 1985 and Allen & Talbot, 1985), 23 species of 4 genera found, mainly *Lutjanus* (17 species). *Symphorus nematophorus* and 3 species of *Pristipomoides* was taken from trawling and handlines. Eigth species including *Symphorichthys spilurus, Etelis cabunculus* found in the Labuan and Kota Kinabalu markets.

Family Caesionidae; consists of 4 genera and 20 species, more than 14 species occurs in the

South China Sea and adjacent areas. Five species found, *Pterocaesio chrysozona, Dipterygonotus balteatus* are commonly obtained as trashfish from trawling, 3 species of *Caesio* are commercial fishes of the Labuan and Kota Kinabalu markets (reference; Carpenter, 1987 and 1988).

Family Haemulidae; over 25 species, 10 genera known from the Indo-Pacific, 10 species of 4 genera found. *Hapalogenys analis* from the St. 7 is the third records from the Southeast Asia since Wongratana (1982) and Lim (1994). *Pomadasys auritus* is recently known from Sarawak waters, frequently sold in Kota Kinabalu market, the species was previously known from a single holotype and other one specimens obtained from the Indian Ocean (T. Wongratana perse. comm., 1997). Five species were obtained by trawling, *Diagramma pictum* is a common fish.

Family Nemipteridae; totally, 5 genera and 64 species were recognized, 26 species of 4 genera were found, 13 species of *Nemipterus* and 3 of *Parascolopsis* obtained mainly from trawling. *Scolopsis* and *Pentapodus* (7 species) are coral reef fishes, commonly found in the Labuan market. References: Russell (1990, 1991 and 1993).

Family Lethrinidae; Carpenter & Allen (1989) revised and regcognized 39 species of Indo-Pacific, 8 species of 2 genera obtained through trawling and handlines.

Family Sciaenidae; 8 species of 6 genera found, 5 from trawling and the rest from the Sarikei to Bintulu markets (references; Trevawas, 1977; Lal Mohan, 1983 and Sirimontraphorn, 1987).

Family Mullidae; over 20 species known in the Indo-West Pacific, 15 species found. Seven species of *Upeneus* are considered as trashfish of trawling, *U. asymmetricus* is the most common. *Parupeneus cinnabarinus* is only species of the genus was obtain by trawling, whereas the other 6 species found in the markets. (references: Gloefelt-Tarp & Kailola, 1984; Allen & Swainston, 1993; De Bruin *et al*., 1994 and Allen, 1997).

Family Labridae; estimated 500 species of 60 genera known from the Indo-Pacific. Six species of 3 genera were obtained from trawling, including 3 unknown *Halichoeres* and *Choerodon robustus* from 100 depth of St. 76, and 7 species of 4 genera found in the Labuan and Kota Kinabalu markets. Totally 13 species found.

Family Chaetodontidae; 3 species found from trawling in a few specimens (references: Chen, 1993; and Randall *et al*., 1997).

Family Pomacentridae; estimated 150 species found in the South China Sea, mostly coral reef inhabitant. Five species found, *Pristotis jerdoni* is commonly obtained from trawling, but a single specimens of *Chromis mirationis* was found in the St. 76 (100 depth).

Family Siganidae; Woodland (1990) reviewed the family, recognized 27 species; this survey obtained 6 species. *Siganus canaliculatus* is the most common trawled species, the others were obtained from the Labuan market.

Family Scombridae; over 25 species known from the South China Sea; 10 species, 5 genera found. Four species were obtained fron trawling, *Scomberomorus lineolatus* was found in the Bintulu market, 5 species of tunas and bonitos are commonly sold along the fish markets. Collette & Nuaen (1983) reviewed the family.

Family Acanthuridae; 4 species found from the Labuan and Kota Kinabalu markets.

Family Trichiuridae; Nakamura & Parin (1993) revised the family and their relatives; at least 5 species known in this region, 4 species found. A large specimens of *Lepturacanthus savala* was taken from handline, three species of 3 genera from trawling. *Trichiurus lepturus* is the most common.

Family Sphyraenidae; 10 species known from the area. This survey found 4 species, from trawling (reference; Gloefelt-Tarp & Kailola, 1984; Masuda *et al*., 1984 and Randall, 1995).

Family Gobiidae; five species found, including two unknown genera. *Priolepis* spp. was obtained with a large sponge.

Family Kurtidae; only *Kurtus indicus* known from the South China Sea, is uncommonly found in the Bintulu market.

Family Pinguipedidae; 3 species is uncommonly found from trawling, *Parapercis filamentosus*

Table 1 The previous catching statistic of trawling survey in the Area II
EFD : Exploratory Fishery division, Bangkok Thailand

Year	Catch/hr	% Fishes	% Trash	Reference
1968	*186*	*53*	*47*	*EFD, 1968*
1969	*442*	*63.1*	*36.9*	*EFD, 1969*
1970	*286*	*56.9*	*43.1*	*EFD, 1970*
1972	*214*	*72*	*28*	*EFD, 1972*
1973	*210*	*73*	*27*	*Pheng, 1985*
1975	*200*	*61*	*39*	*Pheng, 1985*
1977	*149*	*62*	*38*	*Pheng, 1985*
1979	*142*	*55*	*45*	*Pheng, 1985*
1980	*154*	*47*	*53*	*Pheng, 1985*
1981	*141.9*	*55.4*	*44.6*	*Beije & Gambang, 1981*

is the most common.

Order Pleuronectiformes

More than 60 species of 7 families known from the South China Sea, 27 species (see checklist below) were found in this survey. Three species of *Pseudorhombus* (**Paralichthidae**) are commonly taken from trawling. *Heteromycteris matsubarai* (**Soleidae**) is an uncommon, previously known from Japanese waters was taken at the St. 17. References: Punpoka (1964), Mongkolprasit (1967), Menon (1977), Gloefelt-Tarp (1984), Masuda *et al*. (1984), Chen (1993) and Randall (1995).

Order Tetraodontiformes

Over 80 species, 9 families known from the South China Sea. References: Tyler (1968), Gloefelt-tarp & Kailola (1984), Masuda et al. (1984), Kumchirtchuchai (1985), Chen (1993) and Randall (1995).

Family Balistidae*;* *Abalistes stellatus* (possibly undescribed species,: K. Matsuura pers. comm., 1997) is a very common species taken by trawling from most of the station points. Four coral reef species of 3 genera were obtained from the Labuan and Kota Kinabalu markets.

Family Monacanthidae; 12 species of 7 genera obtained from trawling, including *Acreichthys tomentosa* taken by dipnet at Labuan. *Aluterus monoceros* is a common economic species of family.

Family Tetraodontidae; nearly 100 species of 18 genera occur in the Indo-Pacific. Eleven species, 4 genera taken by trawling, but *Tetraodon nigroviridis* was taken by dipnet.

Checklist of fishes obtained and observed (by sight) in the Area II, Sabah and Sarawak. See Appendix 1,2 (m = fish market or from coastal fishing boat, HL= obtained from handlines)

Discussion

In this survey, 518 species were obtained. Previously, species diversity of the Area II has never been recorded but its fishery resources was assessed by several trawling expeditions, both from local and by the Thai DOF, cover 10-100 m depth along the Sarawak coast. Since 1968-1981, its catching unit per hour was very high, 123-442 kg/ hour (Exploratory Fishery Division, 1968; 1969; 1970 and 1972) and by Bejie & Gambang (1981) and Pheng (1985), see Tab. 1. In this collaborative survey, catching result is drastically declined to 3.5-196 kg/hr.

Four of the 23 stations are highly species-richness area, along the middle zone of Sarawak waters, there are Station 48 (70 species), St. 33 (69), 34 (60) and 31 (58 species). Around the western zone of the Sarawak, most of the species are coastal and estuarine species e.g. Ariidae, Clupeidae and Scieanidae. The eastern zone (St. 69, 76) we obtained several deep sea species of the family Moridae, Caproidae and Argentinidae. Demersal fish forms the main component of the trawls with few pelagic

Checklist of fishes obtained and observed (by sight) in the Area II, Sabah and Sarawak. See Appendix 1,2 (m = fish market or from coastal fishing boat, HL= obtained from handlines)

Order Orectolobiformes
Family Hemiscyllidae
Chiloscyllium griseum
C. plagiosum
Order Carcharhiniformes
Family Triakidae
Mustelus sp. 1
M. griseus
Hemitriakis sp. 1 **HL**
Family Carcharhinidae
Carcharhinus borneensis
C. dussumieri
C. hemiodon
C. plumbeus
C. sealei
C. sorrah
Loxodon macrorhinus
Family Sphyrnidae
Sphyrna mokarran
S. leweni
Order Rhinobatiformes
Family Rhinobatidae
Rhynchobatus australae
Order Torpediniformes
Family Narcinidae
Narcine maculata
N. prodorsalis
Order Rajiformes
Family Rajidae
Okamejei boesemani
Okamejei sp. 1
Order Myliobatiformes
Family Dasyatidae
Dasyatis imbricatus
D. kuhlii
D. walga
D. zugei
Himantura gerraddi
H. jenkinsi
Family Myliobatididae
Aetomyleus nichoffi
Family Rhinopteridae
Rhinoptera javanica
Family Gymnuridae
Gymnura poeciura
Family Mobulidae
Mobula taracapana
Order Anguilliformes
Family Muraenidae
Gymnothorax javanicus
G. flavimarginata
G. fimbriata
Gymnothorax sp.
Encheloycore sp.
Strophidon sp.
Uropterygius sp.
Family Congridae
Conger myriaster
Family Synaphobranchidae
Meadia abyssalis
Family Muraenisocidae
Muraenesox cinereus
Congresox talabonoide **HL**

Order Clupeiformes
Family Engraulididae
Stolephorus insularis
S. dubiosus
S. insularis
S. indicus
Encrasicholina heterolol
Setipinna melanochir **m**
S. taty **m**
Thryssa hamiltoni **m**
T. mystax **m**
T. setirostris **m**
Coilia macrognathos **m**
Family Chirocentridae
Chirocentrus dorab
C. nudus **m**
Family Clupeidae
Amblygaster sirm
A. lemuru
Sardinella fimbriata
Sardinella sp. 1
Tenualosa toli **m**
Dussumieria sp.
Ilisha macroptera
Order Aulopiformes
Family Synodontidae
Saurida elongata
S. longimanus
S. tumbil
S. undosquamis **HL**
Saurida sp.
Synodus hoshinonis
Trachinocephalus myops
Order Ophiiformes
Family Ophiidae
Sirembo jerdoni
Sirembo imberis
Sirembo sp.
Family Carapidae
Carapus sp.
Order Siluriformes
Family Ariidae
Arius bilineatus **HL**
A. caelatus **HL**
A. nella **m**
A. thalassinus **HL**
A. venosus **m**
A. maculata
Osteogeniosus militaris **m**
Family Plotosidae
Plotosus caninus **m**
P. lineatus
Order Osmeriformes
Family Argentinidae
Glossanodon sp.
Order Zeiformes
Family Caproidae
Antigonia copros
Order Myctophiformes
Family Myctophidae
Diaphus sp.
Order Gadiformes
Family Bregmacerotidae

Bregmaceros sp.
Family Moridae
Physiculus sp.

Order Beloniformes (reference: Collette, 1984 a, b; Petchsathit, 1992)
Family Belonidae
Ablennes hians **m**
Tylosurus crocodilus
Family Hemiramphidae
Hemiramphus far
Hyporhamphus dussumieri **m**
Rhynchorhamphus malabaricus
Family Exocoetidae
Cypselurus oligolepis
C. poecilopterus
Cypselurus sp.
Order Atheriniformes
Family Atherinidae
Hypoatherius bleekeri
Order Beryciformes
Family Holocentridae
Sargocentron rubrum **HL**
Ostichthys japonicus
Family Berycidae
Centroberyx rubicaudus
Order Gasterosteiformes
Family Pegasidae
Pegasus laternarius
Family Centriscidae
Centriscus scutatus
Centriscus sp.
Aeoliscus sp.
Family Syngnathidae
Hippocampus kuda
Hippocampus sp.
Family Solenostomidae
Solenostomus paradoxus
Family Fistularidae
Fistularis petimba
F. commersoni
Order Lophiiformes
Family Antenaridae
Antennarius striatus
A. dorehensis
Family Lophiidae
Lophiomus setigerus
Lophiomus sp. 1
Lophiomus sp. 2
Family Ogcocephalidae
Halieuteae sp. 1
Halieuteae indica
H. stellata
Family Chaunacidae
Chaunax sp.
Order Scorpaeniformes
Family Scorpaenidae
Choridactylus multibarbus
Pterois russelli
P. mombasae
Scorpaenopsis cirrhosa
Brachypterois serrulata
Scorpaenodes scaber
Scorpaenodes sp.
Minous pictus
Cottapistus cottoides
Inimiscus sinensis
Family Platycephalidae
Elates ransoneti
Sorsogona tuberculata
Sorsogona sp.
Rogadius pristiger
Kamococcius radericensis
Grammoplites scaber
Inegocia japonicus
Thrysanophrys macracanthu
Platycephalus indicus **m**
Family Trigidae
Lepidotrigla spiloptera
Satyricthys rieffeli
Pterygotrigla hemisticta
Pterygotrigla sp.
Family Dactylopteridae
Dactyloptena papilio
D. orientalis
Order Perciformes
Family Priacanthidae
Priacanthus tayenus
Priacanthus sp.
P. macracanthus **HL**
P. sagittarius
Pristigenys niphonia
Family Callionemidae
Repomucenus virgis
Calliruichthys japonicus
Callionemus filamentosus
Callionemus sp.
Dactylopus dactylopus
Bathycallionemus sp.
Family Champsodontidae
Champsodon arafurensis
Champsodon sp.
Family Uranoscopidae
Uranoscopius oligolepis
Family Centropomidae
Lates calcarifer **m**
Psammoperca waigiensis **m**
Family Ambassidae
Ambassis commersoni
Family Serranidae
Cephalopholis boenak **HL**
C. miniatus **HL**
C. cyanostigma **HL**
C. urodeta **m**
C. sonnerati **HL**
C. igarashiensis **m**
Epinephelus areolatus **HL**
E. quoyanus
E. heniochus **HL**
E. sexfasciatus **HL**
E. bleekeri
E. erythurus **HL**
E. diacanthus
E. caeruleopunctatus **m**
E. ongus **m**
E. latifasciatus **m**
E. amblycephalus **m**
E. coioides **HL**
E. fasciatus **HL**
E. merra **m**
E. poecilonotus **m**
Plectopoma leopardus **m**
P. oligacanthus **m**
P. maculatus **m**

Chelidoperca sp.
Pseudanthias marcia
Pseudanthias sp.
Plectanthias sp.
Variola louti **m**
V. albimarginata **m**

Family Apogonidae
Apogon septemstriatus
A. semilineatus
A. quadrifasiatus
A. elioti
A. lineatus
A. melas **m**
A. aureus
A. albimaculatus
A. poecilopterus
A. taeniopterus
A. sealei
A. fasciatus
C. ceramensis
A. carinatus
Rhapdamia gracilis
Sphaeramia orbicularis

Family Sillaginidae
Sillago sihama

Family Lactaridae
Lactarius lactarius

Family Rachycentridae
Rachycentron canadum

Family Carangidae
Parastromateus niger
Selar boops
S. cruemenophthalmus
Alepes kleinii
A. melanoptera
A. djedaba
A. macrura **m**
Carangoides armatus **HL**
C. gymnostethus **m**
C. caerulaeopinnatus **HL**
C. hedlandensis **HL**
C. malabaricus
C. talamparoides **HL**
C. chrysophrys
C. uii
C. fulvoguttatus **m**
C. plagiotaenia **m**
C. bajad **m**
C. equula
C. praeustus **m**
C. ferdau **m**
C. dinema **HL**
C. oblongus
Uraspis uraspis
Atule mate
Selaroides leptolepis
Seriolina nigrofasciata
Alectes indicus
A. cilialis
Atropus atropus
Decapterus russelli
D. kurroides
D. macarellus **HL**
D. macrosoma
Megalaspis cordyla
Caranx sexfasciatus
C. ignobilis **m**
Scomberoides commersonianus **m**
S. tol
S. tala **m**

Family Ariommatidae
Ariomma indicum

Family Nomeidae
Psenopsis anomala

Family Echeinidae
Echeineus naucrates

Family Meneidae
Mene maculata **m**

Family Gerreidae
Gerres macrosoma
G. filamentosus
G. abbriviatus **m**
G. acinaceus
G. poieti **m**
Pentaprion longimanus

Family Leiognathidae
Leiognathus bindus
L. equulus
L. stercorarius
L. fasciatus
L. leuciscus
L. brevirostris **m**
L. lineolatus
L. elongatus
L. splendens
L. blochi
L. smiththurstri **m** (= *L. longipinnis*, D.W. Woodland, pers. comm., 1998)
Secutor indicius **m**
S. ruconius
S. insidiator

Family Lutjanidae
Lutjanus bohar **m**
L. carponotatus **m**
L. erythropterus **HL**
L. fulviflamma **HL**
L. gibbus **m**
L. johni **m**
L. kasmira **m**
L. lemniscatus **m**
L. lineolatus
L. lutjanus **HL**
L. malabaricus **HL**
L. monostigma **HL**
L. quinqueliniata
L. rivulatus **m**
L. russelli **HL**
L. sebae
L. vittus **HL**
Symphorus nematophorus **m**
Symphoricthys spilurus **m**
Etelis cabunculus **m**
Pristipomoides filamentosus
P. multidens **HL**
P. typus

Family Caesionidae
Caesio cuning **m**
C. xanthonota **m**
C. capricornis **m**
Pterocaesio chrysozona
Dipterygonotus balteatus

Family Haemulidae
Diagramma pictum **HL**

Plectorhinchus gibbosus
P. picus **m**
P. lineatus **m**
Hapalogenys analis
Pomadasys kaakan
P. auritus **m**
P. argyreus
P. argentius
Pomadasys sp. **m**

Family Lethrinidae
Gymnocranius elongatus **HL**
G. griseus **HL**
G. frenatus
Lethrinus lentjan **HL**
L. laticaudus **HL**
L. microdon **HL**
L. miniatus
L. ornatus **HL**

Family Sparidae
Argyrops spinifer **HL**

Family Nemipteridae
Nemipterus aurorus
N. bathybius
N. furcosus
N. hexodon **HL**
N. isacanthus
N. japonicus
N. mesoprion
N. nematophorus
N. nemurus
N. peronii
N. tambuloides
N. thosaporni
N. virgatus
Scolopsis monogramma
S. taeniopterus
S. vosmeri
S. margaritifer **m**
S. affinis **m**
S. frenatus **m**
S. ciliatus **m**
Parascolopsis tanyactis
P. inermis
P. eriomma
Pentapodus emeryi **m**
P. bifasciatus **m**
P. setosus

Family Kyphosidae
Kyphosus cinerescens **m**
Proteracanthus sarissophorus **m**

Family Sciaenidae
Otolithoides sp. **m**
Pennahia anea
P. macrocephalus
P. pawak
Chrysochir aureus **m**
Protonibia diacanthus
Nibia albiflora
Johnius sp.

Family Mullidae
Upeneus asymetricus
U. sulphureus
U. moluccensis
U. sondaicus
U. tragula
U. luzonius
U. taeniopterus
Parupeneus cinnabarinus
P. multifasciatus **HL**
P. barberinus **m**
P. barberinoides **m**
P. indicus **m**
P. cyclostoma **m**
P. pleurostigma **m**
Mulloidichthys vanicolensis **m**

Family Pempheridae
Pempheris oualensis **m**
P. xanthopterus **m**

Family Teraponidae
Terapon theraps
T. jarbua

Family Cirhithidae
Cirhithichthys aureus

Family Ephippidae
Ephippus orbis
Platax batavianus **m**
P. orbicularis **m**

Family Drepanidae
Drepene punctata
D. longimana

Family Labridae
Xiphocheilus typus
Cheilinus fasciatus **m**
C. diagrammus **m**
C. chlorurus **m**
C. undulatus **m**
Epibulus insidiator **m**
Choerodon schoenleinii **m**
C. robustus
Halichoeres hartzfeldi
Halichoeres sp. 1
Halichoeres sp. 2
Halichoeres sp. 3
Hemigymnus melapterus **m**

Family Scaridae
Scarus pyrrhurus **m**
S. rivulatus **m**
S. sordidus **m**
Scarus sp. **m**
Leptoscarus waigiensis **m**

Family Pomacentridae
Abudefduf sexfasciatus **m**
Chromis mirationis
Hemiglyphidodon plagiometopon **m**
Pomacentrus melas **m**
Pristotisjerdoni

Family Chaetodontidae
Coradion chryszonus
C. altivelis
Chaetodon guentheri

Family Scatophagidae
Scatophagus argus **m**

Family Monodactylidae
Monodactylus argenteus **m**

Family Toxotidae
Toxotes jaculatrix **m**

Family Siganidae
Siganus canaliculatus
S. virgatus **m**
S. puellus **m**
S. stellatus **m**
S. fuscescens **m**
S. argenteus **m**

Family Acanthuridae
- *Naso lopezi* **m**
- *Acanthurus bleekeri* **m**
- *A. xanthoptera* **m**
- *A. olivaceus* **m**

Family Scombridae
- *Rastelliger kanagurta*
- *Scomberomorus commersoni* **HL**
- *S. guttatus*
- *S. lineolatus* **m**
- *Scomber australisicus*
- *Katsuwonus pelamis* **m**
- *Auxis rochei* **m**
- *A. thazard* **m**

Family Trichiuridae
- *Trichiurus lepturus*
- *Eupleurogrammus glossodon*
- *Tentoriceps cristatus*
- *Lepturacanthus savala* **HL**

Family Stromateidae
- *Pampus argenteus*
- *P. chinensis* **m**

Family Polynemidae
- *Eleutheronema tetradactylum* **m**
- *Polynemus borneensis* **m**
- *P. plebeius* **m**
- *P. sextarius*

Family Sphyraenidae
- *Sphyraena jello* **HL**
- *S. forsteri*
- *S. obtusata* **m**
- *S. putnami* **m**

Family Bleniidae
- *Xiphasia setifer*

Family Gobiidae
- *Trypauchen vagina*
- *Priolepis* sp. 1
- *Priolepis* sp. 2
- Unidentified Gobiid 2 genera, 2 species

Family Kurtidae
- *Kurtus indicus* **m**

Family Pinguipedidae
- *Parapercis pulchellus*
- *P. filamentosa*
- *Parapersis* sp.

Order Pleuronectiformes

Family Psettodidae
- *Psettodes erumei*

Family Bothidae
- *Engyprosopon grandisquama*
- *Arnoglossus aspilos*
- *Arnoglossus* sp. 1
- *Arnoglossus* sp. 2
- *Grammatobothus polyophthalmus*
- *Laeops parviceps*

Family Paralichthyidae
- *Pseudorhombus arsius*
- *P. elevatus*
- *P. diplospilus*
- *P. quinqueocellatus*
- *P. malayanus*
- *P. duplicatus*
- *Pseudorhombus* sp.1

Family Citharidae
- *Branchypleura novaezeelandiae*
- *Branchypleura* sp.
- *Citharoides macrolepidota*

Family Pleuronectidae
- *Samaris cristatus*
- *Samaris* sp.
- *Samariscus longimanus*

Family Soleidae
- *Heteromycteris matsubarai*
- *Synaptera marginata* **m**

Family Cynoglossidae
- *Cynoglossus arel*
- *Cynoglossus* sp.1
- *Cynoglossus* sp.2
- *C. kopsii*
- *C. bilineata* **m**

Order Tetraodontiformes

Family Triacanthidae
- *Trixiphichthys weveri*
- *Tripodichthys oxycephalus*
- *Triacanthus biaculiatus*

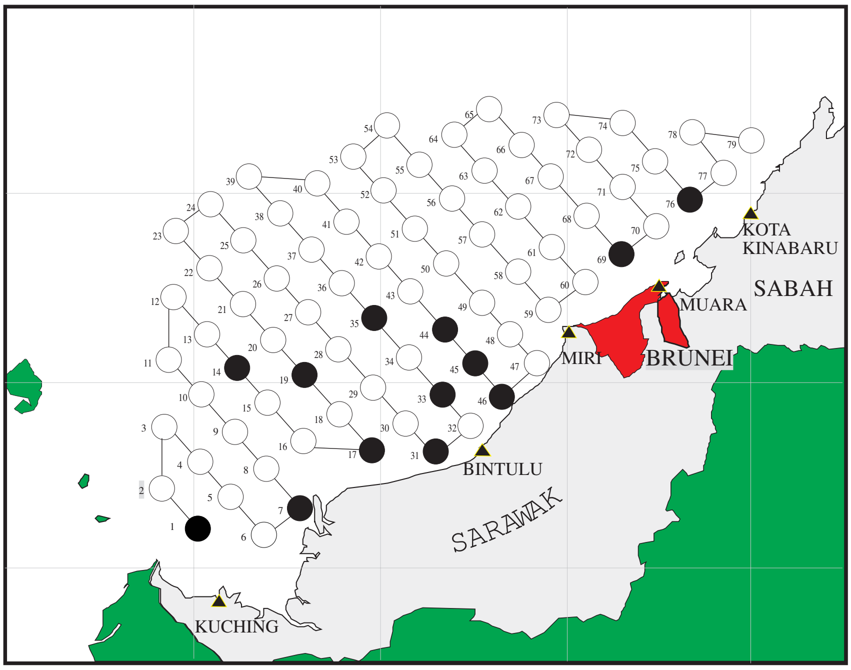
Family Balistidae
- *Abalistes stellatus*
- *Balistoides viridescens* **m**
- *Odonus niger* **m**
- *Sufflumen frenatus* **m**
- *S. chrysopterus* **m**

Family Monacanthidae
- *Acreicththys tomentosa*
- *Paramonacanthus japonicu*
- *Paramonacanthus* sp. 1
- *Paramonacanthus* sp. 2
- *Paramonacanthus* sp. 3
- *Aluterus monoceros*
- *Chaetoderma penicilligeral*
- *Anacanthus barbatus*
- *Pseudoalutarius nasicornis*
- *Thamnaconus hypogyreas*
- *T. striatus*
- *T. modestoides*
- *Thamnaconus* sp.

Family Ostracionidae
- *Tetrosomus gibbosus*
- *T. republicae*
- *Rhyncotracion nasus*
- *R. rhinorhynchos* **m**

Family Tetraodonidae
- *Lagocephalus gloveri*
- *L. lunaris*
- *L. scleratus*
- *L. spadiceus*
- *Lagocephalus inermis*
- *Arothron immaculatus*
- *A. stellatus*
- *Torquigener pallimaculatus*
- *T. parcuspinus*
- *T. kicksi*
- *Tetraodon nigroviridis*
- *Canthigaster rivulata*
- *Xenopterus naritus* **HL**

Family Diodontidae
- *Cyclicthys spilostylos*
- *Diodon histrix*
- *D. holacanthus*
- *Tragulichthys jaculiferus*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MUARA
MIRI
BRUNEI
BINTULU
SARAWAK
KUCHING

Fig. 1

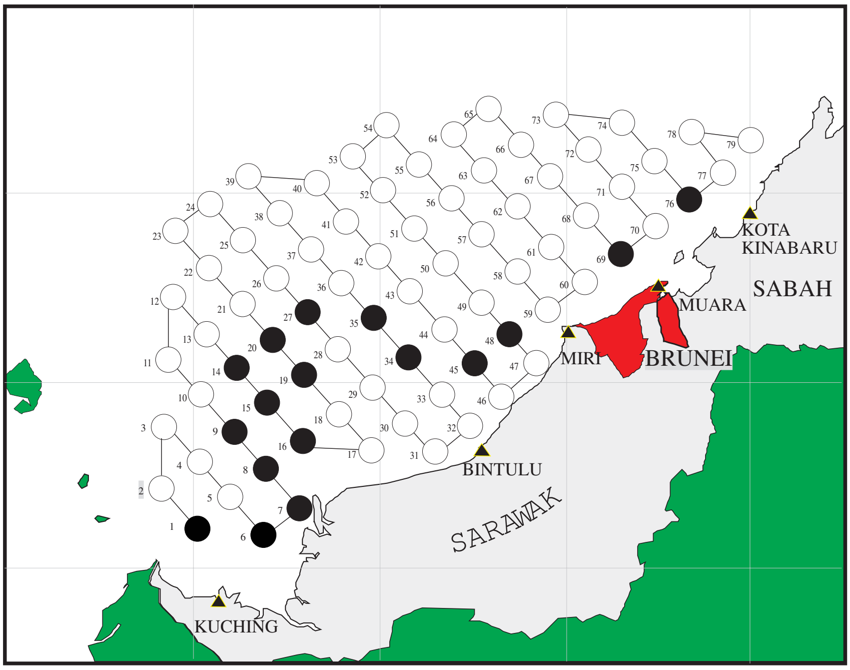
KOTA KINABARU
SABAH
MUARA
MIRI
BRUNEI
BINTULU
SARAWAK
KUCHING

Fig. 2

Table 2.1 Catching results of the Cruise No.1 in the Area II

Station No.	Catch / hr.	% of Fishes	Species	Depth
1	13.9	73.38	18	36-38
5..6	34.5	83.13	31	38-35
7	108	31.48	46	31
10..11	17.6	73.86	30	90-92
14	21.4	67.29	31	91-96
15	22.7	88.1	32	64
17	17	90.11	25	63
19	32	57.81	52	67
31	86	53.49	58	27-30
33	162.91	57.82	69	49
34	104.8	58.2	60	71
35	3.5	51.42	17	85-90
44	196	61.02	56	82-86
45	60	36.33	51	66
46	22	43.18	49	87
69	68	63.23	52	92
76	38	71.05	38	95

Table 2.2 Catching results of the Cruise No.2 in the Area II

Station No.	Catch/hr	Fishes (kg)	Species	Depth
1		25	37	36-37
6		44	44	38-39
7		66	41	-
8		28	37	38
9		23	27	-
14		-	-	88
15		25	53	65
16		4.7	16	45
17		30	49	41
19		34	39	69
20		37	27	90
27		71	43	33
31/32		78	55	21
34		88	47	70-72
35		80	43	87
45		20	45	66
48		144	70	78-79
69		29	48	79
76		90	54	97-87

Table 3 Economic species catching results in each station of the survey Area II

	1	6	7	8	9	14	15	16	17	19	20	27	31/32	34	35	45	48	69	76	
Ariomma indica														6	1.7		92		14	113.2
Priacanthus macracanthus							0.5					5.6		9.5	5.1	2	2.5	2.1	28	54.8
Saurida undosquamis				1.9	7.1					1.2	1.5		9.3	8	17				3.5	49
Upneus moluccensis												22		10	5.3		10		1.3	48.8
Priacanthus tayenus											1		2.3	6	24		1.5	3.5		38.3
Nemipterus nemurus	8	3.3		1.2	4	5	5		1.1	4.2	1.9	1.1							1.1	35.9
Abalistes stellatus					1.4	1	1	1.5	13	2.6	1.2	3.2		2	1.5	2.7	2.5	1.2		35.1
Nemipterus bathybius										4.5	9.3	11							10	35.1
Pentaprion longimanus			9.5		2.2								5.5	12	3.5					32.7
Himantura gerradi			2.3										26							28.1
Decapterus spp.				1.7						2.6							7.6	2.5	13	27.4
Nemipterus nematophorus														7.7	4.7	6.3	3.7			22.4
Lutjanus malabaricus															0.7			4.4	17	22.3
Nemipterus japonicus			5										7	7						19
Diagramma puctum	13			5.6																18.6
Pristipomoides multidens											6.7				8			3.5		18.2
Carongoides malabaricus			14										3.3							16.8
Gymnocranium grisseum							4					9.2			3.5					16.7
Stolephorus spp.														1	0.6		14			15.6
Atule mate		9.5														3.5				13
Upeneus sulphureus													13							12.5
Therapon theraps			12																	12
Saurida tumbil.											2.3	8.3								10.6
Selaroides leptolepis				10																10
Arius bilineatus			8.3											1.5						9.8
Sargocentron rubrum											7.2	2.3								9.5
Gymnura poecilura										1.7	5							2.3		9
Sharks							1.4							7.5						8.9
Sillago shihama	3			5.5																8.5
Nemipterus virgatus												1.4		3.5	1.1	0.9	1			7.9
Nemipterus tambuloides	1	3.6							2.3											6.9
Parupeneus cinnabaricus	0.4						2.3		0.3	3.4										6.4
Scolopsis taeniopterus		4.8							1.3											6.1
Lutjanus lutjanus							1.1							2	2					5.1
Saurida spp.										5										5
Nemipterus thosaporni										1.4		1				1			1.3	4.7
Sardinella spp.																	1.7	3		4.7
Epinephelus coioides									4.5											4.5
Ephippus orbis			4.4																	4.4
Congresox talabonoides													4.1							4.1
Nemipterus isacanthus														2.7		1.3				4
Nemipterus mesoprion		0.3											3.5							3.8
Carangoides malabaricus							1.1										2.5			3.6
Sphyraena forsteri								3.2												3.2
Platax batavianus							2.8													2.8
Seriolina nigrofasciatus									1.4									1.4		2.8
Psettodes erumei													2.7							2.7
Alepes djedaba							2.6													2.6
Rastelliger kanagurta		2.4																		2.4
Pentapodus setosus									1.7											1.7
Scomberomorus guttatus														1.6						1.6
Selar cruemenophthalmus																		1.6		1.6
Lutjanus erythopterus																		1.5		1.5
Uraspis uraspis															1.5					1.5
Epinephelus areolatus							1.4													1.4
Siganus guttatus			1.1																	1.1
Trichiurus lepturus							0.8													0.8
Lutjanus vittatus							0.7													0.7
Megalaspis cordylar			0.6																	0.6
Shellfishes																				
Loligo duvoucelli		15	6.6			3.9			3.5	6	1.2	5.3	2			2.1	5	1.6	1.4	53.6
Loligo chinensis		1.2	2.7		8.4															12.3
Thenus orientalis		3.5								1.4										4.9
Amusium buillotti				2.1					1											3.1
Total	**25**	**44**	**66**	**28**	**23**	**9.9**	**25**	**4.7**	**30**	**34**	**37**	**71**	**78**	**88**	**80**	**20**	**144**	**29**	**90**	**925.9**

fishes, 37 species were obtained in small amount and mostly carangiid fish. Nine demersal economic species which occur almost every station, there are; *Saurida undosquamis, Synodus hoshinonis, Fistularia* spp. *Seriolina nigrofasciata, Pentaprion longimanus, Nemipterus furcosus, Parupeneus cinnabarinus, Abalistes stellatus* and *Gymnocranius grisseus*. Most of the dominant species obtained in this survey are relatively low price species, most of valuable species inhabit in the rocky shoals and near coast areas that the trawling staions are not covered.

The both trawling surveys in some stations we obtained relatively low CPUE because of the deformation of the net during rough climate and also rough bottom interupted trawling to be emergency hauls. The trawling period in 1 hour is may not enough in purpose to investigate te CPUE and in several station points that high potency for coastal fishes habitats were shifted for security of pipeline and oilfield.

Handline in rocky shoal areas and fish markets survey are neccessary to assess the species diversity of the Area that the trawling is unaccessible. Market survey are need to carry out with caution, by select for the landing place that obtained coastal species or from the small-scale fishing activities.

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References

Anonymous, 1969. Results of fisheries and oceanographic surveys on Sunda continental Shelf and South China Sea by R.V. Fisheries reserch No. 2. cruise No. 1/2511. Exploratory Fishing Unit; Dept. Fish., Bangkok; Spec. Publ. SR. 012: 1969, 79 pp. (Thai).

Allen, G.R. FAO species catalogue Vol.6. Snappers of the world. An annotated and illustrated catalogue of Lutjanid species known to date. FAO. Fish. Synop.,(125) Vol.6 : 1985, 208 pp.

_________ . 1997. Marine fishes of South-east Asia. Western Australian Museum. 292 pp.

Allen , G.R. and Talbot , F.H. 1985. Review of the snappers of the genus *Lutjanus* (Pisces : Lutjanidae) from the Indo-Pacific, with the description of a new species. Indo-Pacific Fishes. No.11: 87 p.

Allen, G.R. and Swainston, R.1993. Reef fishes of New Guinea. Publication No.8 Christensen Research Institute, Papua New Guinea.132 p.

________. 1988. The marine fishes of North-western Australia. Western Australian Museum, Perth:201 pp.

Bejie, A. and Gambang, A.C. 1981. Demersal fish resources in Malaysian waters. Fifth trawlsurvey off the coast of Sarawak. (10th July-10th August 1979). Ministry of Agriculture Malaysia.

Carpenter, K.E. 1987. Revision of the Indo-Pacific fish family Caesionidae (Lutjanoidea) , with descriptions of five new species. Indo-Pacific Fishes. No.15: 56 p.

________1988. FAO species catalogue. Vol.8. Fusilier Fishes of the world. An Annotated and Illustrated Catalogue of Caesionid Species Known to Date. FAO. Fish. Synop.,(125) Vol.8 : 75 p.

Carpenter K.E. and Allen, G.R. 1989. FAO species catalogue. Vol.9 Emperor fishes and large-eye breams of the world (Family Lethrinidae). An Annotated and illustrated catalogue of lethrinidae species known to date. FAO. Fish. Synop.(125) Vol.9:118 p.

Castle, P.H.J. 1984. Muraenesocidae. In W. Fischer and G. Bianchi(eds.) FAO species identification sheets for fishery purposes. Western Indian Ocean fishing area 51. Vol.3. FAO,Rome. pag. var.

Chen, S.C. (eds.), 1993. Fishes of Taiwan. National University of Taiwan, Dept. Zool. xx+960 (Chinese).

Collette, B.B. 1984a. Belonidae. In W. Fischer and G. Bianchi(eds.) FAO species identification sheets for fishery purposes. Western Indian Ocean fishing area 51. Vol.1. FAO,Rome. pag. var.

Collette, B.B. 1984b. Hemiramphidae. In W. Fischer and G. Bianchi(eds.) FAO species identification sheets for fishery purposes. Western Indian Ocean fishing area 51. Vol. 2.FAO,Rome. pag. var.

Collette, B.B. and Nauen, C. 1983. FAO. species catalogue. Vol.2. Scombrids of the world. An annotated and illustrated catalogue of tunas , mackerels, bonitos and related species known to date. FAO. Fish. Synop. (125) Vol.2 : 137 p.

Compagno, L.J.V. 1984. FAO. species catalogue. Vol.4,Part 1. Sharks of the world :Hexanchiformes to Lamniformes. An annotated and illustrated catalogue of shark species known to date. FAO. Fish. Synop. (125) Vol.4,Part 1 : 249 p.

_______ . 1984. FAO. species catalogue. Vol.4,Part 2. Sharks of the world :Carcharhiniformes. An annotated and illustrated catalogue of shark species known to date. FAO. Fish. Synop. (125) Vol.4,Part 2 : 655 p.

De Bruin, G.H.P. , Russell, B.C. and Bogusch, A. 1994. The marine fishery resources of Sri Lanka. FAO. species identification field guide for fishery purposes. FAO. Rome. 400 p.

Debelius, H. 1993. Indian Ocean tropical fish guide. Ziethen Farbdruckmedien, Cologne. 321 p.

Eschmeyer, W.N., Hallacher and L.E. Rama-Rao, K.V. 1979a. The Scorpionfish genus *Minous* (Scorpaenidae , Minoinae) including a new species from the Indian Ocean. Proceedings of the California Academy of Sciences (20) Vol. XLI, pp. 453-473.

Eschmeyer, W.N. , Rama-Rao, K.V. and Hallacher, L.E. 1979b. Fishes of the Scorpionfish subfamily Choridactylinae from the Western Pacific and the Indian Ocean. Proceedings of the California Academy of Sciences (21) Vol.XLI, pp. 475-500.

Exploratory Fishery Division, 1968. The results of fishing ground and oceanography survey in the Sunda Shelf and South China Sea, 1968. by R.V. Fishery Exploratory I. Dept. Fisheries, Thailand (Thai):466 p.

________ . 1969. The operation report of demersal and pelagic fishes survey in the South China Sea and Sarawak 1969, by R.V. Fishery Exploratory I and II. Dept. Fisheries, Thailand (Thai): 283 p.

________. 1970. Results of the fishing ground survey by R.V. Fishery Exploratory II, 1970. Dept. Fisheries, Thailand (Thai):368 p.

________. 1972. Results of the fishing ground survey by R.V. Fishery Exploratory II, 1972. Dept. Fisheries, Thailand (Thai):542 p.

Fischer, W. and P.J.P. Whitehead. 1974. (eds). FAO species identification sheets for fisheries purpose, 4 vols. FAO of the United Nation, Rome, no pagination.

Fraser, T.H. and Lachner, E.A. 1985. A Revision of the cardinalfish subgenera *Pristiapogon* and *Zoramia* (Genus *Apogon*) of the Indo-Pacific Region (Teleostei : Apogonidae). Smithsonian Contribution to Zoology. 47 p.

Fritzsche, R.A. 1976. A review of cornetfishes, genus *Fistularia* (Fistularidae) with a discussion of intrageneric relationships and zoogeography. Bull. Mar. Sci. 26(2);196-204.

Gloerfelt-Tarp, T. and Kailola, P.J. 1984. Trawled fishes of Southern Indonesia and Northwestern Australia. The Australian Development Assistance Bureau; Directorate General of Fisheries, Indonesia; German Agency for Technical Cooperation, 406 pp.

Gomon, J.R., 1983. Plotosidae. In W. Fischer and G. Bianchi (eds.) FAO species identification sheets for fishery purposes. Western Indian Ocean fishing area 51. Vol. 1. FAO,Rome. pag. var.

Gushiken, S. 1983. Revision of the Carangid Fishes of Japan. Galaxea 2:135-264.

Heemstra, P.C. and Randall, J.E. 1993. FAO species catalogue.Vol.16. Groupers of the world. (Family Serranidae , Subfamily Epinephelinae). An annotated and illustrated catalogue of the grouper, rockcod, hind, coral grouper and lyretail species known to date. FAO. Fish. Synop. (125) Vol.16 :382 p.

Hora, S.L. 1924.a. Zoological result of tour in far east , Fishes of Talesap, Peninsular Siam. Mem. Asiatic Soc. Bengal, 6 (pt. 1): 463-476.

Jayaram, K.C. 1983. Ariidae. In W. Fischer and G. Bianchi(eds.) FAO species identification sheets for fishery purposes. Western Indian Ocean fishing area 51. Vol. 1. FAO,Rome. pag. Var.

Johnstone, J. 1903. Report on the marine fishes. Fasciuli Malayenses-Zoology, 1: 294-302.

Kuiter, R.H. 1992. Tropical reff-fishes of the Western Pacific Indonesia and adjacent waters. Percetakan PT Gramedia, Jakarta. 314 p.

Kuiter, R.H. and Debelius,H. 1994. Southeast Asia tropical fish guide. IKAN-Unterwarrearchiv, Germany. 321 p.

Kuhlmorgen-Hille, G. 1968. An illustrated field key to the family Leiognathidae in the Gulf of Thailand. Contribution No. 12, Marine Fish. Lab., Dept. Fisheries, Bangkok: 7pp.

Kumchirtchuchai, P. 1985. Taxonomy of the puffers found in the waters of Thailand. Master Thesis Department of Marine Sciences, Chulalongkorn University. 163p. (Thai).

Lal-Mohan, R.S., 1983. Sciaenidae. In W. Fischer and G. Bianchi(eds.) FAO species identification sheets for fishery purposes. Western Indian Ocean fishing area 51. Vol. 1. FAO,Rome. pag. var.

Last, P.R. and Stevens, J.D. 1994. Skarks and rays of Australia CSIRO. Australia. 513 p.

Lim, K.K.P. 1994. First record of *Hapalogenys analis* (Teleostei: Perciformes: Haemulidae)from the Indo-Australian region. the Raffles Bull. Zool. 42(4):983-985.

Mansor, M. I., Kohno, H., Ida, H., Nakamura, H. T., Aznan, Z. and Abdullah, S. 1998. Field guide to important commercial fishes of the South China Sea. SEAFDEC MFRDMD/SP/2.

Masuda, H.; Amaoka, K.; Araga, C. and Yoshino, Y.(eds.) 1984. The fishes of the Japanese Archipelago. Tokai Univ. Press. 456p.

Menon, A.G.K. 1977. A Systematic Monograph of the Tongue Soles of the Genus *Cynoglossus* Hamilton-Bochanan. (Pisces : Cynoglossidae). Smithsonian Contribution to Zoology No 238:129 p.

Michael, S.W. 1993. Reef sharks and ray of the world. Sea Challengers. Monterey, California.107 p.

Monkolprasit, S.P. 1967. Addenda additions to the Pleuronectiformes fauna of the Gulf of Thailand. Kasetsart University Museum of Fisheries.

Nakamura, I. and Parin, N.V. 1993. FAO species catalogue. Vol. 15. Snake mackerels and cutlassfishes of the world. (Family Gempylidae and Trichiuridae). An annotated and illustrated catalogue of the snake mackerels, snoeks, escolars, gemfishes, sackfishes, domine, oilfish, cutlassfishes, scabbardfishes, hairtails and frostfishes known to date.FAO. Fish. Synop. (125) Vol.15 : 136 p.

Nelson, J. S. 1994. Fishes of the world, ed 3. John Wiley & Sons, Inc. New York. 600 p.

de la Paz and Interior, R. 1979. Deep sea fishes off Lubang Island, Philippines. Natural and Applied Science Bull. 31(3-4):101-175.

Palsson , W.A. and Pietsch , T.W. 1989. Revision of the Acanthopterygian fish family Pegasidae (order Gastrosteiformes). Indo-Pacific Fishes. 18:38 p.

Petchsathit, B. 1992. Taxonomy of halfbeak and needdlefish (Pisces:Hemiramphidae, Belonidae) in Thai waters. Master Thesis Department of Biology, Chulalongkorn University (Thai).

Pheng , K. S.. 1985. Coastal Resources of Sarawak. Final Report submitted to Petroleum Nasional Berhad ans Sarawak Shell Berhad. Universiti Sains Malaysia.123 p.

Premcharoen, S. 1993. Toxonomy of Ponyfishes and Silver-Biddles (Pisces: Leiognathidae and Gerreidae) in Thai waters. Master Thesis Department of Marine Sciences, Chulalongkorn University. 176 pp.

Punpoka, S. 1964. A review of The Flatfishes (Pleuronectiformes = Heterosomata) of the Gulf of Thailand and its tributaries in Thailand. Bull. of Kasetsart Univ. 86 p.

Randall, J.E. 1995. Coastal fishes of Oman. Hawaii Univ. Press., 438 p.

Randall , J.E. and Heemstra , P.C. 1991. Revision of Indo-Pacific Groupers (Percifomes : Serranidae : Epinephelinae), with Descriptions of Five New Species. Indo-Pacific Fishes. No.20. Hawaii. 338 p.

Randall , J.E. and Hoese , D.F. 1986. Revision of the groupers of the Indo-Pacific genus *Plectopomus*(Perciformes:Serranidae: Epinephelidae). Indo-Pacific Fishes. No.13:31 p.

Randall, J.E.; Allen, G.R. and Steene, R.C. 1997. Fishes of the Great Barrier Reef and Coral Sea. Crawford House Publ. 557 p.

Randall, J.E.; Ida, H.; Kato, K.; Pyle, R.L. and Earle, J.L. 1997. Annotated checklist of the inshore fishes of the Ogasawara Islands. Nat. Sci. Mus. Monographs No 11, Tokyo.

Rau, N. and Rau, A. 1980. Commercial marine fishes of the central Philippines (Bony fish).D &V Paul Dieriech K.G. & Co.Eschborn, 623p.

Russell, B.C. 1990. FAO species catalogue. Vol.12. Nemipterid fishes of the world (Threadfin breams , whiptail breams , monocle breams , dwarf monocle breams, and coral breams) family Nemipteridae. An annotated and illustrated catalogue of nemipterid species known to date. FAO. Fish. Synop. (125) Vol.12 : 149 p.

_______ 1991. Description of a new species of *Nemipterus* (Pisces: Perciformes: Nemipteridae) from the Western Pacific, with redescription of *Nemipterus maginatus* (Valenciennes), *N. mesoprion* (Bleeker) and *N. nematophorus* (Bleeker). J.Nat. Hist. 25:1379-1389.

________ . 1993. A review of the threadfin breams of the genus *Nemipterus* (Nemipteridae) from Japan and Taiwan, with description of a new species. Jap. J. Ichthyol. 39(4): 295-310.

Sirimontaporn, P.1987. Description of the fishes family Gerreidae and Sciaenidae occuring in the Gulf of Thailand. National. Institute of Coastal Aquaculture Department of Fisheries, Thailand. 46 p.

Smith-Vaniz, W.F. 1984. Carangidae. In W. Fischer and G. Bianchi(eds.) FAO species identification sheets for fishery purposes. Western Indian Ocean fishing area 51. Vol. 1. [pag. var.]. FAO,Rome.

Trewavas , E. 1977. The Sciaenid Fishes of the Indo-West-Pacific. Trans. Zool. Soc. 33. London. 253-541 p.

Tyler, J.C. 1968. A monograph on Plectognath fish of the superfamily Triacanthoidea. Monograph No. 16, The Academy of Natural Sciences of philadelphia. 344 p.

Whitehead, P.J.P. 1985. FAO species catalogue. Vol.1,Part 1. Clupeoid fishes of the world (Suborder Clupeoidei):Chirocentridae, Clupeidae and Pristigasteridae. An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herrings. FAO. Fish. Synop. (125) Vol.7,Part 1:303 p.

Whitehead, P.J.P., Nelson, G.J. and Wongratana, T. 1988. FAO species catalogue. Vol.1,Part 2. Clupeoid fishes of the world (Suborder Clupeoidei):Engraulididae. An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herrings. FAO. Fish. Synop. (125) Vol.7,Part 2 : 579 p.

Wongratana, T. 1975. A record of a flatheadfish. *Thysanophrys papillolabium* Schulty, in the Andaman Sea, with a key to fourteen species of the Platycephalidae from Thai waters(Pisces : Platycephalidae) Phuket Mar. Biol. Cent. Res. Bull. No.7:9 pp.

_________ .1982. Ichthyological observations made during the Andaman cruise of the “Nagasaki-Maru”, 1-14 November 1981. Nat. Hist. Bull. Siam Soc. 30(2):105-124.

Woodland , D.J. 1990. Review of the fish family Siganidae with descriptions of two new species and comments on distribution and biology. Indo-Pacific Fishes. No.19. 136 p.

Kind, Abundance and Distribution of the Fish Larvae in the South China Sea, Area II : Sarawak, Sabah and Brunei Darussalam

Apichart Termvidchakorn

Museum and Aquarium Institute, Department of Fisheries
Phaholyotin RD. Chatuchak, Bangkok 10900 THAILAND

ABSTRACT

Fish larvae samples were obtained from 79 stations in South China Sea of the Sarawak , Brunei and Sabah during the pre northeast monsoon season (August - September 1996) and the post northeast monsoon (April - May 1997). The standard larvae net and bongo net were used for the surface and oblique sampling. The specimens were identified which comprise of 112 families and 186 species of fish larvae observed from both cruises. For the pre northeast monsoon sampling there were 5,156 individuals observed from 86 families and 125 species in the surface horizontal haul and 16,277 individuals from 96 families and 149 species in the oblique haul. The post northeast monsoon collection showed 6,595 individauls from 79 families and 114 species collected in the surface horizontal hauls and 24,450 individauls from 94 families and 158 species observed in the oblique hauls. From the surface horizontal sampling, the abundant larvae observed were *Stolephorus* sp., *Sardinella* sp., *Upeneus* sp., *Myripristis* sp., *Holocentrus* sp., Gobiidae, *Decapterus* sp. and *Diaphus* sp. Specimens from the oblique hauls, Gobiidae, *Bregmaceros rarisquamosus*, *Nemipterus* sp., *Stolephorus* sp. and *Callionymus* sp. were the most species observed abundant in the collection. The mesopelagic fish larvae, *Hygophum* sp., *Myctophum* sp., *Pollichthys* sp. and *Lampadena* sp. were found abundant in the oblique specimens in the deep sea stations. The larvae were collected in more abundant during the early morning, night time and cloudy day sampling.

Introduction

Fish larvae in the South China Sea was an important subject for the fisheries resources study. Fisheries resources management in these area need the knowledge about spawning period, spawning and rearing ground. Due to the limitation of such knowledge in this area, a collaborative research project among the SEAFDEC member countries and the participation of the Department of Fisheries, Thailand was carried out using the M.V. SEAFDEC to investigate the available fish resources as well as the biological and physical oceanographic conditions.

Fish larvae will be investigated for their kinds, abundance and distribution. The objectives of this study were to identify the composition of fish larvae found in this area, as well as the spawning ground, spawning period, rearing ground and period, the information of collected may be used to formulate appropriate fisheries management programme in this area.

Study on fish larvae in Southeast Asia were first conducted by Delsman from 1922-1938 which described and illustrated the larvae of *Chirocentrus dorab*, *Dussumieria hasseltii*, *Clupea* sp., *Engraulis* sp., *Setipinna* sp. and *Myctophidae* sp. from the Java sea.

Previous important studies on the fisheries resources in the South China Sea were also conducted by some fisheries biologist. Vatanachai (1972) showed that there were at least 107 families of fish larvae in the South China Sea. Temvidchakorn (1983) reported that there were 72 families of fish larvae occurred in KH-81-5 cruise which sampling in the South China Sea. The composition were observed Engraulidae 16.02% , Gobiidae 14.98% , Myctophidae 12.23% , Gonostomatidae 10.19% , Lutjanidae 8.58% , Carangidae 6.72% , Bothidae 3.13% , Scombridae 2.88% , Cepolidae 2.28% , Labridae 1.88% , Holocentridae 1.86% and the other families was about 19.25%.

Material and Method

Samplings for the fish larvae were carried out (using M.V. SEAFDCE) from 9 July to 9 August 1996 during the pre northeast monsoon period and the post northeast monsoon period between 25 April and 31 May 1997. There were 79 sampling stations along the coastal and deep sea of Sarawak, Sabah and Brunei Darusalam (Figure 1, Appendix 1,2,3,4). Two types of fish larvae sampling methods were employed. The surface horizontal haul represents a study on the diurnal migration and the economical pelagic families. While the oblique haul used for the whole moss of larvae from surface to the depth of haul. The standard larvae net, 1.30 meter in diameter with a 5 mm. mesh size at the mouth part and 330 micron at the cod end, was used for the surface sampling. The bongo net, 60 cm. in diameter with mesh size 500 micron at the mouth part and 330 micron at the cod end was employed for the oblique haul.

A flow meter was attached to the mouth part of the net to determine the volume of water. The sampling period was 30 minutes with the haul speed at 2 knots. For oblique haul, the net went down to a depth of about 5 meters above the bottom surface (as measured by a depth sensor). however in the deeper area, the net will go down to a maximum depth of 150 meters only.

Collected specimens were preserved in 10% sea water formalin solution immediately after each haul. Sorting and identification was done at the laboratory. After sorting, the fish larvae were transfered and preserved in 4% sea water formalin solution. Species identification was done by using the stereomicroscope. Specimens were identified to the genera or species level. Their abundance and distribution were estimated in term of number of individuals per 1000 cubic meters (No./1000 m^3) of sea water. The classification methods used for fish identification were Delsman (1922,1925,1926,1930,1932,1933,1938) Lies and Rennis (1983) Leis and Trnski (1989), Mito (1996), Moser *et al*(ed) (1984), Okiyama (1988), Fahay (1983), Ozawa 1986., and Termvidchakorn 1983.

Data on temperature, salinity and dissolved oxygen at the surface and 75 meter depth of each station were also recorded and used to determine the relationship with the abundance, and distribution of the fish larvae.

Result

There were 5,156 and 16,277 individuals of fish larvae obtained from the surface and oblique hauls durings the pre northeast monsoon cruise. During the post northeast monsoon cruise, 6,595 and 24,450 individuals were observed from surface and oblique hauls. The specimens were identified which comprise of 112 families and 186 species of the fish larvae both from the pre and post northeast monsoon periods (Table 1, Appendix 5). The pre northeast monsoon specimens showed 86 families and 125 species from the surface horizontal hauls and 96 families and 149 species from the oblique hauls. The post northeast monsoon collection provided 79 families and 114 species from the surface sampling and 94 families and 158 species from the oblique hauls. Their abundance in number per 1000 cubic meters of each stations were showed on Figure 2-5 (Table 1, Appendix 5).

The most abundant fish larvae observed from the surface hauls during the pre and post northeast monsoon were *Stolephorus* sp*., Sardinella* sp., *Myripristis* sp., *Holocentrus* sp., *Upeneus* sp., Gobiidae and *Decapterus* sp.,repectively. For the specimens from the oblique hauls in both cruises, the abundant larvae were Gobiidae, *Bregmaceros rarisquamosus*, *Decapterus* sp., *Nemipterus* sp., *Hygophum* sp., *Callionymus* sp. and *Apogon* sp.,respectively.

The most abundant fish larvae obtained from the surface hauls of the prenortheast monsoon were *Sardinella* sp. (10.22%), *Upeneus* sp.(9.74%) Gobiidae (7.76%), *Myripristis* sp.(6.21%), *Diaphus* sp.(5.68%), *Decapterus* sp.(4.83%), *Stolephorus* sp.(4.00%) and *Selar crumenophthalmus* (3.47%) respectively. Those from the oblique hauls were Gobiidae(32.04%) ,*Bregmaceros rsrisquamosus* (8.68%), *Decapterus* sp.(4.74%), *Apogon* sp.(3.56%), *Lutjanus* sp.(2.70%), *Callionymus* sp.(2.57%), *Benthosema* sp.(2.13%) and *Nemipterus* sp.(2.12%) respectively. During the post northeast monsoon the abundant fish larvae observed at the surface were *Stolephorus* sp.(10.49%), *Myripristis* sp.(8.83%),

Table 1 Species of the fish larvae observed from surface and oblique haul in the survey area for the pre and post monsoon cruise

	Fish larvae	STM - III		STM - IV	
		Surface	oblique	Surface	oblique
1	Megalopidae				
	Megalops cyprinoides	*			
2	Clupeidae				
	Sardinella sp.	*	*	*	*
	Dussumieria sp.	*	*	*	*
3	Engraulidae				
	Stolephorus sp.	*	*	*	*
4	Chirocentridae				
	Chirocentrus dorab	*			
5	Argentinidae				
	Glossanodon sp.		*		
	Argentina kagoshimae		*		
6	Opisthoproctidae				
	Bathylychnop sp.	*			
7	Bathylagidae				
	Bathylagus sp.		*		*
8	Gonostomatidae				
	Diplophos sp.	*	*	*	*
	Pollichthys mauli		*	*	*
	Vinciguerria sp.	*	*	*	*
	Gonostoma sp.	*	*	*	*
	Cyclothone sp.	*	*	*	
	Valenciennellus sp.		*		*
	Maurolicus sp.				*
9	Sternoptychidae				
	Argyropelecus hemigymmus	*	*		*
10	Chauliodontidae				
	Chauliodus sp.	*	*		*
11	Stomiidae				
	Stomias sp.		*	*	*
12	Symphysanodontidae				
	Symphysanodon katayamai		*		
13	Melanostomiidae				
	Melanostomias sp.				*
	Bathophilus brevis		*		*
	Eustomius sp.		*	*	*
14	Idiacanthidae				
	Idiacanthus sp.		*		*
15	Chanidae				
	Chanos chanos	*	*	*	
16	Aulopodidae				
	Aulopus japonicus	*	*	*	*
17	Synodontidae				
	Saurida undosquamis	*	*	*	*
	Synodus variegatus	*	*	*	*
	Trachinocephalus myops	*	*	*	*
18	Chlorophthalmidae				
	Chlorophthalmus sp.		*		*
19	Ipnopidae				
	Ipnops sp.		*	*	*
20	Scopelarchidae				
	Scopelarchus sp.		*		*
	Scopelarchoides sp.				*

Table 1 continue

	Fish larvae	STM - III		STM - IV	
		Surface	oblique	Surface	oblique
21	Notosudidae				
	Scopelosaurus sp.	*	*	*	*
22	Myctophidae				
	Hygophum sp.		*		*
	Benthosema sp.	*	*	*	*
	Diogenichthys sp.		*	*	*
	Myctophum sp.	*	*	*	*
	Symbolophorus evermanni	*	*		*
	Centrobranchus sp.				*
	Tanningichthys sp.				*
	Lampanyctus sp.	*	*		*
	Lobianchia sp.	*			
	Ceratoscopelus sp.				*
	Lampadena sp.	*	*	*	*
	Diaphus sp.	*	*	*	*
	Notoscopelus sp.				*
23	Paralepididae				
	Sudis atrox		*		*
	Paralepis sp.		*		*
	Lestidium sp.	*	*	*	*
	Lestidiops indopacifica	*	*		
	Uncisudis quadrimaculata		*		
	Stemonosudis sp.				*
24	Osmosudidae				
	Osmosudis lowei		*		
25	Alepisauridae				
	Alepisaurus sp.				*
26	Evermanellidae				
	Evermanella sp.		*		*
27	Hemiramphidae				
	Hemiramphus sp.	*	*	*	*
28	Belonidae				
	Tylosaurus coccodylus				*
29	Exocoetidae				
	Exocoetus sp.	*	*	*	*
	Cypselurus sp.	*		*	*
	Hirundichthys sp.		*	*	*
30	Antennariidae				
	Antennarius sp.	*	*	*	*
31	Lophiidae				
	Lophias sp.	*	*	*	*
	Lophiomus sp.				*
32	Chaunacidae				
	Chaunax sp.	*	*	*	*
33	Ceratiidae				
	Cyptopsarus sp.		*		
34	Pegasidae				
	Pegasus sp.	*		*	*
35	Bregmacerotidae				
	Bregmaceros rarisquamosus	*	*	*	*
	Bregmaceros macelellandii		*		*
36	Fistulariidae				
	Fistularia sp.	*	*	*	*

Table 1 continue

	Fish larvae	STM - III		STM - IV	
		Surface	oblique	Surface	oblique
37	Solenostomidae				
	Solenostomus sp.		*		
38	Syngnathidae				
	Syngnathus sp.	*	*		*
	Hippocampus sp.	*			
39	Centriscidae				
	Centriscus scutatus	*	*	*	*
40	Brotulidae				
	Brotula sp.	*	*	*	*
41	Carapidae				
	Carapus sp.	*	*	*	*
42	Diretmidae				
	Diretmoides sp.		*		*
43	Melamphaidae				
	Scopelogadus sp.		*		
	Scopeloberyx sp.		*		*
	Melamphase sp.		*		*
44	Holocentridae				
	Holocentrus sp.	*	*	*	*
	Myripristis sp.	*	*	*	*
45	Sphyraenidae				
	Sphyraena sp.	*	*	*	*
46	Atherinidae				
	Atherina sp.	*			
47	Trachipteridae				
	Trachipterus sp.	*			
48	Percichthyidae				
	Synagrops philippinensis		*	*	*
49	Serranidae				
	Epinephelus sp.	*	*	*	*
	Chelidoperca hirundinacea	*	*		*
	Anthias sp.		*	*	*
50	Theraponidae				
	Therapon jarbua	*	*	*	*
	Therapon theraps	*	*		
51	Priacanthidae				
	Priacanthus tayenus	*	*	*	*
52	Apogonidae				
	Apogon lineatus		*	*	*
	Apogon nigrofasciatus	*	*	*	*
	Apogon sp.	*	*	*	*
	Gymnopogon sp.	*	*	*	*
53	Sillaginidae				
	Sillago sp.	*			
54	Branchiostegidae				
	Branchiostegus sp.		*		*
55	Coryphaenidae				
	Coryphaena hippurus	*	*	*	*
56	Carangidae				
	Decapterus sp.	*	*	*	*
	Selar crumenophthalmus	*	*	*	*
	Megalaspis cordyla				*
	Alectis ciliaris	*	*	*	*
	Caranx ignobilis	*	*	*	*
	Caranx (Selaroides) leptolepis	*	*	*	*
	Caranx mate	*	*	*	*
	Caranx speciosus	*	*	*	*
	Caranx sp.	*	*	*	*

Table 1 continue

	Fish larvae	STM - III		STM - IV	
		Surface	oblique	Surface	oblique
	Elagatis bipinnulata	*	*	*	
	Scomberoides lysan	*	*	*	*
	Zonichthys nigrofasciata	*	*	*	*
57	Parastromatidae				
	Parastromateus niger				*
58	Meneidae				
	Mene maculata		*	*	
59	Bramidae				
	Brama sp.		*	*	*
60	Lutjanidae				
	Lutjanus sp.	*	*	*	*
61	Nemipteridae				
	Nemipterus sp.	*	*	*	*
62	Gerreidae				
	Gerres sp.	*	*	*	*
63	Lobotidae				
	Lobotes surinamensis	*		*	
64	Leiognathidae				
	Leiognathus sp.	*	*	*	*
65	Pomadasyidae				
	Plectorhynchus sp.	*	*	*	*
66	Lethrinidae				
	Lethrinus sp.	*	*	*	*
67	Mullidae				
	Upeneus sp.	*	*	*	*
68	Haemulidae				
	Diagramma sp.				*
69	Monodactylidae				
	Monodactylus argenteus			*	
70	Ephippidae				
	Platax tiara		*	*	*
71	Scatophagidae				
	Scatophagus argus		*	*	
72	Chaetodontidae				
	Chaetodon sp.	*	*	*	*
73	Pomacanthidae				
	Centropyge sp.	*	*		*
74	Pomacentridae				
	Pomacentrus sp.	*			
	Chromis sp.	*	*	*	*
	Abudefduf sp.	*	*	*	*
75	Cepolidae				
	Acanthocepola sp.	*	*	*	*
76	Labridae				
	Halichoeres sp.	*	*	*	*
77	Scaridae				
	Scarus sp.		*	*	*
78	Champsodontidae				
	Champsodon sp.	*	*	*	*
79	Chiasmodontidae				
	Chiasmodon sp.				*
80	Blenniidae				
	Blennius sp.	*	*	*	*
81	Callionymidae				
	Callionymus sp.	*	*	*	*
82	Echeneidae				
	Echeneis naucrates	*	*	*	*
83	Histiophoridae				

Table 1 continue

	Fish larvae	STM - III		STM - IV	
		Surface	oblique	Surface	oblique
	Histiophorus sp.	*	*	*	*
84	Scombridae				
	Rastrelliger sp.	*	*	*	*
	Scomber sp.		*		*
	Scomberomorus sp.	*	*	*	*
	Acanthocybium solandri		*		*
	Euthynus sp.	*	*	*	*
	Auxis sp.		*	*	*
	Katsuwonus pelamis		*	*	*
	Thunnus sp.				*
85	Trichiuridae				
	Trichiurus lepturus	*	*		*
86	Gempylidae				
	Gempylus sp.	*	*	*	*
87	Acanthuridae				
	Acanthurus sp.	*	*	*	*
88	Siganidae				
	Siganus sp.		*	*	*
89	Tetragonuridae				
	Tetragonurus sp.	*	*	*	*
90	Nomeidae				
	Psene cyanophys				*
	Nomeius sp		*		*
	Cubiceps sp.	*	*	*	*
91	Stromatidae				
	Pampus sp.				*
92	Sciaeneidae				
	Sciaena sp.	*	*		*
	Nibea japonicus				*
93	Polynemidae				
	Polynemus sp.	*			
94	Schneideriidae				
	Schneideria sp.	*	*	*	*
95	Typaucheniidae				
	Typanchen sp.	*	*	*	*
96	Trichonotidae				
	Trichonotus sp.		*		
97	Gobiidae	*	*	*	*
98	Platycephalidae				
	Platycephalus sp.	*	*	*	*
99	Scorpaenidae				
	Scorpaenoides sp.	*	*	*	*
	Minous sp.	*	*	*	*
100	Triglidae				
	Lepidotrigla sp.	*	*	*	*
101	Dactylopteridae				
	Dactylopterus sp.	*	*	*	*
102	Psettodidae				
	Psettodes erumei	*	*	*	*
103	Paralichthyidae				
	Paralichthys sp.		*	*	*
	Pseudorhombus sp.	*	*		*
	Samarius sp.		*		
104	Soleidae				
	Solea sp.	*			*
	Aserraggodes sp.	*	*	*	*

Table 1 continue

	Fish larvae	STM - III		STM - IV	
		Surface	oblique	Surface	oblique
105	Bothidae				
	Bothus sp.	*	*	*	*
	Engyprosopon sp.	*	*	*	*
	Arnoglossus sp.	*			*
106	Cynoglossidae				
	Cynoglossus sp.	*	*	*	*
107	Citharidae				
	Brachypleura novaezeelandiae	*	*		*
108	Tetraodontidae				
	Tetraodon sp.	*	*	*	*
109	Diodontidae				
	Diodon sp.	*	*	*	*
110	Balistidae				
	Balistes sp.	*	*	*	*
111	Monacanthidae				
	Monacanthus sp.	*	*	*	*
	Aluterus sp.	*	*	*	*
112	Eel larvae (*Leptocephalus* sp.)	*	*	*	*

Holocentrus sp.(8.04%), *Upeneus* sp.(6.57%) and Gobiidae(5.38%) respectively while the oblique hauls were Gobiidae(29.44%), *Bregmaceros rarisquamosus* (16.26%), *Nemipterus* sp.(2.86%), *Hygophum* sp.(2.78%) and *Callionymus* sp.(2.49%), respectively.

The abundance and distribution of the fish larvae in South China Sea and coastal area of Sarawak, Sabah and Brunei are summarized as followed :

1. Family Megalopidae

Megalopidae larvae which occurred at the surface sample of the pre northeast monsoon cruise were *Megalops cyprinoides* which was only one specimens observed at the station number 19 with the depth of 65 meters.

2. Family Clupeidae

Sardinella sp. *Dussumieria* sp. were 2 genera of Clupeidae larvae occurred in these sampling cruises. *Sardinella* sp. was the most abundant fish larvae from the surface specimens of the pre northeast monsoon. There were 527 and 224 individuals from 20 and 13 stations in the surface sampling from the pre and post northeast monsoon cruises, respectively. The oblique sampling showed 181 and 173 individuals from 11 and 19 stations of the pre and post monsoon cruises, respectively. The larvae were distributed at the stations which the depth less than 100 meters (Figure 6-9).

Dussumieria sp. larvae occurred in both the surface and oblique sampls in pre and post northeast monsoon collection. There were 3 and 4 individuals from 3 and 1 stations in the surface sampling from pre and post northeast monsoon cruise respectively. The oblique sampling showed 23 and 13 individuals from 9 stations each of pre and post northeast monsoon cruise, respectively. The depth of stations which the larvae occurred was less than 75 meters.

3. Family Engraulidae

Engraulidae larvae occurred in both surface and oblique samples with *Stolephorus* sp. was the most abundant in the surface sample of the post northeast monsoon cruises. There were 206 and 692 individuals from 23 and 30 stations in the surface sampling of pre and post northeast monsoon cruises, respectively. The oblique sampling showed 199 and 603 individuals from 21 and 37 stations during pre and post northeast monsoon cruises, respectively. The larvae mostly occurred at the coastal stations which the depth was less than 100 meters (Figure 10-13).

4. Family Chirocentridae

Chirocentrus dorab occurred only in the surface sampling of the pre northeast monsoon cruise. There were 13 individuals from 7 stations of coastal area which the depth was less than 75 meters.

5. Family Argentinidae

Argentinidae was one of the mesopelagic fish and the larvae occurred only in the oblique sampling of the pre northeast monsoon cruise. There were 2 genera of Argentinidae larvae occurred in the specimens. These 2 genera were *Glossanodon* sp. and *Argantina kagoshimae*. Only one specimen of *Glossanodon* sp. occurred in the deep sampling station (Station No.64) which the depth was more than 1,261 meters and 4 individuals of *Argentina kagoshimae* were observed from 3 stations at the deep area.

6. Family Opisthoproctidae

Opisthoproctidae larvae occurred in the surface sampling of the pre northeast monsoon cruise belong to the genus *Bathylychnops* sp. which was a mesopelagic fish. There were 6 individuals observed from 3 stations by the surface haul. The larvae usually occurred in the stations that the depth was more than 100 meters.

8. Family Gonostomatidae

There were 7 genera of Gonostomatid larvae occurred in the surface and oblique sampling of pre and post northeast monsoon cruises. Most of the Gonostomatid larvae obtained from deep area especially in early morning, cloudy day or night time sampling.

Diplophos taenia larvae occurred in both surface and oblique samples of the pre and post northeast monsoon. There were 36 and 2 individuals observed from 9 and 1 stations of surface and oblique samples in the pre northeast monsoon, while the post northeast monsoon period showed 2 and 5 individuals from 1 and 4 stations of the surface and oblique samples.

Pollichthys mauli. larvae occurred in the oblique samples of both pre and post northeast monsoon cruises and surface sample of post northeast monsoon. There was 4 individuals from 4 stations of the surface sampling of the post northeast monsoon. The oblique sampling of pre and post northeast monsoon showed 129 and 370 individuals from 35 and 42 stations. The larvae showed the distribution in the deep area stations.

Vinciguerria sp. larvae occurred in both surface and oblique haul of the pre and post northeast monsoon cruises. There were 1 and 86 individuals from 1 and 27 stations of surface and oblique hauls of the pre northeast monsoon cruises. The post northeast monsoon cruise showed 45 individuals each from 11 and 13 stations of surface and oblique collection.

Gonostoma sp. showed 1 and 221 individuals from 1 and 38 stations of the surface and oblique hauls in pre northeast monsoon cruises. There were 17 and 209 individuals from 8 and 34 stations of the surface and oblique hauls of the post northeast monsoon cruise. Most of the larvae were collected from the oblique hauls in the deep area stations. The surface capture usually occurred in the early morning and night time.

Valenciennellus sp. showed 11 and 17 individuals from 2 and 3 stations in thhe oblique samples of the pre and post northeast monsoon cruises, respectively. The larvae occurred only in the deep area which the depth were than 2000 meters.

Maurolicus sp. occurred in the deep area station showed 4 individuals from station number 61 of the oblique haul in the post northeast monsoon cruise. The depth of this station was more than 2000 meters.

Cyclothone sp. showed 126 and 7 individuals from 28 and 3 stations in the surface and oblique hauls from pre northeast monsoon and 3 individuals from station number 55 in the surface haul of the post northeast monsoon cruise.

9. Family Sternoptychidae

Only one species of *Argyropelecus hemigymnus* occurred in the sampling from surface haul of the pre northeast monsoon while the larvae occurred in oblique sampling of both pre and post monsoon cruises. There were 2 individuals from station number 50 which the depth was more than 200 meters. The oblique samples showed 47 and 58 individuals from 20 and 22 stations of pre and post northeast monsoon cruises.

10. Family Chauliodontidae

Chauliodus sp. larvae occurred in the sampling from both surface and oblique hauls in the pre northeast monsoon cruise and occurred in the haul of the post northeast monsoon cruise. There were 1 and 10 individuals observed from 1 and 6 stations of the surface and oblique hauls of the pre northeast monsoon cruise while the post northeast monsoon cruise only 1 individual each was observed from 5 stations. The larvae usually occurred in stations which the depth was more than 1000 meters.

11. Family Stomiidae

Only one genus of *Stomias* sp. larvae was occurred in these sampling cruises. There were 1 individual observed in each of 5 stations from oblique haul of the pre northeast monsoon cruise. There were 2 and 9 individuals collected from 2 and 6 stations in surface and oblique hauls of the post northeast monsoon cruise. The depth of the stations were more than 100 meters.

12. Family Symyphysanodontidae

Symyphysanodon katayamai larvae occurred only 1 individual was observed from 2 stations by oblique haul of pre northeast monsoon cruise in the deep area stations that the depth was more than 2000 meters.

13. Family Melanostomiidae

Three genus of Melanostomiidae larvae occurred in the samples.

Melanostomias sp. larvae occurred only in the oblique haul of the post northeast monsoon cruise. There were 4 individuals from 2 stations which the depth was more than 200 meters.

Eustomias sp. larvae was observed at 3 and 1 individuals from 2 and 3 stations of surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise provided 1 individual each from 1 and 2 stations of surface and oblique hauls. The larvae occurred in the station which the depth was more than 500 meters.

Bathophilus brevis larvae showed only one individual from station number 38 of the oblique haul of post northeast monsoon which the depth was more than 1000 meters.

14. Family Idiacanthidae

Idiacanthus sp. larvae were observed at 6 and 8 individuals from 4 and 6 stations in the oblique haul of pre and post northeast monsoon cruises, respectively. Larvae occurred in the station which the depth was more than 1000 meters.

15. Family Chanidae

Chanos chanos larvae showed 4 and 3 individuals from 3 and 3 stations of surface and oblique hauls of pre northeast monsoon cruise while the post northeast monsoon cruise only 1 individual was observed each of 6 stations from surface haul. The larvae occurred only in the coastal area.

16. Family Aulopodidae

Aulopus japonicus larvae showed 8 and 1 individuals from 5 and 1 stations by surface and oblique hauls in pre northeast monsoon. The post monsoon cruise 8 and 12 individuals from 4 and 7 station were observed in surface and oblique hauls The depth of occurrence station was more than

1000 meters.

17. Family Synodontidae

Three species of this family were observed in these research cruises. There were *Saurida undosquamis*, *Synodus variegatus* and *Trachinocephalus myops*.

Saurida undosquamis showed 11 and 148 individuals from 5 and 32 stations by surface and oblique hauls from pre northeast monsoon cruise and 29 and 347 individuals from 27 and 41 stations of surface and oblique haul of post northeast monsoon cruise. *Saurida undosquamis* was the most abundant among the 3 species observed especially from the oblique specimens.

Synodus variegatus larvae showed 21 and 40 individuals from 11 and 21 stations by surface and oblique hauls from the pre monsoon cruise. The post monsoon cruise provided 2 and 101 individuals from 2 and 26 stations in surface and oblique haul specimens.

Trachinocephalus myops larvae showed 16 and 33 individuals from 10 and 19 stations of surface and oblique hauls from the pre northeast monsoon cruise. The post northeast monsoon cruise provided 39 and 78 individuals from 16 and 27 stations by surface and oblique hauls. All of the stations observed Synodontidae larvae were coastal area stations.

18. Family Chlorophthalmidae

Chlorophthalmus sp. larvae occurred only in the post northeast monsoon cruise. There were 1 and 11 individuals from 1 and 4 stations of surface and oblique hauls. The depth of the occurrence station was more than 1000 meters.

19. Family Ipnopidae

There were 3 individuals of *Ipnops* sp. larvae from 2 stations by oblique haul in pre northeast monsoon. The post northeast monsoon cruise showed 7 and 1 individuals from 6 and 1 stations of surface and oblique hauls sampling. The depth of the occurrence station was more than 1000 meters.

20. Family Scopelarchidae

There were 2 genus of Scopelachidae larvae occurred in these research cruise. These were *Scopelarchus* sp. and *Scopelarchoides* sp.

Scopelarchus sp. larvae were ocurred at 28 and 15 individuals from 13 and 8 stations of oblique haul from pre and post northeast monsoon cruises, respectively. The depth of the occurrence station was more than 1000 meters.

Scopelarchoides sp. larvae observed only one individual from station number 21 by the oblique haul of post northeast monsoon cruise which the depth of the station was more than 500 meters.

21. Family Notosudidae

Only one genus of *Scopelosaurus* sp. larvae occurred in the sampling from both surface and oblique hauls in the pre and post northeast monsoon cruises. There were 2 and 14 individuals from 2 and 4 stations of surface and oblique hauls from pre northeast monsoon cruise. The post northeast monsoon cruise showed 1 and 3 individuals from one station each of the surface and oblique samples. Depth of occurrence stations was more than 1000 meters.

22. Family Myctophidae

Myctophidae larvae was a large group of mesopelagic fish which occurred in surface samples. There were 13 genus observed *Hygophum* sp., *Benthosema* sp., *Diogenichthys* sp., *Myctophum* sp., *Symbolophorus* sp., *Centrobranchus* sp., *Tanningichthys* sp., *Lampanyctus* sp., *Lobianchia* sp., *Ceratoscopelus* sp., *Lampadena* sp., *Diaphus* sp. and *Notoscopelus* sp.

Hygophum sp. larvae showed 238 and 679 individuals from 28 stations by oblique haul of pre and post northeast monsoon cruises. Most of the larvae occurred in the deep area stations.

Benthosema sp. larvae showed 4 and 346 individuals from 3 and 29 stations of surface and oblique hauls from pre northeast monsoon cruise. There were 80 and 178 individuals from 7 and 20 stations of the surface and oblique hauls from post northeast monsoon cruise. *Benthosema* sp. larvae showed a strongly mesopelagic fish which occurred in the deep area by oblique sampling (Fig.14-15).

Diogenichthys sp. larvae were observed at 95 individuals from 15 stations of the oblique samples from pre northeast monsoon cruise. There were also 46 and 218 individuals from 5 and 22 stations of surface and oblique hauls of post northeast monsoon cruise.

Myctophum sp. larvae showed 103 and 286 individuals from 8 and 45 stations of surface and oblique haul from pre northeast monsoon cruise. There were 129 and 397 individuals also observed from 10 and 41 stations of surface and oblique hauls from post northeast monsoon cruise.

Symbolophorus evermanni larvae showed 1 and 18 individuals from 1 and 2 stations by surface and oblique hauls from pre northeast monsoon and 51individuals from 9 stations of the oblique hauls from the post northeast monsoon cruise.

Centrobranchus sp. larvae observed only 1 individuals from station number 41 by the oblique haul post northeast monsoon cruise.

Tanningichthys sp. larvae showed 13 individuals from 3 stations of the oblique hauls in post northeast monsoon cruise.

Lampanyctus sp. larvae were 89 and 99 individuals from 5 and 11 stations of surface and oblique hauls from pre northeast monsoon cruise and 149 individuals from 17 stations by oblique haul from post northeast monsoon.

Ceratoscopelus sp. larvae were 25 individuals from 2 stations of the oblique samples from post northeast monsoon cruise.

Lobianchia sp. larvae was observed only one individual from station number 67 by the surface haul of pre northeast monsoon cruise.

Lampadena sp. larvae showed 3 and 143 individuals from 1 and 15 stations of the surface and oblique hauls of pre northeast monsoon cruise. The post northeast monsoon provided 102 and 338 individuals from 12 and 26 stations of surface and oblique haul.

Diaphus sp. larvae showed 293 and 332 individuals from 26 and 37 stations of surface and oblique hauls from pre northeast monsoon cruise while the post northeast monsoon samples observed 267 and 161 individuals from 29 and 24 stations from surface and oblique hauls (Figure 16-19).

Notoscopelus sp. larvae were 22 individuals from 4 stations of the oblique haul in post northeast monsoon cruise.

Myctophid larvae usually occurred in the station which the depth was more than 100 meters.

23. Family Paralepididae

Six genus of this family were occurred in these research cruises. There were *Sudis atrox*, *Paralepis* sp., *Lestidium* sp., *Lestidiops* sp., *Uncisudis* sp. and *Stemonosudis* sp.

Sudis atrox larvae occurred only in the oblique samples of both pre and post northeast monsoon cruises. There were 8 and 5 individuals from 6 and 4 stations, respectively.

Paralepis sp. larvae were observed at 21 and 24 individuals from 11 and 8 stations of the oblique hauls of pre and post monsoon cruises.

Lestidium sp. larvae showed 1 and 18 individuals from 1 and 11 stations of surface and oblique hauls from pre and post northeast monsoon cruises. The post northeast monsoon cruise provided 3 and 32 individuals from 2 and 9 stations of surface and oblique hauls from post northeast monsoon cruise.

Lestidiops sp. larvae showed 1 and 2 individuals from 1 station each by surface and oblique hauls from pre northeast monsoon and 1 individual from station number 53 in the oblique haul of the post monsoon cruise.

Uncisudis quadrimaculata larvae were observed at 2 individuals from station number 63 in the oblique haul of pre northeast monsoon cruise.

Stemonosudis sp. larvae were observed at 34 individuals from 11 stations by the oblique haul from pre northeast monsoon cruise.

The occurrence depth of the larvae observed in this family were more than 150 meters.

24. Family Osmosudidae

There were 2 individuals of *Osmosudis lowei* occurred in the oblique haul from 2 stations of pre northeast monsoon cruise. The depth of the occurrence stations were more than 1000 meters.

25. Family Alepisauridae

Only 1 individuals of *Alepisaurus* sp. larvae were occurred in stations number 38 by the oblique hauls from post northeast monsoon cruise. The depth of this station was more than 1000 meters.

26. Family Evermannellidae

There were 1 and 3 individuals observed from 1 and 2 stations by the oblique haul of the pre and post northeast monsoon cruises. The depth of the occurrence station were more than 1000 meters.

27. Family Hemiramphidae

Hemiramphus sp. larvae occurred in these research cruise from both surface and oblique hauls but for the oblique haul, *Hermiramphus sp*. were obtained in the night early morning or the cloundy day stations. There were 89 and 17 individuals observed from 37 and 13 stations by surface and oblique hauls of pre northeast monsoon cruise. The post northeast monsoon showed 66 and 16 individuals from 31 and 9 stations of surface and oblique specimens. Most larvae occurred in the surface haul more than in oblique haul.

28. Family Belonidae

There were 4 individuals from 3 stations of *Tylosaurus coccodylus* occurred only in the oblique haul of the post northeast monsoon cruise.

29. Family Exocoetidae

There were 3 genus of Exocoetid larvae observed in these studies. *Exocoetus* sp., *Cypselurus* sp. and *Hirundichthys* sp. were true pelagic species which occurred mostly in the surface haul which collected at night or early morning and on cloudy day. There were very few specimens collected from each station but *Exocoetus sp*. had a wider distribution and collected at more stations.

Exocoetus sp. larvae showed 28 and 5 individuals from 16 and 5 stations of the surface and oblique hauls of the pre northeast monsoon cruise. There were 30 and 6 individuals observed from 21 and 6 stations of surface and oblique specimens of the post northeast monsoon cruise.

Cypselurus sp. larvae showed 20 and 2 individuals from 14 and 2 stations of the surface and oblique hauls in the pre northeast monsoon cruise. There were 13 and 3 individuals observed from 6 and 3 stations by the surface and oblique hauls of post northeast monsoon cruise.

Hirundichthys sp. larvae occurred only in the post northeast monsoon cruise. There were 28 and 7 individuals observed from 14 and 4 stations of surface and oblique specimens.

30. Family Antennariidae

Antennarius sp. larvae showed 6 and 24 individuals from 4 and 16 stations by surface and oblique hauls from pre northeast monsoon cruise. There were 3 and 34 individuals observed from 3 and 17 stations of surface and oblique haul in post northeast monsoon. Most of the larvae collected by oblique haul and the larvae which observed in the surface collection during night and early morning or cloudy day periods.

31. Family Lophiidae

There were 2 genus of this family occurred *Lophias* sp. and *Lophiomus* sp.

Lophias sp. larvae showed 4 and 25 individuals collected from 3 and 13 stations of surface and oblique hauls from pre northeast monsoon cruise. There were 1 and 40 individuals observed from 1 and 21 stations by surface and oblique hauls from post northeast monsoon cruise.

Lophiomus sp. larvae were observed at 14 individuals from 8 stations by oblique haul from post northeast monsoon cruise.

Larvae of this family occurred mostly in the oblique collection which the depth of the stations were more than 100 meters.

32. Family Chaunacidae

Chaunax sp. larvae showed 9 and 8 individuals collected from 3 and 5 stations of surface and oblique hauls from pre northeast monsoon cruise. There were 1 individual each observed from 1 and 3 stations by surface and oblique hauls in post northeast monsoon cruise. The larvae usually occurred in the near shore stations which the depth was about 100 meters.

33. Family Ceratiidae

Cryptopsarus sp. were observed at 7 individuals from 6 stations by oblique haul from pre northeast monsoon cruise. The depth of the occurrence station was more than 200 meters.

34. Family Pegasidae

Pegasus sp. larvae is a small group of larvae which showed only 1 individuals each from 2 stations by surface sampling of the pre northeast monsoon cruise and also 1 individual each were observed from 4 and 3 stations by surface and oblique samplings in the post northeast monsoon cruise.

35. Family Bregmacerotidae

There were 2 species of Bregmacerotidae occurred in these sampling cruise. These 2 species were *Bregmaceros rarisquamosus* and *B. macelellandii*.

Bregmaceros rarisquamosus occurred in both surface and oblique hauls of pre and post northeast monsoon cruises. There were 33 individuals observed from 12 stations of the surface haul in pre northeast monsoon cruise and 188 individuals from 14 stations in the surface haul from post northeast monsoon cruise. There were 1,412 individuals of larvae from 60 stations in pre northeast monsoon cruise and 3,976 individuals from 68 stations inoblique post northeast monsoon cruise. The most abundant observed in pre northeast monsoon cruise was estimated at 178.62 individuals per 1000 cubic meters from station number 36 and for post northeast monsoon cruise was 460.62 individuals per 1000 cubic meters from station number 43 The bregmaceros larvae occurred in the surface sampling when the light intensity was limited especially in the early morning , cloudy day or at the night time (Figure 20-21).

Bregmaceros macelellandii larvae occurred only in the oblique sampling of both pre and post northeast monsoon cruises. There were 168 and 73 individuals from 35 and 31 stations in pre and post northeast monsoon cruises.

36. Family Fistulariidae

The larvae of *Fistularia sp*. occurred in both surface and oblique samples of pre and post northeast monsoon cruises. There were 4 and 14 individuals from 3 and 10 stations in the surface and oblique samples in the pre northeast monsoon , while the post northeast monsoon showed 9 and 29 individuals from 8 and 17 stations of the surface and oblique samples. They showed the possibility to be a subsurface or demersal species.

37. Family Solenostomidae

Solenostomus sp. larvae is a small family occurred in the oblique haul of the pre northeast monsoon cruise. Only one individuals was observed from station number 1 which is a shallow area.

38. Family Syngnathidae

There were 2 genera of *Syngnathus* and *Hippocampus* larvae occurred in the samples but only 3 specimen of *Hippocampus sp.* were obtained from 2 stations by the surface hauls of the pre northeast monsoon. The *Syngnathus sp*. occurred in both surface and oblique samplings in the pre northeast monsoon. There were 3 and 17 individuals observed from 2 and 6 stations in the surface and oblique hauls of pre northeast monsoon. There were 8 individuals from 5 stations also observed in the oblique hauls of post northeast monsoon cruise.

39. Family Centriscidae

Only one species of *Centriscus scutatus* occurred in both surface and oblique collection. There were 3 and 5 individuals observed in 2 and 4 stations by the surface and oblique haul from pre northeast monsoon cruise. While in the post northeast monsoon observed only one individual each from 1 and 4 stations in the surface and oblique collection.

40. Family Brotulidae

Brotula sp. larvae occurred in both surface and oblique hauls of the pre and post northeast monsoon cruises. There were 19 and 103 individuals from 13 and 30 stations by surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon showed 24 and 163 individuals from 13 and 31 stations in surface and oblique samples.

41. Family Carapidae

Carapus sp. larvae occurred in both surface and oblique hauls of pre and post northeast monsoon cruises. There were 2 and 3 individuals observed from 2 stations in pre northeast monsoon samples. The post northeast monsoon cruise provided 8 and 10 individuals in 5 and 8 stations from surface and oblique hauls.

42. Family Diretmidae

Diretmoides was only one genus of the family Diretmidae which occurred only in the oblique sampling of both pre and post northeast monsoon cruises. There were 5 and 1 individuals observed from 4 and 1 stations in pre and post northeast monsoon cruises.

43. Family Melamphaidae

There were 3 genera of the family Melamphaidae occurred in the oblique samplings of pre and post northeast monsoon cruises. These 3 genera were *Scopelogadus* sp., *Scopeloberyx* sp. and *Melamphase* sp.

Scopelogadus sp. larvae were observed at 4 individuals from 2 stations from the oblique sampling in pre northeast monsoon cruise.

Scopeloberyx sp. larvae were observed at 7 and 15 individuals from 6 and 8 stations by the oblique haul in pre and post northeast monsoon cruise.

Melamphase sp. larvae were observed at 4 and 8 individuals from 3 and 5 stations of oblique haul in pre and post northeast monsoon cruise.

44. Family Holocentridae

The two genus of Holocentrid larvae occurring in the sample were *Holocentrus* sp. and *Myripristis* sp. This family had a possibility to be a pelagic group because of the surface occurrence.

Holocentrus sp. were observed at 153 and 36 individuals from 31 and 23 stations by surface and oblique hauls of the pre notheast monsoon cruise. The post northeast monsoon cruise provided 530 and 54 individuals from 38 and 18 stations by surface and oblique hauls (Figure 22-23).

Myripristis sp. showed 320 and 41 individuals from 17 and 12 stations from surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon provided 582 and 109 individuals from 15 and 13 stations by the surface and oblique hauls (Figure 24-25).

45. Family Sphyraenidae

Only one genus of *Sphyraena sp*. occurred in the sampling of both surface and oblique hauls in the pre and post northeast monsoon cruises. There were 22 and 17 individuals of larvae observed from 13 and 14 stations in surface and oblique haul of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 56 and 43 individuals in 26 and 22 stations from surface and oblique samples. It was very difficult to identify this genus between pelagic and demersal group. but it was an economical important in this area.

46. Atherinidae

Atherina sp. larvae is a small group of larvae which showed 1 and 3 individuals collected from station number 1 and 16 by surface hauls in pre northeast monsoon cruise. The larvae occurred in the shallow and near shore stations.

47. Trachipteridae

Trachipterus sp. larvae is a small family which showed only 1 individual collected from station number 77 by surface haul in pre northeast monsoon cruise which the depth of this station is 95 meters.

48. Family Percichthyidae

Synagrops philippinensis larvae showed 32 individuals collected from 11 stations by oblique haul from pre northeast monsoon cruise while the post northeast monsoon cruise represented 2 and 17 individuals from 1 and 6 stations by surface and oblique hauls of post northeast monsoon cruise.

49. Family Serranidae

There were 3 genera of serranid larvae occurring in the samples from both the surface and oblique hauls with the number in the oblique haul samples higher than surface hauls in both the pre and post northeast monsoon cruise. These 3 genus were *Epinephelus* sp., *Chelidoperca hirundinacea*. and *Anthias* sp. For the surface haul, *Epinephelus* sp. 35 and 66 individuals were collected from 12 and 17 stations of the pre and post northeast monsoon cruises. There were 8 individuals observed in each station of *Anthias* sp. from 4 and 7 stations in the pre and post northeast monsoon cruises. For the oblique haul, there were 72 and 116 individuals of *Epinephelus sp*. observed from 34 stations in both the pre and post northeast monsoon cruises and for *Anthias* sp. 57 and 25 individuals were observed from 26 and 17 stations in the pre and post northeast monsoon cruises. Chelidoperca *hirundinacea* showed 64 and 215 individuals from 12 and 35 stations in the oblique haul of pre and post northeast monsoon cruises.

50. Family Theraponidae

Two species of *Therapon jabua* and *T. theraps* were observed in these sampling cruises. *Therapon jarbua* larvae were observed at 23 and 5 individuals from 12 and 5 stations by surface and oblique sampling in the pre northeast monsoon cruise. The post northeast monsoon provided 28 and 14 individuals in 14 and 1 stations of the surface and oblique specimens which most of the larvae were collected from the surface hauls.

Therapon theraps larvae occurred only in the pre northeast monsoon cruise. There were 16 and 47 individuals observed from 6 and 1 stations by surface and oblique hauls.

The occurrence of *Therapon jarbua* was greater than *Therapon theraps* in term of number and distribution.

51. Family Priacanthidae

There were 23 and 101 individuals of *Priacanthus tayenus* from 8 and 33 stations in the surface and oblique specimens from the pre northeast monsoon samplings. The post northeast monsoon sampling observed 28 and 244 individuals from 15 and 44 stations in the surface and oblique samples. *Priacanthus tayenus* showed a demersal characters as collected from the oblique sampling.

52. Family Apogonidae

There were at least 4 species of apogonid larvae occurring in the sampling of both surface and oblique hauls from the pre and post northeast monsoon cruises. These were *Apogon lineatus, Apogon* *nigrofasciatus, Apogon* sp. and *Gymnopogon* sp. The occurrence of the *Apogon lineatus* in the pre northeast monsoon cruise was 159 individuals observed from 20 stations in the oblique specimens and the post northeast monsoon cruise showed 28 and 136 individuals collected from 9 and 25 stations in the surface and oblique samples. The *Apogon nigrofasciatus* showed 3 and 18 individuals from 2 and 8 stations in the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon showed 3 and 48 individuals from 1 and 18 stations in the surface and oblique hauls. *Apogon sp*. were observed at 55 and 579 individuals from 17 and 47 stations in surface and oblique hauls of pre northeast monsoon while the post northeast monsoon cruise showed 159 and 566 individuals from 30and 50 stations of surface and oblique hauls.

Gymnopogon sp. larvae were observed at 2 and 52 individuals from 1 and 14 stations of surface and oblique haul of pre northeast monsoon cruise. There were 1 and 5 individuals observed from 1 and 7 stations by surface and oblique haul of post northeast monsoon cruise.

53. Family Sillaginidae

Only one individuals of *Sillago sp*. larvae were occurred in station number 76 by the surface collection in pre northeast monsoon cruise.

54. Family Branchiostegidae

Branchiostegus sp. larvae occurred only in the oblique samples of both pre and post northeast monsoon cruises. There were 1 and 12 individuals observed from station number 10 of both pre and post northeast monsoon cruises.

55. Family Coryphaenidae

The specimens which occurred in both sampling cruises were *Coryphaena hippurus*. There were 33 and 24 individuals observed from 21 and 8 stations which occurred in both surface and oblique collections in the pre northeast monsoon while the post northeast monsoon sampling showed 35 and 11 individuals collected from 19 and 8 stations by surface and oblique hauls.

56. Family Carangidae

Carangid is a large group of larvae comprising the *Decapterus sp.*, *Selar crumenophthalmus*, *Megalaspis cordyla*, *Alectis ciliaris*, *Caranx ignobilis*, *Caranx leptolepis* , *Caranx mate* , *Caranx speciosus* , *Caranx sp. Elagatis bipinnulata* , *Scomberoides lysan* and *Zonichthys nigrofasciata.*

Decapterus sp. were obtained from both surface and oblique hauls of the pre and post northeast monsoon cruises. There were 249 and 772 individuals observed from 36 and 42 stations of the surface and oblique specimens in pre northeast monsoon cruise. The post northeast monsoon cruise showed 318 and 601 individuals from 45 and 58 stations of the surface and oblique specimens (Figure 26-29).

Selar crumenophthalmus occurred in both the surface and oblique specimens of the pre and post northeast monsoon cruises. There were 179 and 7 individuals from 18 and 3 stations of the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 46 and 26 individuals from 10 and 1 stationsin the surface and oblique samples.

Megalaspis cordyla larvae occurred only from 2 stations of the post northeast monsoon cruise. There were 50 and 3 individuals observed from station number 20 and 21 while the depth of the station was about 100 meters.

Alectis ciliaris larvae were observed at 2 and 8 individuals from 2 and 6 stations by surface and oblique haul in pre northeast monsoon cruise. The post northeast monsoon cruise showed 20 and 3 individuals collected from 12 and 3 stations by surface and oblique hauls.

Caranx ignobilis larvae showed 17 and 23 individuals collected from 9 and 12 stations by surface and oblique hauls in pre northeast monsoon cruise. The post northeast monsoon cruise provided 28 and 1 individuals from 12 and 1 stations of surface and oblique sampling.

Caranx leptolepis showed 13 and 16 individuals observed from 7 stations by the surface and oblique hauls in the pre northeast monsoon cruise. The post northeast monsoon cruise showed 3 and 32 individuals observed from 2 and 5 stations in the surface and oblique collection.

Caranx mate was collected from both surface and oblique sampling of the pre and post northeast monsoon cruises. There were 2 and 26 individuals from 2 and 7 stations in the surface and oblique haul of the pre northeast monsoon cruise. For the post northeast monsoon cruise, there were 6 and 23 individuals observed from 2 and 8 stations of the surface and oblique specimens.

Caranx speciosus showed 14 and 23 individuals collected from 8 and 6 stations by surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise provided 16 and 29 individuals observed from 6 and 5 stations inthe surface and oblique specimens.

Caranx sp. showed 14 and 111 individuals collected from 12 and 20 stations of the surface and oblique hauls in the pre northeast monsoon cruise. The post northeast monsoon cruise showed 23 and 60 individuals observed from 10 and 15 stations inthe surface and oblique hauls of the post northeast monsoon cruise.

Elagatis bipinnulata larvae showed 11 and 1 individuals observed from 7 and 1 stations by surface and oblique collection of the pre northeast monsoon cruise. The post northeast monsoon cruise were observed 25 individuals from 10 stations by the surface collection.

Scomberoides lysan showed 7 and 2 individuals collected from 5 and 2 stations of the surface and oblique hauls in the pre northeast monsoon cruise. The post northeast monsoon cruise provided 17 and 9 individuals from 11 and 3 stations of the surface and oblique specimens.

Zonichthys nigrofasciata showed 36 and 10 individuals collected from 22 and 9 stations in the surface and oblique specimens of the pre northeast monsoon cruise. The post northeast monsoon cruise provided 16 and 12 individuals from 14 and 7 stations in the surface and oblique collection.

The carangidae larvae usually aggregate to the floating substances like jelly fish, log and sea weed.

57. Family Parastromatidae

Only one species of *Parastromateus niger* larvae occurred in the oblique haul of post northeast monsoon cruise. There were 3 individuals of larvae occurred in station number 11 which the depth was about 100 meters.

58. Family Meneidae

There is only one species of moon fish in the world. *Mene maculata* occurred in the surface collection of pre northeast monsoon and oblique collection of the post northeast monsoon. There were 7 individuals from 5 stations collected by surface haul in the pre northeast monsoon. The post northeast monsoon showed only 1 individual from station number 17 by oblique haul.

59. Family Bramidae

Brama sp. larvae were observed at 5 individuals from 4 stations by oblique haul in pre northeast monsoon collection while the post northeast monsoon cruise showed 1 and 14 individuals from 1 and 8 stations in surface and oblique collection.

60. Family Lutjanidae

Lutjanus sp. occurred in both surface and oblique samples in the pre and post northeast monsoon cruises. There were 119 and 439 individuals observed from 32 and 50 stations in surface and oblique specimens of the pre northeast monsoon. For the post northeast monsoon, there were 171 and 329 individuals collected from 27 and 51 stations in the surface and oblique specimens. The occurrence of the larvae showed demersal characteristic from their abundance and distribution (Figure 30-33).

61. Family Nemipteridae

Nemipterus sp. occurred in both surface and oblique collection of pre and post northeast monsoon cruises but it was more abundance in the oblique sampling. There were 82 and 345 individuals observed from 22 and 39 stations by the surface and oblique sampling in the pre northeast monsoon cruise. The post northeast monsoon cruise showed 27 and 699 individuals collected from 6 and 47 stations by surface and oblique sampling. The larvae showed demersal characteristic in their abundance and distribution (Figure 34-35).

62. Family Gerreidae

Gerres sp. occurred in both surface and oblique hauls of pre and post northeast monsoon cruises. There were 75 and 21 individuals observed from 13 and 4 stations in the surface and oblique hauls of pre northeast monsoon. The post northeast monsoon showed 40 and 52 individuals collected from 10 and 5 stations by the surface and oblique sampling.

63. Family Lobotidae

Lobotes surinamensis is the only one species in this family. The larvae occurred in the surface sampling of both pre and post northeast monsoon cruises. Both sampling cruises showed 5 individuals collected from 3 and 2 stations.

64. Family Leiognathidae

Leiognathus sp. occurred in both surface and oblique hauls of pre and post northeast monsoon cruises. There were 15 and 312 individuals observed from 9 and 30 stations of surface and oblique hauls in the pre northeast monsoon. The post northeast monsoon showed 12 and 233 individuals collected from 7 and 35 stations in the surface and oblique collections (Figure 36-37).

65. Family Pomadasyidae

The genus *Plectorhynchus* occurred in both surface and oblique hauls of the pre and post northeast monsoon sampling. There were 4 and 173 individuals observed from 3 and 22 stations by surface and oblique hauls in the pre northeast monsoon cruise. The post northeast monsoon cruise showed 21 and 252 individuals from 7 and 45 stations in surface and oblique specimens.

66. Family Lethrinidae

Lethrinus sp. showed 6 and 22 individuals from 6 and 11 stations in the surface and oblique hauls of the pre northeast monsoon cruise. For the post northeast monsoon cruise, 10 and 23 individuals were observed from 9 and 15 stations by surface and oblique collection.

67. Family Mullidae

The larvae in this family, *Upeneus sp*., was an abundant species in the surface collection for pre and post northeast monsoon cruises. There were 502 and 149 individuals observed from 49 and 26 stations of the surface and oblique hauls in the pre northeast monsoon cruise. For the post northeast monsoon cruise, 433 and 191 individuals were observed from 50 and 34 stations of the surface and oblique hauls. The larvae showed pelagic characteristic by their abundance and distribution in the surface coolections (Figure 38-41).

68. Family Haemulidae

Six individuals of *Diagramma* sp. larvae were obtained from station number 12 by the oblique hauls in post northeast monsoon cruise.

69. Family Monodachthylidae

Only one individuals of *Monodachthylus argenteus* larvae was occurred in station number 16 of the surface sampling from post norteast monsoon cruise.

70. Family Ephippidae

Platax tiara was identified from pre and post northeast monsoon cruise. Twenty individuals of *Platax tiara* larvae were collected from 8 stations by the oblique haul in pre northeast monsoon cruise. There were 4 and 13 individuals were also observed from 3 and 5 stations in the surface and oblique collections of thhe post northeast monsoon cruise.

71. Family Scatophagidae

Only one individuals of *Scatophagus argus* larvae was obtained from station number 7 of the surface collection in post northeast monsoon cruise which this station was a coastal station.

72. Family Chaetodontidae

Chaetodon sp. was obtained from the surface and oblique hauls of the pre and post northeast monsoon cruises. There were 5 and 6 individuals collected from 3 and 5 stations in the surface and oblique collection in pre northeast monsoon cruise. The post northeast monsoon provided 27 and 5 individuals from 8 and 4 stations by surface and oblique hauls.

73. Family Pomacanthidae

Centropyge sp. larvae occurred in the surface of the pre northeast monsoon and oblique sampling of the pre and post northeast monsoon cruises. One individuals each were observed from 4 stations by surface haul of pre northeast monsoon. There were 3 and 9 individuals observed from 3 and 1 stations by the oblique collection of pre and post northeast monsoon.

74. Family Pomacentridae

There were 3 genera of pomacentrid larvae occurring in these specimens. There were *Pomacentrus* sp., *Chromis sp. and Abudefduf* sp. *Pomacentrus* sp. larvae were obtained only from the surface hauls during the pre northeast monsoon cruise. There were 17 individuals were observed from 3 stations. *Chromis* sp. larvae were occurred in both surface and oblique hauls of the pre and post northeast monsoon sampling, there were 15 and 4 individuals from 7 and 3 stations in the surface and oblique hauls of pre northeast monsoon while the post northeast monsoon cruise provided 43 and 41 individuals from 15 and 11 stations by surface and oblique hauls. *Abudefduf* sp. larvae were also observed from both surface and oblique hauls of pre and post northeast monsoon cruises, there were 15 and 4 specimens from 7 and 3 stations in surface and oblique hauls of pre northeast monsoon while the post northeast monsoon cruise provided 31 and 8 individuals from 8 and 3 stations by surface and oblique collection.

75. Family Cepolidae

Acanthocepola sp. larvae were obtained from both surface and oblique hauls during pre and post northeast monsoon cruises but collection from oblique hauls showed more abundance than surface hauls. There were 3 and 51 individuals collected from 3 and 17 stations in the surface and oblique hauls of the pre northeast monsoon cruise. For the post northeast monsoon cruise, there were 9 and 77 individuals were observed from 4 and 21 stations in the surface and oblique hauls.

76. Family Labridae

Halichoeres sp. larvae occurred in both surface and oblique hauls of the pre and post northeast monsoon cruises. There were 48 and 110 individuals observed from 17 and 36 stations in the surface and oblique hauls of the pre northeast monsoon cruise. For the post northeast monsoon cruise, there were 13 and 262 individuals observed from 5 and 38 stations in the surface and oblique hauls.

77. Family Scaridae

Scarus sp. larvae occurred in the surface haul of the post northeast monsoon cruise but observed in the oblique haul of both pre and post northeast monsoon. There were 91 individuals collected from 27 stations in oblique haul of pre northeast monsoon cruise. The post northeast monsoon cruise provided 8 and 38 individuals from 5 and 20 stations by surface and oblique hauls.

78. **Family Champsodontidae**

The larvae of this family were *Champsodon* sp. There were 5 and 179 individuals observed from 3 and 41 stations by the surface and oblique hauls of the pre northeast monsoon cruise. There were 1 and 238 individuals also collected from 1 and 45 stations by the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon showed 1 and 238 individuals observed from 1 and 45 stations by the surface and oblique hauls (Figure 42-43).

79. Family Chaiasmodontidae

There were 2 individuals of *Chaiasmodon* sp. larvae occurred in station number 49 by oblique haul in post northeast monsoon cruise.

80. Family Blenniidae

Blennius sp. larvae occurred in both surface and oblique hauls of pre and post northeast monsoon cruises. There were 31 and 27 individuals collected from 14 stations by surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon showed 17 and 26 individuals observed from 11 and 16 stations in the surface and oblique haul samples. *Blenneus* sp. was the demersal group.

81. **Family Callionymidae**

Callionymus sp. was an abundant larvae in the oblique haul samples and occurred in both surface and oblique hauls of the pre and post northeast monsoon cruises. There were 17 and 419 individuals collected from 12 and 57 stations by the surface and oblique hauls in pre northeast monsoon cruise. The post northeast monsoon showed 28 and 608 individuals observed from 14 and 63 stations by the surface and oblique sampling. Demersal characteristic showed by this species due to their abundance and distribution in the oblique collection of both cruises (Figure 44-45).

82. Family Echeneidae

Echeneis naucrates larvae occurred in both surface and oblique hauls of pre and post northeast monsoon cruises. There were 11 and 13 individuals observed from 6 stations by surface and oblique hauls in pre northeast monsoon cruise. For the post northeast monsoon cruise, there were 3 and 40 individuals collected from 2 and 16 stations by surface and oblique hauls.

83. Family Histiophoridae

Histiophorus sp. larvae were obtained from both surface and oblique hauls of pre and post northeast monsoon cruises. There was 37 and 5 individuals observed from 16 and 5 stations in the surface and oblique haul in pre northeast monsoon cruise. There were 19 and 2 individuals also collected from 10 and 2 stations of the surface and oblique haul in the post northeast monsoon cruise.

84. Family Scombridae

Scombrid was an economic family which the larvae occurred in both surface and oblique hauls of these cruises.

There were 8 genera of Scombrid larvae occurring in this area. There were *Rastrelliger* sp.,Scomber sp., *Scomberomorus* sp*. Acanthocybium* solandri, *Euthynus* sp., *Auxis* sp*., Katsuwonus* sp. *and Thunnus* sp.

Rastrelliger sp. showed 12 and 82 individuals from 6 and 17 stations in the surface and oblique hauls of pre northeast monsoon. For the post northeast monsoon cruise, there were 16 and 22 individuals observed from 5 and 8 stations by surface and oblique hauls.

Scomber sp. larvae occurred only in the oblique haul of pre and post northeast monsoon cruises. There were 56 and 61 individuals observed from 12 and 21 stations of pre and post northeast monsoon cruises.

Scomberomorus sp. occurred in both surface and oblique hauls of pre and post northeast monsoon cruises. There were 90 and 21 individuals collected from 18 and 9 stations by the surface and oblique hauls of the pre northeast monsoon cruise. For the post northeast monsoon cruise, there were 48 and 62 individuals observed from 8 and 13 stations of the surface and oblique haul samples.

Acanthocybium solandri larvae occurred only in the oblique collection of pre and post northeast monsoon cruises. Only one individual occurred in the station number 51 of the pre northeast monsoon and station number 39 of the post northeast monsoon cruise.

Euthymus sp. occurred in both surface and oblique hauls of pre northeast monsoon cruise. There were 164 and 19 individuals observed from 34 and 9 stations in surface and oblique hauls of pre northeast monsoon cruise. For the post northeast monsoon collection, there were 193 and 56 individuals collected from 26 and 8 stations by the surface and oblique hauls.

Auxis sp. larvae occurred in the oblique hauls of the pre northeast monsoon and in both surface and oblique hauls of post northeast monsoon cruise. There were 56 individuals observed from 24 stations by oblique haul of pre northeast monsoon cruise. The post northeast monsoon showed 200 and 10 individuals from 37 and 4 stations of surface and oblique hauls.

Katsuwonus pelamis larvae were observed at 28 individuals from 8 stations of oblique haul in pre northeast monsoon cruise. There were 59 and 41 individuals also observed from 12 and 7 stations in surface and oblique hauls of post northeast monsoon cruise.

Thunnus sp. larvae were observed at 17 individuals from 6 stations of the oblique haul in post northeast monsoon cruise.

85. Family Trichiuridae

Trichiurus lepturus occurred in both surface and oblique hauls of pre northeast monsoon cruise but in the post northeast monsoon cruise it was observed in the oblique collection. There were 2 and 28 individuals collected from 2 and 11 stations of surface and oblique hauls in the pre northeast monsoon cruise, The post northeast monsoon cruise showed 21 individuals from 10 stations by oblique haul.

86. Family Gempylidae

Gempylidae is a family which related to family Trichiuridae. Gempylus sp. larvae occurred in both surface and oblique sampling of pre and post northeast monsoon cruises. There were 31 and 14 individuals observed from 13 and 10 stations of surface and oblique haul from pre northeast monsoon cruise. The post northeast monsoon cruise provided 61 and 21 individuals from 17 and 12 stations of surface and oblique hauls collection.

87. Family Acanthuridae

Acanthurus sp. larvae occurred in both surface and oblique collection of pre and post northeast monsoon cruises. There were 24 and 36 individuals observed from 11 and 16 stations of surface and oblique hauls in pre northeast monsoon cruise. The post northeast monsoon cruise provided 78 and 20 individuals from 6 and 12 stations in surface and oblique haul collection.

88. Family Siganidae

Siganid was a coastal species which occurred in the shallow water. *Siganus* sp. larvae were observed 3 and 9 individuals from 3 and 2 stations in surface and oblique hauls of pre northeast monsoon cruise. The post northeast monsoon cruise provided 10 and 6 individuals from 6 and 1 stations in surface and oblique haul collections.

89. Family Tetragonuridae

Tetragonurus sp. larvae was a small group occurred in both surface and oblique hauls of pre and post northeast monsoon cruises. There were 1 and 4 individuals observed from 1 and 3 stations in surface and oblique collections of pre northeast monsoon cruise. The post northeast monsoon provided 8 and 2 stations from 2 and 1 stations in surface and oblique collections.

90. Family Nomeidae

There were 3 genera of Nomeidae larvae occurred in these survey cruises. There were *Psene cyanophys*, *Nomeius* sp. and *Cubiceps* sp. which was the most abundant among these 3 genus.

Only one individual of Psene cyanophys larvae occurred at station number 19 by oblique haul in the post northeast monsoon cruise.

Nomeius sp. larvae occurred in the oblique haul of both pre and post northeast monsoon cruises. There were 2 and 8 individuals observed from 2 and 4 stations of pre and post northeast monsoon cruises.

Cubiceps sp. larvae occurred in both surface and oblique hauls of pre and post northeast monsoon cruises. There were 2 and 13 individuals observed from 2 and 6 stations in surface and oblique haul of pre and post northeast monsoon cruises. The post northeast monsoon cruise provided 13 and 16 individuals from 7 and 10 stations in surface and oblique collections.

91. Family Stromatidae

Three individuals of *Pampus argenteus* larvae were obtained from stations number 26 in the oblique hauls of post northeast monsoon cruise collection.

92. Family Sciaeneidae

There were 2 genus of Sciaeneidae occurred in these two survey cruises. There were *Sciaena* sp. and *Nibea japonicus*. For *Sciaena* sp. only one individual was observed in each station number 56 and 31 in the surface collection of pre and post northeast monsoon. There were 122 and 113 individuals observed from 19 and 20 stations in the oblique haul of pre and post northeast monsoon cruise.

Only one individual of *Nibea japonicus* occurred in station number 69 in oblique haul of post northeast monsoon cruise.

93. Family Polynemidae

There were 2 individuals of *Polynemus* sp. larvae occurred in station number 31 in oblique haul of pre northeast monsoon cruise.

94. Family Schneideriidae

Schneideria sp. larvae occurred in both surface and oblique hauls of the pre and post northeast monsoon cruises. There were 2 and 23 individuals collected from 2 and 12 stations by surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 8 and 59 individuals from 2 and 3 stations in the surface and oblique haul samples.

95. Family Typaucheniidae

Typanchen sp. larvae occurred in both surface and oblique hauls of the pre and post northeast monsoon cruises. There were 33 and 143 individuals collected from 15 and 27 stations by the surface and oblique hauls in the pre northeast monsoon cruise. The post northeast monsoon cruise showed 7 and 302 individuals from 3 and 41 stations in surface and oblique haul samples.

96. Family Trichonotidae

Only one individual of *Trichonotus* sp. occurred in station number 17 from the oblique haul of pre northeast monsoon cruise.

97. Family Gobiidae

Gobiidae was the only group of larvae that identified at the family level, being the most abundant larvae in the oblique hauls of both the pre and post northeast monsoon cruise. There were 400 and 5,215 individuals observed from 42 and 77 stations in the surface and oblique hauls of the pre northeast monsoon. The post northeast monsoon showed 355 and 7,197 individuals collected from 49 and 76 stations in surface and oblique haul samples (Figure 46-49).

98. Family Platycephalidae

Platycephalus sp. were obtained from the surface and oblique hauls in the pre and post northeast monsoon cruises. There were 1 and 39 individuals observed from 1 and 14 stations in the pre monsoon cruise. For the post northeast monsoon cruise, there were 5 and 58 individuals collected from 2 and 21 stations of the oblique haul samples.

99. Family Scorpaenidae

There were 2 genera of scorpaenid larvae occurring in both surface and oblique hauls of pre and post northeast monsoon cruises. There were the *Minous* sp. and *Scorpaenoides* sp.

Minous sp. larvae showed 11 and 36 individuals from 8 and 21 stations in the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 44 and 108 individuals from 16 and 36 stations in the surface and oblique samples.

Scorpanoides sp. larvae showed 15 and 25 individuals from 15 and 21 stations by the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 16 and 46 individuals collected from 8 and 24 stations in the surface and oblique haul samples.

100. Family Triglidae

Lepidotrigla sp. larvae was only species identified in the family Triglidae. There were 3 and 20 individuals observed from 3 and 13 stations in the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 4 and 45 individual collected from 4 and 17 station in the surface and oblique hauls.

101. Family Dactylopteridae

Dactylopterus sp. larvae was identified from the family Dactylopteridae. There were 100 and 52 individuals collected from 32 and 18 stations by the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 106 and 30 individuals observed from 19 and 30 stations in the surface samples.

102. Family Psettodidae

Psettodes erumei larvae was obtained from the surface and oblique hauls of the pre and post northeast monsoon cruise. There were 1 and 11 individuals collected from 1 and 7 stations by the surface and oblique hauls in pre northeast monsoon cruise. While the post northeast monsoon cruise showed 2 and 5 individuals observed from 1 and 4 stations in surface and oblique collections.

103. Family Paralichthyidae

There were 3 genera of Paralichthyidae larvae occurred in both surface and oblique sampling of the both cruise. These 3 genus were *Paralichthys* sp., *Pseudorhombus* sp. and *Samarius* sp.

Paralichthys sp. larvae was obtained from both surface and oblique hauls of pre and post northeast monsoon cruises. There were 2 and 30 individuals observed from 1 and 13 stations in surface and oblique hauls of pre northeast monsoon cruise. The post northeast monsoon cruise showed 3 and 33 individuals collected from 2 and 13 stations in surface and oblique haul samples.

Pseudorhombus sp. larvae occurred in the oblique samples of the pre and post northeast monsoon cruises. There were 2 and 12 individuals observed from 2 and 8 stations in pre and post northeast monsoon collections.

Threr were 5 individuals of *Samarius* sp. larvae collected from 3 stations in the oblique haul of pre northeast monsoon cruise.

104. Family Soleidae

There were 2 genera of Soleidae occurred in both sampling cruises. These 2 genus were *Solea* sp. and *Aserragodes* sp.

Solea sp. larvae occurred in both sampling cruises. Only one individual was occurred at station number 32 in the surface collection of pre northeast monsoon collection. While the post northeast monsoon cruise provided 22 individuals from 11 station in the oblique sampling.

Aserraggodes sp. larvae were 4 and 17 individuals collected from 4 and 14 stations by the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon showed 1 and 13 individuals observed from 1 and 10 stations in the surface and oblique hauls.

105. Family Bothidae

There were 3 genus of bothid larvae occurred in both surface and oblique hauls of pre and post northeast monsoon cruises. These 3 genus were *Bothus* sp., *Engyprosopon* sp. and *Arnoglossus* sp.

Bothus sp. larvae showed 26 and 138 individuals collected from 9 and 36 stations by surface and oblique hauls of the pre northeast monsoon cruise. The post monsoon cruise showed 8 and 265 individuals from 5 and 48 stations in surface and oblique haul samples.

Engyprosopon sp. larvae were observed at 46 and 154 individuals from 19 and 37 stations in the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 107 and 253 individuals collected from 26 and 51 stations in the surface and oblique haul samples.

Arnoglossus sp. larvae were observed at 26 individuals from 13 stations in surface sampling of pre northeast monsoon cruise. While the post northeast monsoon cruise showed 140 individuals collected from 34 stations by oblique collections.

106. Family Cynoglossidae

Cynoglossus sp. larvae was obtained from both surface and oblique hauls of pre and post northeast monsoon cruises. There were 13 and 157 individuals observed from 9 and 46 stations in surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 6 and 184 individuals collected from 4 and 43 stations in surface and oblique haul samples.

107. Family Citharidae

Brachypleura novaezeelandiae larvae was the only species identified in the family Cithacidae. There were 2 and 9 individuals from 1 and 4 stations in the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 45 individuals from 20 station in the oblique haul sample.

108. Family Tetraodontidae

Tetraodon sp. larvae was obtained in both surface and oblique hauls of the pre and post northeast monsoon cruises. There were 17 and 52 individuals observed from 10 and 25 stations in the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 57 and 165 individuals from 16 and 39 stations in the surface and oblique haul samples.

109. Family Diodontidae

Diodon sp. larvae was obtained from both surface and oblique hauls in the pre and post monsoon cruise. There were 17 and 13 individuals observed from 11 and 10 stations in the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 9 and 67 individuals collected from 7 and 18 stations in the surface and oblique haul samples.

110. Family Balistidae

Balistes sp. larvae was obtained from both surface and oblique hauls of pre and post northeast monsoon cruises. There were 29 and 48 individuals observed from 22 and 24 stations in the surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 32 and 63 individuals collected from 17 and 16 stations by the surface and oblique haul sampling.

111. Family Monacanthidae

Monacanthus sp. and *Aluterus* sp. were 2 genera of the family Monacanthidae occurring in these sampling cruises.

Monacanthus sp. was obtained from both surface and oblique hauls of pre and post northeast monsoon cruises. There were 27 and 104 individuals observed from 14 and 20 stations in surface and oblique hauls of the pre northeast monsoon cruise. The post northeast monsoon cruise showed 27 and 382 individuals from 11 and 33 stations in the surface and oblique haul samples.

Aluterus sp. showed 5 and 2 individuals collected from 3 and 1 stations by surface and oblique hauls of the pre northeast monsoon cruise. There were 6 and 5 individuals observed from 4 and 3 stations in the surface and oblique hauls of the post northeast monsoon cruise.

112. Eel larvae (*Leptocephalus* sp.)

The eel larvae were sorted out from the sample but were not identified to the family or genus because of time constraint. There were 43 and 99 individuals observed from 13 and 45 stations in surface and oblique hauls of pre northeast monsoon cruise. In post northeast monsoon cruise showed 27 and 75 individuals collected from 10 and 38 stations by surface and oblique sampling.

Discussion

There were very few studies on fish larvae in the South China Sea especially along the Sarawak, Brunei and Sabah area. However there were some information on studied of the fisheries resource in Brunei area. This study was intended to concentrate on species composition (at the genera level), Abundance and distribution of larvae by the surface and oblique samplings. There were about 112 families and 186 species of fish larvae observed in these pre and post northeast monsoon cruises. The results from this study showed that more families of fish larvae were observed than the studies by Vatanachai (1972) and Termvidchakorn (1983) because there were more complete sampling procedures in a large area which cover both shallow and deep area which the sampling stations were well represent most area. The most abundance larvae observed in the surface of pre northeast monsoon sampling was *Sardinella* sp. while in the post northeast monsoon cruise was*Stolephorus* sp. These 2 species were collected mostly during early morning, at night time or cloudy days sampling periods. These larvae were more abundant in the surface sampling may probably due to phototaxis activities. The oblique samples showed more abundant of Gobiidae larvae which consisted about 75% of all specimens in the oblique haul sampling of pre and post northeast monsoon cruises. *Bregmaceros rarisquamosus* larvae was the second most abundant species observed in the oblique collection. Some fish larvae were found aggregrated to foating substances, such as Carangidae and Nomeidae larvae.

In the deep area, mesopelagic fish larvae were occurred in both surface and oblique collections which may be due to the sampling time because of the highly phototaxis activities. *Diaphus* sp., *Benthosoms* sp., *Hygophum* sp. and *Myctophum* sp. usually occurred in the sampling stations that the depth was more than 100 meters. The oblique haul sampling obtained more mesopelagic larvae than the surface haul sampling. The mesopelagic larvae also occurred in the surface haul during the early morning, night time or cloudy day samplings. Some species of mesopelagic larvae may occurred only in the oblique haul due to true mesopelagic character which their diurnal migration in the deep area which the oblique haul operation could cover that depth.

There were some differences between the species composition of larvae observed in the shallow coastal zone and deep area or open sea which was very difficult to identified the occurring because of the slope of the continental shelf. The pelagic and demersal characters of larvae were identified from their abundance and distribution in the surface and oblique sampling.

Larvae which showed pelagic character were *Sardinella* sp., *Stolephorus* sp., *Myripristis* sp., *Holocentrus* sp., *Upeneus* sp., *Decapterus* sp., *Euthynus* sp. and *Diaphus* sp.

The demersal character were Gobiidae, *Bregmaceros rarisquamosus*, *Decapterus* sp., *Apogon* sp., *Nemipterus* sp., *Callionymus* sp., *Hygophum* sp., *Myctophum* sp., *Benthosema* sp.

The factors which effected on the abundant and distribution of larvae were

1. The sampling area which the depth was the limiting factor for species composition and abundant.
2. Sampling time which due to the light intensity can effected on phototaxis activities of larvae.
3. The characteristic of larvae, themselves which mesopelagic families mostly occurred in the

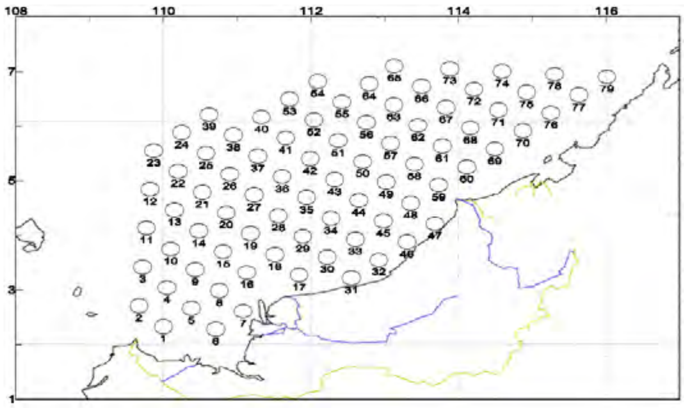


Fig. 1 Oceanographic station of the survey Area II: Sarawak, Sabah and Brunei Darussalam waters

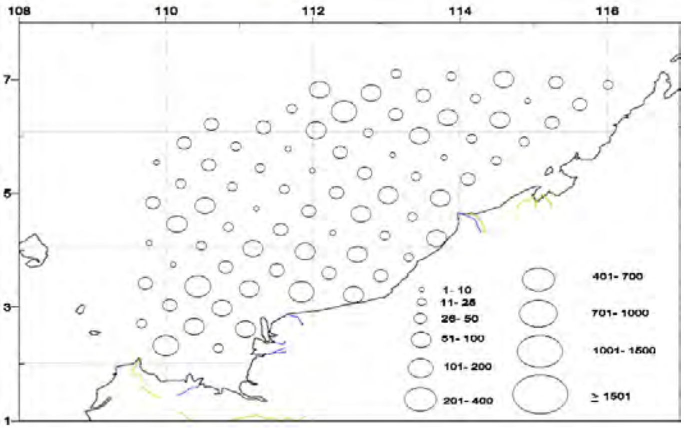


Fig. 2 Abundance and distribution of total fish larvae obtained from the surface haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

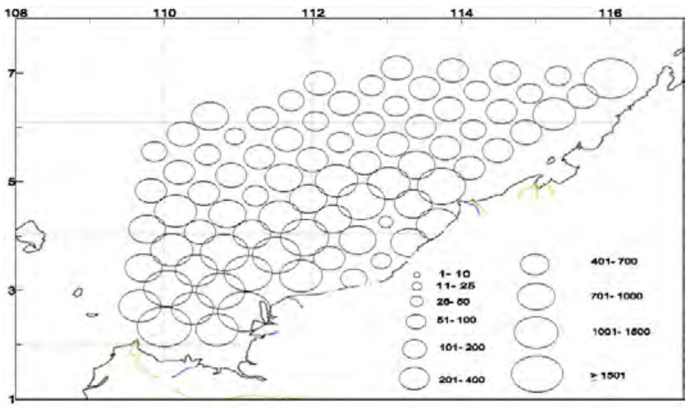


Fig. 3 Abundance and distribution of total fish larvae obtained from the oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

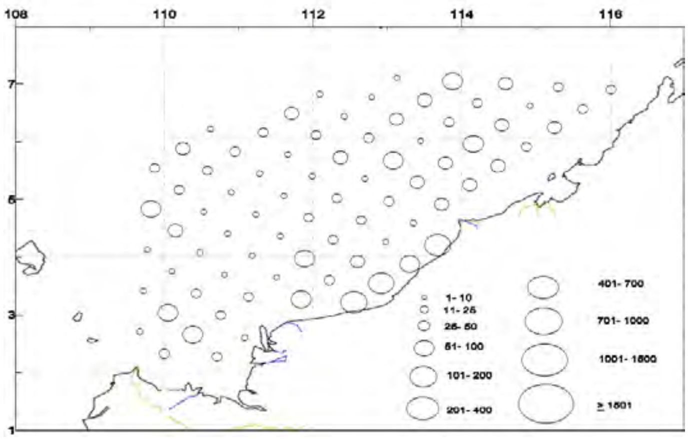


Fig. 4 Abundance and distribution of total fish larvae obtained from the surface haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

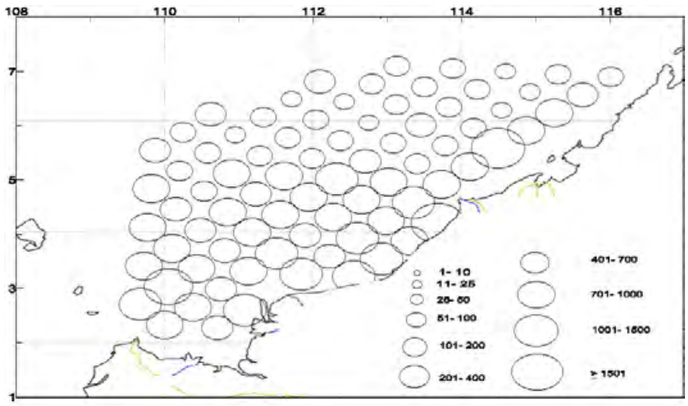


Fig. 5 Abundance and distribution of total fish larvae obtained from the oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

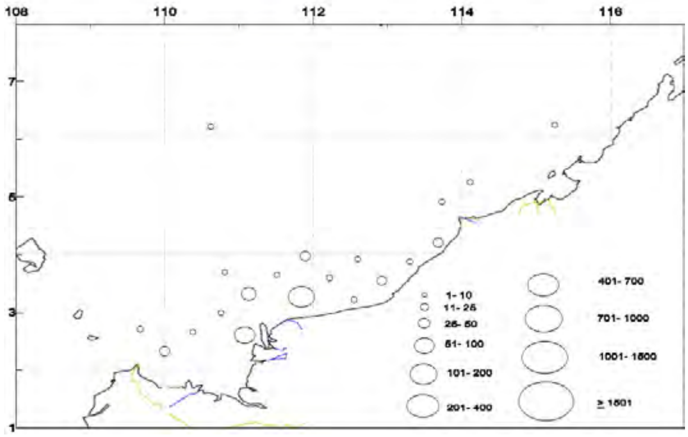


Fig. 6 Abundance and distribution of *Sardinella* sp. larvae (No./ $1000m^3$) obtained from the surface haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

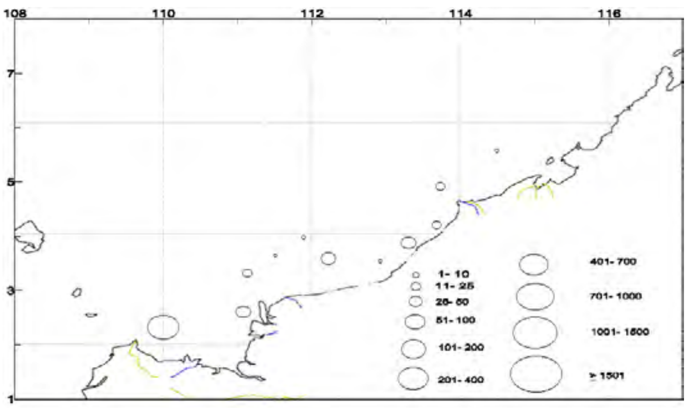


Fig. 7 Abundance and distribution of *Sardinella* sp. larvae (No./ $1000m^3$) obtained from the oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

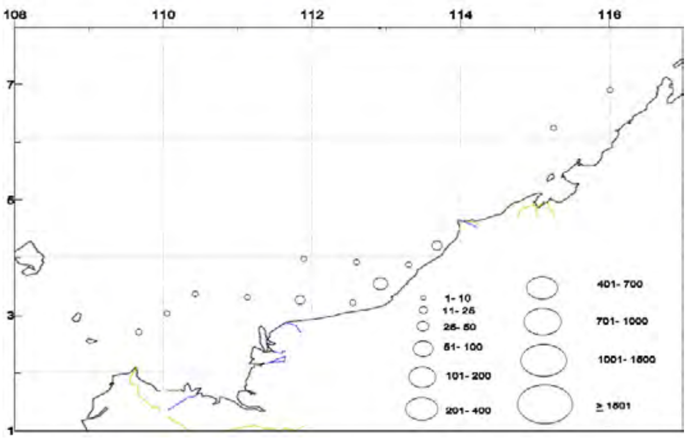


Fig. 8 Abundance and distribution of *Sardinella* sp. larvae (No./ $1000m^3$) obtained from the surface haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

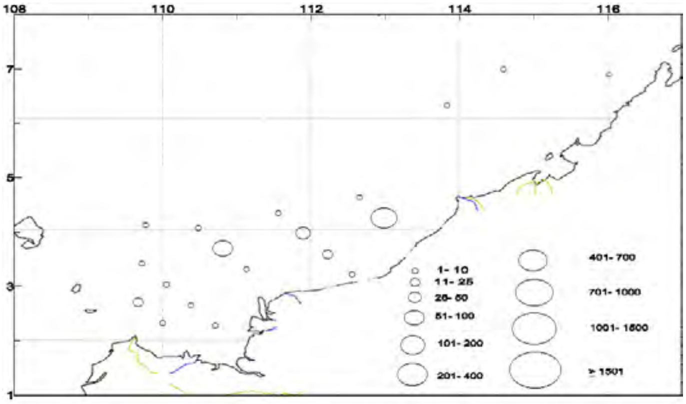


Fig. 9 Abundance and distribution of *Sardinella* sp. larvae (No./ 1000m^3) obtained from the oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

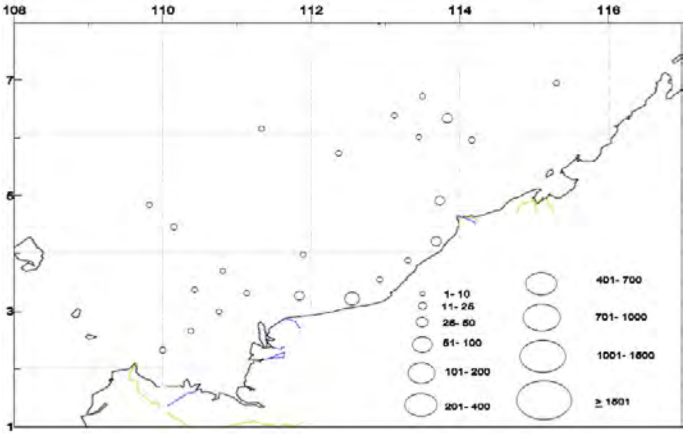


Fig. 10 Abundance and distribution of *Stolephorus* sp. larvae (No./ 1000m^3) obtained from the surface haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

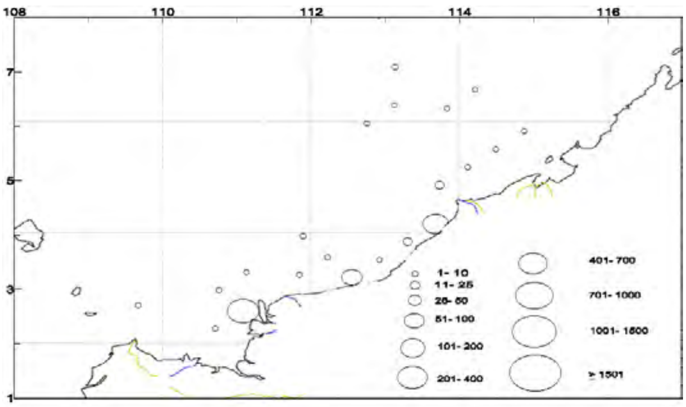


Fig. 11 Abundance and distribution of *Stolephorus* sp. larvae (No./ 1000m^3) obtained from the oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

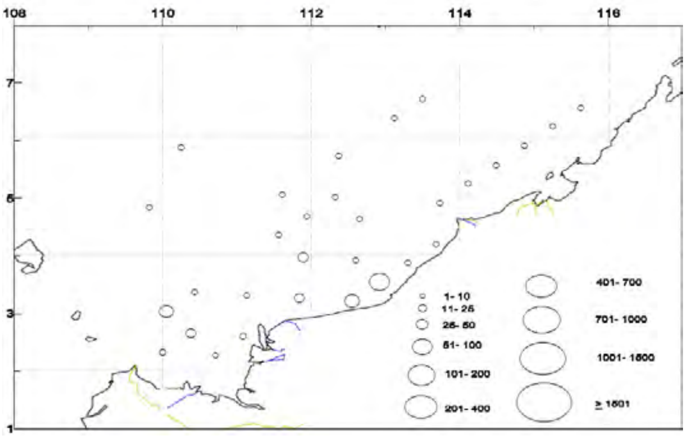


Fig. 12 Abundance and distribution of *Stolephorus* sp. larvae (No./ 1000m^3) obtained from the surface haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

Fig. 13 Abundance and distribution of *Stolephorus* sp. larvae (No./ 1000m[3]) obtained from the oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

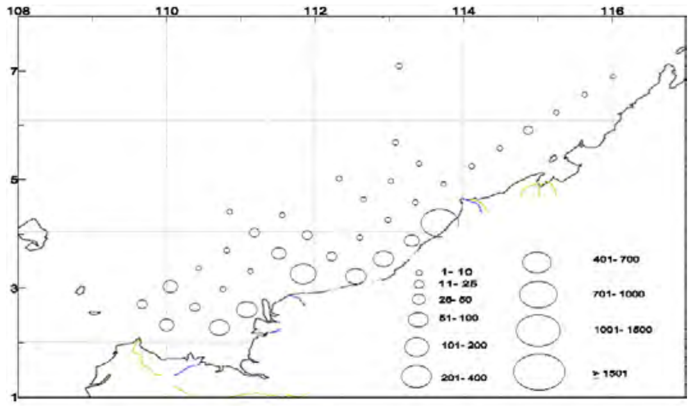


Fig. 14 Abundance and distribution of *Benthosema* sp. larvae (No./ 1000m[3]) obtained from the oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

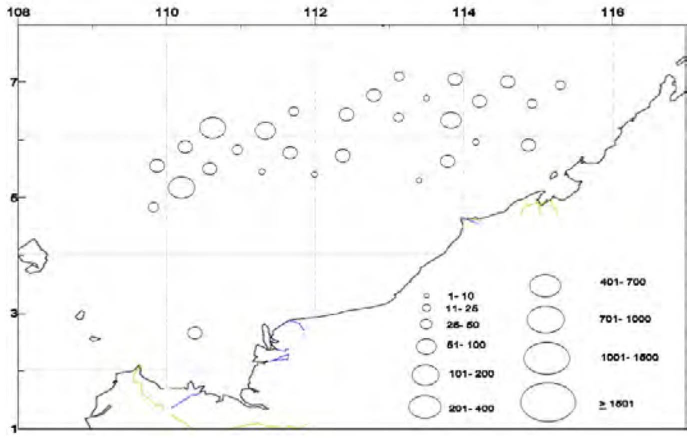


Fig. 15 Abundance and distribution of *Benthosema* sp. larvae (No./ 1000m[3]) obtained from the oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

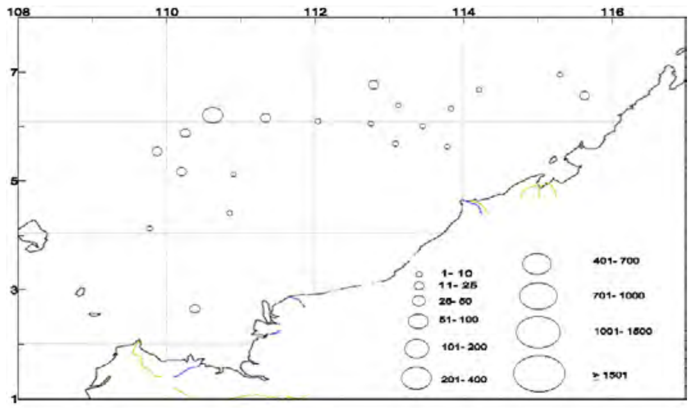
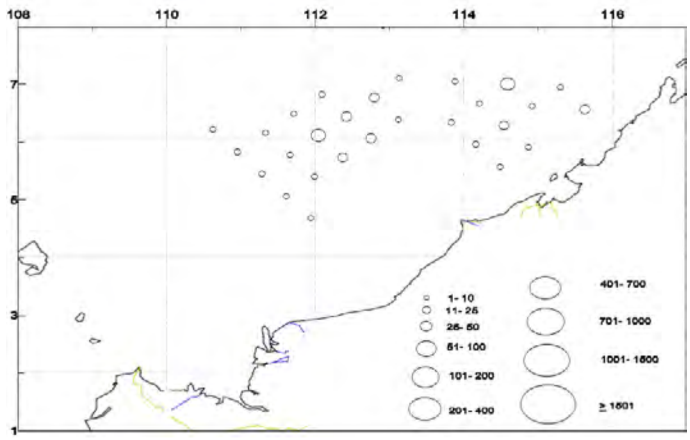


Fig. 16 Abundance and distribution of *Diaphus* sp. larvae (No./ 1000m[3]) obtained from the surface haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC



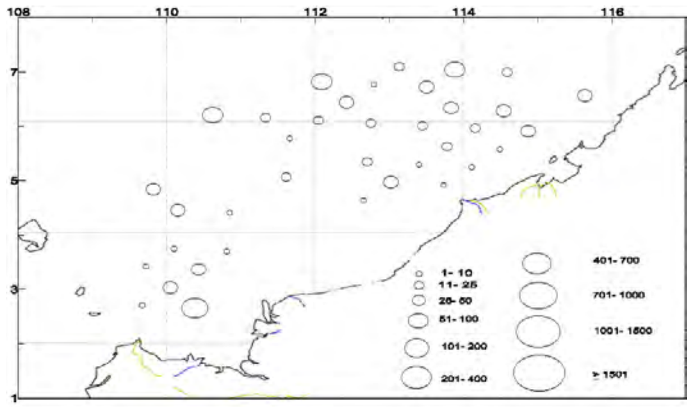


Fig. 17 Abundance and distribution of *Diaphus* sp. larvae (No./ 1000m^3) obtained from the oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

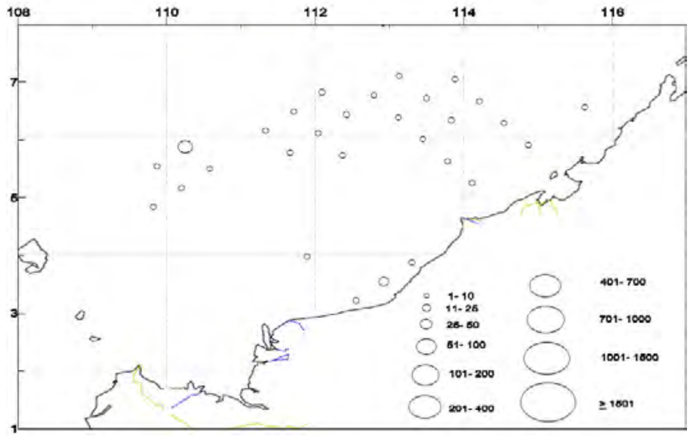


Fig. 18 Abundance and distribution of *Diaphus* sp. larvae (No./ 1000m^3) obtained from the surface haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

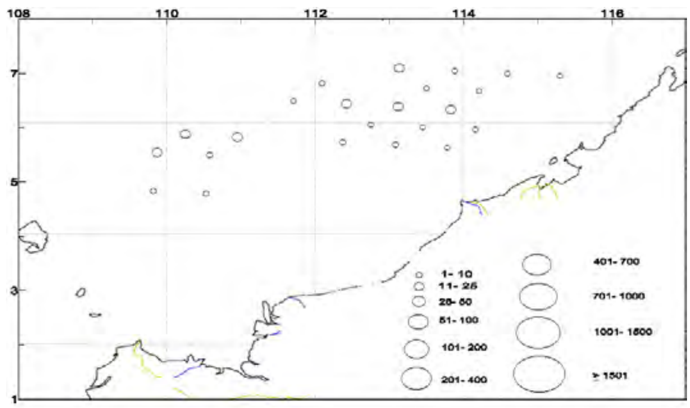


Fig. 19 Abundance and distribution of *Diaphus* sp. larvae (No./ 1000m^3) obtained from the oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

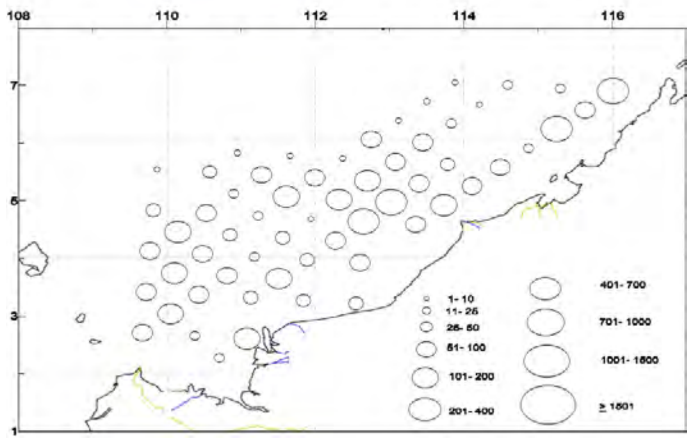


Fig. 20 Abundance and distribution of *Bregmaceros rarisquamosus* larvae (No./1000m^3) obtained from the oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

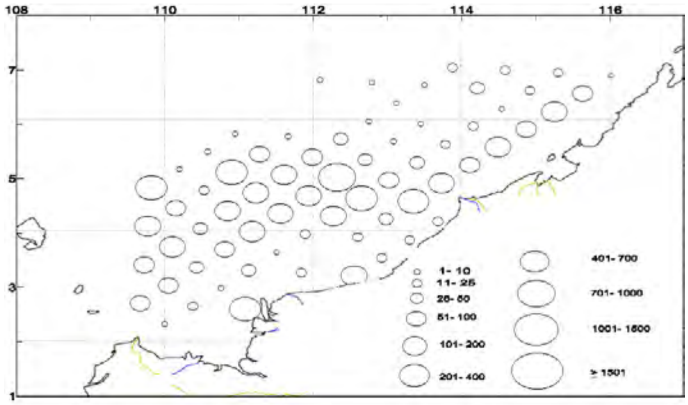


Fig. 21 Abundance and distribution of *Bregmaceros rarisquamosus* larvae (No./1000m^3) obtained from the oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

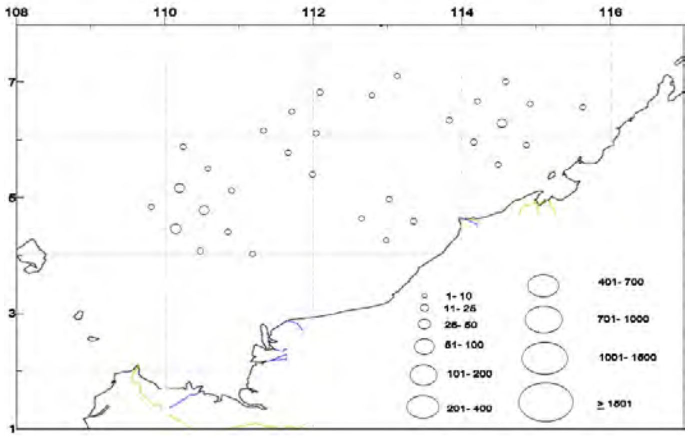


Fig. 22 Abundance and distribution of *Holocentrus* sp. larvae (No./1000m^3) obtained from surface haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

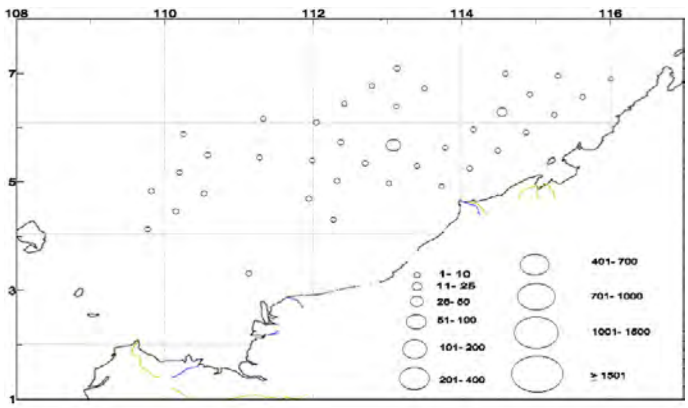


Fig. 23 Abundance and distribution of *Holocentrus* sp. larvae (No./1000m^3) obtained from surface haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

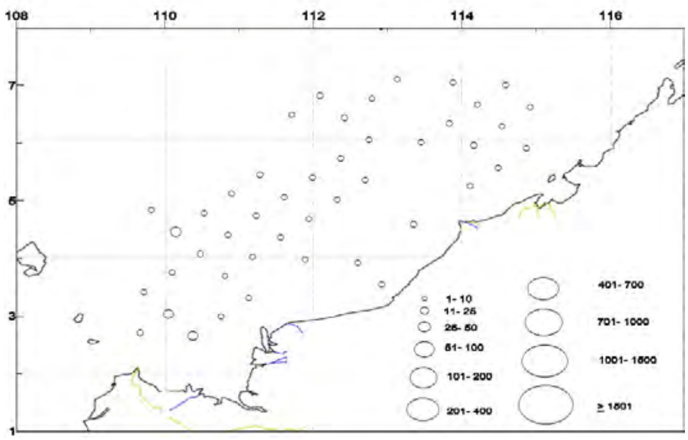


Fig. 24 Abundance and distribution of *Myripristis* sp. larvae (No./1000m^3) obtained from surface haul in the Area II between July and 9 August 1996 by M.V.SEAFDEC

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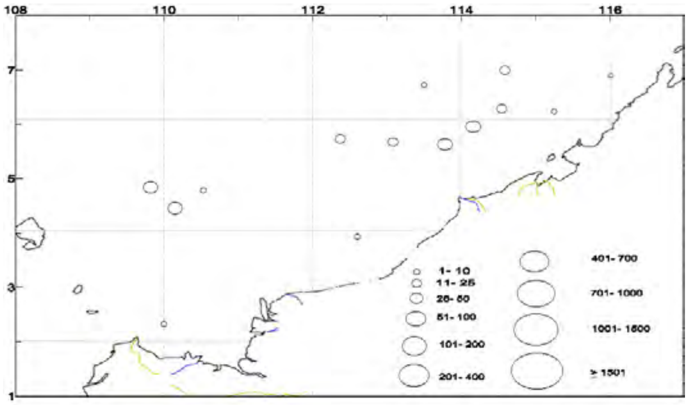

Fig. 25 Abundance and distribution of *Myripristis* sp. larvae (No./ 1000m^3) obtained from surface haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

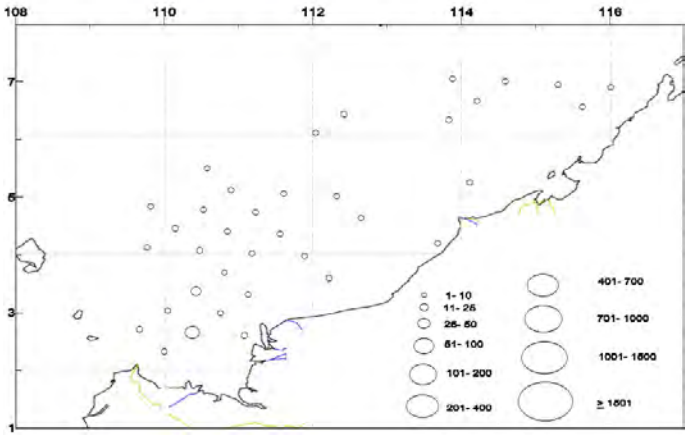

Fig. 26 Abundance and distribution of *Decapterus* sp. larvae (No./ 1000m^3) obtained from surface haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

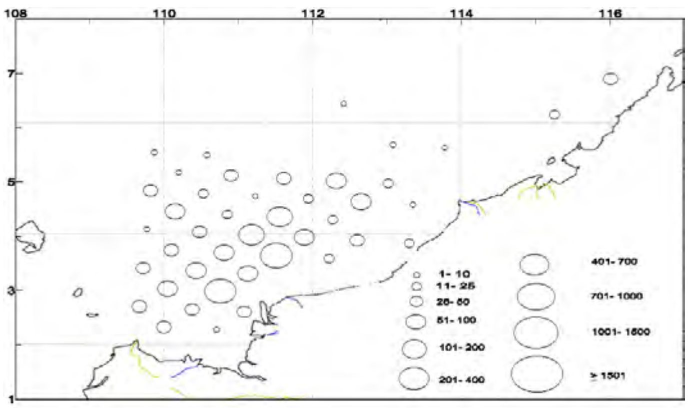

Fig. 27 Abundance and distribution of *Decapterus* sp. larvae (No./ 1000m^3) obtained from oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

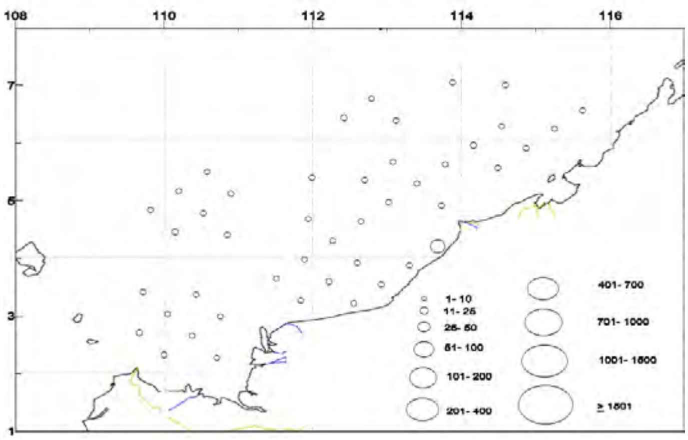

Fig. 28 Abundance and distribution of *Decapterus* sp. larvae (No./ 1000m^3) obtained from surface haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

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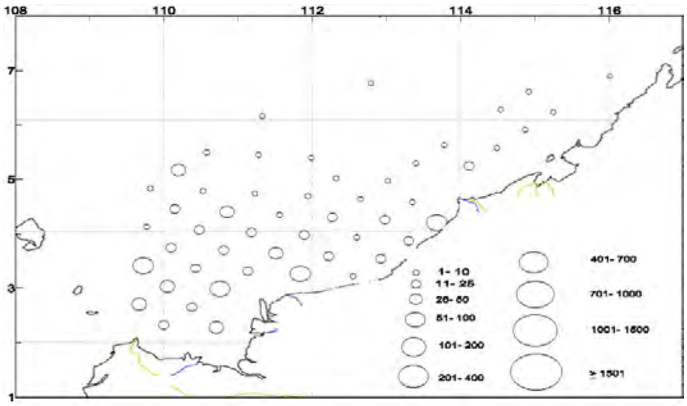

Fig. 29 Abundance and distribution of *Decapterus* sp. larvae (No./1000m^3) obtained from oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

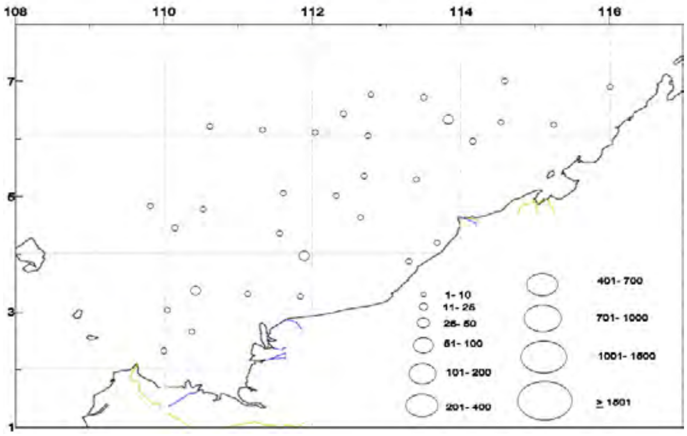

Fig. 30 Abundance and distribution of *Lutjanus* sp. larvae (No./1000m^3) obtained from surface haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

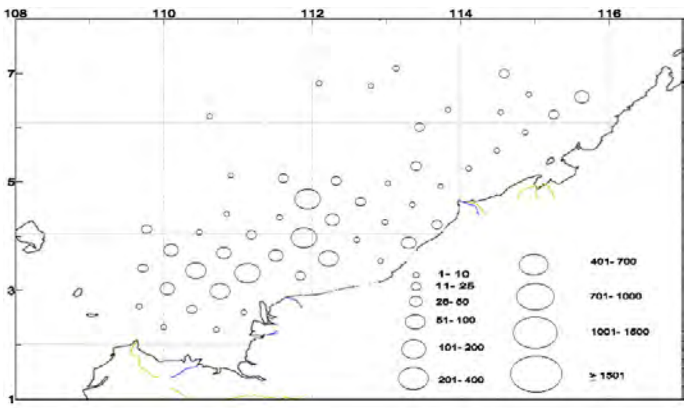

Fig. 31 Abundance and distribution of *Lutjanus* sp. larvae (No./1000m^3) obtained from oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

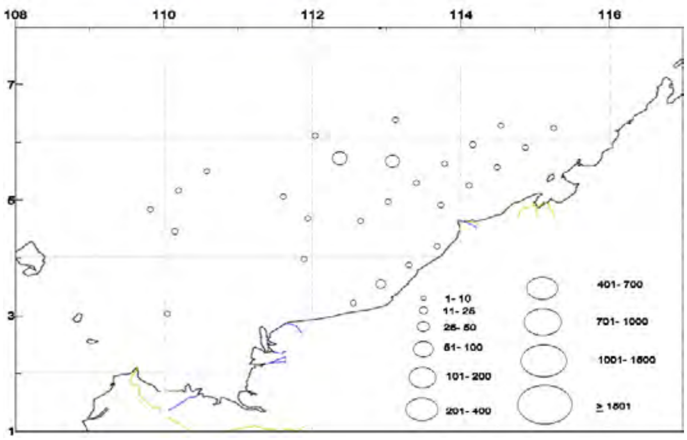

Fig. 32 Abundance and distribution of *Lutjanus* sp. larvae (No./1000m^3) obtained from surface haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

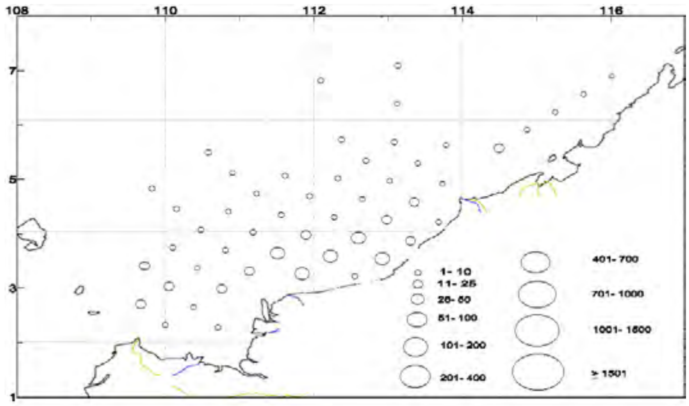

Fig. 33 Abundance and distribution of *Lutjanus* sp. larvae (No./$1000m^3$) obtained from oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

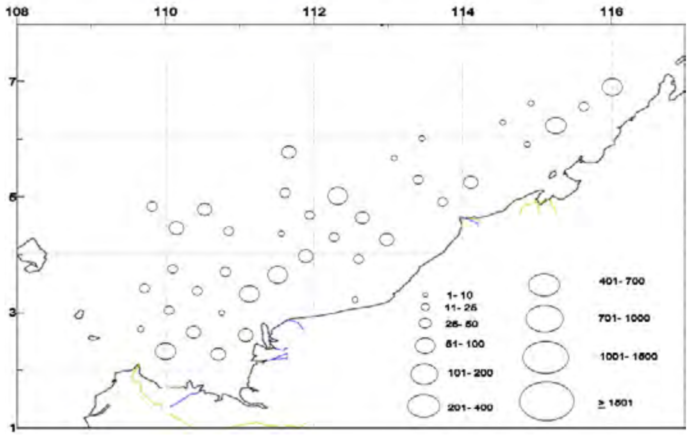

Fig. 34 Abundance and distribution of *Nemipterus* sp. larvae (No./$1000m^3$) obtained from oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

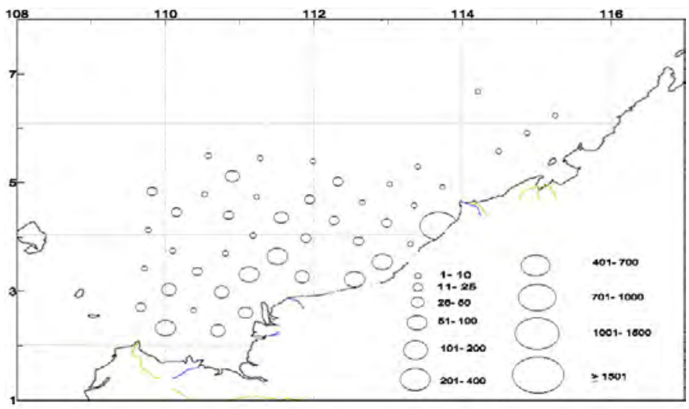

Fig. 35 Abundance and distribution of *Nemipterus* sp. larvae (No./$1000m^3$) obtained from oblique haul in the Area II between 25 April and 31 May 1996 by M.V.SEAFDEC

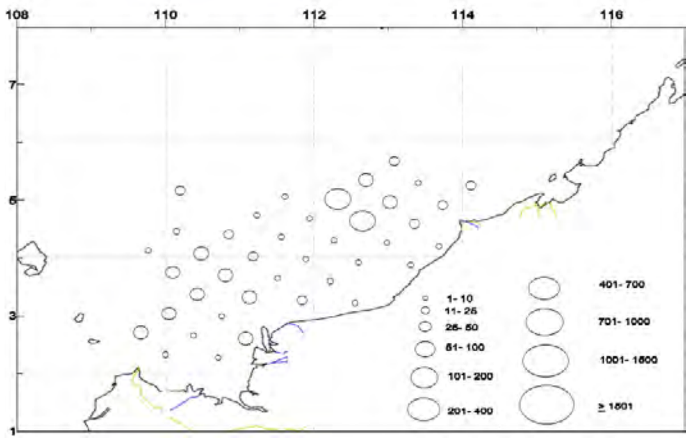

Fig. 36 Abundance and distribution of *Leiognathus* sp. larvae (No./$1000m^3$) obtained from oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

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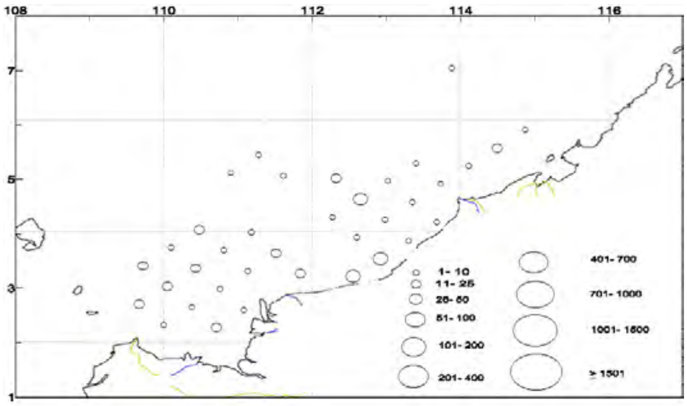

Fig. 37 Abundance and distribution of *Leiognathus* sp. larvae (No./ 1000m^3) obtained from oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

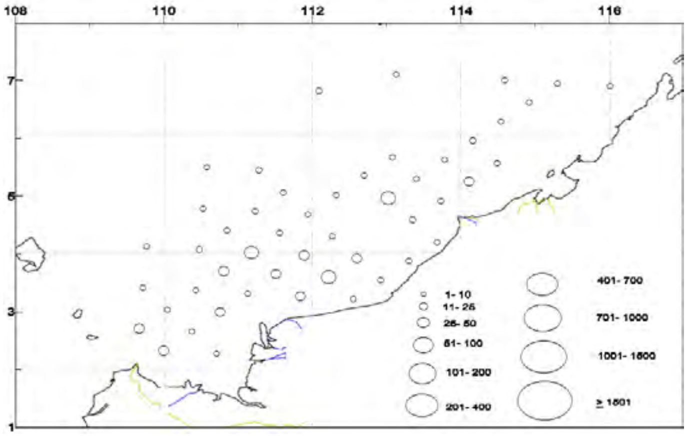

Fig. 38 Abundance and distribution of *Upeneus* sp. larvae (No./ 1000m^3) obtained from surface haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

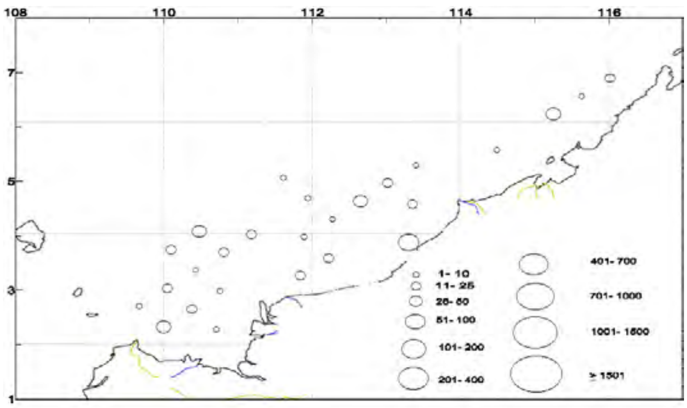

Fig. 39 Abundance and distribution of *Upeneus* sp. larvae (No./ 1000m^3) obtained from oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

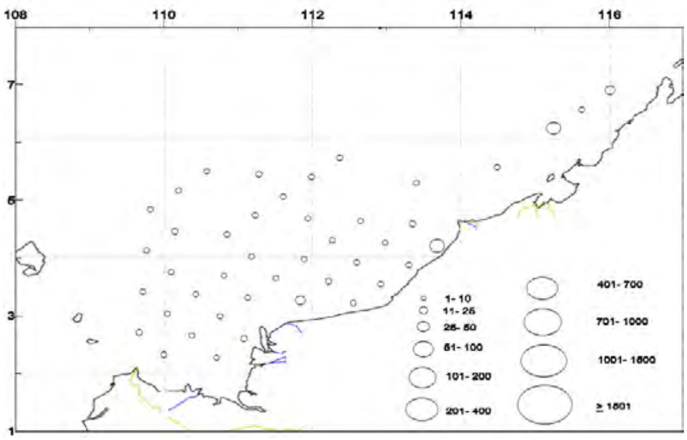

Fig. 40 Abundance and distribution of *Upeneus* sp. larvae (No./ 1000m^3) obtained from surface haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

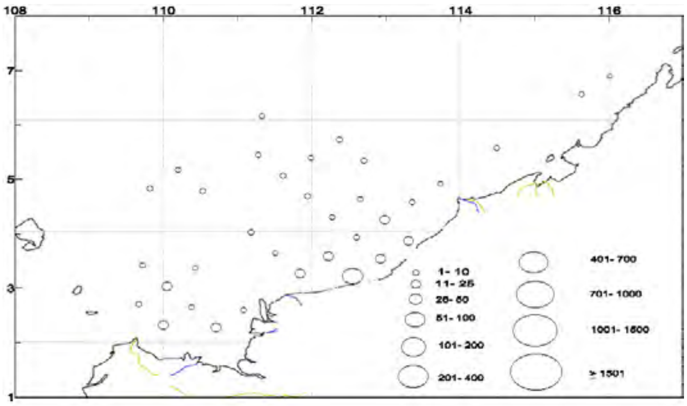

Fig. 41 Abundance and distribution of *Upeneus* sp. larvae (No./1000m^3) obtained from oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

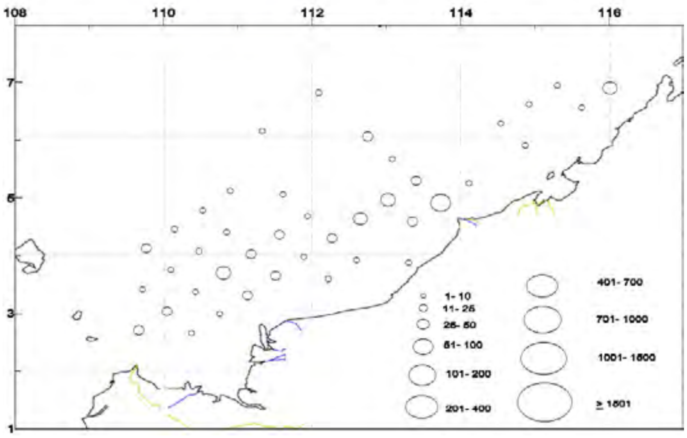

Fig. 42 Abundance and distribution of *Champsodon* sp. larvae (No./1000m^3) obtained from oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

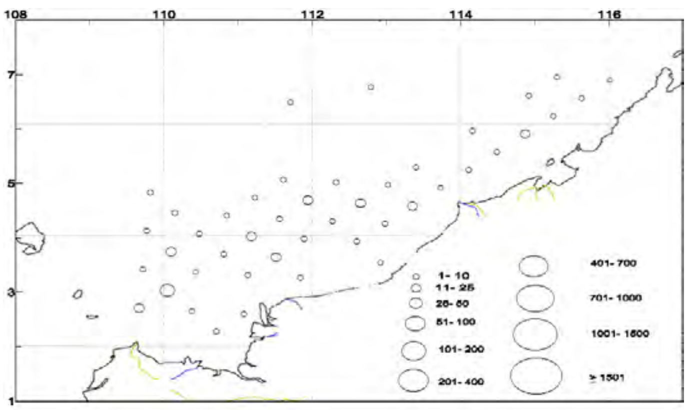

Fig. 43 Abundance and distribution of *Champsodon* sp. larvae (No./1000m^3) obtained from oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

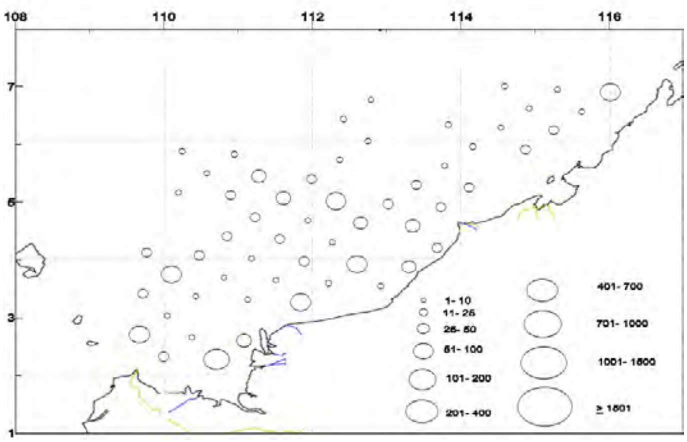

Fig. 44 Abundance and distribution of *Callionymus* sp. larvae (No./1000m^3) obtained from oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

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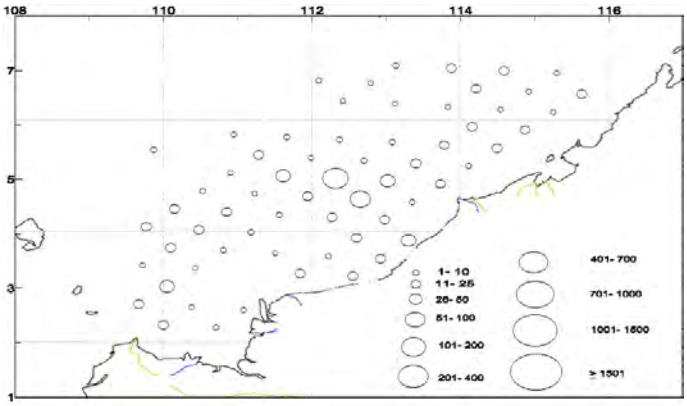

Fig. 45 Abundance and distribution of *Callionymus* sp. larvae (No./1000m^3) obtained from oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

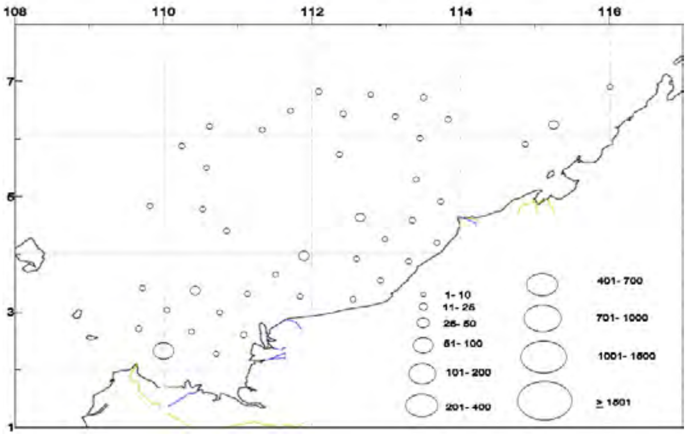

Fig. 46 Abundance and distribution of *Gobiidae* larvae (No./1000m^3) obtained from surface haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

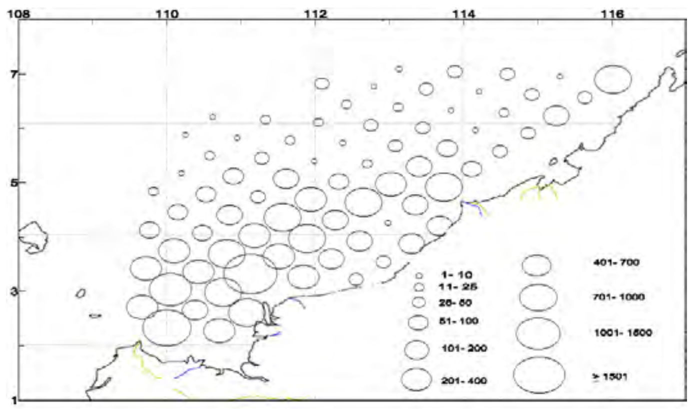

Fig. 47 Abundance and distribution of *Gobiidae* larvae (No./1000m^3) obtained from oblique haul in the Area II between 9 July and 9 August 1996 by M.V.SEAFDEC

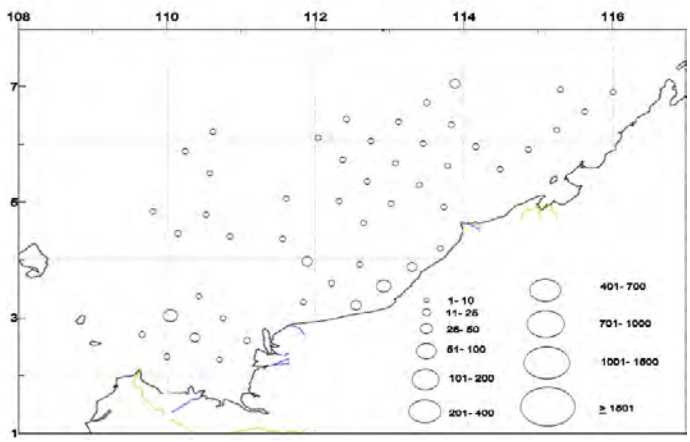

Fig. 48 Abundance and distribution of *Gobiidae* larvae (No./1000m^3) obtained from surface haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

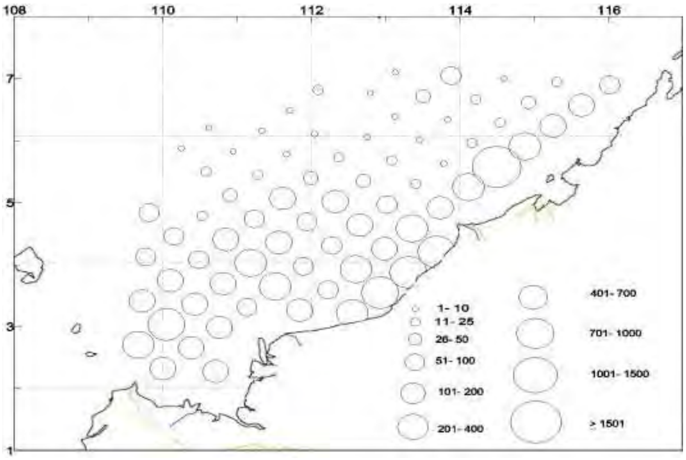

Fig. 49 Abundance and distribution of *Gobiidae* larvae (No./1000m^3) obtained from oblique haul in the Area II between 25 April and 31 May 1997 by M.V.SEAFDEC

deep area and were collected by oblique haul or surface haul in the early morning, night time and cloudy day sampling.

Conclusion

1. There were three character of fish latvae occurred in these sampling cruise. These were pelagic, demersal and mesopelagic larvae.
2. Mesopelagic larvae occurred in the deep area station which mostly collected by oblique haul.
3. Phototaxis were effected to the abundant of mesopelagic larvae
4. Fish larvae found in abundance from surface haul of the pre and post northeast monsoon cruise were *Sardinella* sp., *Stolephorus* sp., *Myripristis* sp., *Holocentrus* sp., *Upeneus* sp., *Decapterus* sp. and *Euthynus* sp., respectively. For the oblique hauls, these were Gobiidae, *Bregmaceros rarisquamosus*, *Decapterus* sp.,*Apogon* sp., *Nemipterus* sp., *Callionymus* sp., *Hygophum* sp., *Myctophum* sp. and *Benthosema* sp., respectively.
5. Fish larvae in the shallow water or coastal area were more abundant than the deeper water or open sea.

Acknowledgements

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References

Delsman, H.C. 1922. Fish eggs and larvae from the Java sea. 2. *Chirocentrus dorab* (Forsk). *Treubia*, 3: 38-46.

Delsman, H.C. 1925. Fish eggs and larvae from the Java sea. 4. *Dussumieria hasseltii*, Blkr. *Treubia*, 6: 297-307.

Delsman, H.C. 1926. Fish eggs and larvae from the Java sea.7. The genus *Clupia. Treubia*, 8: 218-239.

Delsman, H.C. 1930. Fish eggs and larvae from the Java sea. 12. The genus *Engraulis*. *Treubia*, 11: 275-281.

Delsman, H.C. 1932. Fish eggs and larvae from the Java sea. 19. The genus *Setipinna. Treubia*, 14: 109-114.

Delsman, H.C. 1933. Fish eggs and larvae from the Java sea. 23. A few more *Clupea* eggs. *Treubia*, 14: 249-254.

Delsman, H.C. 1938. Fish eggs and larvae from the Java sea. 24. *Myctophoidea.Treubia*, 16: 415-420.

Fahay, Michae P. 1983. Guide the early stages of merine fishes occurring in the Western North Atlantic Ocean, Cape Hatteras to the Southern Scotian Shelf. Journal of Northwest Atlantic Fisheries Science. 4 : 430.

Fish and Wildlife Service. 1978. Development of fishes of the Mid Atlantic Bight : An atlas of egg, larvae and juvenile stages, Vol. 1-6 US. Dept. Int. Biol. Serv. Prog. FWS/OBS - 78/12.

Leis, J.M. and D.S. Rennis. 1983. The larvae of Indo-Pacific coral reef fishes. New South Wales. Univ. Press Australia 2691 p.

Leis, J.M. and T. Trnski. 1989. The larvae of Indo-Pacific shore fishes. New South Wales. Univ. Press Australia 371 p.

Mito, S. 1966. Fish eggs and larvae. In illustrations of the marine plankton of Japan, Vol. 7 editor by S. Motoda. Tokyo: Shoyo Sha.74 p.

Moser, H.G. (ed). 1983. Ontogeny and systematics of fishes special Publication Number 1.American Society of Ichthyologists and Herpetologists. Allen Press Inc. KS. USA. 760 p.

Okiyama, M. 1988. An atlas of the early life stage fishes in Japan. Tokai Univ. Press. 1154 p.

Ozawa, T. 1986. Studies on the oceanic icthyoplanktons in the Western North Pacific. Kyushu University Press. 430 p.

Temvidchakorn, A. 1983. Studies on the development and distribution of the carangid fishes in the Kuroshio and adjacent region. D. Agri. thesis. University of Tokyo. 429 p.

Vatanachai, S. 1972. The identification of fish eggs and fish larvae obtained from the servery cruise in the South China Sea. Third symeposium on marine fisheries, Marine Laboratory. M.F 272-10 p. 1-27.

Appendix 1 The surface holizontal haul data of standard fish larvae net obtained from M.V.SEAFDEC in 1996

Stn. No.	Date	Time	Position		Depth	Rev	Volume
			Latitude	Longitude	(m.)		(m3)
1	7/10/96	0606-0638	02-20.0N	110-00.0E	36	16280	1840.908
2	7/10/96	1029-1100	02-42.8N	109-40.3E	54	17502	1979.089
3	7/10/96	1624-1652	03-25.3N	109-43.3E	79	18353	2075.318
4	7/10/96	2040-2108	03-02.5N	110-03.0E	66	14935	1688.818
5	7/11/96	0600-0630	02-39.8N	110-22.6E	85	15774	1738.69
6	7/11/96	1021-1048	02-17.0N	110-42.3E	41	14001	1583.203
7	7/11/96	1447-1506	02-36.8N	111-04.9E	35	10483	1185.395
8	7/11/96	1853-1918	02-59.5N	110-45.3E	39	15762	1782.333
9	7/12/96	0548-0618	03-22.3N	110-25.6E	65	20365	2302.831
10	7/12/96	1013-1043	03-45.1N	110-05.9E	85	15572	1760.848
11	7/12/96	1428-1503	04-07.8N	109-46.2E	100	14221	1608.080
12	7/12/96	2016-2044	04-50.3N	109-49.2E	118	14794	1672.874
13	7/13/96	0539-0607	04-27.6N	110-08.9E	115	15560	1759.491
14	7/13/96	1003-1033	04-04.8N	110-28.6E	94	15954	1804.044
15	7/13/96	1417-1443	03-42.1N	110-48.3E	66	18001	2035.515
16	7/13/96	1836-1901	03-19.3N	111-07.9E	62	14320	1619.275
17	7/14/96	0703-0723	03-16.3N	111-50.3E	29	14907	1685.652
18	7/14/96	1120-1145	03-39.1N	111-30.6E	50	11853	1340.312
19	7/14/96	1559-1626	04-01.8N	111-10.9E	70	8625	975.297
20	7/14/96	2030-2100	04-24.6N	110-51.2E	89	17223	1947.540
21	7/15/96	0539-0608	04-47.3N	110-31.5E	117	14078	1591.910
22	7/15/96	0957-1025	05-10.1N	110-11.8E	145	14515	1641.325
23	7/15/96	1409-1439	05-32.8N	109-52.0E	145	18530	2095.333
24	7/15/96	1839-1907	05-52.6N	110-14.8E	530	14177	1603.105
25	7/16/96	0537-0605	05-29.9N	111-34.5E	207	12625	1427.608
26	7/16/96	1013-1042	05-07.1N	110-54.2E	123	16618	1879.128
27	7/16/96	1431-1500	04-44.4N	111-13.9E	95	17864	2020.023
28	7/16/96	1852-1921	04-21.6N	111-33.7E	80	13596	1537.407
29	7/17/96	0540-0610	03-58.9N	111-53.4E	57	16335	1847.127
30	7/17/96	1011-1040	03-36.1N	112-13.0E	32	15828	1789.796
31	7/17/96	1910-1936	03-13.4N	112-32.7E	22	15122	1709.963
32	7/19/96	0537-0605	03-33.1N	112-55.4E	32	16847	1905.023
33	7/19/96	1004-1032	03-55.9N	112-35.7E	48	15025	1698.995
34	7/19/96	1423-1451	04-18.6N	112-16.0E	71	20181	2282.024
35	7/19/96	1839-1908	04-41.1N	111-56.3E	87	18210	2059.148
36	7/20/96	0540-0608	05-04.1N	111-36.6E	109	19602	2216.552
37	7/20/96	1018-1047	05-26.9N	111-16.8E	446	14517	1641.551
38	7/20/96	1440-1510	05-49.6N	110-57.1E	1063	16129	1823.833
39	7/20/96	1930-1958	06-12.4N	110-37.3E	1234	11272	1274.614
40	7/21/96	0538-0608	06-09.4N	111-19.8E	922	13231	1496.133
41	7/21/96	1020-1050	05-46.6N	111-39.6E	1300	11654	1317.809
42	7/21/96	1510-1540	05-23.9N	111-59.3E	132	16858	1906.267
43	7/21/96	1923-1953	05-01.1N	112-19.0E	105	15541	1757.343
44	7/22/96	0537-0605	04-38.4N	112-38.7E	90	13402	1515.469
45	7/22/96	1000-1028	04-15.6N	112-58.5E	67	13231	1496.133
46	7/22/96	1422-1442	03-52.9N	113-18.1E	22	10872	1229.382
47	7/22/96	1819-1840	04-12.7N	113-40.8E	28	10955	1238.768
48	7/24/96	0848-0918	04-35.4N	113-21.1E	79	16183	1829.939
49	7/24/96	1258-1328	04-58.2N	113-01.4E	105	15964	1805.175
50	7/24/96	1719-1748	05-20.9N	112-41.7E	520	12228	1382.716
51	7/25/96	0540-0610	05-43.7N	112-21.9E	192	17239	1949.349
52	7/25/96	1002-1032	06-06.4N	112-02.2E	1650	10298	1164.476
53	7/25/96	1519-1952	06-29.2N	111-42.4E	1941	17704	2001.930
54	7/25/96	2054-2123	06-48.9N	112-05.2E	2008	11546	1305.597
55	7/26/96	0542-0612	06-26.2N	112-24.9E	1318	7771	878.728
56	7/26/96	1026-1056	06-03.4N	112-44.7E	1136	12755	1442.308
57	7/26/96	1500-1529	05-40.7N	113-04.5E	2355	16425	1857.304
58	7/26/96	2009-2038	05-17.9N	113-24.2E	1622	14514	1641.212
59	7/27/96	0538-0607	04-55.2N	113-43.9E	95	11458	1295.646
60	7/27/96	0947-1017	05-15.0N	114-06.6E	235	13997	1582.751
61	7/27/96	1403-1434	05-37.7N	113-46.9E	2142	17952	2029.974
62	7/27/96	1910-1939	06-00.5N	113-27.1E	2567	8855	1001.304
63	7/28/96	0540-0608	06-23.2N	113-07.4E	1623	13890	1570.651
64	7/28/96	1050-1120	06-46.0N	112-47.6E	1261	11600	1311.703
65	7/28/96	1532-1602	07-05.7N	113-10.4E	1535	16646	1882.294
66	7/28/96	2013-2044	06-43.0N	113-30.1E	1883	11573	1308.650
67	7/29/96	0542-0612	06-20.2N	113-49.9E	2820	15394	1740.721
68	7/29/96	1055-1125	05-57.5N	114-09.7E	1785	12426	1405.105
69	7/29/96	1547-1617	05-34.7N	114-29.4E	100	16471	1862.505
70	7/29/96	2014-2044	05-54.5N	114-52.1E	125	15104	1707.928
71	7/31/96	1359-1430	06-17.2N	114-32.4E	2078	15522	1755.195
72	7/31/96	1811-1841	06-40.0N	114-12.6E	2867	11380	1286.826
73	7/31/96	2327-2358	07-02.7N	113-52.8E	1836	13121	1483.695
74	7/1/96	0855-0925	06-59.8N	114-35.4E	2893	12293	1390.066
75	7/1/96	1408-1439	06-37.0N	114-55.2E	1751	19169	2167.589
76	7/1/96	1910-1940	06-14.3N	115-14.9E	111	15244	1723.759
77	7/2/96	0537-0607	06-34.0N	115-33.7E	95	12719	1438.237
78	7/2/96	1006-1037	06-56.8N	115-17.9E	1498	11181	1264.324
79	7/2/96	1616-1647	06-53.8N	116-00.4E	42	10270	1161.310

Appendix 2 The oblique haul data of bongo net obtained from M.V.SEAFDEC in 1996

Stn. No.	Date	Time	Position		Depth	Depth of	Rev	Volume
			Latitude	Longitude	(m.)	hual (m)		(m3)
1	7/10/96	0606-0638	02-20.0N	110-00.0E	36	30	18040	439.891
2	7/10/96	1029-1100	02-42.8N	109-40.3E	54	50	22091	538.671
3	7/10/96	1624-1652	03-25.3N	109-43.3E	79	74	19900	485.246
4	7/10/96	2040-2108	03-02.5N	110-03.0E	66	61	16696	407.119
5	7/11/96	0600-0630	02-39.8N	110-22.6E	85	80	16305	397.584
6	7/11/96	1021-1048	02-17.0N	110-42.3E	41	35	18706	456.131
7	7/11/96	1447-1506	02-36.8N	111-04.9E	35	30	7820	190.684
8	7/11/96	1853-1918	02-59.5N	110-45.3E	39	34	18512	451.400
9	7/12/96	0548-0618	03-22.3N	110-25.6E	65	60	22100	538.891
10	7/12/96	1013-1043	03-45.1N	110-05.9E	85	80	15193	370.469
11	7/12/96	1428-1503	04-07.8N	109-46.2E	100	95	17137	417.872
12	7/12/96	2016-2044	04-50.3N	109-49.2E	118	110	16072	391.903
13	7/13/96	0539-0607	04-27.6N	110-08.9E	115	110	16110	392.830
14	7/13/96	1003-1033	04-04.8N	110-28.6E	94	89	18418	449.108
15	7/13/96	1417-1443	03-42.1N	110-48.3E	66	61	16362	398.974
16	7/13/96	1836-1901	03-19.3N	111-07.9E	62	50	17778	433.502
17	7/14/96	0703-0723	03-16.3N	111-50.3E	29	24	11656	284.222
18	7/14/96	1120-1145	03-39.1N	111-30.6E	50	45	13446	327.870
19	7/14/96	1559-1626	04-01.8N	111-10.9E	70	65	19238	469.103
20	7/14/96	2030-2100	04-24.6N	110-51.2E	89	85	18615	453.912
21	7/15/96	0539-0608	04-47.3N	110-31.5E	117	110	15565	379.540
22	7/15/96	0957-1025	05-10.1N	110-11.8E	145	140	13895	338.819
23	7/15/96	1409-1439	05-32.8N	109-52.0E	145	140	19847	483.953
24	7/15/96	1839-1907	05-52.6N	110-14.8E	530	150	14175	345.646
25	7/16/96	0537-0605	05-29.9N	111-34.5E	207	150	16050	391.366
26	7/16/96	1013-1042	05-07.1N	110-54.2E	123	115	17450	425.504
27	7/16/96	1431-1500	04-44.4N	111-13.9E	95	90	17853	453.331
28	7/16/96	1852-1921	04-21.6N	111-33.7E	80	75	10602	258.521
29	7/17/96	0540-0610	03-58.9N	111-53.4E	57	52	21130	515.238
30	7/17/96	1011-1040	03-36.1N	112-13.0E	32	25	19588	477.638
31	7/17/96	1910-1936	03-13.4N	112-32.7E	22	15	17067	416.165
32	7/19/96	0537-0605	03-33.1N	112-55.4E	32	27	18780	457.935
33	7/19/96	1004-1032	03-55.9N	112-35.7E	48	43	18931	437.233
34	7/19/96	1423-1451	04-18.6N	112-16.0E	71	65	17911	436.745
35	7/19/96	1839-1908	04-41.1N	111-56.3E	87	80	17666	430.771
36	7/20/96	0540-0608	05-04.1N	111-36.6E	109	100	20407	497.608
37	7/20/96	1018-1047	05-26.9N	111-16.8E	446	150	9920	241.891
38	7/20/96	1440-1510	05-49.6N	110-57.1E	1063	150	18113	441.671
39	7/20/96	1930-1958	06-12.4N	110-37.3E	1234	150	11109	270.884
40	7/21/96	0538-0608	06-09.4N	111-19.8E	922	150	16948	413.263
41	7/21/96	1020-1050	05-46.6N	111-39.6E	1300	150	15122	368.738
42	7/21/96	1510-1540	05-23.9N	111-59.3E	132	125	19018	463.739
43	7/21/96	1923-1953	05-01.1N	112-19.0E	105	100	13212	322.164
44	7/22/96	0537-0605	04-38.4N	112-38.7E	90	85	13569	330.869
45	7/22/96	1000-1028	04-15.6N	112-58.5E	67	62	17861	435.526
46	7/22/96	1422-1442	03-52.9N	113-18.1E	22	17	11481	279.955
47	7/22/96	1819-1840	04-12.7N	113-40.8E	28	23	11464	279.541
48	7/24/96	0848-0918	04-35.4N	113-21.1E	79	74	13786	336.161
49	7/24/96	1258-1328	04-58.2N	113-01.4E	105	100	16139	393.537
50	7/24/96	1719-1748	05-20.9N	112-41.7E	520	150	7684	187.368
51	7/25/96	0540-0610	05-43.7N	112-21.9E	192	150	18778	457.887
52	7/25/96	1002-1032	06-06.4N	112-02.2E	1650	150	18977	462.739
53	7/25/96	1519-1952	06-29.2N	111-42.4E	1941	150	21013	512.385
54	7/25/96	2054-2123	06-48.9N	112-05.2E	2008	150	16400	399.901
55	7/26/96	0542-0612	06-26.2N	112-24.9E	1318	150	13974	340.745
56	7/26/96	1026-1056	06-03.4N	112-44.7E	1136	150	12169	296.731
57	7/26/96	1500-1529	05-40.7N	113-04.5E	2355	150	16118	393.025
58	7/26/96	2009-2038	05-17.9N	113-24.2E	1622	150	10498	255.985
59	7/27/96	0538-0607	04-55.2N	113-43.9E	95	90	11961	291.659
60	7/27/96	0947-1017	05-15.0N	114-06.6E	235	150	13787	336.185
61	7/27/96	1403-1434	05-37.7N	113-46.9E	2142	150	12617	307.656
62	7/27/96	1910-1939	06-00.5N	113-27.1E	2567	150	9052	220.726
63	7/28/96	0540-0608	06-23.2N	113-07.4E	1623	150	10725	261.521
64	7/28/96	1050-1120	06-46.0N	112-47.6E	1261	150	16879	411.581
65	7/28/96	1532-1602	07-05.7N	113-10.4E	1535	150	16505	402.461
66	7/28/96	2013-2044	06-43.0N	113-30.1E	1883	150	8257	201.340
67	7/29/96	0542-0612	06-20.2N	113-49.9E	2820	150	12770	311.386
68	7/29/96	1055-1125	05-57.5N	114-09.7E	1785	150	12455	303.705
69	7/29/96	1547-1617	05-34.7N	114-29.4E	100	95	12947	315.702
70	7/29/96	2014-2044	05-54.5N	114-52.1E	125	120	10487	255.717
71	7/31/96	1359-1430	06-17.2N	114-32.4E	2078	150	20655	503.656
72	7/31/96	1811-1841	06-40.0N	114-12.6E	2867	150	11773	287.075
73	7/31/96	2327-2358	07-02.7N	113-52.8E	1836	150	9512	231.943
74	7/1/96	0855-0925	06-59.8N	114-35.4E	2893	150	12160	296.512
75	7/1/96	1408-1439	06-37.0N	114-55.2E	1751	150	20540	500.852
76	7/1/96	1910-1940	06-14.3N	115-14.9E	111	105	7082	172.689
77	7/2/96	0537-0607	06-34.0N	115-33.7E	95	90	14290	348.450
78	7/2/96	1006-1037	06-56.8N	115-17.9E	1498	150	18377	448.108
79	7/2/96	1616-1647	06-53.8N	116-00.4E	42	36	7541	181.687

Appendix 3 The surface holizontal haul data of standard fish larvae net obtained from M.V.SEAFDEC in 1997

Stn. No.	Date	Time	Position		Depth	Rev	Volume
			Latitude	Longitude	(m.)		(m3)
1	5/1/97	0555-0625	02-20.0N	110-00.0E	35.5	14265	3323.137
2	5/1/97	1027-1053	02-42.8N	109-40.3E	57.1	13809	3216.909
3	5/1/97	1548-1618	03-25.3N	109-43.3E	80	19051	4438.071
4	5/1/97	2035-2100	03-02.5N	110-03.0E	67	11154	2598.407
5	5/2/97	0550-0618	02-39.8N	110-22.6E	73	17128	3990.094
6	5/2/97	1008-1033	02-17.0N	110-42.3E	41.7	13418	3125.822
7	5/2/97	1404-1432	02-36.8N	111-04.9E	35	14552	3389.996
8	5/2/97	1822-1850	02-59.5N	110-45.3E	40	13080	3047.083
9	5/3/97	0554-0624	03-22.3N	110-25.6E	64	16998	3959.810
10	5/3/97	1015-1045	03-45.1N	110-05.9E	85	16061	3741.529
11	5/3/97	1440-1509	04-07.8N	109-46.2E	100	18313	4266.149
12	5/3/97	2017-2045	04-50.3N	109-49.2E	119	11262	2623.566
13	5/4/97	0550-0616	04-27.6N	110-08.9E	113	16688	3887.593
14	5/4/97	1006-1035	04-04.8N	110-28.6E	92	14666	3416.553
15	5/4/97	1418-1446	03-42.1N	110-48.3E	66	15091	3515.56
16	5/4/97	1837-1906	03-19.3N	111-07.9E	65	13280	3093.674
17	5/5/97	0552-0620	03-16.3N	111-50.3E	29	11920	2776.852
18	5/5/97	1014-1043	03-39.1N	111-30.6E	48	10928	2545.758
19	5/5/97	1420-1448	04-01.8N	111-10.9E	71	17143	3993.589
20	5/5/97	1833-1901	04-24.6N	110-51.2E	90	9470	2206.107
21	5/6/97	0549-0619	04-47.3N	110-31.5E	118	16554	3856.377
22	5/6/97	1006-1034	05-10.1N	110-11.8E	145	12834	2989.775
23	5/6/97	1436-1505	05-32.8N	109-52.0E	145	17334	4038.083
24	5/6/97	1852-1922	05-52.6N	110-14.8E	530	15643	3644.153
25	5/7/97	0545-0615	05-29.9N	111-34.5E	200	11395	2654.549
26	5/7/97	1002-1032	05-07.1N	110-54.2E	123	10723	2498.002
27	5/7/97	1421-1449	04-44.4N	111-13.9E	95	16502	3844.263
28	5/7/97	1835-1905	04-21.6N	111-33.7E	80	14132	3292.154
29	5/8/97	0550-0620	03-58.9N	111-53.4E	57	15294	3562.85
30	5/8/97	1010-1037	03-36.1N	112-13.0E	32	10071	2346.114
31	5/9/97	1924-1950	03-13.4N	112-32.7E	21	12065	2810.631
32	5/10/97	0547-0614	03-33.1N	112-55.4E	34	13752	3203.630
33	5/10/97	0948-1017	03-55.9N	112-35.7E	49	14923	3476.423
34	5/10/97	1410-1440	04-18.6N	112-16.0E	73	15693	3655.800
35	5/10/97	1838-1908	04-41.1N	111-56.3E	88	13680	3186.857
36	5/11/97	0549-0618	05-04.1N	111-36.6E	110	14715	3427.968
37	5/11/97	0957-1027	05-26.9N	111-16.8E	435	16805	3914.849
38	5/11/97	1434-1504	05-49.6N	110-57.1E	1071	15675	3651.607
39	5/11/97	1925-1955	06-12.4N	110-37.3E	1234	13673	3185.226
40	5/12/97	0547-0617	06-09.4N	111-19.8E	1173	16174	3767.853
41	5/12/97	1016-1046	05-46.6N	111-39.6E	1304	15985	3723.824
42	5/12/97	1450-1520	05-23.9N	111-59.3E	136	16469	3836.575
43	5/12/97	1857-1925	05-01.1N	112-19.0E	105	12031	2802.710
44	5/13/97	0547-0617	04-38.4N	112-38.7E	89	13342	3108.118
45	5/13/97	0940-1010	04-15.6N	112-58.5E	67	19896	4634.920
46	5/13/97	1344-1412	03-52.9N	113-18.1E	22	14764	3439.383
47	5/13/97	1740-1809	04-12.7N	113-40.8E	30	7558	1760.692
48	5/15/97	1250-1320	04-35.4N	113-21.1E	79	9534	2221.016
49	5/15/97	1705-1734	04-58.2N	113-01.4E	106	18661	4347.218
50	5/15/97	2113-2143	05-20.9N	112-41.7E	560	25008	5825.798
51	5/16/97	0547-0617	05-43.7N	112-21.9E	192	15558	3624.351
52	5/16/97	1004-1034	06-06.4N	112-02.2E	1584	16324	3802.796
53	5/16/97	1504-1534	06-29.2N	111-42.4E	1951	15956	3717.068
54	5/16/97	2021-2051	06-48.9N	112-05.2E	2009	14020	3266.063
55	5/17/97	0546-0616	06-26.2N	112-24.9E	1279	13742	3201.301
56	5/17/97	1030-1100	06-03.4N	112-44.7E	1081	17864	4161.551
57	5/17/97	1504-1534	05-40.7N	113-04.5E	2352	13420	3126.288
58	5/17/97	2047-2117	05-17.9N	113-24.2E	1617	14542	3387.666
59	5/18/97	0549-0619	04-55.2N	113-43.9E	95	13880	3233.449
60	5/18/97	1000-1030	05-15.0N	114-06.6E	233	7088	1651.202
61	5/18/97	1539-1609	05-37.7N	113-46.9E	2151	14122	3289.824
62	5/18/97	2040-2110	06-00.5N	113-27.1E	2556	14278	3326.166
63	5/19/97	0547-0617	06-23.2N	113-07.4E	1603	13204	3075.969
64	5/19/97	1009-1039	06-46.0N	112-47.6E	1267	12676	2952.968
65	5/19/97	1430-1500	07-05.7N	113-10.4E	1555	15496	3609.908
66	5/19/97	1858-1928	06-43.0N	113-30.1E	1885	14261	3322.205
67	5/20/97	0549-0618	06-20.2N	113-49.9E	1816	12315	2868.870
68	5/20/97	1032-1102	05-57.5N	114-09.7E	1792	13557	3158.203
69	5/21/97	2104-2134	05-34.7N	114-29.4E	104	12150	2830.432
70	5/22/97	0548-0618	05-54.5N	114-52.1E	132	12227	2848.370
71	5/22/97	1008-1038	06-17.2N	114-32.4E	2026	15541	3620.391
72	5/22/97	1500-1530	06-40.0N	114-12.6E	2865	15144	3527.907
73	5/22/97	1937-2007	07-02.7N	113-52.8E	1838	10390	2420.427
74	5/23/97	0546-0616	06-59.8N	114-35.4E	2893	12942	3014.935
75	5/23/97	1035-1105	06-37.0N	114-55.2E	1733	13084	3048.015
76	5/23/97	1504-1534	06-14.3N	115-14.9E	107	15927	3710.312
77	5/24/97	0551-0620	06-34.0N	115-33.7E	95	14605	3402.343
78	5/24/97	1006-1036	06-56.8N	115-17.9E	1504	13603	3168.919
79	5/24/97	1545-1612	06-53.8N	116-00.4E	45	15114	3520.918

Appendix 4 The oblique haul data of bongo net obtained from M.V.SEAFDEC in 1997

St. No.	Date	Time	Position		Depth	Depth of	Rev	Volume
			Latitude	Longitude	(m.)	hual (m)		(m3)
1	5/1/97	0555-0625	02-20.0N	110-00.0E	35.5	30	16489	896.929
2	5/1/97	1027-1053	02-42.8N	109-40.3E	57.1	52	13056	710.189
3	5/1/97	1548-1618	03-25.3N	109-43.3E	80	75	21610	1175.489
4	5/1/97	2035-2100	03-02.5N	110-03.0E	67	62	10910	593.456
5	5/2/97	0550-0618	02-39.8N	110-22.6E	73	68	15638	850.638
6	5/2/97	1008-1033	02-17.0N	110-42.3E	41.7	37	11836	643.826
7	5/2/97	1404-1432	02-36.8N	111-04.9E	35	30	17290	940.500
8	5/2/97	1822-1850	02-59.5N	110-45.3E	40	35	10798	587.634
9	5/3/97	0554-0624	03-22.3N	110-25.6E	64	59	14042	763.823
10	5/3/97	1015-1045	03-45.1N	110-05.9E	85	80	16650	905.687
11	5/3/97	1440-1509	04-07.8N	109-46.2E	100	95	16736	910.365
12	5/3/97	2017-2045	04-50.3N	109-49.2E	119	110	13164	716.064
13	5/4/97	0550-0616	04-27.6N	110-08.9E	113	106	15232	828.554
14	5/4/97	1006-1035	04-04.8N	110-28.6E	92	87	14292	777.422
15	5/4/97	1418-1446	03-42.1N	110-48.3E	66	60	16631	904.653
16	5/4/97	1837-1906	03-19.3N	111-07.9E	65	60	13003	707.306
17	5/5/97	0552-0620	03-16.3N	111-50.3E	29	25	12068	656.446
18	5/5/97	1014-1043	03-39.1N	111-30.6E	48	43	14214	773.179
19	5/5/97	1420-1448	04-01.8N	111-10.9E	71	66	17118	931.144
20	5/5/97	1833-1901	04-24.6N	110-51.2E	90	85	14015	762.354
21	5/6/97	0549-0619	04-47.3N	110-31.5E	118	113	15754	856.948
22	5/6/97	1006-1034	05-10.1N	110-11.8E	145	140	12724	692.130
23	5/6/97	1436-1505	05-32.8N	109-52.0E	145	125	17797	968.079
24	5/6/97	1852-1922	05-52.6N	110-14.8E	530	150	10030	545.588
25	5/7/97	0545-0615	05-29.9N	111-34.5E	200	150	10181	553.802
26	5/7/97	1002-1032	05-07.1N	110-54.2E	123	118	14974	814.520
27	5/7/97	1421-1449	04-44.4N	111-13.9E	95	90	15943	867.229
28	5/7/97	1835-1905	04-21.6N	111-33.7E	80	75	16583	902.042
29	5/8/97	0550-0620	03-58.9N	111-53.4E	57	53	13340	725.637
30	5/8/97	1010-1037	03-36.1N	112-13.0E	32	25	10942	595.197
31	5/9/97	1924-1950	03-13.4N	112-32.7E	21	16	12245	666.074
32	5/10/97	0547-0614	03-33.1N	112-55.4E	34	29	12092	657.752
33	5/10/97	0948-1017	03-55.9N	112-35.7E	49	44	14000	761.538
34	5/10/97	1410-1440	04-18.6N	112-16.0E	73	68	14126	768.392
35	5/10/97	1838-1908	04-41.1N	111-56.3E	88	83	12964	705.185
36	5/11/97	0549-0618	05-04.1N	111-36.6E	110	105	13084	711.712
37	5/11/97	0957-1027	05-26.9N	111-16.8E	435	150	13674	743.805
38	5/11/97	1434-1504	05-49.6N	110-57.1E	1071	120	23390	1272.313
39	5/11/97	1925-1955	06-12.4N	110-37.3E	1234	150	16024	871.635
40	5/12/97	0547-0617	06-09.4N	111-19.8E	1173	150	16098	875.660
41	5/12/97	1016-1046	05-46.6N	111-39.6E	1304	150	16355	889.640
42	5/12/97	1450-1520	05-23.9N	111-59.3E	136	130	21130	1149.379
43	5/12/97	1857-1925	05-01.1N	112-19.0E	105	100	11215	610.047
44	5/13/97	0547-0617	04-38.4N	112-38.7E	89	84	11109	604.281
45	5/13/97	0940-1010	04-15.6N	112-58.5E	67	62	19819	1078.066
46	5/13/97	1344-1412	03-52.9N	113-18.1E	22	17	16210	881.753
47	5/13/97	1740-1809	04-12.7N	113-40.8E	30	25	2470	134.357
48	5/15/97	1250-1320	04-35.4N	113-21.1E	79	74	20208	1099.226
49	5/15/97	1705-1734	04-58.2N	113-01.4E	106	100	16082	874.790
50	5/15/97	2113-2143	05-20.9N	112-41.7E	560	120	20272	1102.708
51	5/16/97	0547-0617	05-43.7N	112-21.9E	192	150	16615	903.783
52	5/16/97	1004-1034	06-06.4N	112-02.2E	1584	150	14337	779.870
53	5/16/97	1504-1534	06-29.2N	111-42.4E	1951	150	15150	824.093
54	5/16/97	2021-2051	06-48.9N	112-05.2E	2009	150	14351	780.631
55	5/17/97	0546-0616	06-26.2N	112-24.9E	1279	150	12808	696.699
56	5/17/97	1030-1100	06-03.4N	112-44.7E	1081	120	24954	1357.388
57	5/17/97	1504-1534	05-40.7N	113-04.5E	2352	150	13680	744.132
58	5/17/97	2047-2117	05-17.9N	113-24.2E	1617	150	20026	1089.326
59	5/18/97	0549-0619	04-55.2N	113-43.9E	95	90	7744	421.240
60	5/18/97	1000-1030	05-15.0N	114-06.6E	233	150	6140	333.989
61	5/18/97	1539-1609	05-37.7N	113-46.9E	2151	150	18132	986.301
62	5/18/97	2040-2110	06-00.5N	113-27.1E	2556	150	16566	901.118
63	5/19/97	0547-0617	06-23.2N	113-07.4E	1603	150	14274	776.443
64	5/19/97	1009-1039	06-46.0N	112-47.6E	1267	150	14474	787.322
65	5/19/97	1430-1500	07-05.7N	113-10.4E	1555	150	14817	805.980
66	5/19/97	1858-1928	06-43.0N	113-30.1E	1885	150	11756	639.475
67	5/20/97	0549-0618	06-20.2N	113-49.9E	1816	150	12909	702.193
68	5/20/97	1032-1102	05-57.5N	114-09.7E	1792	120	14471	787.159
69	5/21/97	2104-2134	05-34.7N	114-29.4E	104	95	16700	908.407
70	5/22/97	0548-0618	05-54.5N	114-52.1E	132	125	16234	883.058
71	5/22/97	1008-1038	06-17.2N	114-32.4E	2026	150	16478	896.331
72	5/22/97	1500-1530	06-40.0N	114-12.6E	2865	150	16988	924.073
73	5/22/97	1937-2007	07-02.7N	113-52.8E	1838	150	11345	617.118
74	5/23/97	0546-0616	06-59.8N	114-35.4E	2893	150	17064	928.207
75	5/23/97	1035-1105	06-37.0N	114-55.2E	1733	150	16724	909.712
76	5/23/97	1504-1534	06-14.3N	115-14.9E	107	100	15271	830.675
77	5/24/97	0551-0620	06-34.0N	115-33.7E	95	90	12300	669.066
78	5/24/97	1006-1036	06-56.8N	115-17.9E	1504	150	14080	765.890
79	5/24/97	1545-1612	06-53.8N	116-00.4E	45	40	11884	646.437

Appendix 5 The occurrence of the fish larvae obtained in the survey station of Area II.
STM-III = First Cruise (9 July - 9 August 1996).
STM-IV = Second Cruise (25 April - 31 May 1997)

Stn.No.	STM-III				STM-IV			
	Surface		Oblique		Surface		Oblique	
	T.No.	T.N./1000m^3	T.No.	T.N./1000m^3	T.No.	T.N./1000m^3	T.No.	T.N./1000m^3
1	267	145	826	1878	76	23	435	485
2	39	20	413	767	25	8	513	722
3	54	26	315	649	31	7	559	476
4	71	42	605	1486	239	92	693	1168
5	174	98	355	893	202	51	586	689
6	24	15	341	745	36	12	236	367
7	101	85	320	1678	10	3	755	803
8	103	58	549	1216	40	13	219	373
9	372	162	527	978	76	19	377	494
10	11	6	334	902	12	3	419	463
11	15	9	155	371	28	7	386	424
12	49	29	126	322	215	82	433	605
13	112	64	283	720	154	40	322	389
14	33	18	171	381	5	1	177	228
15	70	34	429	1075	12	3	371	350
16	129	80	1277	2946	44	14	314	444
17	323	192	231	813	144	52	557	849
18	54	40	482	1470	16	6	675	873
19	95	97	283	603	12	3	642	689
20	48	25	223	491	20	9	375	492
21	84	53	138	364	9	2	135	158
22	25	15	74	218	43	14	120	173
23	5	2	63	130	47	12	211	218
24	71	44	77	223	152	42	103	189
25	62	43	75	192	65	24	98	177
26	26	14	109	256	9	4	447	549
27	10	5	52	119	16	4	334	385
28	62	40	218	843	10	3	475	527
29	175	95	627	1217	214	60	208	289
30	81	45	184	385	28	12	147	247
31	103	60	77	185	309	110	664	997
32	68	36	39	85	503	157	589	895
33	104	61	233	533	90	26	626	822
34	4	2	238	545	43	12	387	504
35	68	33	241	559	36	11	300	425
36	40	18	281	565	25	7	298	419
37	22	13	60	248	34	9	106	143
38	23	13	40	91	47	13	100	79
39	64	50	115	425	12	4	262	301
40	66	44	118	286	42	11	146	167
41	8	6	79	214	15	4	167	188
42	7	4	93	201	38	10	205	178
43	45	26	223	962	35	12	565	926
44	110	73	493	1490	70	23	394	652
45	23	15	19	44	24	5	633	587
46	29	24	180	643	230	67	616	699
47	106	86	213	762	217	123	363	2702
48	27	15	142	422	14	6	864	786
49	99	55	347	882	101	23	271	310
50	54	39	62	331	22	4	155	141
51	62	32	85	186	161	44	127	141
52	78	67	80	173	56	15	98	126
53	23	12	58	113	100	27	61	74
54	112	86	141	353	18	6	186	238
55	91	104	125	367	25	8	53	76
56	32	22	87	293	85	20	97	71
57	8	4	127	323	297	95	114	153
58	36	22	136	531	160	47	163	150
59	72	56	335	1149	113	35	205	497
60	55	35	102	303	54	33	188	563
61	9	4	106	345	165	50	187	190
62	99	99	88	397	21	6	183	203
63	49	31	52	199	86	28	100	129
64	89	68	70	170	23	8	122	155
65	24	13	97	241	32	9	91	113
66	50	38	71	353	86	26	94	147
67	171	98	111	356	45	16	101	144
68	25	18	58	191	202	64	123	156
69	36	19	91	288	77	27	1680	1849
70	28	16	85	332	38	13	411	465

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

Jutamas Jivaluk

Department of fisheries/ Thailand

ABSTRACT

The samples of 79 stations in Sarawak, Sabah and Brunei Darusalam waters were collected by M.V.SEAFDEC on 4 July - 9 August 1996 and on 25 April - 31 May 1997. Thirty-eight groups of zooplankton were found in this study. Copopoda dominated the zooplankton population, followed by Ostracoda and Chaetognatha in both period. Biomass vary from 0.11-1.54 ml/m^3 (average 0.44±0.25) and 0.09-1.76 ml/m^3 (average 0.45±0.33) in July and May respectively. Abundance vary from 72-681 no/m^3 (average 232±125) and 35-1,383 no/m^3 (average 251±216) in July and May respectively. T-test shows no significant difference of biomass and abundance between July and May.

Key words Zooplankton, biomass, abundance, Sarawak, Sabah, Brunei Darussalam

Introduction

It is generally recognized that zooplankton occupy an important role in the economy in the sea, both as consumer of phytoplankton and as contributors to the next higher trophic levels. Numerous studies have shown that small zooplankton (e.g. copepods, tintinnids, cladocerans, larval molluscs) are important component of larval fish food [Houde & Lovdal (1982)], [Balbontin, *et al.* (1986)], [Anderson (1994)]. Hence, variation in the availability of these organisms has been hypothesized to be related to the larval survival and the subsequent recruitment to the adult population of marine fishes [Cushing (1975)].

Few papers are studied in Sarawak, Sabah and Brunei Darusalam waters. Most of them worked on fisheries [Beales (1982)], [Lee (1982)], [Wong (1982)]. Some investigated on heavy metal in sediment [Imail (1993)]. Thus the distribution and composition of zooplankton in this areas is poorly known. However, there were many papers worked on the seasonal abundance and distribution of zooplankton in the nearby areas such as the Gulf of Thailand [Brinton (1963), [Suvapepun (1977)], [Suwanrumpha (1980)].

The propose of the present investigation is to describe the zooplankton community in Sarawak, Sabah and Brunei Darusalam waters, and provide an estimation of abundance, composition, biomass and their distribution.

Method

The samples of 79 stations in the Sarawak, Sabah and Brunei Darusalam waters were collected by M.V.SEAFDEC on 4 July - 9 August 1996 and on 25 April - 31 May 1997 (Table 1 & Fig. 1). Plankton was collected using 0.03 mm mesh net attached to 60 cm. diameter bongo frames. A flow-meter, attached within the aperture of the net, measured the amount of water filtered. At each station a 30 minutes oblique tow of the bongo net was made with the ship speed was about 2 knots. The depth of the haul was 5 meters above the sea bottom for the station that the depth less than 155 meters and 150 meters for the station that the depth over than 155 meters except in the strong current station, the hauling depth was 120 meters.The samples were preserved in 10 % buffered formalin-seawater immediately. In the laboratory, the displacement volume of total zooplankton was measured after large gelatinous zooplankton had been removed. The samples were subsampled with Falsom Plankton Splitter and then count to taxon. Data on biomass and abundance were standardized per cubic metre.

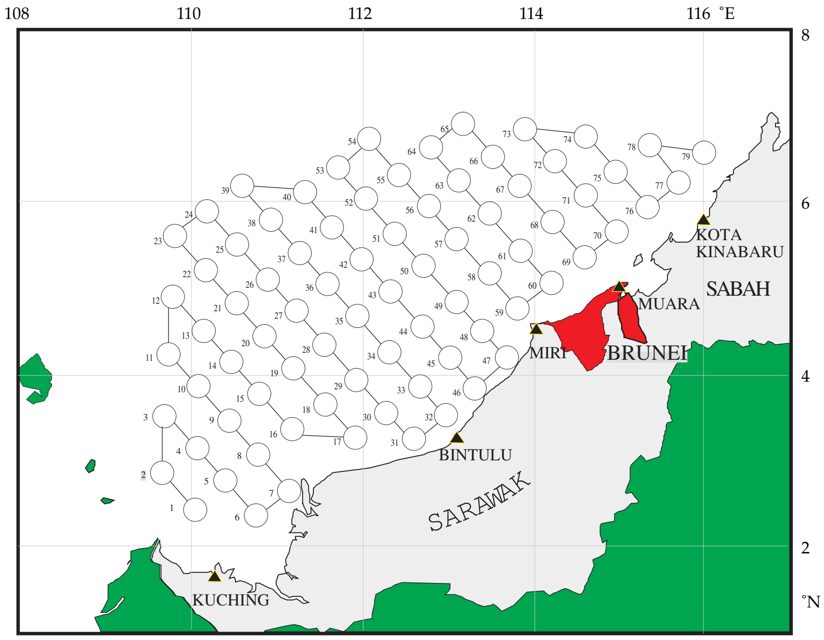

Fig. 1 79 sampling stations off Sarawak, Sabah and Brunei Darussalam

Results

Biomass and abundance of total zooplankton

July period

Biomass and abundance of total zooplankton were showed in Appendix A (Fig. A1 and A2). Biomass vary from 0.11-1.54 ml/m^3 (average 0.44±0.25) that station 31 (near Bintulu) has the highest biomass. Zooplankton biomass quite high in Sarawak's water and near Kota Kinabaru which were neritic zone. Abundance vary from 72-681 no/m^3 (average 232±125) and station 31 (near Bintulu) also has the highest abundance due to high number of siphonophora, medusae, cladocera, salp and thecosomes.

May period

Biomass and abundance of total zooplankton were showed in Appendix A (Fig. A1 and A2). Biomass vary from 0.09-1.76 ml/m^3 (average 0.45±0.33) which station 7 has the highest biomass. Zooplankton biomass quite high in Sarawak's water than in Sabah and Brunei Darusalam water. Abundance vary from 35-1383 no/m^3 (average 251±216) which station 7 has the highest abundance due to high number of siphonophora, medusae, chaetognatha, copepod, *Lucifer* spp. and bivalves larvae.

In May, abundance of zooplankton in Sarawak water was higher than other areas but in July the abundance showed not much difference among 3 areas.

In comparison of plankton biomass collected in July and May, it was found that biomass in May was higher than that in July at 29 stations (36.71 %) which 37 stations (46.84 %) had lower biomass and 13 stations (16.46 %) were not different. The abundance in May was higher than that in July at 32 stations (40.51 %) and zooplankton abundance in May was less than that in July at 37 stations (46.84 %) while 10 stations (12.66 %) was not different (Table 3 and 4). However, T-test of biomass and abundance of zooplankton between July and May indicated that the difference was not significant (Table 5).

Table 1 Information of all survey stations in the Area II

Stn. No.	Date	Time	Date	Time	Position		Depth
					Latitude	Longitude	(m)
1	7/10/96	0606-0638	5/1/97	0555-0625	02-20.0 N	110-00.0 E	36
2	7/10/96	1029-1100	5/1/97	1027-1053	02-42.8 N	109-40.3 E	54
3	7/10/96	1624-1652	5/1/97	1548-1618	03-25.3 N	109-43.3 E	79
4	7/10/96	2040-2108	5/1/97	2035-2100	03-02.5 N	110-03.0 E	66
5	7/11/96	0600-0603	5/2/97	0550-0618	02-39.8 N	110-22.6 E	85
6	7/11/96	1021-1048	5/2/97	1008-1033	02-17.0 N	110-42.3 E	41
7	7/11/96	1447-1506	5/2/97	1404-1432	02-36.8 N	111-04.9 E	35
8	7/11/96	1853-1918	5/2/97	1822-1850	02-59.5 N	110-45.3 E	39
9	7/12/96	0548-0618	5/3/97	0554-0624	03-22.3 N	110-25.6 E	65
10	7/12/96	1013-1043	5/3/97	1015-1045	03-45.1 N	110-05.9 E	85
11	7/12/96	1428-1503	5/3/97	1440-1509	04-07.8 N	109-46.2 E	100
12	7/12/96	2016-2044	5/3/97	2017-2045	04-50.3 N	109-49.2 E	118
13	7/13/96	0539-0607	5/4/97	0550-0616	04-27.6 N	110-08.9 E	115
14	7/13/96	1003-1033	5/4/97	1006-1035	04-04.8 N	110-28.6 E	94
15	7/13/96	1417-1443	5/4/97	1418-1446	03-42.1 N	110-48.3 E	66
16	7/13/96	1836-1901	5/4/97	1837-1906	03-19.3 N	111-07.9 E	62
17	7/14/96	0703-0723	5/5/97	0550-0620	03-16.3 N	111-50.3 E	29
18	7/14/96	1120-1145	5/5/97	1014-1043	03-39.1 N	111-30.6 E	50
19	7/14/96	1559-1626	5/5/97	1420-1448	04-01.8 N	111-10.9 E	70
20	7/14/96	2030-2100	5/5/97	1833-1901	04-24.6 N	110-51.2 E	89
21	7/15/96	0539-0608	5/6/97	0549-0619	04-47.3 N	110-31.5 E	117
22	7/15/96	0957-1025	5/6/97	1006-1034	05-10.1 N	110-11.8 E	145
23	7/15/96	1409-1439	5/6/97	1436-1505	05-32.8 N	109-52.0 E	145
24	7/15/96	1839-1907	5/6/97	1852-1922	05-52.6 N	110-14.8 E	530
25	7/16/96	0537-0605	5/7/97	0545-0615	05-29.9 N	110-34.5 E	207
26	7/16/96	1013-1042	5/7/97	1002-1032	05-07.1 N	110-54.2 E	123
27	7/16/96	1431-1500	5/7/97	1421-1449	04-44.4 N	111-13.9 E	95
28	7/16/96	1852-1921	5/7/97	1835-1905	04-21.6 N	111-33.7 E	80
29	7/17/96	0540-0610	5/8/97	0550-0620	03-58.9 N	111-53.4 E	57
30	7/17/96	1011-1040	5/8/97	1010-1037	03-31.5 N	112-08.0 E	32
31	7/17/96	1910-1936	5/9/97	1924-1950	03-13.4 N	112-32.7 E	22
32	7/19/96	0537-0605	5/10/97	0547-0614	03-33.1 N	112-55.4 E	32
33	7/19/96	1004-1032	5/10/97	0948-1017	03-55.9 N	112-35.7 E	48
34	7/19/96	1423-1451	5/10/97	1410-1440	04-18.6 N	112-16.0 E	71
35	7/19/96	1839-1908	5/10/97	1838-1908	04-41.1 N	111-56.3 E	87
36	7/20/96	0540-0608	5/11/97	0549-0618	05-04.1 N	111-36.6 E	109
37	7/20/96	1018-1047	5/11/97	0957-1027	05-26.9 N	111-16.8 E	446
38	7/20/96	1440-1510	5/11/97	1434-1504	05-49.6 N	110-57.1 E	1063
39	7/20/96	1930-1958	5/11/97	1925-1955	06-12.4 N	110-37.3 E	1234
40	7/21/96	0538-0608	5/12/97	0547-0617	06-09.4 N	111-19.8 E	922
41	7/21/96	1020-1050	5/12/97	1016-1046	05-46.6 N	111-39.6 E	1300
42	7/21/96	1510-1540	5/12/97	1450-1520	05-23.9 N	111-59.3 E	132
43	7/21/96	1923-1953	5/12/97	1857-1925	05-01.1 N	112-19.0 E	105
44	7/22/96	0537-0605	5/13/97	0547-0617	04-38.4 N	112.38.7 E	90
45	7/22/96	1000-1028	5/13/97	0940-1010	04-15.6 N	112-58.5 E	67
46	7/22/96	1422-1442	5/13/97	1344-1412	03-52.9 N	113-18.1 E	22
47	7/22/96	1819-1840	5/13/97	1740-1809	04-12.7 N	113-40.8 E	28
48	7/24/96	0848-0918	5/15/97	1250-1320	04-35.4 N	113-21.1 E	79
49	7/24/96	1258-1328	5/15/97	1705-1734	04-58.2 N	113-01.4 E	105
50	7/24/96	1719-1748	5/15/97	2113-2143	05-20.9 N	112-14.7 E	520
51	7/25/96	0540-0610	5/16/97	0547-0617	05-43.2 N	112-21.0 E	192
52	7/25/96	1002-1032	5/16/97	1004-1034	06-06.4 N	112-02.2 E	1650
53	7/25/96	1519-1592	5/16/97	1504-1534	06-29.2 N	111-42.4 E	1941
54	7/25/96	2054-2123	5/16/97	2021-2051	06-48.9 N	112-05.2 E	2008
55	7/26/96	0542-0612	5/17/97	0546-0616	06-26.2 N	112-24.9 E	1318
56	7/26/96	1026-1056	5/17/97	1030-1100	06-03.4 N	112-44.7 E	1136
57	7/26/96	1500-1529	5/17/97	1504-1534	05-40.7 N	113-04.5 E	2355
58	7/26/96	2009-2038	5/17/97	2047-2117	05-17.9 N	113-24.3 E	1622
59	7/27/96	0538-0607	5/18/97	0549-0619	04-55.2 N	113-43.9 E	95
60	7/27/96	0947-1017	5/18/97	1000-1030	05-15.0 N	114-06.6 E	235
61	7/27/96	1403-1434	5/18/97	1539-1609	05-37.7 N	113-46.9 E	2142
62	7/27/96	1910-1939	5/18/97	2040-2110	06-00.5 N	113-27.1 E	2567
63	7/28/96	0540-0608	5/19/97	0547-0617	06-23.2 N	113-07.4 E	1623
64	7/28/98	1050-1120	5/19/97	1009-1039	06-46.0 N	112-47.6 E	1261
65	7/28/96	1532-1602	5/19/97	1430-1500	07-05.7 N	113-10.4 E	1535
66	7/28/96	2013-2044	5/19/97	1858-1928	06-43.0 N	113-30.1 E	1883
67	7/29/96	0542-0612	5/20/97	0549-0618	06-20.2 N	113-49.9 E	2820
68	7/29/96	1055-1125	5/20/97	1032-1102	05-57.5 N	114-09.7 E	1785
69	7/29/96	1547-1617	5/21/97	2104-2134	05-34.7 N	114-29.4 E	100
70	7/29/96	2014-2044	5/22/97	0548-0618	05-54.5 N	114-52.1 E	125
71	7/31/96	1359-1430	5/22/97	1008-1038	06-17.2 N	114-32.4 E	2078
72	7/31/96	1811-1841	5/22/97	1500-1530	06-40.0 N	114-12.6 E	2867
73	7/31/96	2327-2358	5/22/97	1937-2007	07-02.7 N	113-52.8 E	1836
74	8/1/96	0855-0925	5/23/97	0546-0616	06-59.8 N	114-35.4 E	2893
75	8/1/96	1408-1439	5/23/97	1035-1105	06-37.0 N	114-55.2 E	1751
76	8/1/96	1910-1940	5/23/97	1504-1534	06-14.3 N	115-14.9 E	111
77	8/2/96	0537-0607	5/24/97	0551-0620	06-34.0 N	115-37.7 E	95
78	8/2/96	1006-1037	5/24/97	1006-1036	06-56.8 N	115-17.9 E	1498
79	8/2/96	1616-1647	5/24/97	1545-1612	06-53.8 N	116-00.4 E	42

Table 2 Biomass of zooplankton (ml./m^3) in Sarawak, Sabah and Brunei Darussalam waters

Station	July	May	Station	July	May	Station	July	May
1	0.61	0.88	**28**	0.84	0.71	**55**	0.44	0.31
2	0.94	0.65	**29**	0.91	0.60	**56**	0.25	0.23
3	0.57	0.35	**30**	0.77	0.77	**57**	0.19	0.29
4	0.52	0.76	**31**	1.54	1.38	**58**	0.24	0.18
5	0.92	0.52	**32**	0.71	0.35	**59**	0.34	0.29
6	0.93	0.78	**33**	0.67	0.65	**60**	0.37	0.14
7	0.80	1.76	**34**	0.61	0.73	**61**	0.40	0.09
8	0.57	1.35	**35**	0.48	0.39	**62**	0.27	0.16
9	0.38	1.33	**36**	0.14	0.39	**63**	0.56	0.16
10	0.59	1.24	**37**	0.2	0.17	**64**	0.21	0.16
11	0.28	0.52	**38**	0.25	0.31	**65**	0.38	0.20
12	0.18	0.48	**39**	0.55	0.29	**66**	0.34	0.37
13	0.24	0.23	**40**	0.61	0.29	**67**	0.43	0.28
14	0.20	0.24	**41**	0.22	0.35	**68**	0.28	0.15
15	0.45	0.52	**42**	0.22	0.27	**69**	0.46	0.12
16	0.85	0.58	**43**	0.27	0.52	**70**	0.35	0.18
17	0.69	0.83	**44**	0.53	0.36	**71**	0.28	0.14
18	0.73	0.61	**45**	0.47	0.81	**72**	0.30	0.09
19	0.33	0.41	**46**	0.65	0.55	**73**	0.31	0.17
20	0.23	0.46	**47**	0.32	0.66	**74**	0.42	0.20
21	0.16	0.37	**48**	0.46	0.41	**75**	0.26	0.11
22	0.14	0.18	**49**	0.52	0.44	**76**	0.22	0.53
23	0.17	0.25	**50**	0.31	0.13	**77**	0.66	0.74
24	0.28	0.37	**51**	0.28	0.14	**78**	0.74	0.16
25	0.15	0.25	**52**	0.33	0.40	**79**	0.56	0.27
26	0.11	0.47	**53**	0.22	0.35			
27	0.24	0.94	**54**	0.43	0.32			

Table 3 Total abundance of zooplankton (no/m^3) in Sarawak, Sabah and Brunei Darussalam waters.

Station	July	May	Station	July	May	Station	July	May
1	315	378	**28**	424	533	**55**	215	141
2	363	450	**29**	408	344	**56**	148	125
3	406	172	**30**	306	438	**57**	140	162
4	269	360	**31**	681	888	**58**	108	115
5	623	384	**32**	391	168	**59**	228	177
6	406	735	**33**	223	266	**60**	223	78
7	415	1,383	**34**	265	298	**61**	555	100
8	193	513	**35**	198	230	**62**	138	70
9	193	538	**36**	111	288	**63**	205	57
10	332	607	**37**	159	197	**64**	128	73
11	149	280	**38**	161	114	**65**	231	79
12	157	324	**39**	256	108	**66**	187	88
13	218	153	**40**	193	139	**67**	178	64
14	158	134	**41**	95	162	**68**	138	58
15	384	434	**42**	168	254	**69**	269	87
16	418	297	**43**	219	424	**70**	181	185
17	72	552	**44**	240	193	**71**	208	87
18	341	384	**45**	273	403	**72**	164	39
19	251	203	**46**	85	171	**73**	134	69
20	109	255	**47**	141	219	**74**	163	87
21	92	255	**48**	117	247	**75**	145	35
22	92	98	**49**	263	266	**76**	254	228
23	145	155	**50**	257	114	**77**	288	208
24	175	132	**51**	197	119	**78**	80	66
25	87	140	**52**	209	116	**79**	504	122
26	75	405	**53**	152	122			
27	219	554	**54**	242	130			

Zooplankton Analyses

Thirty-eight groups of zooplankton were found in this study. Major groups found in Sarawak, Sabah and Brunei Darusalam as well as their total numbers and percentages are presented in Table 6. Per cent composition , average abundance and frequency of occurrence of some zooplankton July and May are shown in Table 7-9. Pattern of distribution of the most common forms are shown in Appendix A (Figs. A3 - A18)

Coelenterata

This phylum include Medusae and Siphonophora, comprising together 3.8 % of the total zooplankton population (Table 6). These plankters are major predators in the planktonic food web. In both period, the Medusae found to be very common but in low number. Large number were observed near Bintulu in July (2 no/m^3). While the number increase in May especially in Sarawak water, the highest number was 4 no/m^3. However, most of the medusae found in neritic stations.

Siphonophora also found to be very common and in fare number in both period. In May, their number was high in sarawak water but in July high number was found both in Sarawak and Brunei waters. Furthermore, the number of individual of siphonophora in May was lower than in July. Most of them distributed in neritic stations.

Ctenophora

The ctenophores formed less than 0.1 % of the total zooplankton population. The percent occurrence was only 5 % in July and 11 % in May. The greatest number was 1 no/m^3 in May.

Mollusca

Molluscs were the second most abundant group of zooplankton, forming 8.9 % of the total zooplankton population (Table 6). This group was composed of bivalve and gastropod veligers, the heteropod, the thecosomes (shelled pteropod), the gymnosomes (naked pteropod), nudibranchia (sea slug) and cephalopod larvae. Veliger larvae of gastropod (57.9 %) and bivalve (14.6 %) and the thecosomes (23.4 %) accounted for the majority of the planktonic molluscs.

Bivalve veligers were most abundant in neritic rather than oceanic stations. The amount of them was similar in both period. The highest number occurred in Sarawak water (41 no/m^3) in May.

Gastropod veliger were most abundant in neritic rather than oceanic stations. In May, the amount of them was quite high in Sarawak water while during July the number was lower in the study areas.

The heteropod were very common in this study. Sarawak water showed higher abundance than other areas. The highest number was 1 and 10 no/m^3 in July and May respectively. Most of them dispersed neritic zone for both period.

The thecosomes (shelled pteropod) found to be very common for both period. The highest abundance was found in May (112 no/m^3) which higher than in July especially in Sarawak water.However, in May the thecosomes distributed neritic rather than oceanic stations while in the July the pattern of distribution were similar.

The gymnosomes (naked pteropod) were rare in July (28 % occurrence) but quite common in May (35 % occurrence). Most of them distributed oceanic in Brunei and Sabah waters. They quite rare in Sarawak water. The highest abundance was only 1 no/m^3 in both period.

Nudibranchia were found only in May in low number (1 no/m^3) in one station.

Cephalopod larvae were occasionally present in zooplankton samples. They formed less than 1 % of zooplankton population. The average number for both period was no differences. However, they can be found neritic and oceanic stations.

Cladocera

Cladocera formed only 1.4 % of the total zooplankton population but they were very common in both period. Most of cladoceran distributed at neritic zone in Sarawak water for both period. The average abundance was 3 and 6 no/m^3 in July and May respectively.

Ostracoda

Among the Crustacea, Ostracoda were second to Copepoda in abundance, but they comprised only 10 % of the total zooplankton population. They observed to be very common but not in large number. In July showed higher abundance (average 29 no/m^3) than in May (average 19 no/m^3). The distribution pattern were similar for both neritic and oceanic stations in July. But most of them dispersed neritic in May.

Copopoda

Copepods were the most abundant in this study area, comprising 52 % of the total zooplankton population. The average number of copepod was 118 and 133 no/m^3 in July and May respectively. They dispersed throughout the study areas.

Cirrepedia

Cirripedia larvae were found to be very common for both period but in low number (average 1 no/m^3). The great number were found neritic in both season especially in Sarawak water and were rarely present at oceanic stations. Anyway, they can be found in Brunei water and Sabah water in great number in July as well. The distribution of larvae reflects that of the adults barnacles which are mostly benthic intertidal animals. This low overall abundance indicates the limited occurrence of barnacles along Sarawak, Sabah and Brunei water.

Lucifer

Lucifer spp. were very common and formed only 0.5 % of the total zooplankton population. The highest number was 19 no/m^3 in May. The average abundance showed no different in both period. Most of *Lucifer* spp. distributed neritic rather than oceanic especially in Sarawak water.

Brachyura

Brachyura larvae were very common but low in number. They found most abundant at the neritic stations (near Bintulu and Kota Kinabaru) in July and near Miri in May. The average abundance of brachyura larvae was similar in both period (1 no/m^3).

Shrimp larvae

Caridea and Penaeidae larvae were regular component in the zooplankton population, constituting 2.1 % of total zooplankton. The abundance was high at neritic stations for both period especially in Sarawak water (28 and 36 no/m^3 in July and May respectively). The average abundant showed no differences between both period.

Phyllosoma

Phyllosoma larvae were occasionally present in zooplankton samples especially neritic stations between Miri and Bintulu and the west of Sarawak water. The average abundance in both period were not difference.

Mysidacea

Mysidacea were very common. They formed 0.4 % of total zooplankton. The most abundant found in July (13 no/m^3) while only 6 no/m^3 in May in Sarawak water. Mysidacea distributed neritic and oceanic stations in both period.

Euphausiacea

Euphausiacea were very rare in this study. They found only 8 % occurrence in July and 10 % occurrence in May.

Anomura larvae

occurred regularly in the zooplankton samples. They found most abundant at neritic stations especially in Sarawak water and along the coast. The largest number was found in May (17 no/m^3). The average abundance showed no differences between both period.

Stomatopod

Stomatopod larvae were very common in July and common in May and occurred in low numbers, forming 0.1 % of total zooplankton. The largest number was found in July (2 no/m^3). The average abundance showed no differences between both period.

Other Crustacea

The remaining crustacea consisted of amphipod, isopod and cumercea. Amphipod were very common while isopod and cumercea were rare for both season. Amphipod dispersed throughout the whole area in both season but in July, high number occurred neritic and oceanic stations while only

Table 4. Differences of total abundance and biomass of zooplankton from Sarawak, Sabah and Brunei Darussalam waters between July and May.

	Abundance		Biomass	
	No. of Station	Percentage	No. of Station	Percentage
Increase	32	40.51	29	36.71
Decrease	37	46.84	37	46.84
Constant	10	12.66	13	16.46

Table 5. Probability (p) of null hypothesis (significant p < 0.0500) from t-test for comparing biomass and abundance between July and May.

	P
Biomass	0.7684
Abundance	0.376

Table 6. Total number and percentages of major groups of zooplankton in Sarawak, Sabah and Brunei Darussalam waters at 79 stations

Taxon	Totol	Percentage with in group	Overall percentage
I. Coelenterata	1,464	-	3.83
A. Medusae	92	6.3	0.2
B. Siphonophora	1372	93.7	3.6
II. Ctenophora	1.41	-	<0.1
III. Mollusca	3384.2	-	8.9
A. Bivalvia - veliger	492.9	14.6	1.3
B. Gastropoda			
1. veliger	1960.9	57.9	5.1
2. Heteropod	122.1	3.6	0.3
3. Thecosomata	791.6	23.4	2.1
4. Gymnosomata	13.6	0.4	<0.1
5. Nudibranchia	0.5	<0.1	<0.1
C. Cephalopoda - larvae	2.8	<0.1	<0.1
IV. Arthropoda	27096.8	-	71.1
A. Cladocera	549	2	1.44
B. Ostracoda	3818	14.1	10
C. Copepoda	19816	73.1	52
D. Cirripedia - larvae	123.3	0.5	0.3
E. Amphipoda, Isopoda, Cumercea	1043	3.8	2.7
F. Decapoda			
1. Lucifer spp.	207.4	0.7	0.5
2. Brachyuran	53.7	0.2	0.1
3. Caridea and Penaeidae larvae	791.7	2.9	2.1
4. Phyllosoma larvae	6.9	<0.1	<0.1
5. Anomuran	396.8	1.5	1
G. Stomatopod larvae	34	0.1	0.1
H. Mysidacea	156	0.6	0.4
I. Euphausiacea	101	0.4	0.3
VI. Chaetognatha	2969.2	-	7.8
VII. Chordata	2461.8	-	6.5
A. Thaliacea	914.3	37.1	2.4
B. Lavacea - Oikopleura spp.	1145	46.5	3
C. Pyrosomata	8.8	0.4	<0.1
D. Fish egg and larvae	393.7	16	1
VIII. Invertebrate larvae (Cyphonautes, actinotroch, polychaet larvae, brachiopod, echinodermata, ascidian)	720.9	-	1.9
IX. Other (nemertean, platyhelminthes)	20.9	-	<0.1
Grand total	**38119.4**	**-**	**100**

Table 7. Per cent composition of some zooplankton in Sarawak, Sabah and Brunei Darussalam waters in July and May.

	July		May	
Rank	**Taxon**	**Composition (%)**	**Taxon**	**Composition (%)**
1	Copepoda	50.8	Copepoda	53.1
2	Ostracoda	12.7	Ostracoda	7.6
3	Chaetognatha	9.1	Chaetognatha	6.6
4	Gastropod larvae	4.4	Gastropod larvae	5.9
5	Siphonophora	4.3	Laevacean	4
6	Amphipoda	3.6	shelled Pteropod	3.3
7	Shrimp larvae	2.2	Siphonophora	3
8	Thaliacea	2.1	Thaliacea	2.7
9	Laevacean	1.9	Echinodermata	2.3
10	Anomura larvae	1.4	Cladocera	1.9

Table 8 Taxonomic list of zooplankton found in Sarawak, Sabah and Brunei Darusalam.
The average abundance of zooplankton:

+++ = >10 no./m^3

++ = 6-10 no./m^3

+ = 0-5 no./m^3

Taxon	Abundance		Taxon	Abundance	
	July	May		July	May
Medusae	+	+	Anomura larvae	+	+++
Siphonophora	++	++	Brachyura larvae	+	+
Ctenophora	+	+	Stomatopod larvae	+	+
Nemertinea	+	+	Heteropoda	+	+
Cyphonautes larvae	-	+	naked Pteropod	+	+
Actinotroch larvae	+	+	shelled Pteropod	+	+++
Chaetognatha	+++	+++	Nudibranchia		+
Polychaeta	+	+	Cephalopoda	+	+
Cladocera	+	++	Gastropod larvae	+++	+++
Ostracoda	+++	+++	Bivalve larvae	+	++
Copepoda	+++	+++	Echinodermata larvae	+	+
Cirripedia larvae	+	+	Larvacean	+	+++
Amphipoda	++	+	Thaliacea	+	++
Isopoda	+	+	Ascidian larvae	+	-
Mysidacea	+	+	Pyrosomata	-	++
Cumacea	+	+	Brachiopod larvae	+	+
Euphausiacea	+	+	Platyhelminthes	+	+
Lucifer spp.	+	+	Fish eggs	+	+
Phyllosoma larvae	+	+	Fish larvae	+	+
Shrimp larvae	+	+			

neritic stations in May .The average abundance was higher in July (8 no/m^3) than in May (5 no/m^3).
Chaetognatha

Chaetognatha were the third most abundant in this area, forming 7.8 % of total zooplankton. They were observed to be very common in both season. In July, they found great number near Kuching, Brunei and Kota Kinabaru. The highest abundance was 60 no/m^3. While in May, they found great number in Sarawak water which highest abundance was 105 no/m^3. Anyway, the average abundance of chaetognatha was higher in July (21 no/m^3) than May (16 no/m^3). Most of them distributed neritic rather than oceanic for both season.

Chordata

Chordata were the fourth most abundant group of zooplankton, comprising 6.5 % of the total zooplankton population (Table 6). This group was composed of Thaliacea (Salp), Larvacea (Oikopleura

Table 9 Taxonomic list of zooplankton found in Sarawak, Sabah and Brunei Darusalam. Frequency of occurence: R = Rare , C = Common, VC = Very Common.

Taxon	Frequency		Taxon	Frequency	
	July	May		July	May
Medusae	VC	VC	Anomura larvae	VC	VC
Siphonophora	VC	VC	Brachyura larvae	VC	VC
Ctenophora	R	R	Stomatopod larvae	VC	C
Nemertinea	VC	R	Heteropoda	VC	VC
Cyphonautes larvae	-	R	naked Pteropod	R	C
Actinotroch larvae	R	R	shelled Pteropod	VC	VC
Chaetognatha	VC	VC	Nudibranchia	-	C
Polychaeta	VC	VC	Cephalopoda	R	R
Cladocera	VC	VC	Gastropod larvae	VC	VC
Ostracoda	VC	VC	Bivalve larvae	VC	VC
Copepoda	VC	VC	Echinodermata larvae	VC	VC
Cirripedia larvae	VC	VC	Larvacean	VC	VC
Amphipoda	VC	VC	Thaliacea	VC	VC
Isopoda	R	R	Ascidian larvae	R	-
Mysidacea	VC	VC	Pyrosomata	-	C
Cumacea	R	R	Brachiopod larvae	C	R
Euphausiacea	R	R	Platyhelminthes	R	R
Lucifer spp.	VC	VC	Fish eggs	VC	VC
Phyllosoma larvae	R	-	Fish larvae	VC	VC
Shrimp larvae	VC	VC			

spp.) Pyrosomata and fish eggs and larvae.

Thaliacea (Salp) were very common organisms. The highest number was found in July (113 no/m^3) near Bintulu (St. 31). Most of them distributed neritic and oceanic. However, the average abundance in both season showed no differences.

Larvacea (Oikopleura spp.) were the second most abundant group of chordata (46.5 %) and comprised 3 % of total zooplankton. They found to be very common for both season. The highest was found at St. 27 (51 no/m^3) in May. The average abundance of larvacea was higher in May (10 no/m^3) than in July (4 no/m^3). However, the distribution pattern were similar for both neritic and oceanic stations.

Pyrosomata were seldom in this study. They found only in May in fair number. The distribution was scattered throughout the study area.

Fish eggs and larvae were very common but in low number, forming only 1 % of total zooplankton. Except for station 37 which found high number of fish eggs (104 no/m^3). The highest number of fish larvae was 7 no/m^3 at St. 16 in July. Fish eggs and larvae found to be more abundant neritic in both season. The average abundance showed no differences between July and May.

Invertebrate larvae

Invertebrate larvae, comprising 1.9 % of zooplankton population, composed of cyphonautes, actinotroch, polychaet, brachiopod, echinodermata and ascidian.

Cyphoneutes were found only in May while ascidian found only in July in low number. They distributed neritic rather than oceanic.

Actinotroch found only 1 and 3 stations in July and May in low number. Brachyopod were occasionally present but not high in number. Most of them distributed neritic rather than oceanic.

Polychaet larvae were very common organisms but in low number. The highest number was 3 no/m^3 at station 70 in May. The average abundance in both season showed no difference. The distribution was scattered throughout the study area.

Echinodermata larvae consisted of asteroidea (starfish larvae), holothuroidea (sea cucumber larvae), echinoidea (sea urchin larvae) and ophiuroidea (brittle star larvae). They were the regular component in the zooplankton samples but in low number. The average abundant in May (7 no/m^3) was a little bit higher than in July (2 no/m^3). Anyway, the abundance occurred in the neritic stations in both period.

Other

The remaining zooplankton found in the samples comprising of nemertean and platyhelminthes. Both of them formed less than 0.1 % of total zooplankton.

The relationship between fish larvae and their predators

Large carnivorous zooplankters namely, Medusae, Siphonophora, Ctenophora and Chaetognatha are planktonic predators on fish larvae. In this paper will concern only Medusae, Siphonophora and Chaetognatha. The relationship between fish larvae and their predators is shown in Fig. 2-5. The correlation between fish larvae and Medusae, Siphonophora and Chaetognatha was 0.5058, 0.5531 and 0.7204 , respectively, at 95 % confidence. Ctenophora present in small number in the samples so that their relationship with fish larvae was not studied.

The relationship between fish larvae and their prey

The relationship between fish larvae and copepoda is shown in Fig. 6. The correlation of fish larvae and copeoda which were their prey was 0.7132 at 95 % confidence

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Discussion

The biomass and abundance of zooplankton in Sarawak, Sabah and Brunei Darusalam's waters in this investigation was lower than in the Gulf of Thailand and the east coast of Malaysia Peninsular in both period (Jivaluk, in print). The higher biomass were in the areas where the water depth less than 200 m.(neritic zone), mainly in Sarawak water. This result agreed with Santhankumari (1991) who found the standing stock of zooplankton was relatively high in the neritic zone of the west coast of India. Abundance of zooplankton also showed the same phenomenon particularly in May. Fallahi (1993) found that zooplankton in the southern part of the Caspian Sea showed decrease in the abundance from littoral zone to the pelagic zone . It was concluded that Sarawak water is more productive than other area in this study. There were no significant difference of biomass and abundance between May and July.

The result of this investigation indicated that Copepods was the most dominant group followed by Ostracoda and Chaetognatha. Although species composition of Copepods and other groups was not studied. However, geographical diversity gradients obtained in this study, based on the groups at the primary sorting level, will serve to give an idea of geographical distributions of animal communities.

It is obvious that collecting-time affect the zooplankton biomass, abundance and their distribution. In May, many organisms were increase in number such as Medusae, Ctenophora, Cladocera, Copepoda, phyllosoma larvae, brachyura larvae, Thecosomata, Heteropoda, Gastropoda larvae, Appendicularia, Thaliacea and fish eggs. Some organisms were decrease such as Siphonophora, Chaetognatha, Ostracoda, Amphipoda, Gymnosomata. Sribyatta (1996) found higher values of zooplankton in the northeast monsoon and southwest monsoon in the Gulf of Thailand.

Many papers notes that the samples which contained the highest number of organism such as Euphausiacea (Barange, 1989), Mysidacea (Mathew et al. 1990), phyllosoma larvae (Kathirvel, 1990, Kathirvel and James, 1990), stomatopod larvae (Reddy and Shanbhogue, 1990) and cephalopod larvae (Sarvesan and Meiyappan, 1990, Meiyappan et al. 1990) as well as zooplankton biomass (Krishnakumari and Loswami, 1993, Koppelmann and Weikert, 1997) were all collected during night , suggesting that they showed a pronounced diurnal vertical migration(Paulinose and Aravindakshan, 1977).

There are many factors both biotic and abiotic which involve the variations in larval fish survival. Predators and preys are one of the most important biotic causes (Lasker and Smith, 1977). Large carnivorous zooplankters namely, Medusae, Siphonophora, Ctenophora and Chaetognatha are planktonic predators on fish larvae. [Fraser (1969)], [Suwanrunpha (1983[2])]. The consumption of fish larvae by each medusae varying from 50 to 15,000. In this investigation, indicated a high correlation between fish larvae and their predator, especially chaetognatha. Thus their presence in numbers of zooplankton could have a serious effect on the recruitment of larval fish and could be very significant for the fish stocks and for the fishing industry.

Numerous studies have shown that small zooplankton, particularly copepods, eggs and larval stages of crustaceans, larval molluscs, ciliates and other unicellular organisms, are important components of larval fish food [Houde & Lovdal (1982)], [Balbontin *et al*. (1986)], [Nagasawa (1993)], [Anderson (1994)]. In this investigation found a high correlation between fish larvae and their prey, especially copepods. Positive correlations indicated that fish trend to aggregate where the standing crop of copepods which were their food is greatest. But Sameoto (1972) found no significant correlation between biomass of copepods and the estimated abundance of herring larvae.

Many works point out that zooplankton was influencing on fisheries. Krisshnapillai and Bhat (1981) found that the fish catch/hour was maximum in October which was the most productive month of the zooplankton. Jacob *et al*. (1981) noted that the peak periods in the zooplankton biomass were found to coincide with the peak seasons of pelagic fisheries. Suseelan *et al*.(1985) also found that pelagic fish catch, consisting mostly of anchovies and lesser sardines, showed clear peaks, closely following the primary and secondary peaks of zooplankton. Unfortunately, information about the fisheries in this investigated areas was not available, so that relationship of fish catch and zooplankton abundance was not studied

Reference

Anderson, J.T.: Feeding ecology and condition of larval and pelagic juvenile redfish, Sebastes spp. *Mar. Ecol. Prog. Ser*., 104(3), 211-226 (1994).

Balbontin, F., M., Garreton & J. Neuling: Stomach content and prey size of the fish larvae from Bransfield Strait (SIBEX-Phase 2, Chile*). Ser. Cient. Inst. Antart. Chil*.,35, 125-144 (1986).

Barange, M.: Daily variation of the zooplankton at a mix station off Namibia. *Collect. Sci. Pap*.,16(2), 11-23 (1989).

Beales, R.W.: Brunei fisheries and research. *ICLARM NEWSL*., 5(1), 20-21 (1982).

Cushing, D.H.: Marine ecology and fisheries, Cambridge, 1975, pp.1-278.

Fallahi, M.: Plankton survey in the southern part of the Caspian Sea. Iran. *Fish Bull*., 4, 3-7 (1993).

Fraser, J.H.: Experimental feeding of some Medusae and Chaetognatha. *J. Fish. Res. Bd. Cand*., 26, 1743-1762 (1969).

Houde, E. & Lovdal, J.D.: Variability in Ichthyoplankton and microzooplankton abundance and feeding of fish larvae in Biscayne Bay, Florida. *Est. Coast. Sh. Sci*., 18, 403-419 (1982).

Ismail, A.: Heavy metal concentration in sediments off Bintulu, Malaysia. *Mar. Pollut. Bull*., 27(12), 706-707 (1993).

Jacob, R.M., N.K. Ramachandram & K.R. Vasantha.: Zooplankton in relation to hydrography and pelagic fisheries in the inshore waters of Virhinjam, Trivandrum. *J. Mar. Biol. Assoc. India*., 23(1-2), 62-76 (1981).

Jivaluk, J.: Distribution, abundance and composition of zooplankton in the Gulf of Thailand and the east coast of Malaysia Peninsular. inprint.

Kathirvel, M.: On the collections of phyllosoma larvae by Isaacs-Kidd Midwater Trawl from the west coast of India. Proc. of the First Workshop of Scientific Result of FORV, Sagar Sampada, 5-7 June 1989, Cochin. Publish by Central Marine Fisheries Research Institute, Cochin (India),1990, pp. 141-146.

Kathirvel, M. & D.B. James: The phyllosoma larvae from Andaman and Nicobar waters. Proc. of the First Workshop of Scientific Result of FORV, Sagar Sampada, 5-7 June 1989, Cochin. Publish by Central Marine Fisheries Research Institute, Cochin (India), 1990, pp. 147-150.

Koppelmann, R & H. Weikert: Deep Arabian Sea mesozooplankton distribution. Intermonsoon, October 1995. *Mar. Biol*., 129(3), 549-560 (1997).

Krishnakumari, L. & L. Loswami: Biomass and biochemical composition from northwest Bay of Bengal during January 1990. *Indian J. Mar. Sci*., 22(2), 143-145 (1993).

Krisshnapillai, S. & G.J. Subramonia Bhat.: Note on the abundance of zooplankton and trawler catch during the post monsoon months along the northwest coast of India. *J. Mar. Biol. Assoc. India*., 23(1-2), 208-21 (1981).

Lasker, R., and P. Smith: Estimation of the effects of environmental variations on the eggs and larvae of the northern anchovy. *Calif. Coop. Oceanic Fish. Invest. Rep.*, 19,128-137, (1977)

Lee, S.B. Country situation paper - Malaysia (Sarawak). The status at the rural coastal fisheries in Sarawak. in Report of the Workshop on the Development of the Rural Coastal Fisheries, 15-24 March 1982, Manila, Philippines, Publ. by FAO/UNDP, Manila (Philippines),1982, pp. 24-33.

Mathew, K.J., G. Anthony, T.S. Naomi & K. Solomon: On the quantitative abundance of Mysidacea collected from the eastern Arabian Sea and the Bay of Bengal. Proc. of the First Workshop of Scientific Result of FORV, Sagar Sampada, 5-7 June 1989, Cochin. Publish by Central Marine Fisheries Research Institute, Cochin (India), 1990, pp. 109-114.

Meiyappan, M.M., R. Sarvesan & K.P. Nair: Preliminary studies of the distribution and abundance of planktonic cephalopod in the India Exclusive Economic Zone and adjacent seas. Proc. of the First Workshop of Scientific Result of FORV, Sagar Sampada, 5-7 June 1989, Cochin. Publish by Central Marine Fisheries Research Institute, Cochin (India), 1990, pp. 115-121.

Nagasawa, T.: Planktonic larvae and pelagic juveniles of the rockfish, *Sebastes minor* (Scorpaenidae). *Jap. J. Ichthyol*., 40(1), 87-97 (1993).

Paulinose, V.T. and P.N. Aravindakshan: Zooplankton biomass, abundance and distribution in the North and Northern Arabian Sea. Proceeding of the Symposium on Warm Water Zooplankton. National Institute of Oceanography, GOA, India, 1977, pp. 132-136.

Reddy, H.R.V. & S.L. Shanbhogue: Distribution and abundance of stomatopod larvae in the EEZ of India. Proc. of the First Workshop of Scientific Result of FORV, Sagar Sampada, 5-7 June 1989, Cochin. Publish by Central Marine Fisheries Research Institute, Cochin (India), 1990, pp. 122-130.

Sameoto, D.D.: Distribution of Herring (*Cluplea harengus*) larvae along the southern coast of Nova Scotia with observations on their growth and condition factor. *J. Fish. Res. Bd. Cand*., 29, 507-515 (1972).

Santhankumari, V.: Zooplankton standing stock and community structure along Karnataka Coast, west coast of India. *J. India. Fish Assoc*., 21, 21-30 (1991).

Sarvesan, R. & M.M. Meiyappan: Qualitative and quantitative distribution ofplanktonic cephalopods in the Exclusive Economic Zone of the west coast of India. Proc. of the First Workshop of Scientific Result of FORV, Sagar Sampada, 5-7 June 1989, Cochin. Publish by Central Marine Fisheries Research Institute, Cochin (India), 1990, pp. 101-108.

Sribyatta, P.: Variation of zooplankton in the Gulf of Thailand 1976-1994. Tech.Paper No 4/2539. Mar. Fish. Envi. Group, Mar. Fish. Div., Dept. of Fish., 1996, 58 p.

Suseelan C., P.P. Pillai, M.A. Pillai and K.R. Nair: Some observations on the trend of Zooplankton and its probable influence on local pelagic fisheries at Colachel during 1973-74. *Indian J. Fish.*, 32(3), 375-386 (1985).

Suwanrumpa, W: Zooplankton in the Inner Gulf of Thailand. I. Seasonal abundance and distribution of zooplankton 1975-1976. Technical Paper No 22/6. Mar. Fish. Envi. Group, Mar. Fish. Div., Dept. of Fish., 1980, 23 p.

Suwanrumpa, W.: Zooplankton in the western Gulf of Thailand. II. Relation of zooplankton displacement volumes and fish eggs, fish larvae abundance collected during January to October, 1981. Tech.Paper No 25/12. Mar. Fish. Envi. Group, Mar. Fish. Div., Dept. of Fish., 1983[1], 21 p.

Suwanrumpa, W.: Zooplankton in the western Gulf of Thailand. III. Relation between the distribution of zooplankton predators and fish larvae collected during January to October, 1981. Tech.Paper No 25/13. Mar. Fish. Envi. Group, Mar. Fish. Div., Dept. of Fish., 1983[2], 18 p.

Suvapepun, P.: Variability of plankton quantity in the Inner Gulf of Thailand. Mar. Fish. Lab., Technical Paper No. 7/1977, 1977, 12 p.

Wong, L.M.: Country situation paper - Malaysia (Sabah). The status at the rural fisheries in Sabah. in Report of the Workshop on the Development of the Rural Coastal Fisheries, 15-24 March 1982, Manila, Philippines, Publ. by FAO/UNDP, Manila (Philippines), 1982, pp. 24-33.

Fig. 2 Relationship between fish larvae (y) and Medusae (x)at 95% confidence

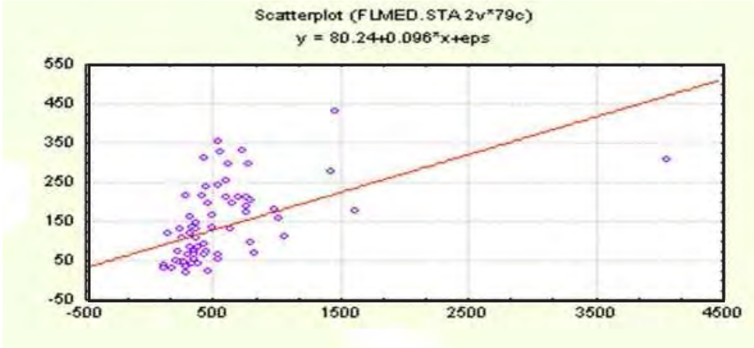


Fig. 3 Relationship between fish larvae (y) and Siphonophora (x) at 95% confidence

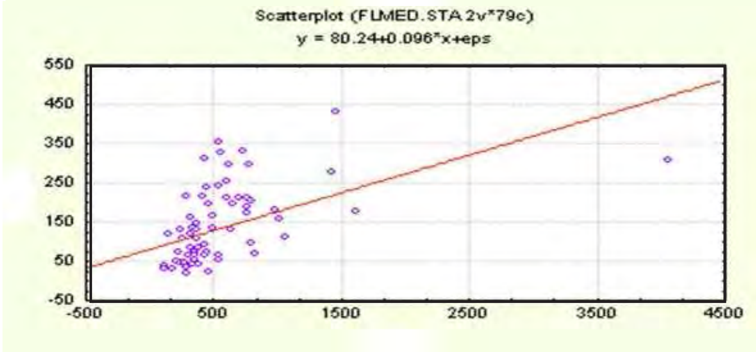


Fig. 4 Relationship between fish larvae (y) and Chaetognatha (x) at 95% confidence

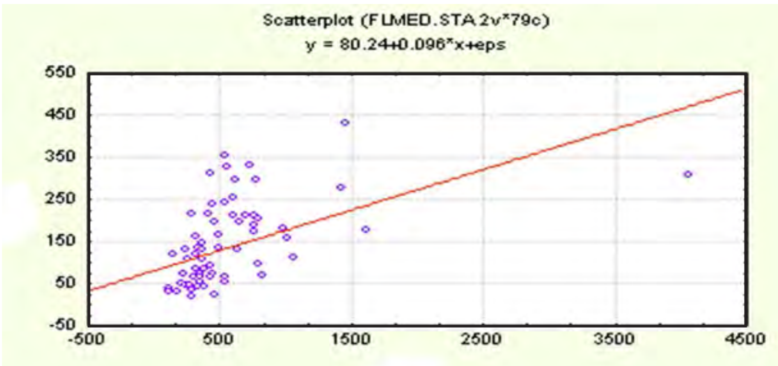


Fig. 5 Relationship between fish larvae (y) and predators (x) (Medusae + Siphonophora+ Chartognatha at 95% confidence

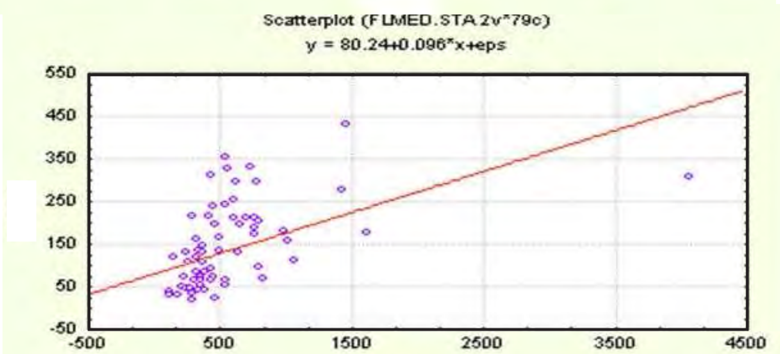
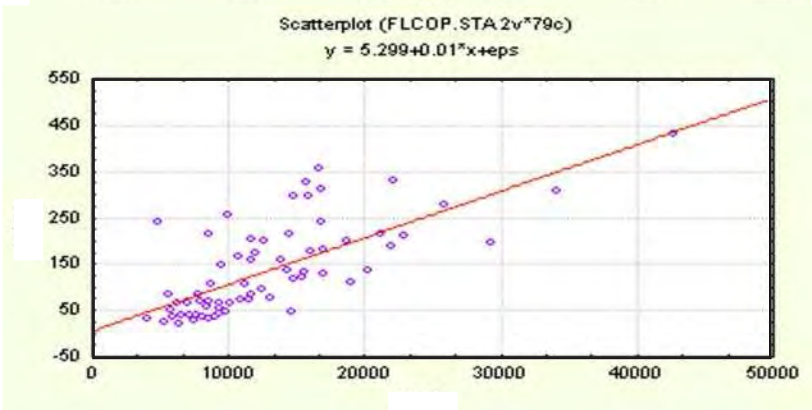


Fig. 5 Relationship between fish larvae (y) and Copepoda (x) at 95% confidence



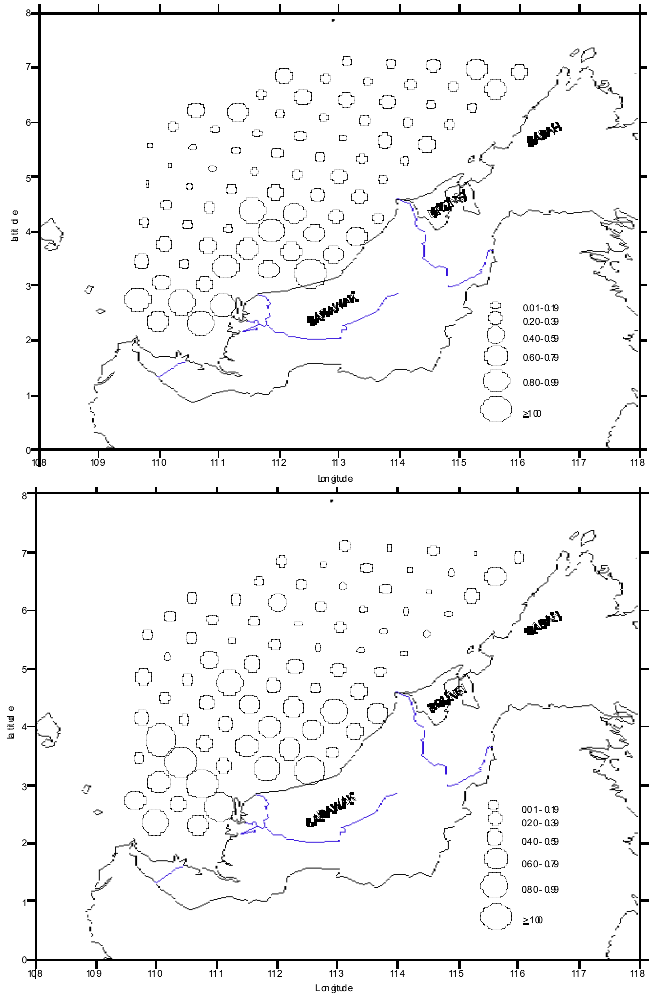


Fig. A1 Biomass of total zooplankton from July-August 1996 and April-May 1997

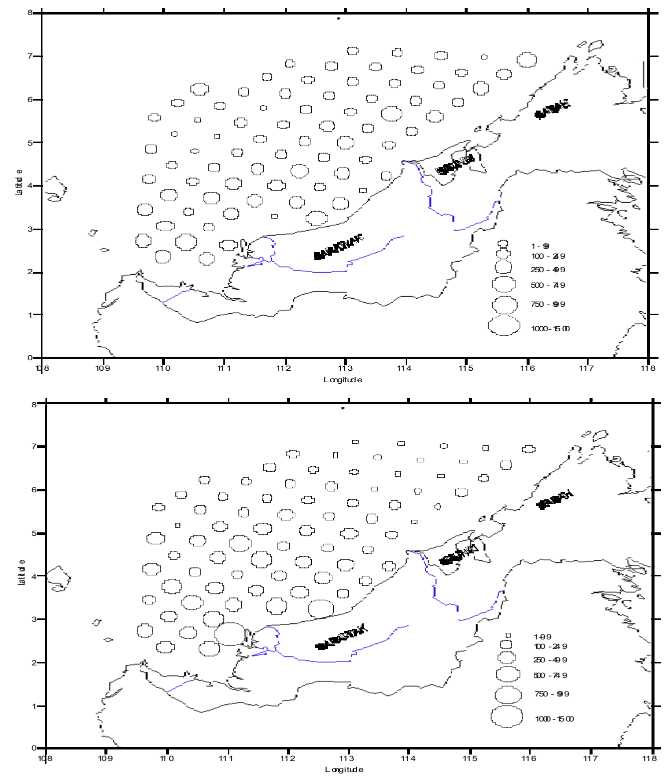


Fig. A2 Abundance of total zooplankton from July-August 1996 and April-May 1997

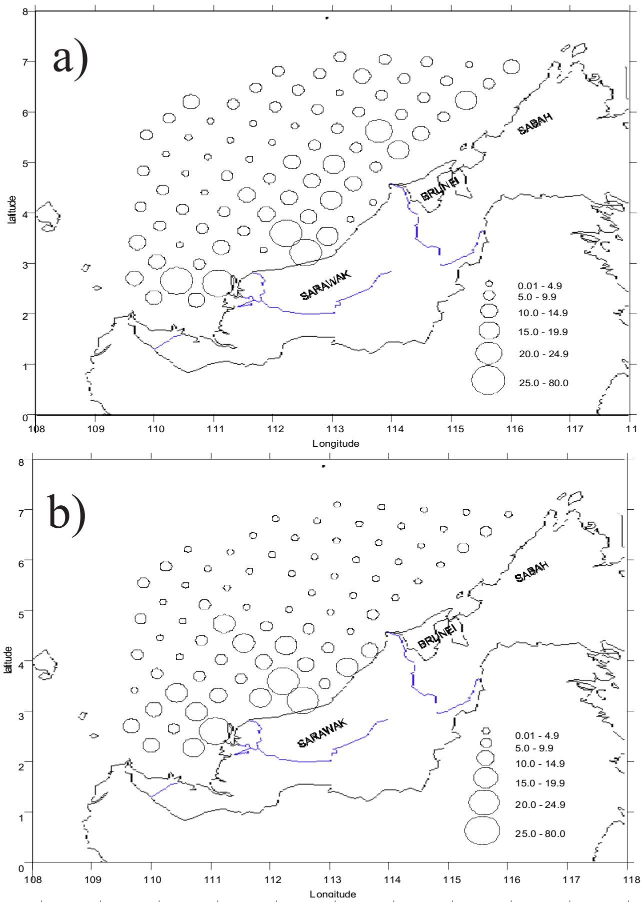


Fig. A3 Distribution and abundance of Siphonphora from July-August 1996 (a) and April-May 1997(b)

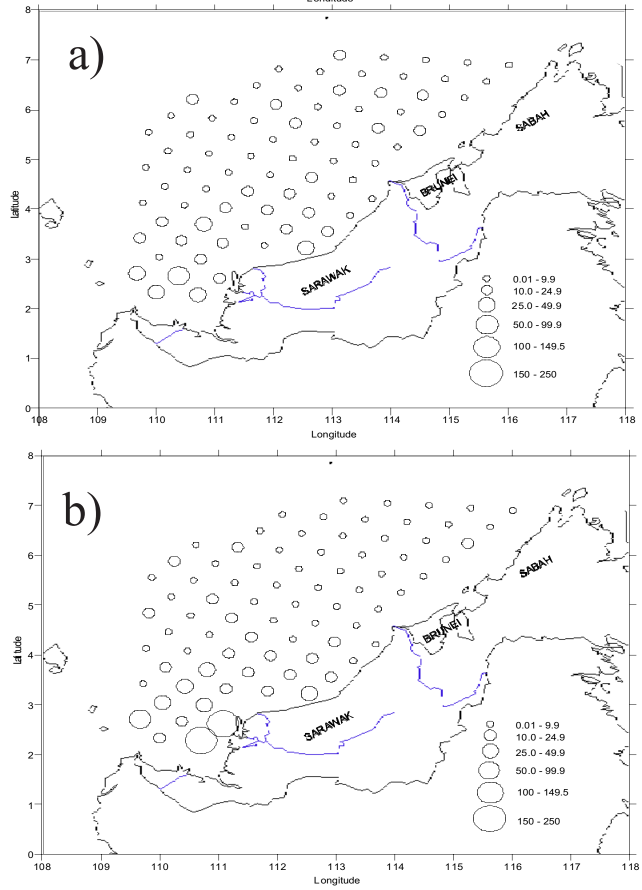


Fig. A4 Distribution and abundance of Gastropod from July-August 1996 (a) and April-May 1997(b)

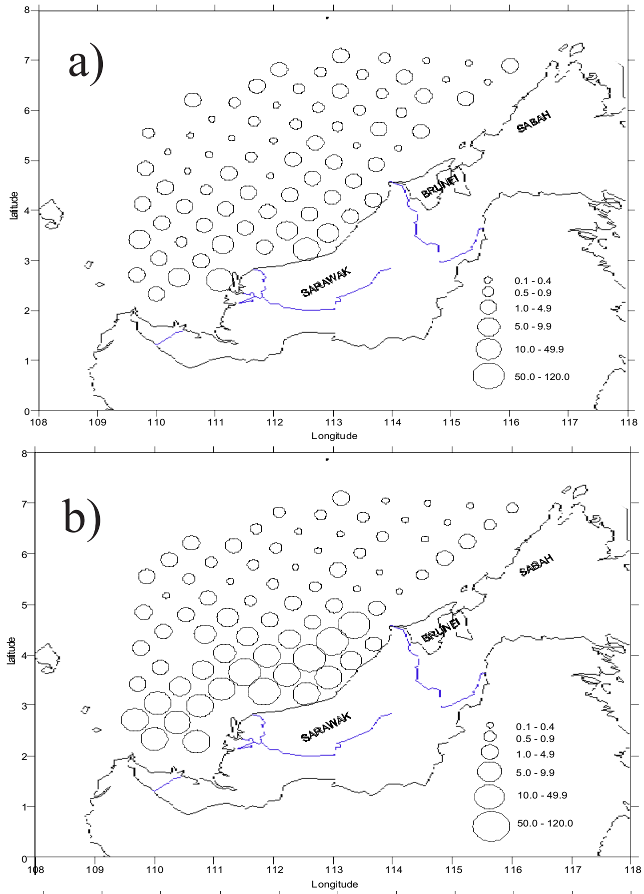


Fig. A5 Distribution and abundance of Thecosomata from July-August 1996 (a) and April-May 1997(b)

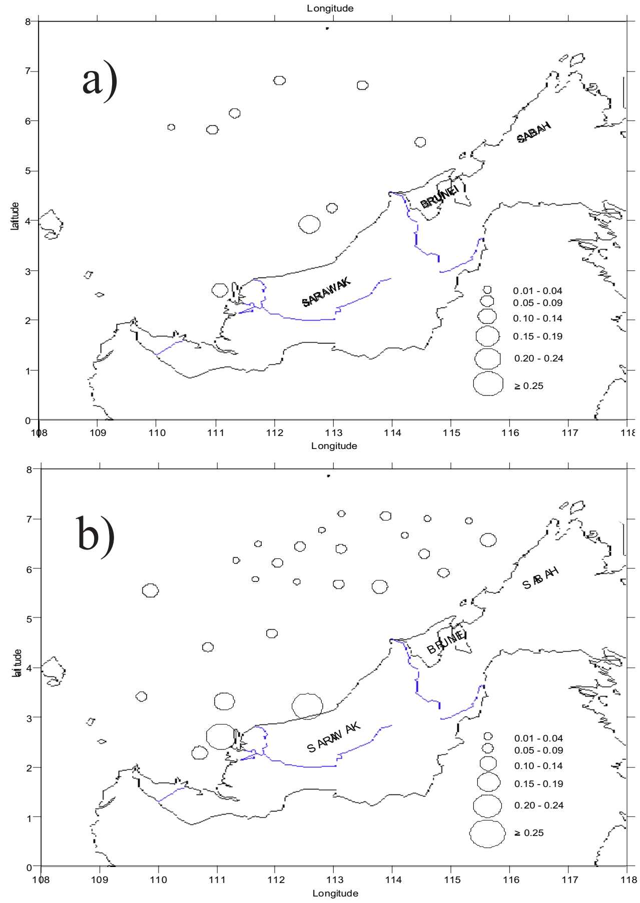


Fig. A6 Distribution and abundance of Cephalopod larvae from July-August 1996 (a) and April-May 1997(b)

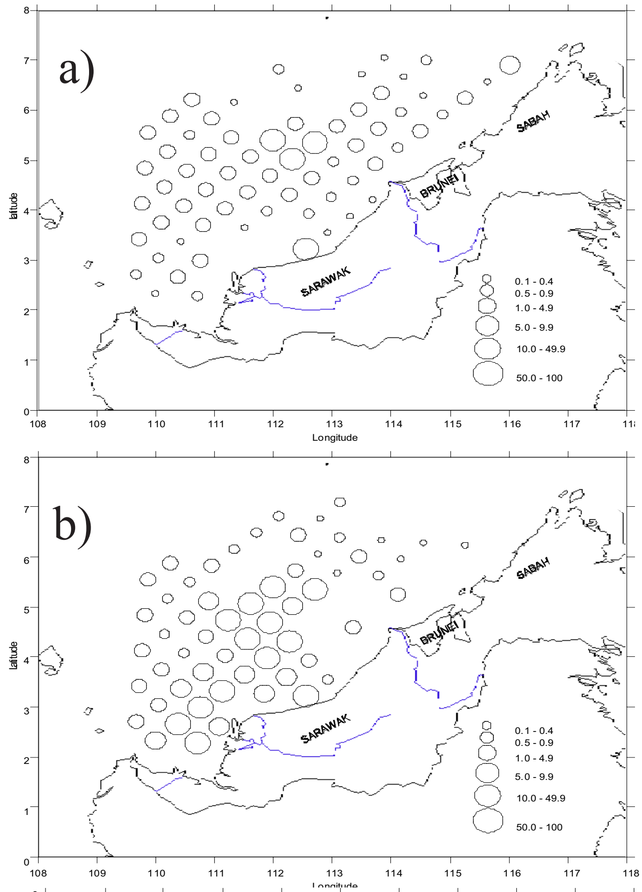


Fig. A7 Distribution and abundance of Cladocera from July-August 1996 (a) and April-May 1997(b)

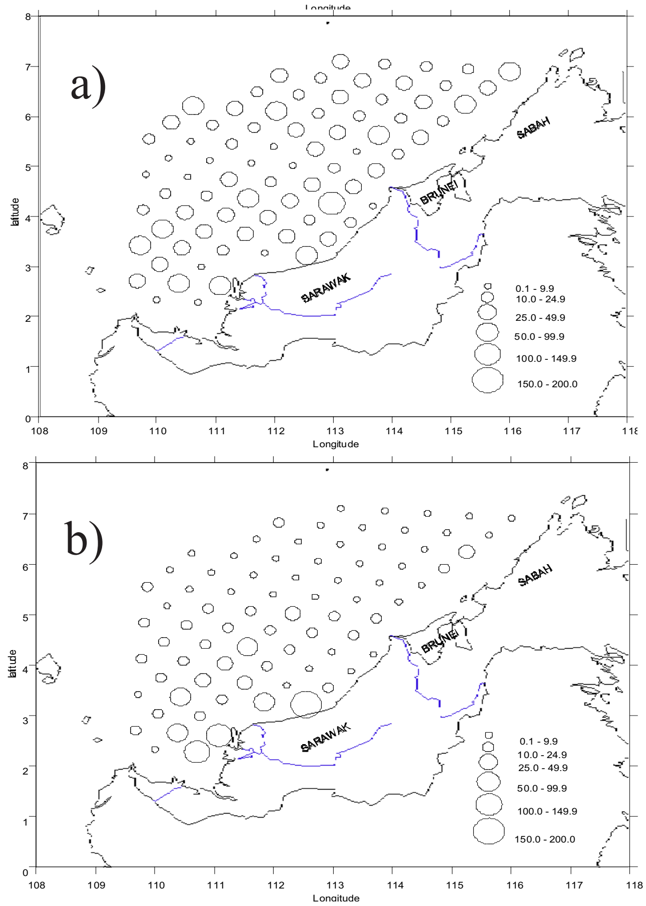


Fig. A8 Distribution and abundance of Ostracoda from July-August 1996 (a) and April-May 1997(b)

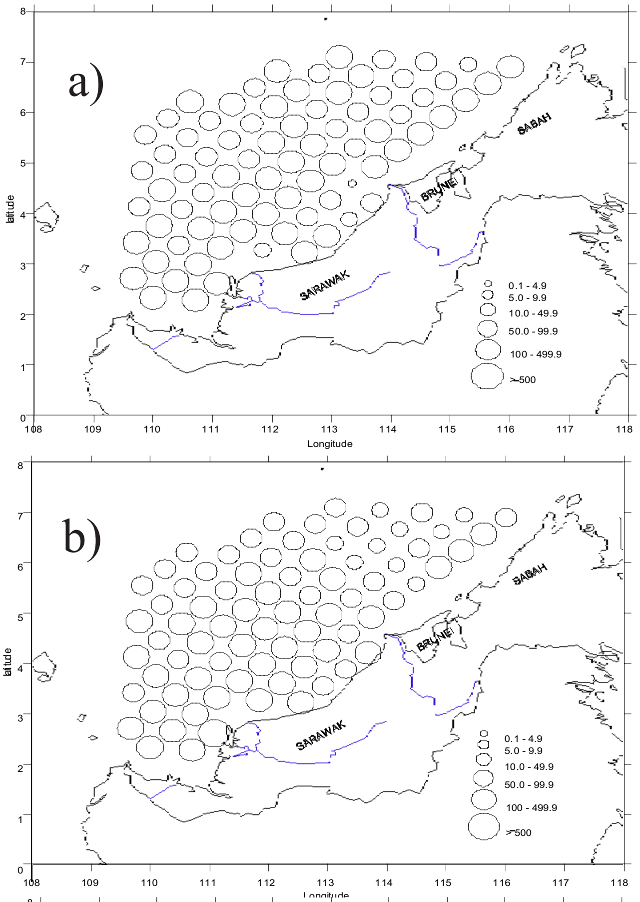


Fig. A9 Distribution and abundance of Copepoda from July-August 1996 (a) and April-May 1997(b)

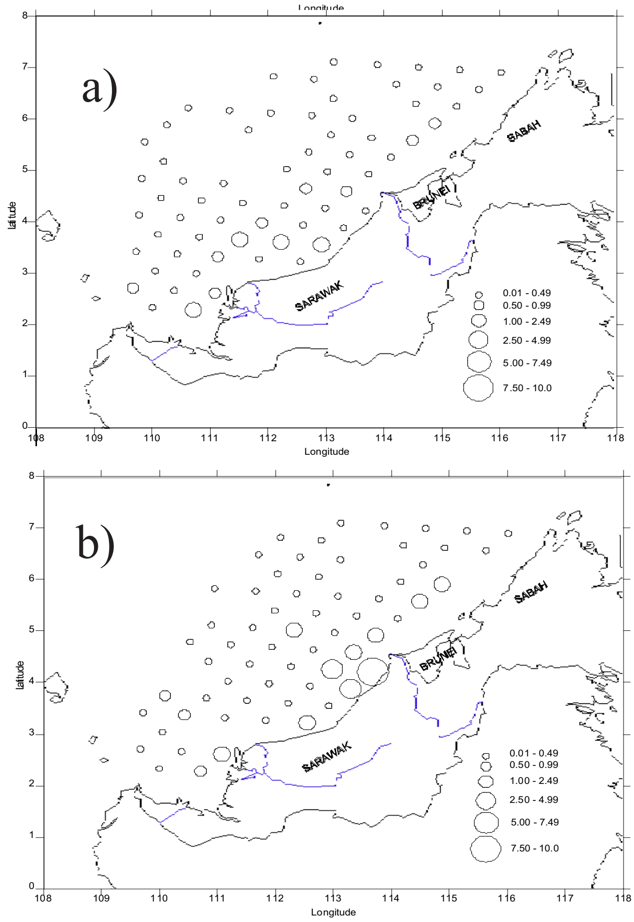


Fig. A10 Distribution and abundance of brachyura from July-August 1996 (a) and April-May 1997(b)

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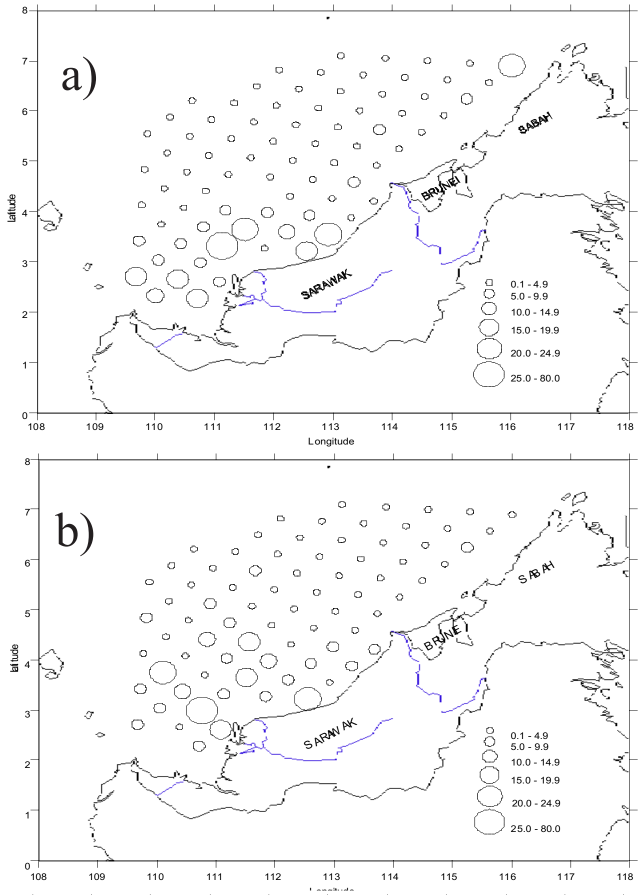

Fig. A11 Distribution and abundance of shrimp larvae from July-August 1996 (a) and April-May 1997(b)

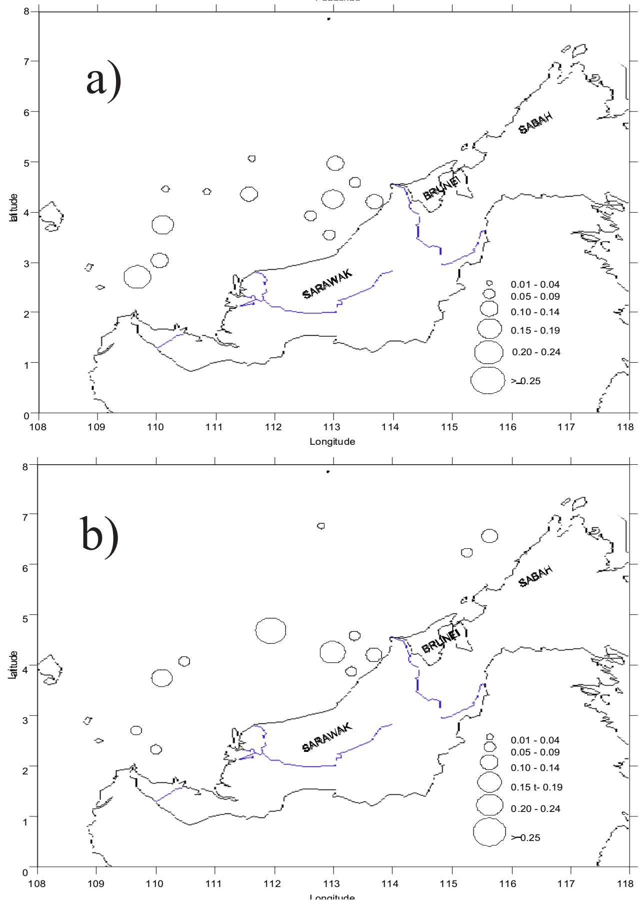

Fig. A12 Distribution and abundance of Phyllosoma larvae from July-August 1996 (a) and April-May 1997(b)

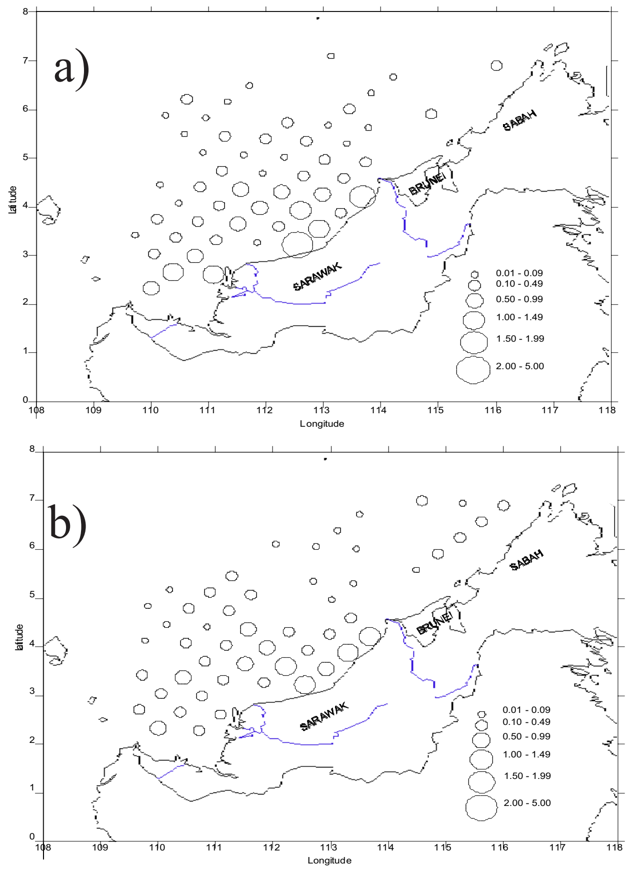

Fig. A13 Distribution and abundance of Stomatopod larvae from July-August 1996 (a) and April-May 1997(b)

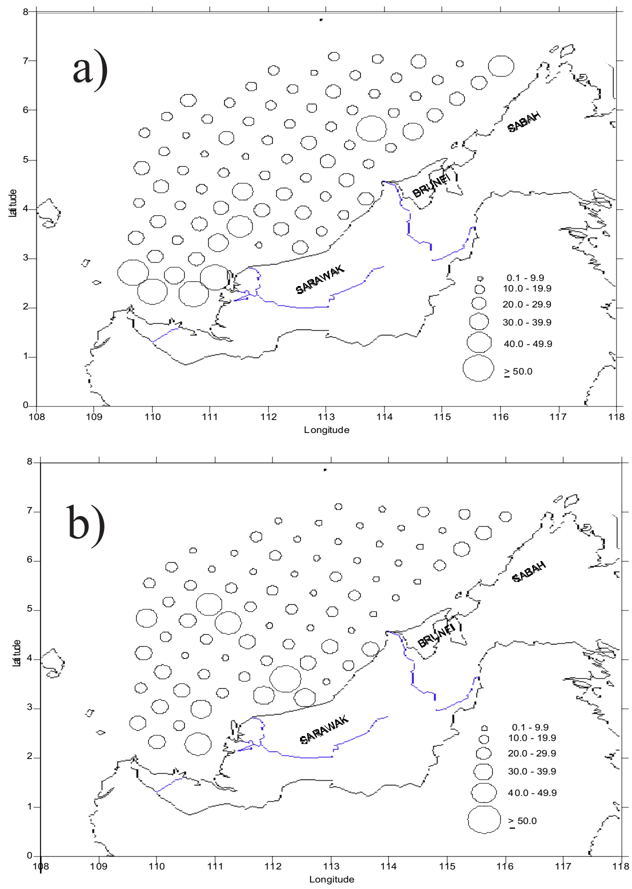

Fig. A14 Distribution and abundance of Chaetognatha from July-August 1996 (a) and April-May 1997(b)

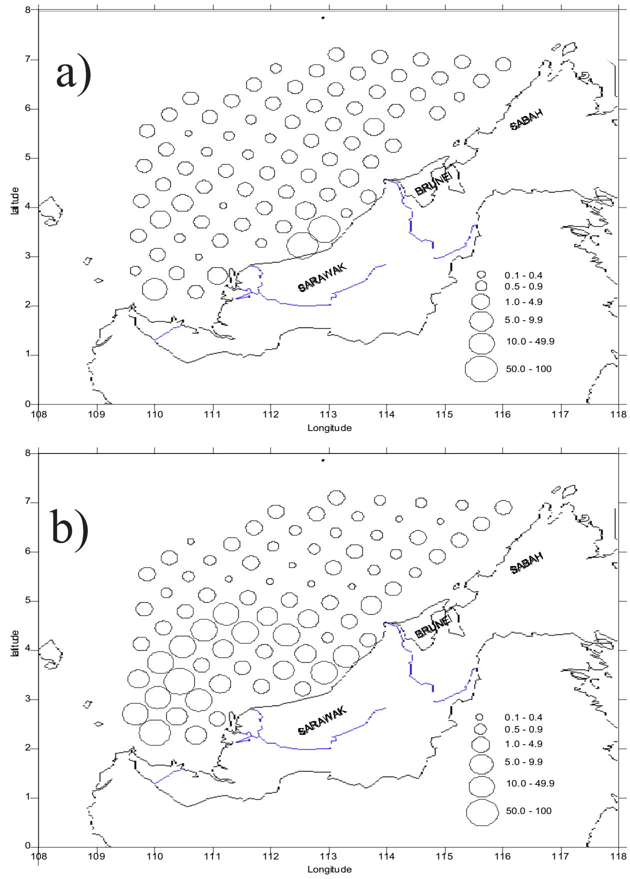

Fig. A15 Distribution and abundance of Thaliacea from July-August 1996 (a) and April-May 1997(b)

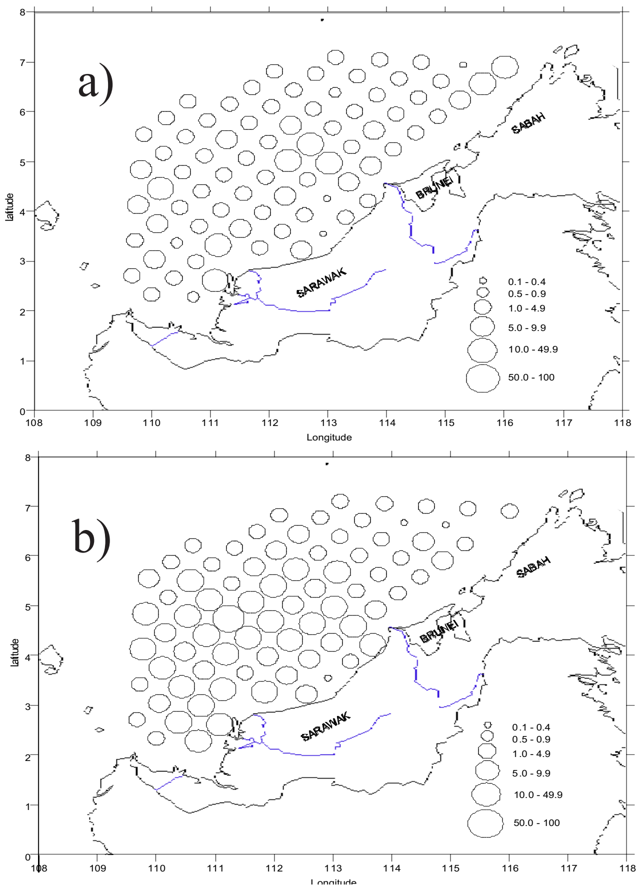

Fig. A16 Distribution and abundance of Larvacea from July-August 1996 (a) and April-May 1997(b)

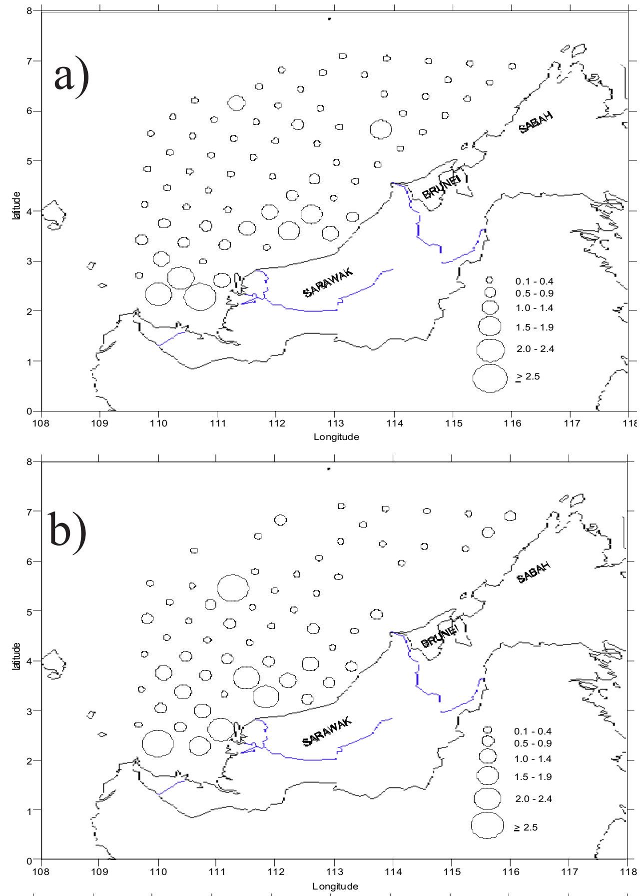

Fig. A17 Distribution and abundance of fish eggs from July-August 1996 (a) and April-May 1997(b)

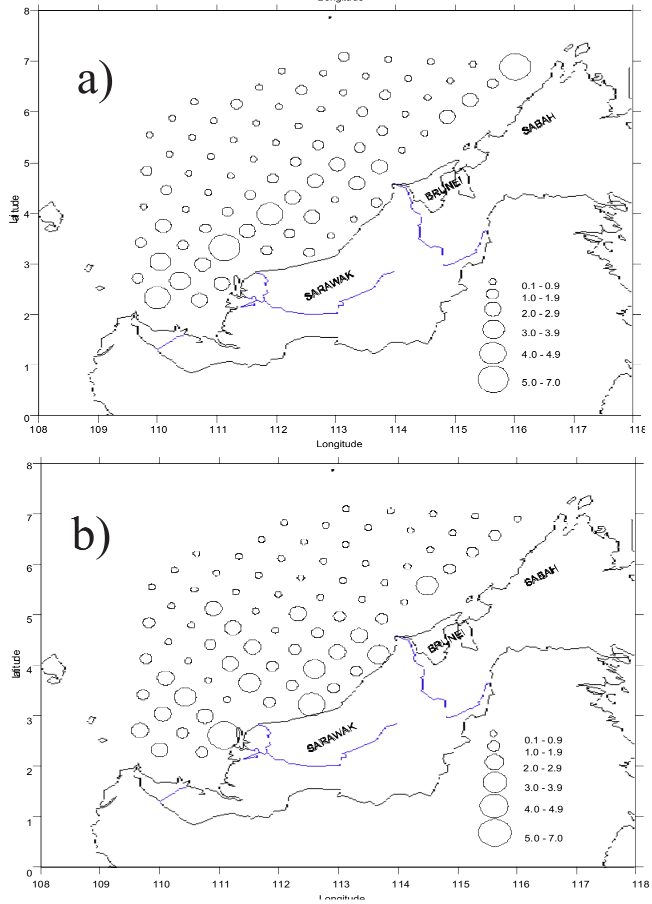

Fig. A18 Distribution and abundance of fish larvae from July-August 1996 (a) and April-May 1997(b)

S2/FB4<THAITHAVORN>

Distribution of Dinoflagellate Cysts in the Surface Sediment of South China Sea : Area 2. Off Sabah, Sarawak and Brunei Darussalam

Thaithaworn Lirdwitayaprasit

Department of Marine Sciece, Chulalongkorn University,
Phya Thai Road, Bangkok, Thailand.

ABSTRACT

The surface sediment samples of 47 stations in Sabah, Sarawak and Brunei Darussalam waters were collected by M.V. SEAFDEC for identification and quantitative analysis of benthic dinoflagellate cysts. A total of 18 dinoflagellate cyst belonging to family Gonyaulacaceae, Pyrophacaceae and Protoperiniaceae were identified. The cyst density in this area was in a range of 6 to 278 cysts/cm^3 with *Spiniferites bulloideus* was the dominant species. Cysts of harmful species were not observed in this study but a small number of *Alexandrium* cyst-like was found at a station near coastal area of Sarawak.

Key words : distribution, dinoflagellate cyst, south China Sea

Introduction

The distribution of modern organic-walled dinoflagellate cysts in middle and hight latitudes of the North Atlantic , North of Japan and Southern Indian Ocean has been well documented [e.g. Wall *et al*.(1977) , Harland (1983), Matsuoka (1987), Marret and de Vernal(1997)]. Some studies have been shown the relationship between cyst assemblages and sea - surface conditions, including temperature, salinity, seasonality and extent of sea-ice cover. A few studies have reported on neritic dinoflagellate cyst off Australia and New Zealand[Bolch and Hallegraeff (1990), McMinn (1990, 1991, 1992)].

In contrast with the southeast Asian waters the distribution of dinoflagellate cyst in this area is poorly documented. Recently , Asian waters have some severe problems deal with the toxic algal blooms. The toxic red tides of *Pyrodinium bahamense* were reported for the first occurrences along the coasts of Brunei and Sabah, the Philippines and Eastern Indonesia in 1976, 1983 and 1994, respectively [Maclean (1983), Wiadnyana *et al*.(1996)]. The bloom reoccurred annually in the Philippines waters since 1991 [Bajarias and Relox (1996)]. High cyst density that was found in surface sediment of the incident area could function as seed population to initiate the motile cells for the next bloom.

The study on distribution of dinoflagellate cyst in off shore waters was first carried out in the Gulf of Thailand and the east coast of Peninsular Malaysia by M.V. SEAFDEC under the collaborative research programme between Thai and Malaysian scientists. To provide more information on the abundance and distribution of dinoflagellate cyst in southeast Asian waters , the study in areas off Sabah, Sarawak and Brunei Darussalam was carried on under the same collaborative programme.

Materials and Methods

Surface sediment samples of 47 stations in Sabah , Sarawak and Brunei Darussalam waters were collected by gravity corer or grab during the collaborative research cruises from 4 July -9 August 1996 and repeated again from 25 April - 31 May 1997 by M.V. SEAFDEC. The study area was shown in Fig.1.

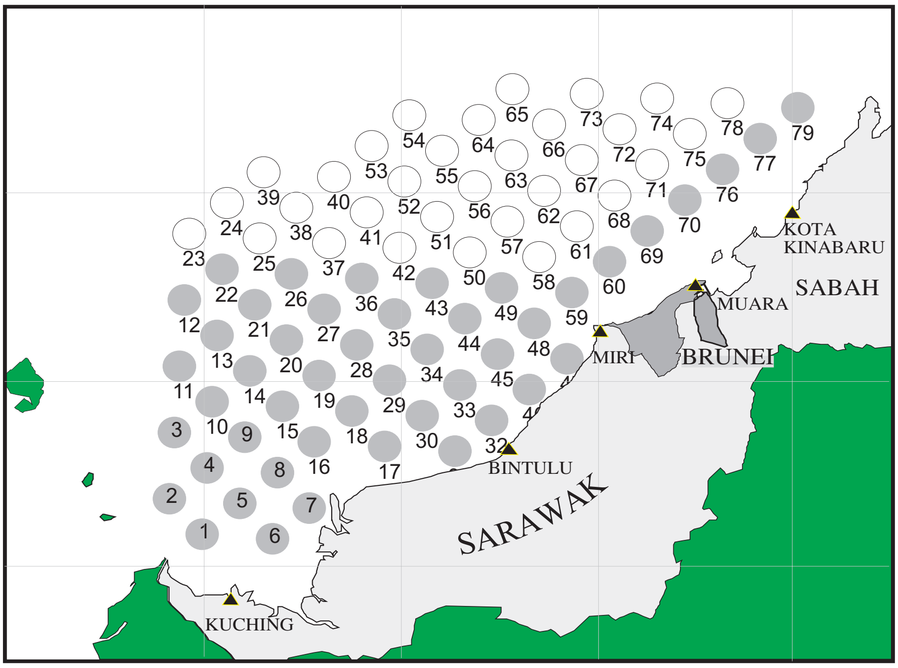

Fig. 1 Area and sediment sampling station in Sabah, sarawak and Brunei Darussalam waters

The first centrimetre of surface sediment samples from the corer or sub-sampling from the grab was prepared for identification and quantitative analysis of benthic dinoflagellate cysts by using the method described by Matsuoka et al. (1989). Surface sediment temperature , surface sediment characteristic and water depth were recorded when the sample was collected. Sample of each station was divided into two portion. A small portion was for cyst germination experiment on the ship board, the remaining portion was kept in formalin at final concentration of 5% for cyst identification in laboratory.

The main references used in this study for identification purpose were : Matsuoka and Fukuyo(1996), Matsuoka (1985,a,b,c) and Matsuoka(1987). Sedgwick Rafter chamber was used for counting cyst under the light microscope.

Results and Discussion

Environmental Conditions

The water depth, surface sediment temperature and surface sediment characteristic was shown in table 1. There was slightly different in this data set between the two cruises but has an identical surface sediment characteristic. Water depth and surface sediment temperature were in the range of 20-146 metres and 17.5-29.5 ^{0}c , respectively. The sample collecting periods of the first cruise, July-August, 1996, and the secound cruise, April-May, 1997, could be considered in the same season which was one reason why the physical parametres were not so different and there was no clear relationship between these parameters and cyst densities.

Abundance and Distribution

The modern dinoflagellate cysts of 18 species belonging to family Gonyaulacaceae(6 species), Pyrophacaceae (1 species), Protoperidiniaceae (9 species) and uncertain family (2 species) were identified and shown in table 2. The abundance and distribution of both cruises were almost the same with average cyst densities were shown in table 3 and Fig. 2-19.Cysts in the

surface sediment sample were found in a range of 6-278 cysts/cm.^{3} which was very low density compared with the cyst density in other areas such as in the southern Indian Ocean which found in a range of 200-50,000 cysts/cm.^{3} at depth from 375-
4350 metres[Marret and de Vernal(1997)]. Cyst s in surface sediments of the Gulf of Thailand and east coast of Peninsular Malaysia were also very low density with a range of 12-84 cysts/cm.^{3} [Lirdwitayaprasit (1998)].

Spiniferites bulloideus was the dominant species in this study with 63.8% occurrence in 47 stations. Lirdwitayaprasit (1998) reported that genus *Spiniferites* was also the dominant species in the Gulf of Thailand and the east coast of Peninsular Malaysia. From this results suggested that this species widely distributed in southeast Asian waters.

Protoperidiniaceae found in this area is composed of more species than other family in this study but was low cyst density and low percentage occurrence in comparision with the Upper Gulf of Thailand that is a high productive area. The protoperidiniacean cyst abundance associated with high diatom productivity and closely related to the rich dissolved nutrients such as the upwelling areas [Bujak (1984) and Mutsuoka (1987)].

Although cyst harmful species have not been observed in this study but a small number of *Alexandrium* cyst-like was found at station 7 located near the coastal area of Sarawak. The cyst of toxic *Pyrodinium bhamense var. compressum* was not found in this study might probably due to the sampling stations which located in off shore area.

Cyst Germination Experiment

Several test tubes were used for cyst germination experiments on the ship board but no germinating cell was observed which was probably due to the unfavorable laboratory conditions or long dormancy period of the cysts.

Conclusions and Recommendations

1. *Spiniferites bulloideus* was the dominant species in this sutdy.
2. This study provided more information on the distribution of dinoflagellate cysts off Sabah, Sarawak and Brunei Darussalam which is useful for promoting red tide and / or cyst monitoring programme in this area.
3. *Alexandrium* cyst-like was found in small number at the coastal station of Sarawak. It is important to note that almost of the member in this genus were reported as the PSP (Paralytic Shellfish Poisoning) toxin producing organism.

Acknowledgement

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References

Bajarias, F.F.A. and Jr.J.R. Relox :Hydrological and climatological parameters associated with the *Pyrodinium* blooms in Manila Philippines, in "Harmful and Toxic Algal Blooms"(ed. by T. Yasumoto, Y. Oshima and Y. Fukuyo), Intergovernmental Oceanographic Commission of UNESCO, Paris, 1996, pp. 49-52.

Bolch,C.J. and G.M. Hallegreaff : Dinoflagellate cysts in recent sediments from Tasmania, Australia. Bot. Mar., 33,173-192(1990).

Bujak, J.P. : Dinoflagellate cysts and acritarchs from the Ecocene Barton Beds of Southern England, in "Dinoflagellate Cysts and Acritrachs from the Ecocene Barton Beds of

Southern England" (ed. by J.P.Bujak) Paleontology (Special Paper), 24 ,36-91(1980).

Harland, R. : Distribution maps of recent dinoflagellate cysts in bottom sediments from the North Atlantic Ocean and adjacent seas. Paleontology,26(2) , 321-387(1983).

Lirdwitayaprasit, T. : Distribution of dinoflagellate cysts in the surface sediment of the South China Sea area 1 : The Gulf of Thailand and the east coast of Peninsular Malaysia, in " Proceedings of Report on Marine Fisheries Resource and Environmental Studies in the South China Sea, Area 1 : the Gulf of Thailand and the East Coast of Peninsular Malaysia. (in press).

Maclean. J.L. : An overview of *Pyrodinium* red tides in the western Pacific, in " Biology, Epidemiology and Management of *Pyrodinium* Red Tides" (ed. by G.M. Hallegraeff and J.L. Maclean) ICLARM Contribution No 585, 1989, pp.1-7.

Marret, F. and A. de Vernal. : Dinoflagellate cyst distribution in surface sediments of the southern Indian Ocean. Mar. Micropaleon, 29, 367-392(1997).

Matsuoka, K. : Archeopyle structure in modern gymnodinialean dinoflagellate cysts. Rev. Paleonbot. Palynolo. ,44 ,217-231(1985 a).

Matsuoka, K.: Organic-walled dinoflagellate cysts from surface sediments of Nagasaki Bay and Senzaki Bay, west Japan. Bull. Fac. Lib. Art. Nagasaki Univ., Nat . Sci. Vol. 25, No. 2, 21-115(1985 b).

Matsuoka, K. : Cyst and thecate forms of *Pyrophacus steinii* (Schiller) Wall et Dale. Trans. Proc. Paleont. Soc. Japan, N. S. No. 140, pp .240- 262(1985 c).

Matsuoka, K. and Y. Fukuyo : Cyst and motile morphology of a colonial dinoflagellate *Pheopolykrikos hartmannii* (Zimmermann) comb. Nov. J. Plank. Res. 8(4),8-11(1986).

Matsuoka, K. : Organic-walled dinoflagellate cysts from surface sediments of Akkeshi Bay and Lake Soroma, North Japan. Bull. Fac. Lib. Art. Nagasaki Univ. Nat. Sci. Vol. 28 No. 1 , 35-123(1987).

Matsuoka, K., Y. Fukuyo and D.M. Anderson : Method for dinoflagellate cyst studies, in " Biology, Epidemiology and Management of *Pyrodinium* Red Tides" (ed. by G.M. Hallegraeff and J.L. Maclean) ICLARM contribution No. 585. , 1989, pp .231-234.

McMinn, A. : Recent dinoflagellate cyst distribution in eastern Australia. Rev. Paleonbot. Palynol., 65,305-310(1990).

McMinn, A. : Recent dinoflagellate cysts from estuaries on the central coast of New South Wales, Australia. Micropaleontology, 37(3), 269-287(1991).

McMinn, A. : Recent and late Quaternary dinoflagellate cyst distribution on the continental shelf and slope of south-eastern Australia. Palynology, 16,13-24(1992).

Wall, D., Dale, B., G.P. Lohmann and W.K. Smith : The environment and climatic distribution of dinoflagellate cysts in modern sediments from regions in the North and South Atlantic Ocean and adjacent seas. Mar. Micropaleont. 2 ,121-200(1977).

Wiadnyana, N. N., T. Sidabutar, K. Matsuoka, T. Ochi, M. Kodama and Y. Fukuyo : Note on the occurence of *Pyrodinium bahamense* in the eastern Indonesian waters, in "Harmful and Toxic Algal Blooms" (ed. by T. Yasumoto, Y. Oshima and Y. Fukuyo), Intergovernmental Oceanographic Commission of UNESCO, Paris, 1996,pp.53-56.

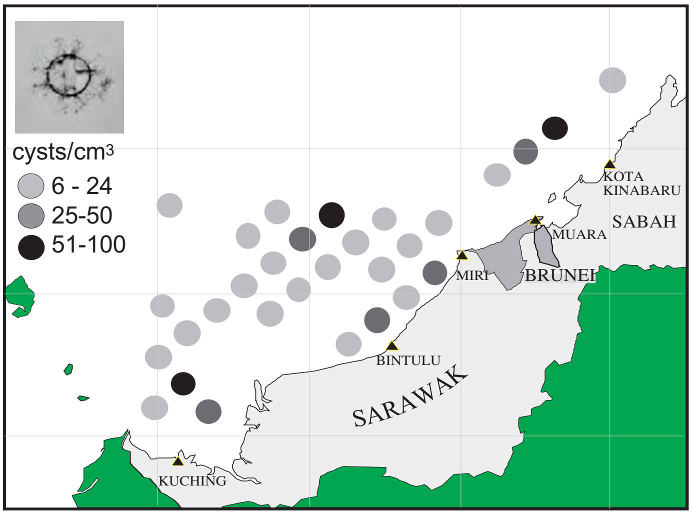

Fig. 2 Distribution and abundance of *Spiniferites bulliodeus*

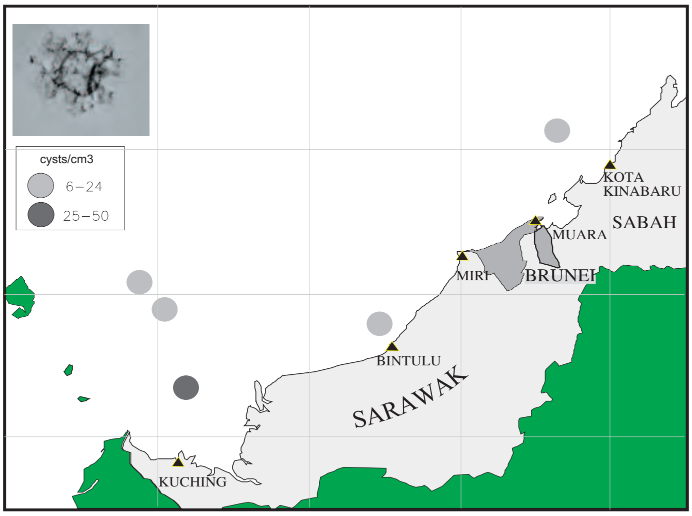

Fig. 3 Distribution and abundance of *Spiniferites cf. mirabilis*

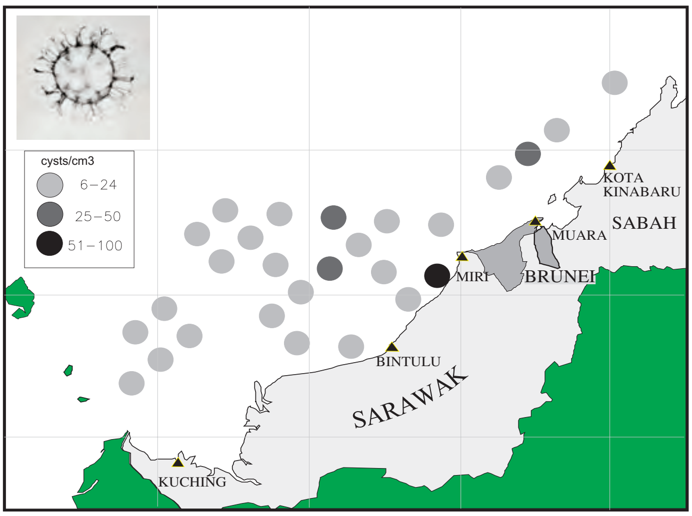

Fig. 4 Distribution and abundance of *Spiniferites ramosus*

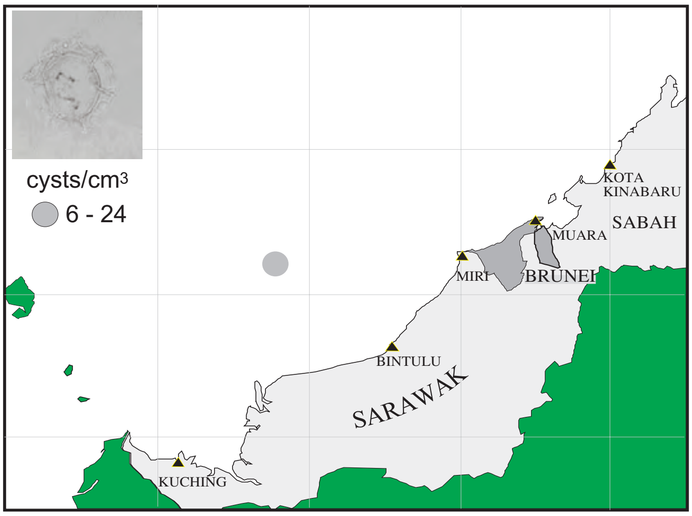

Fig. 5 Distribution and abundance of *Spiniferites cf. rubinus*

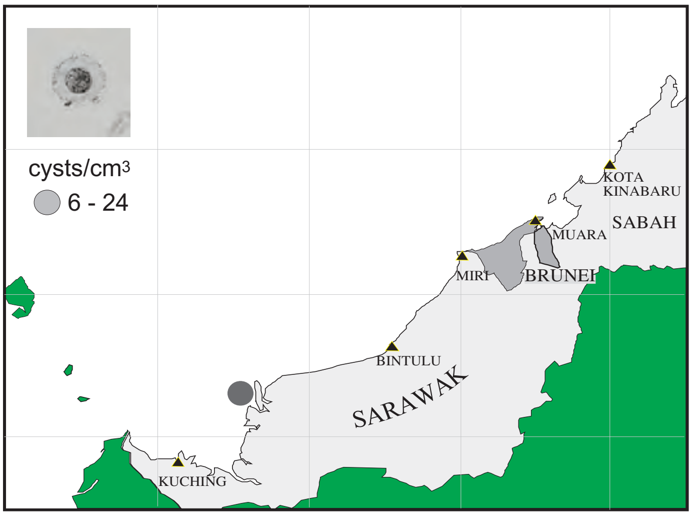

Fig. 6 Distribution and abundance of *Alexamdrium sp.*

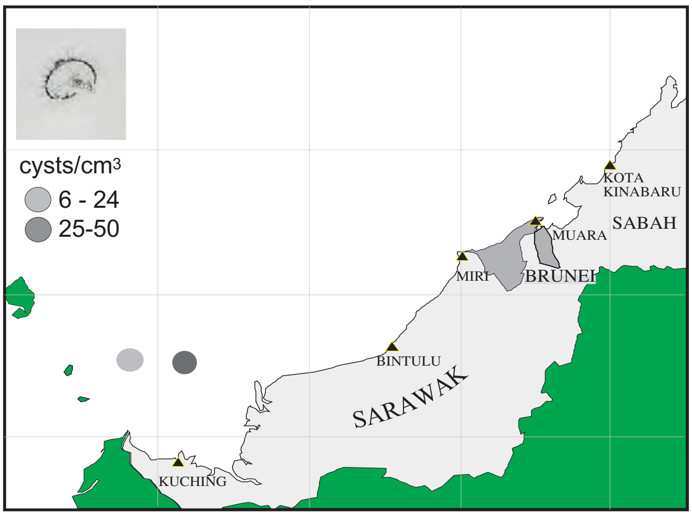

Fig. 7 Distribution and abundance of *Lingulodinium machaerophorum*

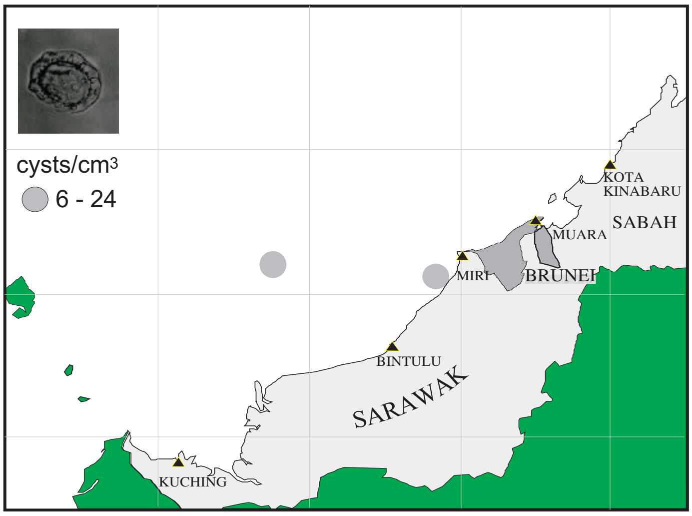

Fig. 8 Distribution and abundance of *Tuberculodinium vancampoae*

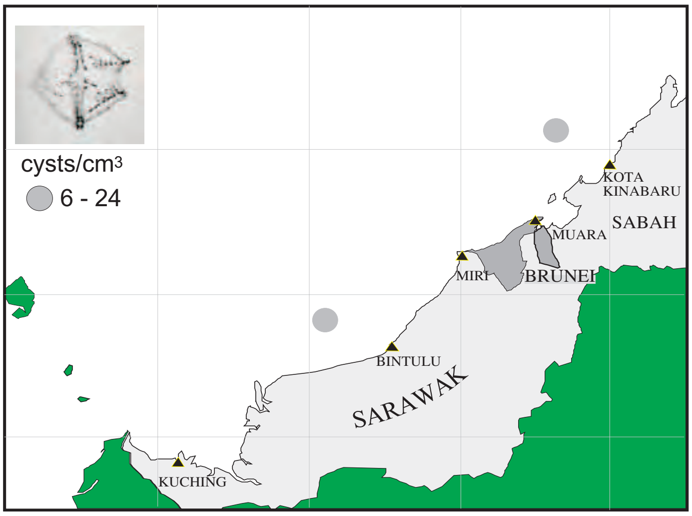

Fig. 9 Distribution and abundance of *Trinoventedium cf. capitatum*

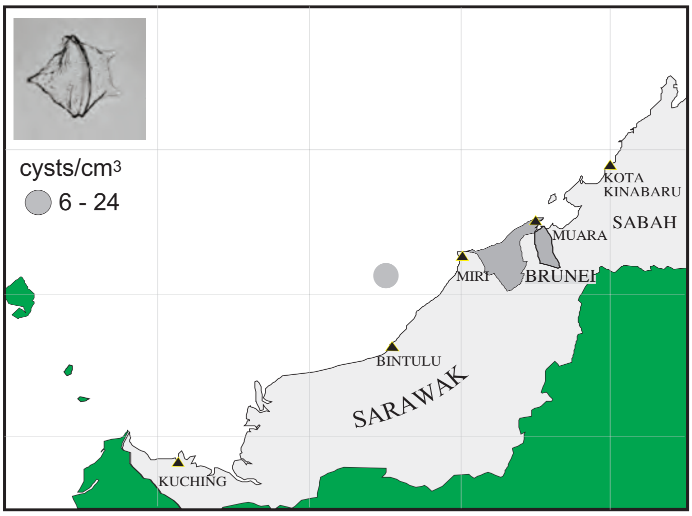

Fig. 10 Distribution and abundance of *Protoperidinium* sp1

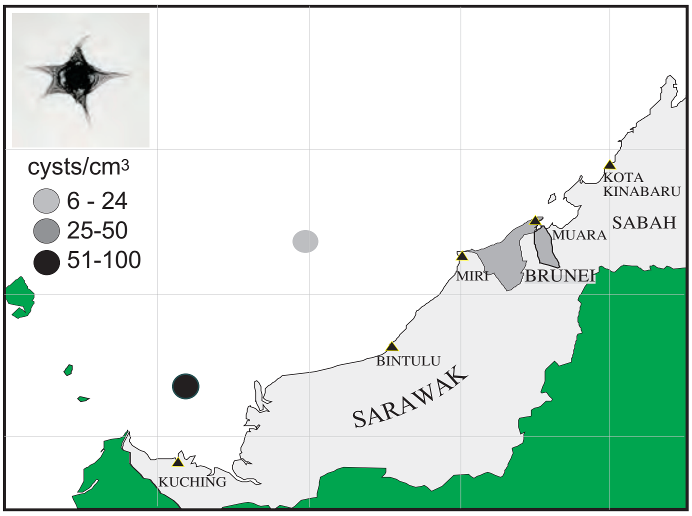

Fig. 11 Distribution and abundance of *Protoperdinium* sp2

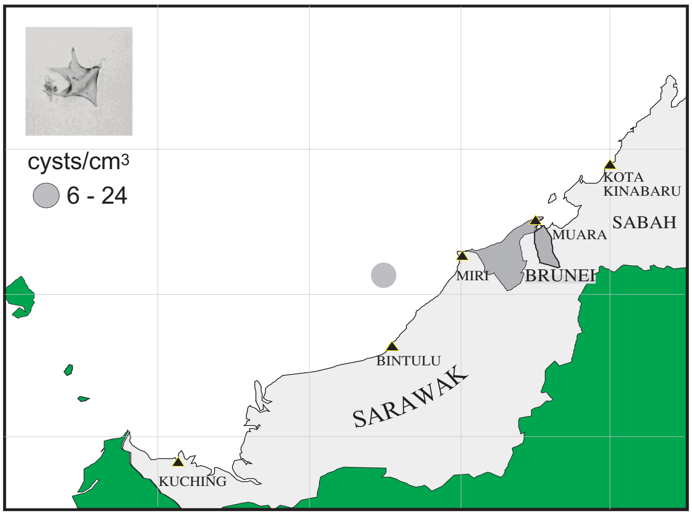

Fig. 12 Distribution and abundance of *Protoperidinium* sp3

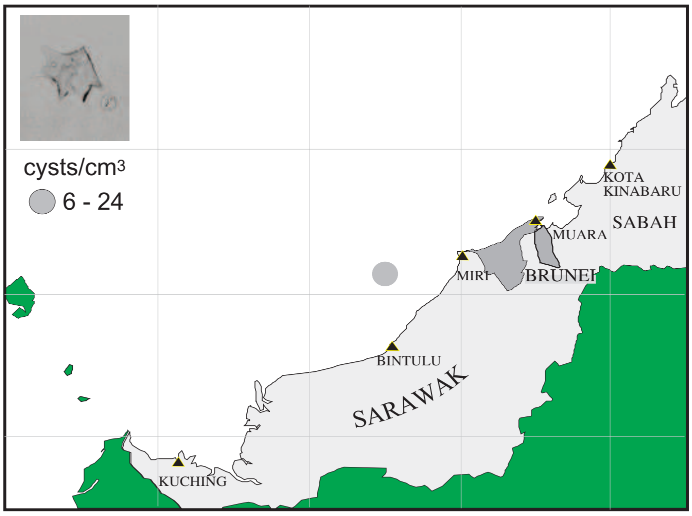

Fig. 13 Distribution and abundance of *Protoperidinium* sp4

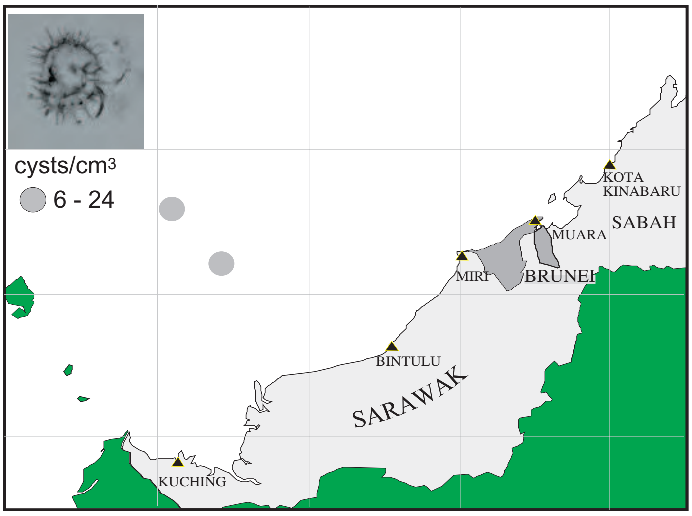

Fig. 14 Distribution and abundance of *Selenopemphix cf. quanta*

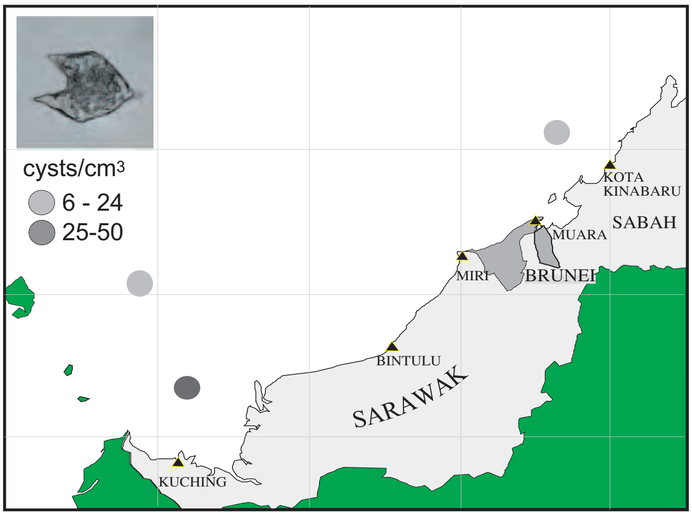

Fig. 15 Distribution and abundance of *Protoperidinium* sp5

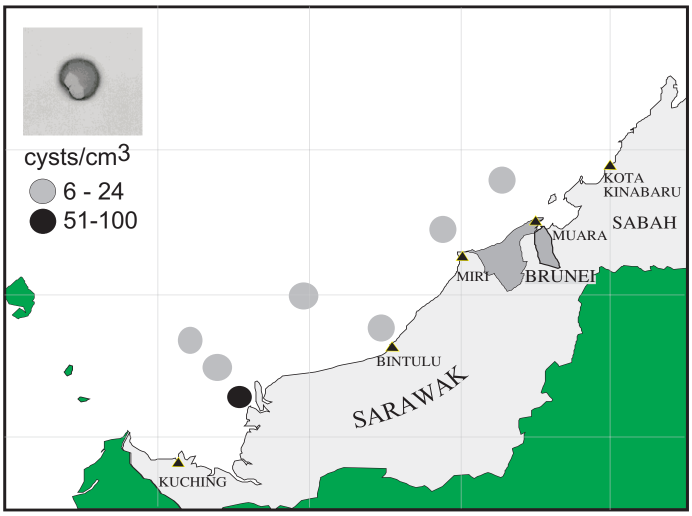

Fig. 16 Distribution and abundance of *Protoperidinium* sp6

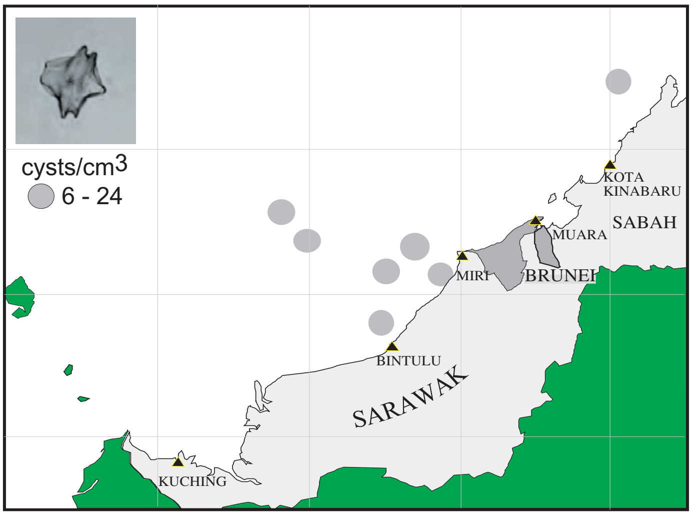

Fig. 17 Distribution and abundance of *Protoperidinium* sp7

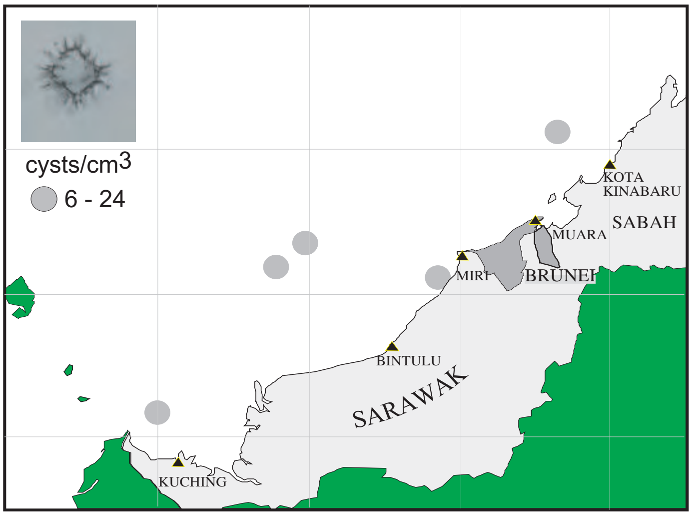

Fig. 18 Distribution and abundance of Dinoflagellate Cyst Type A

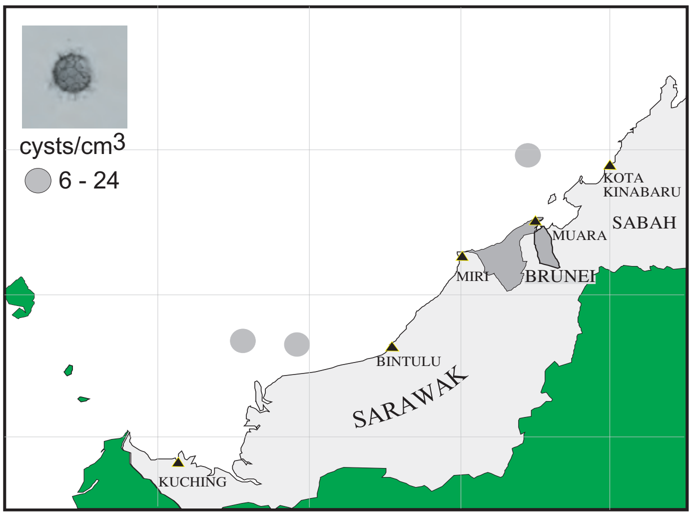

Fig. 19 Distribution and abundance of Dinoflagellate Cyst Type B

Table 1 Physical parameter of the surface sediment samples and total cyst density
1 = the first cruise, 2 = the second cruise

station	water depth (m.)		sediment temp.(c.)		surface sediment characteristic	cysts/cm^3	
	1	2	1	2		1	2
1	35.00	37.00	26.00	27.60	brownish coarse sandy mud	12	12
2	54.50	57.00	23.50	25.50	brownish coarse sandy mud	12	12
3	69.80	81.00	21.00	22.50	brownish fine sandy mud with shell fragments	5	7
4	66.00	67.00	24.60	24.30	brownish fine sandy mud with shell fragments	32	36
5	79.00	77.00	24.00	24.60	brownish fine sandy mud with shell fragments	270	286
6	43.50	41.00	29.00	26.20	brownish fine sandy mud with shell fragments	48	52
7	32.60	35.00	27.00	27.40	brownish fine sandy mud with shell fragments	90	112
8	39.00	40.80	29.00	27.60	brownish coarse sandy mud with shell fragments	4	8
9	67.50	65.00	25.20	24.10	brownish fine sandy mud with shell fragments	24	26
10	86.00	85.00	26.80	21.50	brownish fine sandy mud with shell fragments	22	24
11	100.00	101.00	23.30	20.80	brownish fine sandy mud with shell fragments	15	19
12	118.50	118.00	19.10	20.50	brownish fine sandy mud with shell fragments		_
13	115.00	114.00	19.80	20.40	brownish fine sandy mud with shell fragments		_
14	94.00	91.40	22.20	21.00	brownish fine sandy mud with shell fragments		_
15	65.50	66.00	23.40	23.00	brownish fine sandy mud with shell fragments	16	18
16	62.70	66.00	24.90	24.90	brownish fine sandy mud with shell fragments	10	12
17	30.00	29.50	28.50	27.70	brownish coarse sandy mud with shell fragments	18	16
18	45.00	48.10	27.30	26.40	brownish coarse sandy mud with shell fragments	12	10
19	70.00	71.60	23.60	23.70	brownish fine sandy mud with shell fragments	7	5
20	90.00	90.70	20.90	21.00	brownish fine sandy mud with shell fragments	12	12
21	119.00	118.00	19.80	20.20	brownish fine sandy mud with shell fragments	6	6
22	146.00	143.00	18.20	18.80	brownish fine sandy mud with shell fragments	22	24
26	123.00	123.00	18.60	19.60	brownish fine sandy mud with shell fragments	6	6
27	95.50	95.00	18.90	20.20	brownish fine sandy mud with shell fragments	18	18
28	79.00	80.00	21.90	21.40	brownish fine sandy mud	30	30
29	56.00	56.00	25.40	25.00	brownish fine sandy mud with shell fragments	22	26
30	32.00	34.00	29.20	27.80	brownish coarse sandy mud with shell fragments	6	6
31	21.50	21.00	29.80	29.00	brownish mudy clay	34	38
32	34.00	32.00	29.60	27.60	brownish fine sandy mud	58	64
33	49.00	51.20	26.50	25.90	brownish mudy clay		_
34	71.00	73.20	22.90	23.60	brownish mudy clay	70	76
35	88.00	88.00	22.00	22.20	brownish mudy clay	73	73
36	108.00	110.00	23.80	20.70	brownish fine sandy mud with shell fragments	74	72
43	105.00	105.00	20.00	20.60	brownish fine sandy mud with shell fragments	98	98
44	89.00	89.00	20.80	22.50	brownish fine sandy mud with shell fragments	20	28
45	66.00	67.10	23.30	23.90	brownish fine sandy mud with shell fragments	80	88
46	20.00	22.50	29.10	28.60	brownish fine sandy mud with shell fragments	44	52
47		29.50		27.20	brownish fine sandy mud with shell fragments	168	174
48	78.00	78.00	22.00	23.30	brownish fine sandy mud with shell fragments	48	48
49	105.00	106.00	19.50	19.00	brownish fine sandy mud with shell fragments	36	36
59	96.00	95.50	19.80	21.90	brownish fine sandy mud with shell fragments	36	36
60							NO
69	97.00	100.00	20.00	20.70	brownish fine sandy mud with shell fragments	58	62
70	124.00	140.00	18.30	17.40	brownish fine sandy mud with shell fragments	88	106
76	109.00	100.00	19.60	23.40	brownish coarse sandy mud with coral fragments	140	152
77	96.50	92.00	19.80	21.90	brownish fine sandy mud with shell fragments		_
79		57.00		25.60	brownish fine sandy mud with shell fragments	48	64

Note : _ = no cyst was observed
NO = no sediment sample could be collected

Table 2 List of dinoflagellate cysts found in the surface sediment samples

Paleontological name for cyst	Biological name for motile cell	% occurence
Gonyaulacaceae		
1. *Spiniferites bulloideus*	*Gonyaulax scrippsae*	63.80
2. *Spiniferites cf. mirabilis*	*Gonyaulax spinifera complex*	10.60
3. *Spiniferites ramosus*	*Gonyaulax spinifera complex*	57.40
4. *Spiniferites cf. rubinus*	*Gonyaulax sp.*	2.10
5. *Alexandrium sp.*	*Alexandrium sp.*	2.10
6. *Lingulodinium machaerophorum*	*Lingulodinium polyedrum*	4.30
Pyrophacaceae		
7. *Tuberculadinium vancampoae*	*Pyrophacus stenii*	4.30
Protoperidiniaceae		
8. *Trinoventedinium cf. capitatum*	*Protoperidinium pentagonum*	4.30
9. *Trinoventedinium sp.1*	*Protoperidinium sp.1*	2.10
10. *Stelladinium sp.1*	*Protoperidinium sp.2*	4.30
11. *Stelladinium sp.2*	*Protoperidinium sp.3*	2.10
12. *Stelladinium sp.3*	*Protoperidinium sp.4*	2.10
13. *Selenopemphix cf. quanta*	*Protoperidinium conicum*	4.30
14	*Protoperidinium sp.5*	6.40
15	*Protoperidinium sp.6*	14.90
16	*Protoperidinium sp.7*	14.90
Uncertain Family		
17. Dinoflagellate cyst type A.		10.60
18. Dinoflagellate cyst type B.		6.40

Table 3. Abundance and distribution of all identified dinoflagellate cyst taxa

	average total cyst descities (cysts/cm^3)																																							
Station	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**34**	**35**	**36**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**59**	**69**	**70**	**76**	**79**
Gonyaulacaceae																																									
Spiniferites bulloideus	6			17	76	25			6	6		11			6	6			11		12	12	6		12	37	24	37	24	61	12	24	24	49	24	12	12	24	37	86	11
Spiniferites cf. miranilis					25					6	17															12														24	
Spiniferites ramosus		6	6	17					6	11				11	6		6	6		6	6	6	12		24		37		24	37	12	12	24	98		24	12	24	49	12	11
Spiniferites cf. rubinus																						6																			
Alixandrium sp. 1							25																																		
Lingulodinium machaerophorum		6			25																																				
Pyrophacaceae																																									
Tuberculodinium vancampoae																								6																	
Protoperidiniaceae																																									
Trinoventedinium cf. capitatum						25																		6																12	
Protoperidinium sp. 1																																24									
Protoperidinium sp. 2					102																							12													
Protoperidinium sp. 3					25																																				
Protoperidinium sp. 4																																12									
Selenopemphix cf. quanta																	6		6																						
Protoperidinium sp. 5					25							6																												12	
Protoperidinium sp. 6							76	6	23														6		12												12	12			
Protoperidinium sp. 7																											12	12	24			12		12	12						23
Uncertain Family																																									
Dinoflagellate cyst type A	6																					6						12						12							11
Dinoflagellate cyst type B													11	6																									12		
Total	12	12	6	34	278	50	101	6	25	23	17	17	11	17	12	6	12	6	23	6	18	30	24	6	36	61	73	73	72	98	24	84	48	171	48	36	36	60	98	146	56

Temporal Changes in the Abundance of Macrobenthos in the South China Sea, Area II: Sarawak, Brunei and Sabah

MONTIRA PIAMTHIPMANUS

Department of Fisheries

ABSTRACT

The macrobenthic fauna in the South China Sea (Sarawak, Brunei and Sabah) was surveyed during pre NE monsoon (4 Jul.- 8 Aug. 1996) and post NE monsoon (25 Apr.-31 May 1997). Over 90 species were collected by Smith-McIntyre grab of 47 stations.

The overall density of macrobenthic fauna in Sarawak, Brunei and Sabah area was 100 ind. m^{-2} on average in the pre NE monsoon and 167 ind.m^{-2} on average in the post NE monsoon. Most species were carnivore/scavengers followed by deposit-feeder and fewer suspension-feeder or herbivores both in the pre and post NE monsoon. There was a marked seasonal variation in faunal composition between the pre and post NE monsoon. During the pre NE monsoon polychaeta was the most abundance followed by crustacea while during the post NE monsoon crustacea was the most abundance followed by polychaete and the remaining groups of macrobenthic fauna which were poorly represented in the survey areas both in the pre and post NE monsoon periods. All the diversity indecies decline from the pre to post NE monsoon.

Key words: Macrobenthic fauna; Abundance; Sarawak, Brunei and Sabah

Introduction

There are many reports on pollution impact to benthic fauna and benthic succesion after local extinction of native fauna such as Pearson (1975), Tsutaumi and Kikuchi (1983). Therefore, The benthic fauna continue to be the subject of much research in the fields of hydrobiology and ecology because of the important of benthic organisms in the nutrition of fishes and as biological indicators of marine pollution.

Since the South China Sea has supported a commercial fishery such as purse seine and trawl fisheries for many decades but little work has been done on biological oceanography in this area. Therefore, the collaborative research project between SEAFDEC's Training Department (TD) in Thailand and Marine Fisheries Resources Development and Management Department (MFRDMD) in Malaysia have initiated a research programme survey on biological oceanography in the South China Sea which aim at providing a necessary information for management of the environment and fishery resources in the South China Sea. The first survey area had already been done in the western part of the Gulf of Thailand and the east coast of Peninsular Malaysia within the exclusive economic zones of Thailand and Malaysia during 1995-1996 and the second survey area is now carried out in Sarawak, Brunei and Sabah area between 1996-1997.

The study of macrobenthic fauna is part of the biological oceanographic data survey under the collaborative research project since benthic study may serve as base line information to evaluate the existing demersal stocks and may also serve as a baseline study of future investigations on environmental changes. Therefore, any fluctuation in either their quality and quantity will directly affect the abundance of demersal fish which are an important fishery resources in the sea.

In this study will examine in some detail of distribution and seasonal change of faunal composition, density and diversity of macrobenthic fauna in the South China Sea along Sarawak, Brunei and Sabah.

Materials and methods

1) Sampling area

The survey areas are in the South China Sea along Sarawak, Brunei and Sabah. A total of 79 survey stations were set up for the collaborative research project but the survey of macrobenthic fauna were sampled only 47 stations with water depth between 20m to 240m, due to the limitation of time and equipment to depth (Fig.1). The investigations were carried out on board MV SEAFDEC from 4 July -8 August 1996 (pre NE monsoon) and 25 April - 31 May 1997 (post NE monsoon).

2) Sampling methods

One sample of bottom sediment was collected using Smith-McIntyre grab (area coverage 0.1 m^2) at 47 stations. The sediment was wash through a set of sieves, the smallest one with a mesh sieve of 0.5 mm. The benthic animal remaining on the sieve was sorted out and fixed in 10% formaldehyde solution in sea water on board and were subsequently identified and count separately for each taxa in the laboratory. The number of individuals of 5 taxonomic groups (Polychaeta, Crustacea, Mollusca, Echinodermata and Other groups) were recorded. The individuals of each species group were counted and placed into different feeding type- herbivores, deposit-feeders, carnivores/scavengers and suspension-feeders by consulting Fauchald (1977) and Day (1967) for polychaetes and Ruppert and Barnes (1991) for the remaining phyla.

3. Sediment Analysis

A sample of approximately 200 g sediment was collected from the surface of the grab sample to determine grain size composition (clay, clayey sand, sandy clay and sand) by the Wentworth scale (1922) and Shetard (1954) methods.

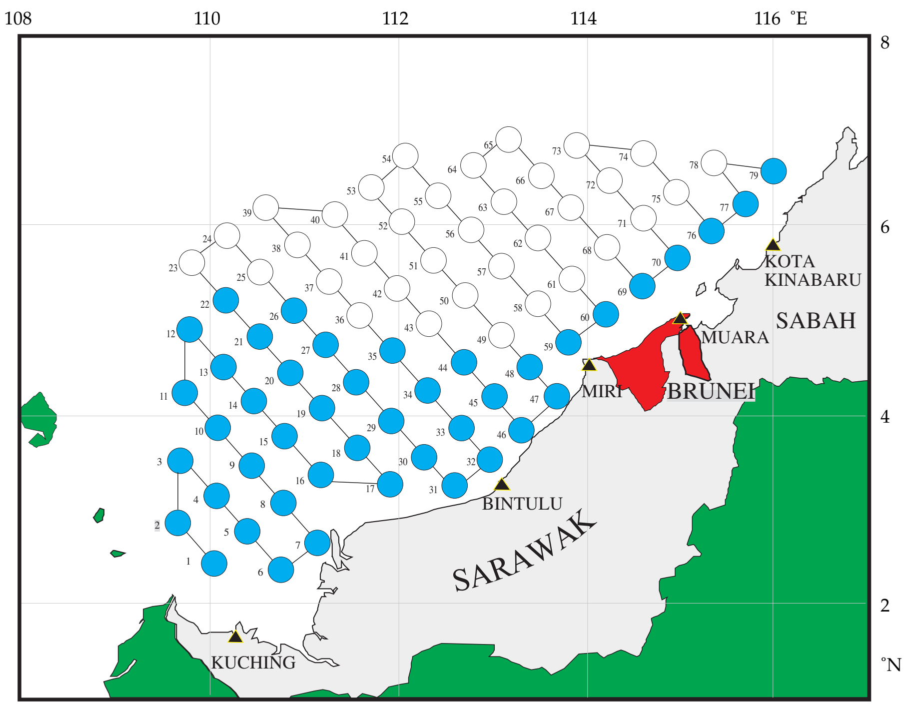

Fig. 1 Survey area and sampling stations

○ The Oceanographic stations

● Macrobenthic sampling survey stations

4. Analysis

i) Estimation of the difference in abundance of macrobenthic fauna (ind. m^{-2}) in the South China Sea (Sarawak, Brunei and Sabah) between the pre and post NE monsoon periods. The results of these calculations are summarised in the Table (- decrease, 0 no difference, + increase).

ii) Estimation of species diversity, richness index and evenness index of macrobenthic fauna in the South China Sea (Sarawak, Brunei and Sabah) between the pre and post NE monsoon periods. Diversity Index was calculated from Shannon and Weaver's (1949) formula as reported in Ludwig, J.A. and J. F. Reynolds (1988).

$$H' = -\sum_{i=1}^{s}(p_i \ln p_i)$$

Richness index was calculated from Margalef (1958) formula.

$$R = (s-1)/\ln(n)$$

Evenness index was calculated by modified Hill's ratio (1973b)

$$E = (N_2 - 1)/(N_1 - 1)$$

where N_1 (number of abundant species in the sample) = $e^{H'}$

N_2 (Number of very abundant species) = $1/\lambda$

$$\lambda = \sum_{I=1}^{s} n_i(n_i-1)/n(n-1)$$

Results

Sediment characteristics

Sediment characteristics in the South China Sea (Sarawak, Brunei and Sabah) were described as sand, sandy clay, clayey sand and clay. The bottom sediment of the survey area is mainly covered by sandy clay. It accounts for 38.30% of the survey area. The latter are clayey sand and clay which account for 27.66 % and 19.15 % respectively. Sand sediment is the lowest sediment fraction in the survey areas which account for 14.89 % (Table 1 and Fig. 2)

1. The abundance and distribution of macrobenthic fauna

The overall average abundance of macrobenthic fauna in Sarawak, Brunei and Sabah was 100 ind. m^{-2} in the pre NE monsoon and 167 ind. m^{-2} in the post NE monsoon. The five groups of macrobenthic fauna found in Sarawak, Brunei and Sabah are polychaete, crustacea, mollusca, echinodermata and others. Polychaete was the dominant taxa (53.0%) in the benthic communities in the pre NE monsoon while crustacea was the dominant taxa (58.7 %) in the post NE monsoon (Table 2). The average abundance of macrobenthic fauna varied from 10 to 320 ind.m^{-2} in the pre NE monsoon and 20 to 670 ind.m^{-2} in the post NE monsoon. High density areas of macrobenthic fauna occurred in Sarawak area at station 30 with water depth of 34 m in the pre NE monsoon and station 46 with water depth of 22 m in the post NE monsoon (Table 3).

The abundance of macrobenthic fauna in Sarawak, Brunei and Sabah increased from the pre NE monsoon to post NE monsoon (Fig.3). Over 90 species of macrobenthic fauna were recorded both in the pre and post NE monsoon.

The feeding type of macrobenthic fauna presented in the survey areas were mostly carnivores/ scavengers (62.59%) followed by deposit feeders (35.02%), Suspension feeder (2.31%) and herbivore (0.08%) (Table 4).

Polychaete

Polychaetes were the most abundant group of macrobenthic fauna in the pre NE monsoon. The

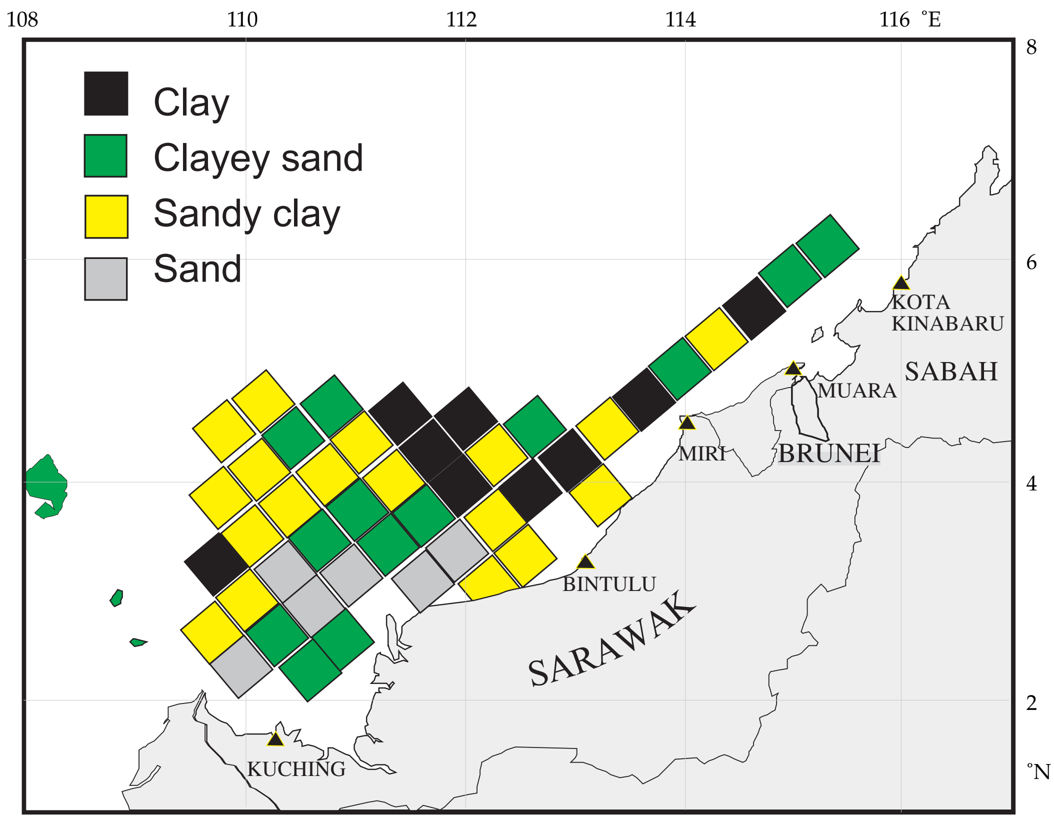

Fig. 2 The sediment types in the study area

overall average abundance of polychaete was 53 ind.m^{-2} (53.00%) in the pre NE monsoon and 60 ind.m^{-2} (35.90%) in the post NE monsoon (Table 2). During pre NE monsoon the abundance of polychaete varied from 10 to 230 ind.m^{-2} and most abundance at station 31 with water depth of 21 m where the sediment was sandy clay. While during the post NE monsoon, the abundance of polychaete varied from 10 to 180 ind.m^{-2} and the most abundance occurred at station 47 with water depth of 29 m where the sediment was sandy clay (Table 1 and 3). A total of 32 families of polychaete were identified and Capitellidae occurred at most stations (Table 4).

Crustacea

Crustaceans were the most abundant group of macrobenthic fauna in the post NE monsoon. The overall abundance of crustacea was 37 ind.m^{-2} (37.00%) on average which varied from 0 to 170 ind.m^{-2} in the pre NE monsoon and 98 ind.m^{-2} (58.70%) on average which varied from 0 to 500 ind.m^{-2} in the post NE monsoon. The highest density of crustacea occurred at station 9 and station 30 in pre NE monsoon and station 46 in post NE monsoon (Table 2 and 3). It should be noted that the bottom sediment of stations 9, 30 and 46 were all sand (Table 1). Amphipod was the most abundance and occurred every station in the survey area (Table 4).

Echinodermata

The overall abundance of echinoderm was 4 ind.m^{-2} (4.0%) varying from 0 to 40 ind.m^{-2} in pre NE monsoon and 4 ind.m^{-2} (2.4%) varying from 0 to 30 ind.m^{-2} in post NE monsoon (Table 2 and 3). Brittle stars was the most abundance of this group (Table 4).

Mollusca

This group was found very few in number. The abundance of mollusc was only 1 ind.m^{-2} on average both in the pre and post NE monsoon and ranged from 0 to 20 ind.m^{-2} and 0 to 10 ind.m^{-2} in

Table 1. The sediment types of sampling station.

Sediment types	Station number
sand	1,8,9,16,17,30,46
sandy clay	2,4,10,11,12,13,14,20,22,27,28,31,32,33,44,47,59,70
clayey sand	5,6,7,15,18,19,21,26,29,49,69,77,79
clay	3,34,35,36,43,45,48,60,76

Table 2. Average abundance of macrobenthic fauna in the first and second periods in the South China Sea (Sarawak, Brunei and Sabah).

Macrobenthic fauna	Abundance ind. m^{-2} (%)	
	First period	Second period
Polychaete	53 (53.00%)	60(35.90 %)
Crustacea	37 (37.00%)	98 (58.70%)
Mollusca	1 (1.00%)	1 (0.60%)
Echinodermata	4 (4.00%)	4 (2.40%)
Others	5 (5.00%)	4(2.40%)
Total macrobenthic fauna	100 (100%)	167 (100%)

the pre and post NE monsoon respectively (Table 2 and 3). It should be noted that mollusc were occurred in low density of the survey area.

Others

This category includes nemerteans, sipunculans, anthozoa, porifera, amphioxus and fish which were poorly represented in comparison with other major taxonomic groups. On average this group contributed 5 ind.m^{-2} (5.0%) in the pre NE monsoon. and 4 ind.m^{-2} (2.4%) in the post NE monsoon, ranging from 0 to 40 ind.m^{-2} in the pre NE monsoon and 0 to 20 ind.m^{-2} in the post NE monsoon (Table 3).

2. Variation in abundance with depth

It appears that the highest density of macrobenthic fauna were occurred at water depth of 0-60 m both in the pre and post NE monsoon with the highest density of polychaete in the pre NE monsoon and crustacea in the post NE monsoon. It is remarkable that polychaeta occurred at every range of water depth between 0-240 m both in the pre and post NE monsoon. The abundance of crustacea occurred at water depth between 0-240 m in the pre NE monsoon and occurred at water depth between 0-180 m in the post NE monsoon. Mollusc, echinodermata and others group were not found at water depth from 181 to 240m (Fig. 4 a and b).

3. Changes in abundance of macrobenthic fauna between the pre and post NE monsoon periods.

The results of the analysis of changes in abundance of macrobenthic fauna in South China Sea (Sarawak, Brunei and Sabah) between the post and pre NE monsoon periods are presented in Table 5. About 85% and 90% of the survey areas show a marked difference in abundance of polychaete and crustacea groups respectively and about 50% of survey area show the difference in abundance of echinoderm while the abundance of mollusc has remained steadily for both pre and post NE mon-

Table 3. Average abundance of macrobenthic fauna (ind.m^{-2}) in the first and second survey periods.

St.	Depth	Polychaeta		Crustacea		Mollusca		Echinodermata		Others		Total	
	(m)	first	second	first	second	first	second	first	second	first	second	first	second
1	38	10	30	20	170	0	0	0	0	0	20	30	220
2	55	30	50	10	410	0	0	10	0	0	0	50	460
3	81	20	90	110	50	0	0	0	10	0	10	130	160
4	66	70	60	80	20	0	0	0	10	10	0	160	90
5	79	50	20	20	0	0	0	10	0	10	0	90	20
6	43	40	10	90	240	0	0	10	0	0	0	140	250
7	33	80	10	40	260	0	0	0	30	10	0	130	300
8	40	30	10	20	20	10	0	10	0	10	0	80	30
9	68	10	20	170	50	0	0	10	0	10	0	200	70
10	87	40	20	0	70	0	0	0	0	0	0	40	90
11	101	30	60	60	60	0	0	0	0	0	20	90	140
12	118	60	50	20	30	0	0	0	0	0	0	80	80
13	115	30	50	60	50	0	0	0	20	10	0	100	120
14	93	60	40	60	30	0	0	10	0	10	0	140	70
15	66	20	50	80	110	0	0	0	0	0	10	100	170
16	66	150	90	40	30	0	10	0	20	10	10	200	160
17	33	40	40	40	230	0	0	0	10	10	10	90	290
18	49	0	60	20	130	0	0	10	10	10	0	40	200
19	71	50	60	40	140	0	0	0	0	10	0	100	200
20	90	60	30	50	90	0	0	0	0	0	20	110	140
21	119	40	20	0	290	0	0	0	0	0	0	40	310
22	146	20	60	0	90	0	0	0	0	0	0	20	150
26	123	60	40	50	0	10	0	0	0	10	10	130	50
27	95	30	70	30	60	0	0	20	10	10	20	90	160
28	80	70	80	0	60	0	0	0	0	10	0	80	140
29	56	70	70	10	180	0	0	10	0	10	0	100	250
30	34	140	130	170	280	0	0	0	10	10	10	320	430
31	21	230	150	30	130	0	0	0	10	10	0	270	290
32	34	40	90	80	130	0	0	10	0	10	20	140	240
33	51	80	110	70	130	20	0	10	0	0	10	180	250
34	73	30	30	10	60	0	0	0	10	0	0	40	100
35	88	10	70	0	30	0	0	0	0	0	0	10	100
36	110	50	50	10	0	0	0	0	0	0	0	60	50
43	105	10	30	0	0	0	0	0	0	0	0	10	30
44	89	30	30	10	20	0	0	0	0	0	0	40	50
45	67	60	20	10	10	0	0	0	0	0	0	70	30
46	22	140	140	90	500	0	0	0	10	40	20	270	670
47	29	70	180	20	190	0	0	40	20	0	0	130	390
48	78	60	40	10	10	0	0	0	0	10	0	80	50
49	106	40	30	30	0	0	0	0	10	0	0	70	40
59	96	50	120	0	40	0	0	0	0	10	0	60	160
60	233	60	60	20	0	0	0	0	0	0	0	80	60
69	100	10	40	0	20	0	0	0	0	0	0	10	60
70	140	50	110	0	20	0	0	0	0	0	10	50	140
76	109	40	100	0	50	0	0	0	0	0	10	40	160
77	96	30	80	50	70	0	0	10	10	0	0	90	160
79	57	110	50	20	30	0	0	0	10	0	0	130	90

Table 4. List of macrobenthic fauna in the South China Sea (Sarawak, Brunei and Sabah)

Macrobenthic fauna	F	Stations
Phylum Porifera	S	15,16,17,18,20,27,29
Phylum Coelenterata		
Class Anthozoa	S	11,26,46,
Phylum Nemertea	C	1,4,5,7,11,14,17,19,20,26,27,28,32,46
Phylum Sipuncula	D	1,3,29,31,32
Phylum Mollusca		
Class Gastropoda		
Fam. Nassariidae		
Zeuxis sp.	C	16
Fam. Strombidae		
Terebellum sp.	H	33
Class Pelecypoda		
Fam. Veneridae	S	8
Pitar sp.	S	26
Fam. Solecurtidae		
Azorinus sp.	S	33
Phylum Annelida		
Class Polychaeta		
Fam. Orbiniidae		
Orbinia sp.	D	18,49
Fam. Paraonidae	D	4,7,32,47,60,70
Fam. Cossuridae		
Cossura sp.	D	45,60
Fam. Spionidae	D	30,31,44,46,60,70,76,79
Prionospio sp.	D	4,10,13,14,16,21,26,28,31,32,33,35,44,46,47,59,77,79
Fam. Magelonidae		
Magelona sp.	D	59,60
Fam. Trochochaetidae		
Trochochaeta sp.	D	79
Fam. Poecilochaetidae		
Poecilochaetus sp.	D	11,19,22,30,31,43,47,70
Fam. Cirratulidae	D	1,2,4,6,13,27,28,30,31,36,45,60
Fam. Capitellidae	D	3,4,7,10,13,14,15,16,18,20,22,26,27,28,30,31,32,33,34,36,43,45, 60,69,70,76,79
Fam. Maldanidae	D	3,10,13,14,15,16,17,19,21,22,27,28,29,30,31,33,34,35,36,45,47,59, 76,79
Maldane sp.	D	26
Fam. Opheliidae		
Armandia sp.	D	32
Ophelina sp.	D	15,33,70,76,79
Polyophthalmus sp.	D	1,
Tachytrypane sp.	D	46
Fam. Scalibregmidae	D	13,48,49,70
Fam. Phyllodocidae	C	9,19,33
Fam. Aphroditidae	C	30
Fam. Polyodontidae	C	46
Fam. Sigalionidae	C	2,6,8,16,21,22,30,33,43,46,47,59,76,79
Fam. Hesionidae	C	12,49
Fam. Pilargiidae	C	43,46,49,59
Fam. Syllidae	C	3,4,5,7,10,11,13,14,20,22,29,30,33,35,45,46,48,69,70,76,79
Fam. Nereidae	C	12,31,46,47,59,76
Fam. Glyceridae		
Glycera sp.	C	4,8,11,12,14,15,27,28,31,32,36,46,70
Fam. Goniadidae		
Goniada sp.	C	5,15
Fam. Nephtyidae	C	11,12,16,79
Aglaophamus sp.	C	2,4,8,17,28,31,33,34,35,36,45,46,48,60,76
Inermonephtys sp.	C	30
Micronephthys sp.	C	29,31,32,47
Fam. Amphinomidae		
Chloeia sp.	C	17,19,49
C. flava	C	30,46

Table 4. Continue

Macrobenthic fauna	F	Stations
Fam. Onuphidae	C	1,2,4,7,11,19,20,26,27,30,31,32,36,44,45,46,48,59,77
Diopatra sp.	C	8,14,33,46,77
Fam. Eunicidae		
Eunice sp.	C	4,5,19,20,29,31,69,76
Lysidice sp.	C	2,5,29
Marphysa sp.	C	22,26,31,32,70
Nematonereis sp.	C	76
Fam. Lumbrineridae	C	2,3,4,12,14,16,17,21,26,28,29,30,31,32,33,45,46,47,59,60,70,77,79
Fam. Sternaspidae		
Sternaspis sp.	D	9,16,28,29,31,33,47,49
Fam. Flabelligeridae	D	5,70,77
Pherusa sp.	D	16,29,31,47
Fam. Terebellidae	D	3,19,30,44,46
Pista sp.	D	2,12,28
Fam. Trichobranchidae		
Terebellides sp.	D	3,7,20,21,28,31,47,70,76
Fam. Sabellidae	S	6,13,18,26,32
Chone sp.	S	12
Unidentified Polychaeta		1,2,3,4,6,7,9,10,11,12,14,16,17,18,19,20,22,26,27,28,29,31,32,33, 34,35,36,44,46,47,48,49,59,60,77,79
Crustacea		
Class Malacostraca		
Order Stomatopoda		
Fam. Squillidae	C	16
Clorida sp.	C	6
Levisquilla sp.	C	13,27,32,79
Oratosquilla sp.	C	33
Order Decapoda		
Metapenaeus sp.	C	18
Alpheus sp.	C	3,6,9,11,17,19,20,21,28
Leptochela sp.	C	17,18,19,27,77
Ogyrides sp.	C	29
Callianassa spp.	D	1,3,4,6,7,9,10,11,12,13,14,15,17,19,20,21,22,26,27,29,30,31,32,33, 46,47,59,77,79
Upogebia spp.	D	1,17,29,31,32,33,49
Unidentified shrimp	C	15,17,18,29,30,31,32,46,47
Fam. Raninidae		
Raninoides sp.	C	34
Fam. Parthenodidae	C	4
Fam. Portunidae		
Portunus sp.	C	9,30
Fam. Leucosidae		
Arcania sp.	C	1,21,30
Fam. Goneplacidae	C	20,29
Eucrate sp.	C	1,7,15,18,33
Fam. Pinnotheridae	C	9,29,47
Fam. Xanthidae	C	4
Liagore rubromaculata	C	16
Fam. Ocypodidae		
Macrophthalmus sp.	C	69,77
Unidentified crab	C	2,6,7,16,18,33,34,44,45,47,59,79
Order Amphipoda	C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,26,27,28, 29,30,31,32,33,34,35,44,46,47,48,49,59,60,69,70,76,77,79
Order Isopoda	C	2,7,8,10,13,17,21,27,29,30,32,46,48
Unidentified crustacea	C	3,6,8,13,20,36,46,76
Phylum Echinodermata		
Class Ophiuroidea	D	2,3,4,5,6,7,9,13,14,16,17,18,27,29,30,31,32,34,46,47,49,77,79
Class Echinoidea		
Fam. Brissidae		
Brisopsis luzonica	D	18
Fam. Loveniidae		
Lovenia sp.	D	27
Fam. Spatangidae		
Maretia sp.	D	8

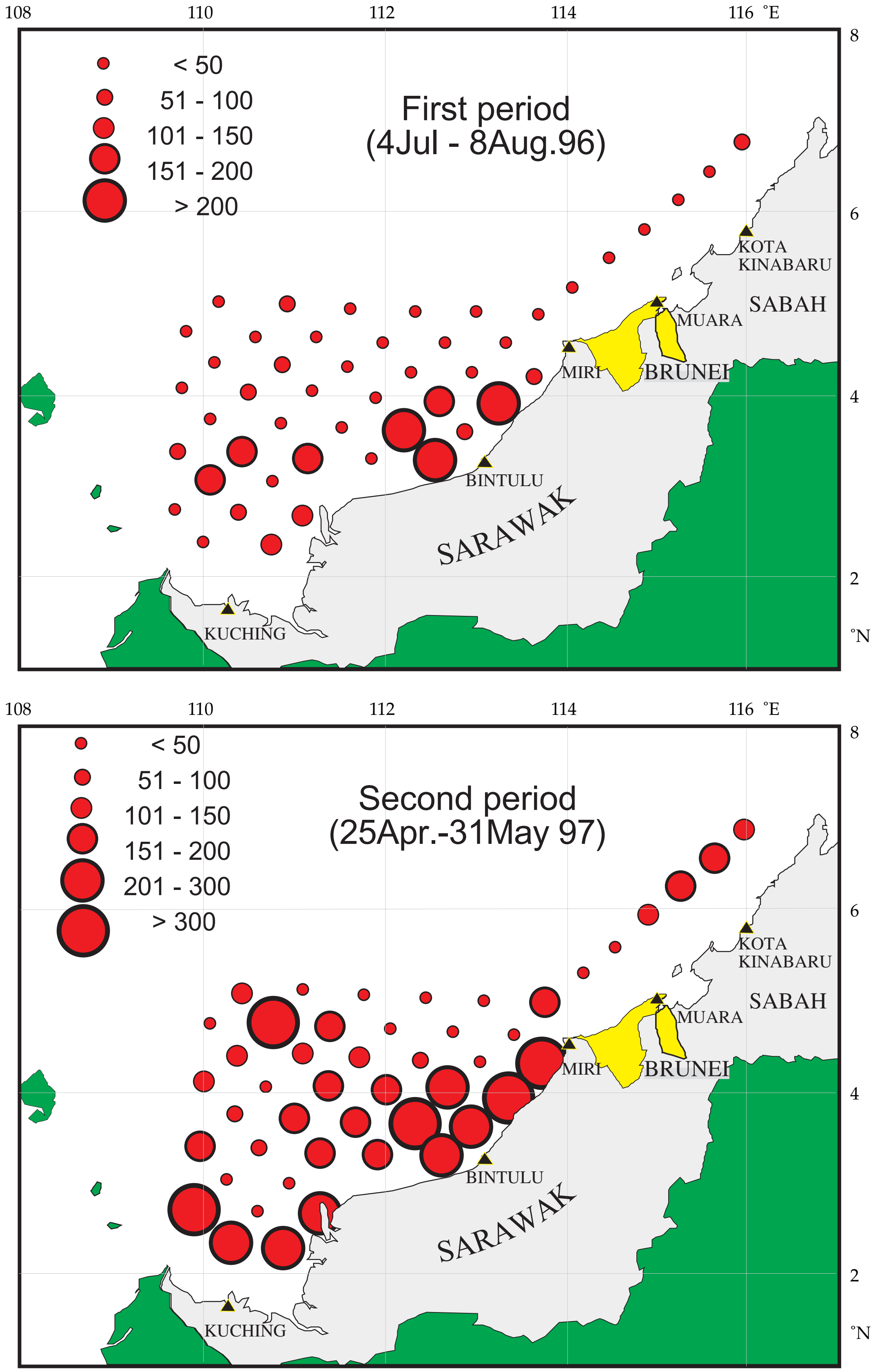

Fig. 3 The abundance of macrobenthic fauna (ind. m^{-2}) in the South China Sea (Sarawak, Sabah and Brunei Darussalam).

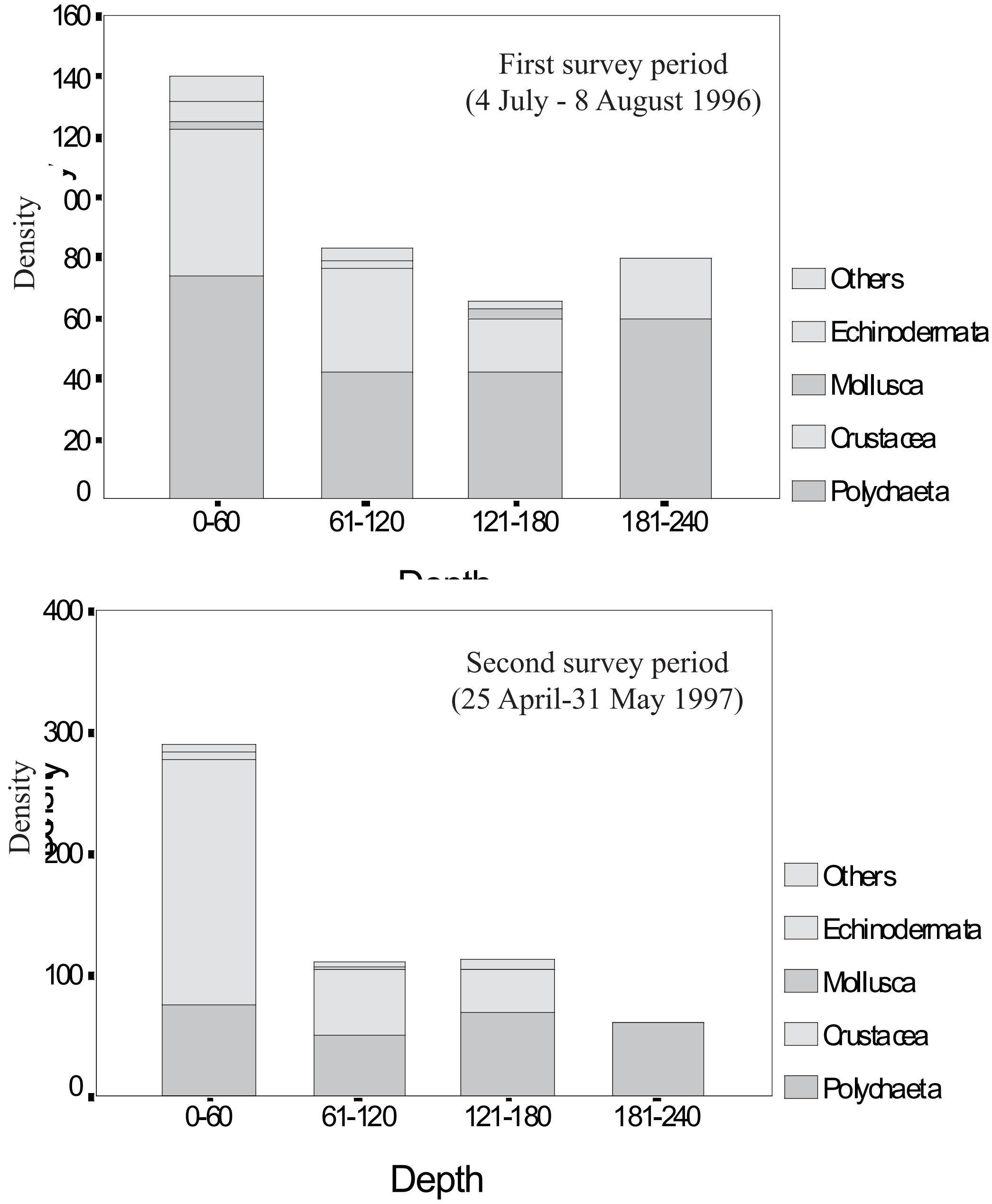

Fig. 4 The total density of macrobenthic fauna (ind.m^{-2}) as a function of depth (m) in the first survey period and second survey period

soon. By and large, nearly 98% of the survey area show a marked difference in abundance of macrobenthic fauna between the post and pre NE monsoon periods.

Polychaete

It was found that nearly 47% of the survey area show the increase in abundance of polychaete from pre NE monsoon to post NE monsoon periods. The increase in abundance of this group ranging from 10 to 110 ind.m^{-2} with 50% of the increase in abundance was found 35 ind.m^{-2}, whereas about 38% of the survey area show the decrease in abundance of this group from the pre to post NE monsoon period. The decrease of the abundance ranging from 10 to 80 ind.m^{-2} with about 50% of decreased abundance was found 20 ind.m^{-2} (Fig. 5a and b).

Frequency	stem	& Leaf
3.00	0 .	111
8.00	0 t	22223333
4.00	0 f	4455
6.00	0 s	666677
.00	0 .	
1.00	1 .	1
Stem width:	100	
Each leaf:	1 case (s)	

a) increase (22 stations)

Frequency	stem	& Leaf
2.00	Extremes	(-80), (-70)
2.00	-6 .	00
.00	-5 .	
1.00	-4 .	0
3.00	-3 .	000
6.00	-2 .	000000
4.00	-1 .	0000
Stem width:	10	
Each leaf:	1case (s)	

b) decrease (18 stations)

Fig. 5 Stem and Leaf plot of changes in abundance of polychaete for 40 stations between the first and second survey periods

Crustacea

This group has shown a marked difference in abundance between the pre and post NE monsoon periods. Nearly 66 % of the survey area show the increase in abundance from pre to post NE monsoon. The increase in abundance of crustacea ranged from 10 to 290 ind.m^{-2}, except station 2 (400 ind.m^{-2}) and station 46 (410 ind.m^{-2}). In addition, 50% of the increase in abundance was found 60 ind.m^{-2}. On the other hand, about 23 % of the survey area show the decrease in abundance of this group from the pre to post NE monsoon. The decrease in abundance ranged from 10 to 60 ind.m^{-2} except at station 9 (120 ind.m^{-2}) with 50% of the decrease in abundance was found 30 ind.m^{-2} (Fig. 6a and b).

Frequency	stem	& Leaf
11.00	0 .	11122233344
7.00	0 .	5556679
4.00	1 .	0011
5.00	1 .	55779
1.00	2 .	2
1.00	2 .	9
2.00	Extremes	(400), (410)
Stem width:	100	
Each leaf:	1 case (s)	

a) increase (31 stations)

Frequency	stem	& Leaf
1.00	Extremes	(-120)
2.00	-6 .	00
1.00	-5 .	0
.00	-4 .	
2.00	-3 .	00
2.00	-2 .	00
3.00	-1 .	000
Stem width:	10	
Each leaf:	1 case (s)	

b) decrease (11 stations)

Fig. 6 Stem and Leaf plot of changes in abundance of crustacea for 42 stations between the first and second survey periods

Echinoderm

About half of the survey area show no different in abundance of echinoderm while 25 % of the survey area show the increase of abundance and 23.4 % of the survey area show a decline of abundance of this group during the pre and post NE monsoon periods. The increase in abundance of this group ranged from 10 to 30 ind.m^{-2} and were mostly found 10 ind.m^{-2}. Whereas the decrease of abundance ranged from 10 to 20 ind.m^{-2} and were mostly found at 10 ind.m^{-2} (Fig. 7a and b)

```
Frequency     stem &  Leaf
   9.00        1 .   000000000
    .00        1 t
    .00        1 f
    .00        1 s
    .00        1 .
   2.00        2 .   00
   1.00  Extremes    (30)
Stem width:       10
Each leaf:         1 case (s)
```

a) increase (12 stations)

```
Frequency     stem &  Leaf
   1.00  Extremes     (-20)
  10.00        -1 .   0000000000

Stem width:       10
Each leaf:         1 case (s)
```

b) decrease (11 stations)

Fig. 7 Stem and Leaf plot of changes in abundance of echinoderm for 23 stations between the pre and post NE monsoon periods.

Mollusca

The abundance of this group nearly remained steady between the pre and post NE monsoon periods. About 92 % of the survey area show no different in abundance of mollusk between the pre and post NE monsoon periods (Table 5).

Table 5. Changes in abundance of macrobenthic fauna between the first survey period (4Jul.- 8A 1996) and the second survey period (25Apr- 31 May 1997) .

Diff.bet. first &second	no. of station					
survey periods	Polychaete	Crustacea	Echinoderm	Mollusca	Others	Macrobenthos
+	22(46.81%)	31(65.96%)	12(25.53%)	1(2.03%)	10(21.28%)	33(70.20%)
0	7(14.89%)	5(10.63%)	24(51.06%)	43(91.49%)	22(46.80%)	1(2.10%)
-	18(38.30%)	11(23.40%)	11(23.40%)	3(6.38%)	15(31.91%)	13(27.70%)

Total macrobenthic fauna

When consider of total macrobenthic fauna, it was found that 70.20 % of the survey area show the increase in abundance of macrobenthic fauna between the pre and post NE monsoon periods. While nearly 28 % of the survey area show the decrease in abundance from pre to post NE monsoon. The increase in abundance of this group ranged from 10 to 270 ind.m^{-2}, except station 2 (410 ind.m^{-2}) and station 46 (400 ind.m^{-2}). About 50 % of the increase in abundance of total macrobenthic fauna was 90 ind.m^{-2}. The decrease in abundance of this group ranged from 10 to 80 ind.m^{-2} except station 9 (130 ind.m^{-2}) and about 50 % of the decrease in abundance was 40 ind.m^{-2} (Fig. 8a and b).

4. Changes in diversity of macrobenthic fauna between the pre and post NE monsoon periods.

Over 90 taxa of macrobenthic fauna were identified both in the pre and post NE monsoon periods in the South China Sea (Sarawak, Brunei and Sabah). According to Table 6, all of the diversity indices declined from the pre to post NE monsoon. The Shannon diversity index never exceed 3.56 both in the pre and post NE monsoon periods.

The richness index of macrobenthic fauna decreased from the pre to post NE monsoon periods. The large increase in the total number of individuals found in the post NE monsoon (7870 ind.m^{-2}) while the total number of individuals in the pre NE monsoon found 4710 ind.m^{-2}.

Evenness decrease from the pre to post NE monsoon sample. During the post NE monsoon a few species (7species) represented by a lot of indiviuduals in contrast with those in the pre NE monsoon a large number of species (21 species) represented by a lot of individuals (Table 6). Parker, 1975 mentioned that low diversity and high population levels of a few species denote some major stress condition which eleminates many species, but promotes survival of a few. Therefore, the shifting of monsoon may increase level of environment stress and will result on decrease diversity, decrease species richness, decrease evenness.

Frequency	stem &	Leaf
6.00	0 .	122233
11.00	0 .	55566777799
7.00	1 .	0001123
4 .00	1 .	5679
1.00	2 .	0
2.00	2 .	67
2.00	Extremes	(400), (410)

Stem width: 100
Each leaf: 1 case (s)

a) increase (33 stations)

Frequency	stem &	Leaf
1.00	Extremes	(-130)
1.00	-8 .	0
3.00	-7 .	000
.00	-6 .	
1.00	-5 .	0
3.00	-4 .	000
2.00	-3 .	00
1.00	-2 .	0
1.00	-1 .	0

Stem width: 10
Each leaf: 1 case (s)

b) decrease (13 stations)

Fig. 8 Stem and Leaf plot of changes in abundance of total macrobenthic fauna for 46 stations between the first and second survey periods

Table 6. Species diversity of macrobenthic fauna observed in two sampling periods in the South China Sea (Sarawak, Brunei and Sabah).

Indices	First survey period (4Jul.-8Aug. 1996)	Second survey period (25Apr.-31May 1997)
Diversity (H')	3.56	2.95
Richness (R)	12.51	10.5
Evenness (E)	0.6	0.35
N_1	35.08	19.08
N_2	21.45	7.25
Total no. of individuals	4710	7870

Table 7. Average abundance of macrobenthic fauna in the South China Sea (Area I and Area II)

Survey area	Macrobenthic fauna (ind.m-^{2})	
	1st survey period	2nd survey period
Area I: Gulf of Thailand and east coast of Peninsular Malaysia	88	97
Area II: Sarawak, Brunei and Sabah	100	167

Conclusion and discussion

It is appeared from the results that the overall abundance of macrobenthic fauna in Sarawak, Brunei and Sabah were different between the pre and post NE monsoon periods. During the post NE monsoon the density of macrobenthic fauna were more abundance than those in the pre NE monsoon and the density of macrobenthic fauna tended to increase with decreasing of water depth as can be seen from Fig. 4.

Similarly, the result of faunal composition show the different between the pre and post NE monsoon. During the pre NE monsoon polychaeta was the most abundance followed by crustacea and echinodermata etc.. Whereas during the post NE monsoon crustacea was the most abundance with the tremendous increase of amphipod, followed by polychaeta and echinodermata etc.. However when compare to the first survey in the Gulf of Thailand and east coast of Pennisular Malaysia (area I) by Piamthipmanus (1998), the faunal composition were similar both in the pre and post NE monsoon periods in that polychaete was the dominant group both in the pre and post NE monsoon periods.

In addition, the abundance of macrobenthic fauna in Sarawak area were more abundance than those in Brunei and Sabah area both in the pre and post NE monsoon periods. However, the stations in Brunei and Sabah were taken in an area in considerably deeper water than those in Sarawak. Bakus (1990) reported that the effect of depth is a factor in controlling population density of macrobenthic fauna.

It should be noted that the overall abundance of macrobenthic fauna both in the pre and post NE monsoon periods from the present investigation of Sarawak, Brunei and Sabah (area II) was much higher than those in the first survey of the Gulf of Thailand and east coast of Peninsular Malaysia (area I) by Piamthipmanus (1998) (Table 7). This probably due to the massive entry of trawlers in the Gulf of Thailand have damaged the sea bottom. Caddy (1973) also reported that scallop dredges, beam trawls and otter trawls with tickler chains have been shown to disturb the macrobenthic fauna and damage the sea bottom. It is also remarkable that the highest density of macrobenthic fauna both in the area I and area II occurred in sand area.

The diversity indices also show the decline from pre to post NE monsoon. Hylleberg *et al.* (1985) reported that the amplitude and direction of the monsoon wind and the shifting of monsoon has a considerable impact in term of sediment disturbance, this would have an effect directly on the density and diversity of macrobenthic fauna. Different species react different to change of environment. This is fairly clear from the density of amphipod during the post NE monsoon had increased more than fourfold of those in the pre NE monsoon.

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References

Bakus, G.J. (1990). Quantitative ecology and marine biology. Oxford & IBH publishing Co. Pvt. Ltd., New Delhi, 159 pp.

Caddy, J.F. (1973). Underwater observation on tracks of dredges and trawl and some effects of dredging on scallop grounds. J. Fish. Res. Board Can., 30, pp.173- 180.

Day, J.H. (1967). A monograph on the polychaeta of Southern Africa, part 1-2. Trustees of the Brithis Museum (Natural History), London. 878pp.

Fauchald, K. (1977). The polychaete worms, Definitions and keys to the orders, families and genera. Natural History Museum of Los Angeles county. Sciences Series 28, 188pp.

Hill, M.O. (1973b). Diversity and evenness: A unifying notation and its consequences. Journal of Ecology, 61, pp.225-236.

Hylleberg, J., A. Nateewathana, & B.Chantananthawej (1985). Temporal changes in sediment characteristics on the west coast of Phuket Island. Phuket Mar. Biol. Cent. Res. Bull., 37,16 pp.

Ludwig, J.A. and J. F. Reynolds (1988). Statistical ecology: A primer on methods and computing. John Wiley & Sons , NewYork, pp. 85-103.

Margalef, R. (1958). Information theory in ecology. General Systematics 3, pp.36-71.

Parker, R.H. (1975). The study of benthic communities a model and review. Elsevier Oceanography Series 9, Elsevier, Amsterdam, pp.235-248.

Pearson, T. (1975). The benthic ecology of Loch Linnhe and Loch Eil, a sea-loch system on the west coast of Scotland, VI. Changes in the benthic fauna attributable to organic enrichment. J. exp. mar. Biol. Ecol., 20, pp.1- 41.

Piamthipmanus, M. (1998). Temporal changes in the abundance of macrobenthos in the South China Sea, Area I : Gulf of Thailand and East Coast of PenninsularMalasia (in press).

Ruppert, E. E. and R. D. Barnes (1991). Invertebrate Zoology. Saunders College Publishing, Fortworth, 1056pp.

Tsutsumi, H. and T. Kikuchi (1983). Benthic ecology of a small cove with seasonaloxygen depletion caused by organic pollution. Publ. Amakusa Mar. Biol. Lab., pp.17-40.

Stock Assessment by Hydro-Acoustic Method in the South China Sea Area II: Sabah, Sarawak, Brunei Darussalam

Hadil bin Rajali[1], Albert Chuan Gambang[1] Idris Abdul Hamid[2], Raja Bidin bin Raja Hassan[3], , Daud Awang[1], Kunimune Shiomi[3], and Shunji Fujiwara[3]

1 Fisheries Research Institute(Sarawak), P.O.Box 2243, 93744 Kuching, Sarawak, Malaysia
2 Fisheries Department, Ministry of Industry and Primary Resources, Brunei Darussalam
3 SEAFDEC/MFRDMD, Fisheries Garden, Chendering, 21080 Kuala Terengganu, Malaysia

ABSTRACT

Acoustic resource surveys were conducted by M/V SEAFDEC off Sarawak, Brunei and the east coast of Sabah from July 10 to August 2, 1996 for pre-NE monsoon season and from May 1 to May 24, 1997 for post-NE monsoon season, using the scientific echosounder FQ-70, developed by Furuno Electric Co. Japan. Collected raw values of backscattering strength (SV) from the 200 kHz transducer were carefully corrected and filtered to eliminate the influence of plankton. These corrected SV values were divided into pelagic and demersal fish, and were used to estimate the biomass of pelagic and demersal multi-species in the limited coastal waters off Sarawak. *Decapterus macrosoma* for pelagic fish and *Priacanthus macracanthus* for demersal fish were selected as representative species, based on the fisheries statistics, landing place survey, and research vessel survey in order to estimate biomass. The standard length (SL) and weight of these representative species were obtained from research vessel survey and supported by previous literatures. Target strength (TS) of these representative species were calculated using formula TS = 20 log(SL) - 66. The distribution of the SV values for pelagic fish showed distinct difference between pre and post Northeast (NE) monsoon seasons along the coastal waters. Greater concentrations of SVs were observed from depth 100 and 200m on the continental shelf along the survey area for both the seasons. The estimated biomass of multi-species fish off coastal Sarawak waters for the pre and post NE monsoon seasons was 120,000 tonnes (100,000 tonnes of pelagic fish and $2x10^5$ tonnes of demersal fish) and 470,000 tonnes (360,000 tonnes of pelagic fish and 110,000 tonnes of demersal fish), respectively. Estimated Maximum Sustainable Yield (MSY) was 83,000 tonnes for pelagic fish and 31,000 tonnes for demersal fish when using Cadima's model.

Key words: Acoustic survey, Multi-species biomass estimation, Sarawak, Brunei, and the east coast of Sabah waters, MSY

Introduction

Fish stock assessment is a growing necessity in many countries in Southeast Asian region bordering the South China Sea waters. In Sarawak, Brunei Darussalam and the east coast of Sabah waters are the same as other tropical regions, with complexity of biological characteristics, such as the multitude of fish species and spawning throughout the year, or the inherent characteristics of fisheries hinder the collection of reliable landing statistics throughout the area. Suitable fish stock assessment methods are not readily available in this region. SEAFDEC has been making efforts to develop appropriate stock assessment procedures, using hydro- acoustic method (Rosidi et al., 1998). Hydro-acoustic method seems to be a more appropriate among others to meet overall goal of the quick stock assessment, although the method does not give a complete answer for the tropical multi-species condition.

This report examines whether distributions of volume backscattering strength (SV) collected by the scientific echosounder FQ-70 off Sarawak, Brunei Darussalam and the east coast of Sabah waters are influenced by the Northeast monsoon, and presets one approach of stock assessment including biomass estimation off Sarawak.

Materials and Methods

Two hydro-acoustic surveys, using the scientific echosounder FQ-70 (Furuno Electric Co.), were carried out simultaneously with oceanographic studies by M/V SEAFDEC off Sarawak, Brunei Darussalam and the east coast of Sabah. The first survey was conducted from July 10 to August 2, 1996 designated as the pre Northeast (NE) monsoon season. The second survey was carried out from May 1 to May 24, 1997 designated as the post NE monsoon season. These timing of the surveys were primarily to examine whether the NE monsoon season (November to March) affects the distribution of fish in the survey area.

Calibration of FQ-70 was done prior to each survey near Oceanographic Station 1 (2∞19’N, 110∞00’E) off Kuching, Sarawak in July 9, 1996 for the first survey, and in April 30, 1997 for the second survey. The source level, receiving sensitivity, and the gain of amplifier were measured by means of a hydrophone. Parameter settings of the acoustic system, based on the Calibration results, were shown in Table 1.

Survey transect was set between oceanographic stations. Both surveys were conducted along the same transect as shown in Figure 1. The total number of transects was 78, and were assigned in ascending order from 1 to 78. The transects were cruised throughout day- and nighttime at a speed of approximately 10 knots.

Data Collection

The hydro-acoustic system was set up to process echo and output of the volume backscattering strength (SV in dB/m^3) in real time from depth of 10m to 200m at horizontal intervals of 0.1 nautical mile. The depths were set into 10 layers as shown in Table 2. Layers 1 to 8 were set between 10m to 200m from the surface, while layers 9 and 10 were set between 1 to 10m from the bottom.

The SV values from the low frequency (50kHz) and the high frequency (200kHz) transducers were both recorded. However, only the values from the high frequency transducer were used in data processing and subsequently in the fish biomass estimation. The data were recorded in the following forms:

1. Numeric data of integrated result of echo signals which were recorded in a floppy disk through data analyser FQ-770.
2. Print-out of the numeric data from the results of the integrated echoes (This output was also recorded simultaneously in a floppy disk).
3. Echo signals including echo of vertical distribution curve, which were traced on the recording paper through the recorder unit FQ-706.
4. Analog data for echo signals and log data which were recorded on a video tape.

Only the numeric data on a floppy disk and in printed form were used to process the SV values. The traced echo signals were only used as a reference. Analog data in the video tapes were not utilized due to the absence of the post data analyser.

SV Correction

Noise from other electric devices and unlocked echoes due to rough sea conditions may create errors to the collected raw SV values. Besides noise and bottom unlocked echoes, the raw SV values may also be affected by plankton and other dense micronecton. Therefore, these raw SV values need to be corrected prior to further analysis.

The graphical method was used to correct SV values obtained by chance from noise of other electric devices and bottom unlocked echoes. The SV values were plotted against integration number for each depth layer of 1 to 8 and average of layers 9 and 10. From the graphs, extremely high echo traces were carefully corrected by referring to the recording paper. These were termed as the Corrected SV values.

The corrected SV values were further filtered to select the values from fish, using five-point moving average. These filtered SV values will be called the Calculated SV values.

The calculated SV values for each transect were averaged vertically from depth layer 1 to 8 for each integration number, and horizontally from the first integration number to the end. The calculated SV were sorted out into pelagic and demersal fish. Average SV values of layers 9 and 10 were considered as demersal fish. The values remained from the subtraction of the SV values of layers 9 and 10, from the total SV values of layers 2 to 8, were considered as pelagic fish. The overall averaged calculated SV values throughout transects within the specified area for pelagic and demersal fish were used for fish biomass estimation.

Biomass estimation

The pelagic and demersal multi-species fish biomass off Sarawak waters within Malaysian EEZ was only estimated due to the availability of necessary information. Area of the biomass estimation is only limited coastal waters at the shallower than 100m in depth as shown in Figure 1. Table 3 shows transect number for biomass estimation. The area was calculated based on transects accorded with grids of 30' in latitude by 30' in longitude.

The following expression was used to estimate fish biomass:

$$Q = (sv / ts)\ w \bullet a \bullet d \qquad (1)$$

where Q : Biomass
$sv = 10^{(SV/10)}$:Backscattering strength
$ts = 10^{(TS/10)}$: Target strength
w : average fish weight(g)
a : survey area(m^2)
d : layer depth(m)

Target strength (TS) was estimated using the following equation from Furusawa (1990):

$$TS = 20 \log SL - 66 \qquad (2)$$

Where TS : Target strength(dB)
SL : Fish standard length(cm)

To determine single TS for biomass estimation, a representative species was used in this report. The representative species for pelagic and demersal fish were determined in two steps, using the same method by Rosidi *et al*.(1998). Selection of possible detected pelagic and demersal fish for FQ-70 was listed in Table 4. Representative pelagic and demersal fish groups were selected based on the catch statistics of the major fishing gears operating in the biomass estimation area off Sarawak waters within Malaysian EEZ. Then the representative species was determined in examining information from the previous landing statistics and literatures. After determining the representative species, necessary information on standard length and average weight were calculated from the landing survey data.

Maximum Sustainable Yield (MSY) Estimation

MSY is one of the important management goals. When catch and effort data from the fishery statistics are available, the surplus production models (Schaefer, 1954 and Fox, 1970) can be applied. In Sarawak, these historic statistics are not readily available to fit these models to estimate MSY. In spite of these models, Cadima's empirical equation (Troadec, 1977), modifying Gulland's model (1971), are applicable to estimate MSY using biomass estimated by the hydro-acoustic method:

$$MSY = X \cdot (Y + M \cdot B) \qquad (3)$$

where X : Constant

M: Annual natural mortality

B: Biomass for exploited fish stocks

Y: Average annual yield

Cadima's model is applied for exploited stock while Gulland's model is for unexploited stock. In Sarawak waters, both pelagic and demersal fish stock are rather exploited and, therefore, Cadima's model is employed. In this present study, constant X is set at 0.2 followed the results of the simulation study by Beddington and Cooke (1983).

For the model, average annual yield in 1996 and 1997 accorded with the survey periods was obtained from landing statistics of Sarawak Department of Fisheries (Anon., 1996 and 1997). Annual natural mortality, M, for both the models was estimated by a linear relationship between logarithms of maximum age and natural mortality rate applied by a method of Hoenig (1983):

$$ln(M) = a + b\ ln\ (A) \qquad (4)$$

where M: Annual natural mortality

A: Maximum age (years)

a and b: Model parameters

To estimate the parameters a and b of equation (4), three parameters of Von Bertalanffy growth curve (L•, K, and t_0) (von Bertalanffy, 1934) were used. Information on these parameters for various fish in South China Sea were obtained from Mohsin (1996). For each fish, the maximum age (A), and annual natural mortality (M) were obtained by the following methods. A is estimated from Von Bertalanffy Growth Curve parameters when L_t set at 98 % of L• in the following equation:

$$A = t_o - (1/K)\ ln\ (1 - L_t/L\bullet) \qquad (5)$$

where L• : maximum length

K : Growth coefficient

t_0 : age at length L=0

L_t : length at age t

M was estimated by the following empirical equation of Pauly (1980):

$$ln\ M = -0.0152 - 0.279\ ln\ L\bullet + 0.6543\ ln\ K + 0.463\ ln\ T \qquad (6)$$

where M : Annual natural mortality

L•: maximum length

K : Growth coefficient

T : Average annual temperature at the surface(∞C).

The surface water temperature in tropical waters are relatively constant at approximately 27-28

∞C (Chua and Charles, 1980). In this analysis, T was set at 27 ∞C.

Results

Figure 2 shows an example of echogram with SV vertical distribution curves for both high and low frequency. When fish school appeared, SV for high and low frequency showed the almost same level of SV values. However, from the low frequency between depth 40-80m, continuous SV (averaged 60dB) were recorded.As recorded by Termvidehakorn (1998) presented in the same seminar, there appeared to be abundance of surface fish, fish larvae and mesopelagic fish larvae especially during early morning, night time and during cloudy day. Beside fish larvae, Jivaluk (1998) reported in the same seminar, that copepoda dominated the zooplankton population followed by ostracoda and chaetognatha.Boonyapiwat (1998) reported during the same cruise that the quantity of phytoplankton in the chlorophyll maximum layer (18-70m in the coastal area) and 45-80m in offshore area was most abundant among 3 layers (surface, seasonal thermocline and chlorophyll maximum depth). Due to such continuous and dense echoes attributed to abundant fish larvae,zooplankton and phytoplankton, only SV values from high frequency were used for further analysis.

SV Distribution

The distributions of the calculated SV values of pelagic and demersal fish for pre and post NE monsoon seasons for each transect were shown in Figures 3 to 6. There are apparent differences in SVs between seasons and areas.

Figures 3 and 4 show the distribution of pelagic fish. These figures showed that higher SV appeared in post NE monsoon season. There were higher SV values in depth between 100 and 200m on the continental shelf along the Sarawak, Brunei and Sabah for both seasons.

Distributions of SV values in Figures 5 and 6 for demersal fish showed an apparent difference between seasons and areas which were similar to the those of the pelagic. In post NE monsoon, higher SV values were distributed off shore as well as coastal waters while higher SV values were distributed only offshore for pre NE monsoon. There were apparent larger SV values in depth between 100 and 200m on the continental shelf along the Sarawak, Brunei, and Sabah for both seasons.

Biomass Estimation

Fishing activities off the survey area is limited to the coastal waters up to 60 nm. It is difficult to obtain fishing information on further off shore waters in order to estimate biomass. In this report, the biomass estimation is just the coastal waters off Sarawak (Figure 1). Total area for biomass estimation is 61,378 km^2.

Decapterus macrosoma and *Priacanthus macracanthus* are the representative species for biomass estimation of pelagic and demersal fish respectively. These species were recorded as one of the dominant species caught during the demersal survey in the same area (Richard *et al*., 1998 and Vidthayanon 1998). The standard length, estimated TS and average weight are shown in Table 5.

Results of biomass estimation of pelagic and demersal fish off the coastal waters of Sarawak within Malaysia EEZ between the two seasons were shown in Table 5. The estimated density and biomass of pelagic fish for pre and post NE monsoon seasons were 1.61 tonnes/km^2 and 100,000 tonnes, and 5.87 tonnes/km^2 and 360,000 tonnes respectively. Using the same data, for waters <100m Yuttana estimated the biomass to be 105,949.99 tonnes for pre-monsoon season and 314,746.01 tonnes for post-monsoon which are quite similar to our estimates. Albert and Hadil (1998) reported that the average estimated density for pelagic was 1.74 tonnes/km2 and the average estimated biomass of 216,300 tonnes. The estimated density and biomass of demersal fish for pre and post NE monsoon were 0.30 tonnes/km^2 and 20,000 tonnes and 1.83 tonnes/km^2 and 110,000 tonnes, respectively. This estimated biomass is comparable to that of Albert and Hadil (1998) at 108,078 tonnes using swept area method. Total biomass of multi-species fish for the pre-and post-NE monsoon seasons were 120,000 tonnes and 470,000 tonnes, respectively. Differences of estimated biomass is very large

Table 1. Parameter settings derived from calibration work of the acoustic system FQ-70 prior to the survey off Sarawak, Brunei, and Sabah waters.

Parameters	July/Aug. 1996		May 1997	
Frequency (kHz)	50	200	50	200
Source Level(dB)	215.1	220.0	212.3	218.1
Pulse Duration(ms)	1.2	1.2	1.2	1.2
Beam Width(dB)	-14.5	-16.1	-14.5	-16.1
Absorption Coefficient(dB)	9.9	92.7	9.9	92.7
Receiving Sensitivity(dB)	-185.6	-194.9	-186.8	-197.7
Amplifier Gain(dB)	49.0	50.3	49.8	50.4

Table 2. Depth layers and ranges of SV integration off Sarawak, Brunei, and Sabah waters.

Depth Layer	Ranges(m)
1	10-20
2	20-40
3	40-60
4	60-80
5	80-100
6	100-130
7	130-160
8	160-200
9	10-5 (from Bottom)
10	5 -1 (from Bottom)

Table 3 Transect for biomass estimation off Sarawak waters within the Malaysian EEZ.

Transect number between the oceanographic Stations
St. 1-2, 2-3, 3-4, 4-5, 7-8, 8-9
St. 15-16, 16-17, 17-18, 28-29, 29-30
St. 32-33, 33-34, 44-45, 45-46, 47-47
Total number of transects 20

Table 4 List of pelagic and demersal fish based on the Annual Fisheries Statistics, Department of Fisheries, Ministry of Agriculture, Malaysia (1996).

Fish Group	
Pelagic	**Demersal**
Sphyraena jello/S. optusa	Callyodon spp./Thalassoma spp.
Rachycentrom canadus	Upeneus spp.
Alectis indica/Caranx spp.	Drepane punctata
Megalaspis cordyla	Caesio spp.
Carangoides spp.	Tachysurus spp./Arius spp./
Polynemus spp./Eleutheronema	Osteogenius spp.
teradactylum	
Selar spp.	Siganus spp.
Sardinela spp.	Sciaena spp./Otolithoides spp.
Decapterus spp.	Otolithus spp./Johnius spp.
Elagatis bipinnulatus	Pomadasys spp.
Scomberoides commersonianus	Lutjanus spp.
Stolephorus spp.	Plectrorhinchus picfus
Rastrelliger spp.	Nemipterus spp.
Scomberomorus spp.	Pristipomoides typus
Trichiurus lepturus	Leiognathus spp./Gazz spp./
Abalostes stellaris	Secutor spp.
Fomio niger/Pompus spp.	Saurida spp.
Liza spp./Valamugil spp.	Plotosus spp.
	Lactarius lactarius
	Sillago sihama/S. maculuta
	Scolopsis spp.

Table 5. Estimated biomass with additional information for demersal and pelagic fish off Sawarak waters within Malaysian EEZ in pre and post Northeast monsoon season, using FQ-70.

		Northeast Monsoon	
		Pre(Jul/Aug, 1996)	Post(May, 1997)
Area for biomass estimation (km^2)		61,378	
Pelagic	Decapterus macrosoma		
	Depth layer(m)	181	181
	SV(dB)	-80.0	-73.8
	SL (cm)	22 ^{*1}	16^{*2}
	TS(dB)	- 40.8	- 41.6
	Weight(g)	71^{*1}	52^{*2}
	Density(tonnes/km^2)	1.61	5.58
	Biomass(10,000 tonnes)	10	36
Demersal	Priacanthus macracanthus		
	Depth layer(m)	9	9
	SV(dB)	-72.7	-64.8
	SL (cm)	15.4^{*3}	15.4^{*3}
	TS(dB)	- 42.3	- 42.3
	Weight(g)	81.2^{*3}	81.2^{*3}
	Density(tonnes/km^2)	0.30	1.83
	Biomass(10,000 tonnes)	2	11

1) Data ontained from the Mukah landing place in July and August 1998.
2) Data ontained from the Mukah landing place in March 1998.
3) Data ontained from the Malaysian EEZ Survey off Sarawak in May-Sep., 1998.

between pre and post NE monsoon seasons.

MSY Estimation

A total of 151 cases of Von Bertalanffy growth parameters, L•, K and t_0 of more than 30 species were obtained from Mohsin (1996). The relationship between A and M were shown in Figure 7. Following the empirical formula a linear relationship between logarithms of A and M is:

Ln M = 1.656 + 0.780 ln A (r^2 = 0.88, n=151).

Maximum age for *Decapterus macrosoma* and *Priacanthus macracanthus* were estimated at 4.21 and 3.26 years respectively. However their parameters are as listed in Table 6 if using the Von Bertalanffy growth curve. Estimated natural mortality, M was 1.71 for *Decapterus macrosoma* and 2.08 for *Priacanthus macracanthus*.

Estimated MSY is shown in Table 7. Using the average catch in 1996 and 1997 for selected species as indicated in Table 4, MSY is estimated MSY at 83,000 tonnes for pelagic fish and 31,000 tonnes for demersal fish.The results were comparable to the 86,892 tonnes as estimated using Fox (exploited model) and 80,031 tonnes using Fox (unexploited model) for pelagic fish and 54,000 tonnes for demersal (Albert and Hadil 1998). Average catch of pelagic and demersal fish in 1996 and 1997 is 22 % and 51 % of MSY, respectively. Catch of pelagic fish has not been reached at MSY level.

Discussion

This paper presents one of the approaches for multi-species stock assessment using hydro-acoustic method to estimate fish biomass. This survey has collected only SV values without fish echoes identification. Future survey design need to include the fish echo identification with appropriate fishing methods, such as mid-water trawl or vertical longline.

Distribution of SV in Figures 3 and 4 for pelagic fish showed apparent difference between seasons and areas. There is higher SV values during post NE monsoon season than pre NE monsoon season. At the moment, it is difficult to find suitable causes for the changes of SV distributions. This change might be correlated in respond to the oceanographic condition in between Northeast monsoon and Southwest monsoon seasons especially in terms of distribution of water masses and currents (Liong, 1974). Appearance of the coastal waters and the occurrence of upwelling off Sarawak during Northeast monsoon season seems to have close relationship to the distributions of SV in pre and post NE monsoon seasons. Anomalously high biomass of phytoplankton were recorded by Snidvong (1998) in the vicinity of the area, specifically at stations 37 and 38, could be partially related to the upwelling nearby. There were no great variations of temperature, salinity and density values of the water mass due to pronounced mixing effect (Saadon *et al.* 1998). Geostrophic current pattern contributing to the divergence as well as convergence inferred from horizontal circulation matched quite well with the observed vertical migration of the pynocline of the area which is an indication of upwelling and downwelling (Snidvong 1998). Average trawl catch rates obtained by KK MANCHONG during the same periods; July/August, 1996(Pre NE monsoon) was 4.36 kg/hour and April/May 1997(Post NE monsoon) was 5.42 kg/hour (Richard *et al*. 1998) although diferrences were not large between seasons. The results between the acoustic method and the trawl survey also show the similar seasonal trend.

The acoustic survey by R/V Rastrelliger in the coastal waters of Sarawak during June and July in 1986 showed the density of pelagic fish at 2.41 tonnes/km^2 (Anon, 1987). The present survey estimated the average density of pelagic fish in these waters during July and August at 1.83 tonnes/km^2. The results obtained in this study seemed to be comparable to the previous one.

Recently, Total Allowable Catch (TAC) has been discussed and is compulsively set under the Law of the Sea of the United Nations. Under this TAC, one of the important management goals is the Maximum Sustainable Yield (MSY). However, recent interpretations have shown to secure more

Table 6 Estimated natural mortality with additional information for demersal and pelagic fish

Species	Von Bartalanffy Growth Parameters *1 K	L∞	t_0	Maximum Age, A (year)	Estimated M
Decapterus macrosoma	0.93	33.0	0	4.21	1.71
Priacanthus macracanthus	1.20	23.7	0	3.26	2.08

*1 Parameters of Von Bertalanffy Growth for *Decapteru macrosoma and Priacanthus macracanthus* were obtained from Ingles and Pauly (1984) and Dwiponggo *et al*. (1986), respectively

Table 7 Estimated MSY for pelagic and demersal fish, using Cadima's equation based on the biomass from the acoustic survey off Sarawak between 1996 and 1997.

Fish Group	Average Catch *1 (tonnes)	Average Biomass (tonnes)	MSY (tonnes)	2/3MSY (tonnes)
Pelagic	18,000	231,000	83,000	55,000
Demersal	16,000	66,000	31,000	20,000

*1 Average catch between 1996 and 1997 for the selected fish of pelagic and demersal fish (Table 4), derived from landing statistics of Sarawak Department of Fisheries (Anon., 1996 and 1997).

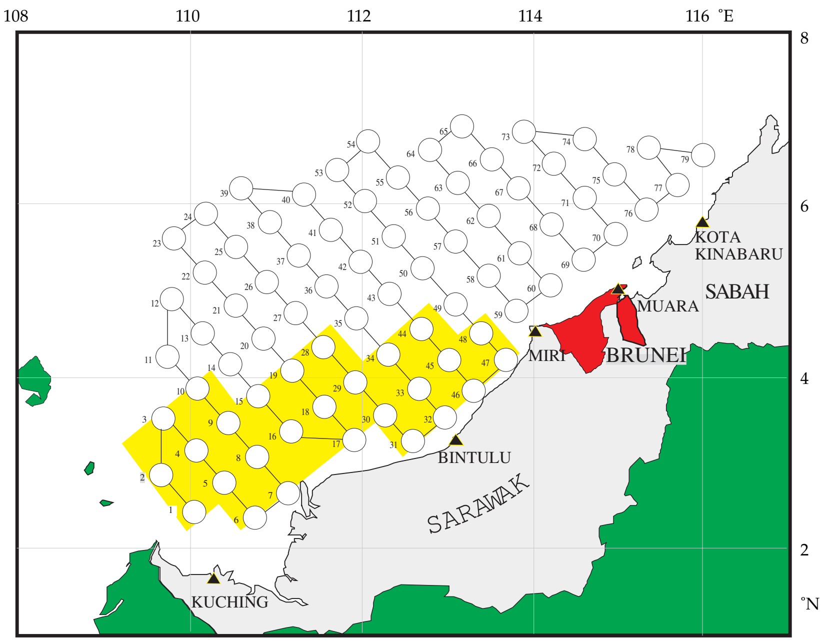

Fig. 1. Survey transects for the acoustic survey off Sarawak, Brunei and Sabah waters in July-August 1996 and May 1997. Number indicates the oceanographic station

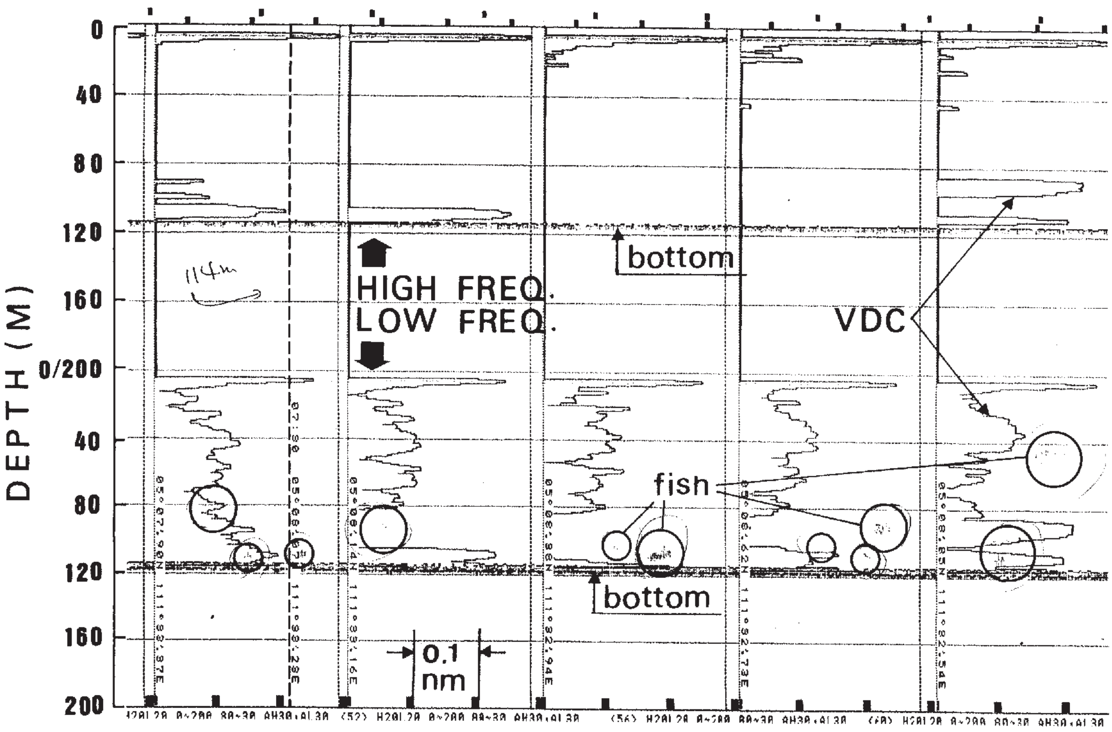

Fig. 2. An example of large fish school echograms with SV vertical distribution curve (VDC) between station no. 36 and 37 during day-time in May, 1997

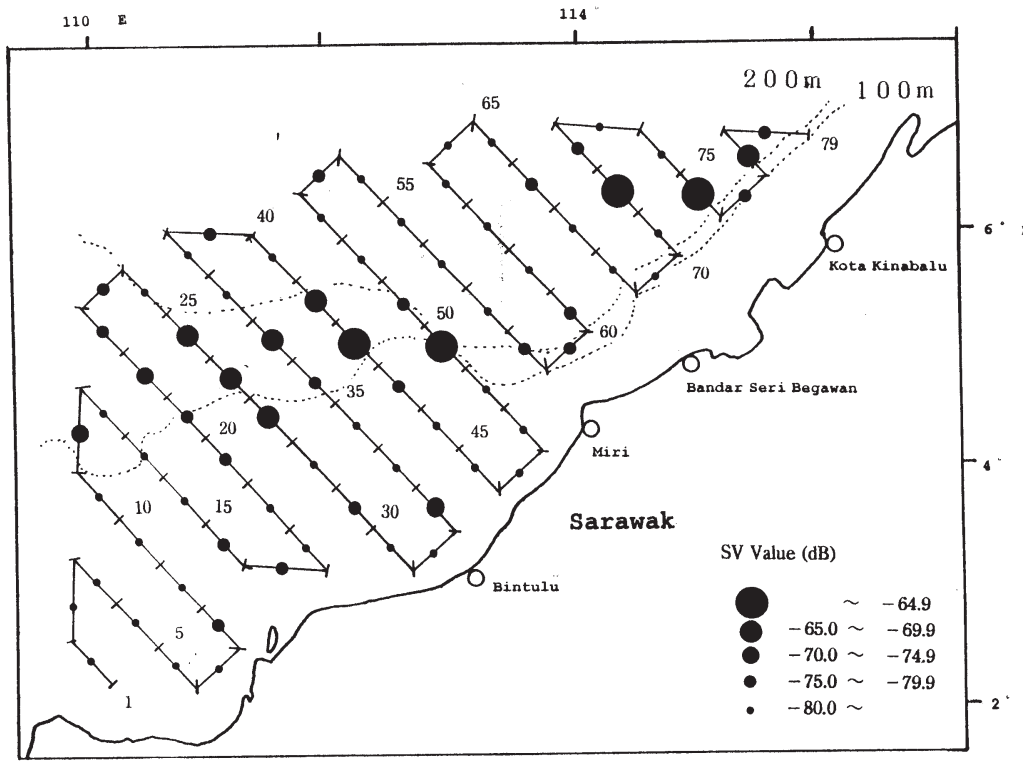

Fig. 3. SV value distribution for the pelagic fish along transects off Sarawak, Brunei and Sabah waters in July-August 1996 (Pre Northeast monsoon). Number indicates the oceanographic station

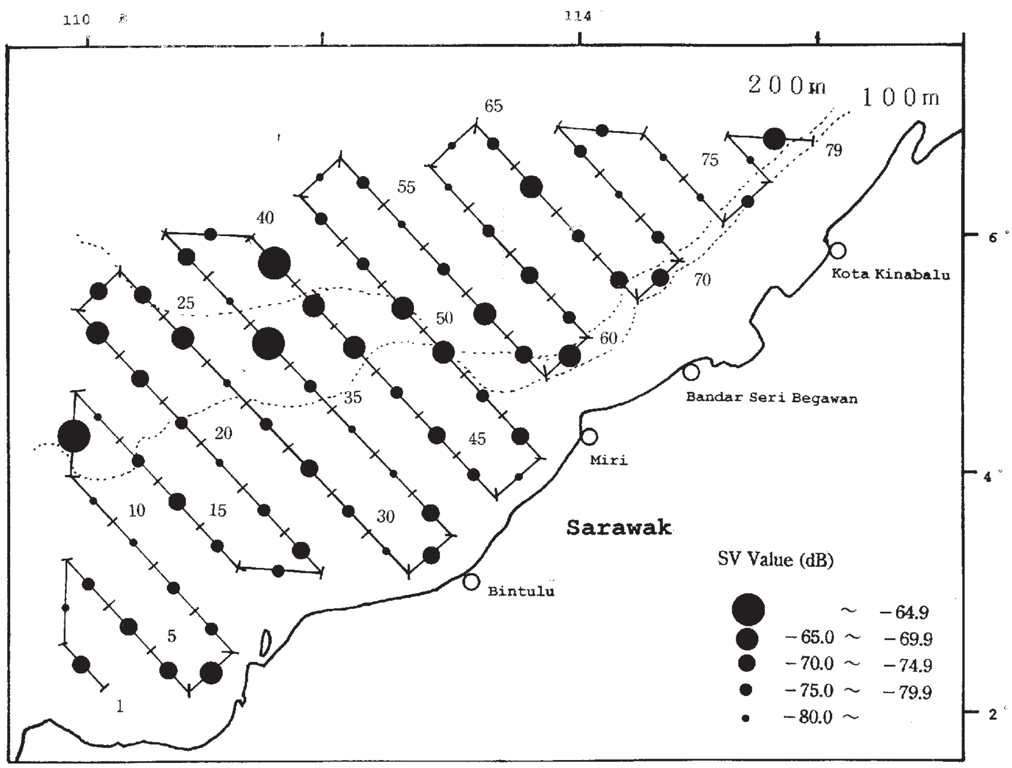

Fig. 4. SV value distribution for the pelagic fish along transects off Sarawak, Brunei and Sabah waters in May 1997 (Post Northeast monsoon). Number indicates the oceanographic station

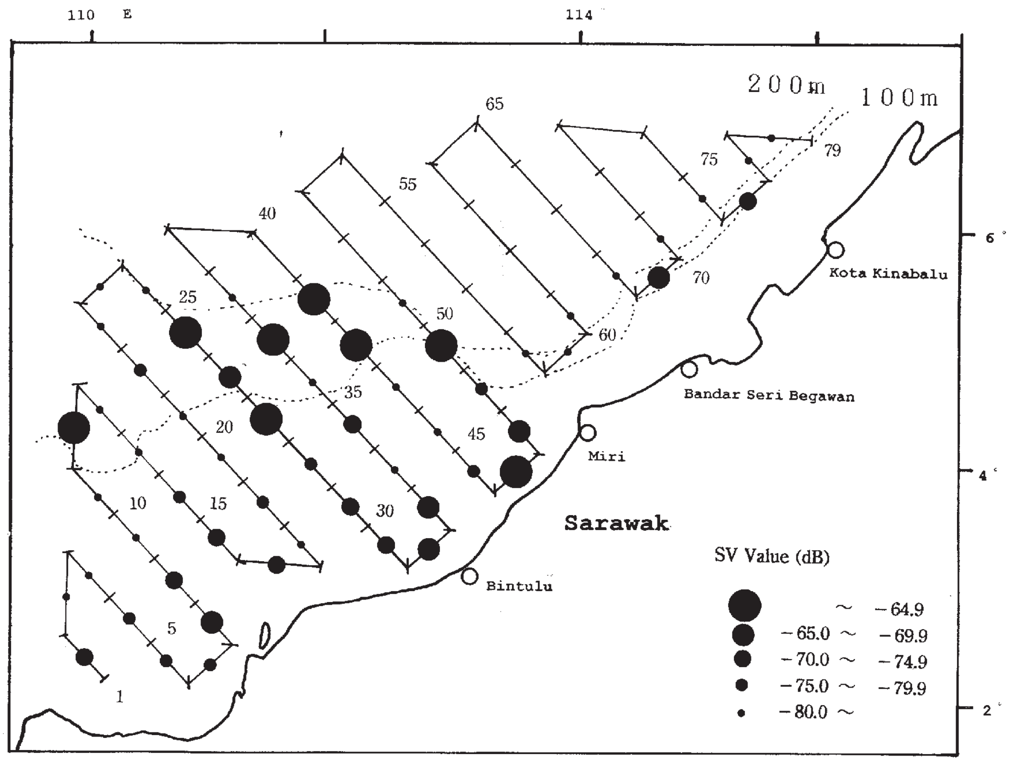

Fig. 5. SV value distribution for the demersal fish along transects off Sarawak, Brunei and Sabah waters in July-August 1996 (Pre Northeast monsoon). Number indicates the oceanographic station

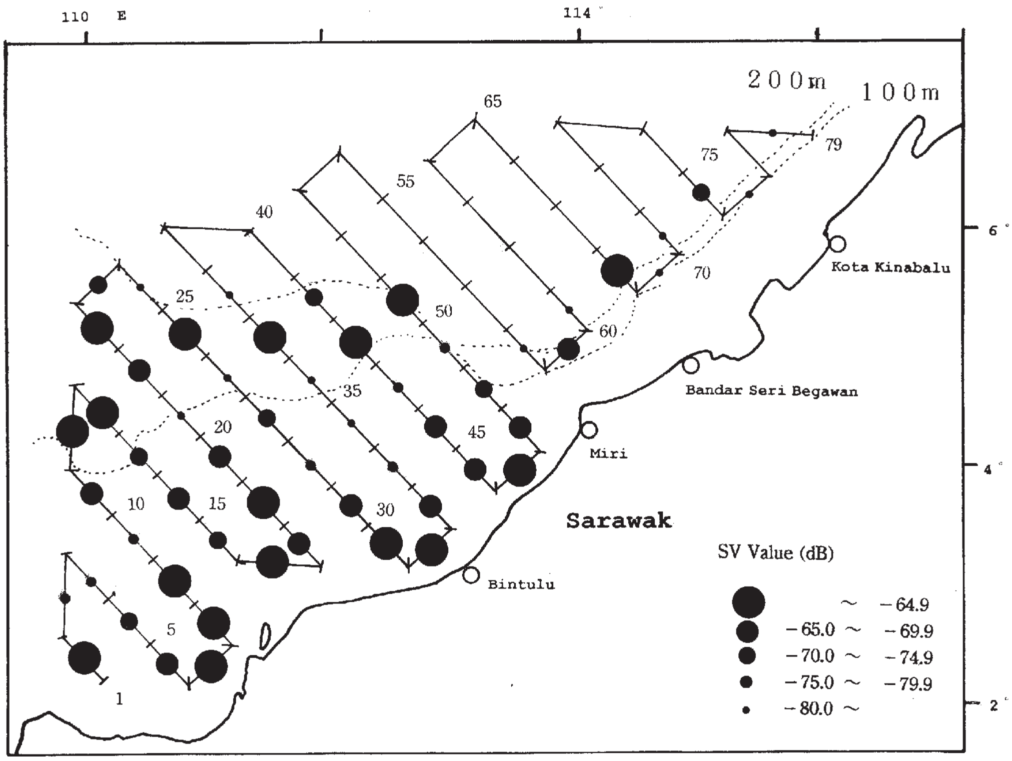

Fig. 6. SV value distribution for the demersal fish along transects off Sarawak, Brunei and Sabah waters in May 1997 (Post Northeast monsoon). Number indicates the oceanographic station

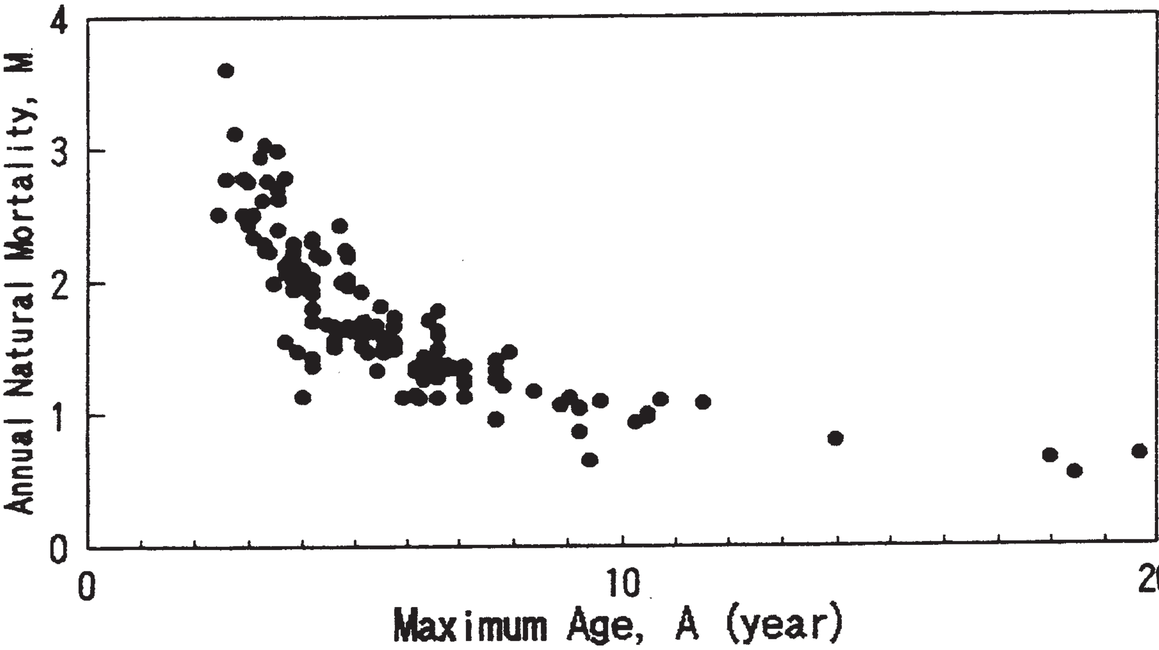

Fig. 7. The relationship between logarith of maximum age (A) and annual natural mortality rate (M), Information was obtain from Mohsin (1996).

conservative management goals, the biological reference point should be less than the MSY (FAO, 1993). In the fisheries management of New Zealand, 2/3 of the MSY is used as the biological reference point (Annala, 1993). When this measure is practiced to the present results, the biological reference points for pelagic and demersal fish were estimated at 55,000 tonnes and 21,000 tonnes, respectively (Table 7). Average catch of pelagic and demersal fish in 1996 and 1997 is 33 % and 77 % of 2/3 of the MSY, respectively. As the result of using this 2/3 of the MSY, both pelagic and demersal fish show potential increase in production from the present level of catch.

The MSY or 2/3 of the MSY mentioned above, are based on annual basis. Seem that the obtained SV values appeared to change seasonally, an appropriate management measures should be taken carefully to consider the effects of the season. Periodical surveys are needed to address these changes with a view of formulating suitable localized fisheries management strategies.

This report shows one of the approaches taken to get estimates of fish biomass. Even though the report is based on a number of assumptions, nevertheless it is a positive step towards introducing the hydro-acoustic method for stock assessment in the tropical region. More efforts are necessary to further improve the precision and accuracy of this multi-species biomass estimation. For example, the representative species need to be correctly identified, including the TS values and weight used in the estimation. Further analyses with Geostatistical method (Pititgas, 1993) can provide the confidence interval of fish biomass estimation. Also, since the Geographical Information System (GIS) is able to show the visualized images of relationships between SV values (or estimated biomass) and the environmental factors, which include distribution and abundance of plankton, the use of this technique is another useful tool for examining the existence of such relationships.

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References

Albert,C.G. and Hadil, R. 1998.Resources potential and Sustainability: the basis for biomass estimate and its exploitation pattern. In Proceedings of Fisheries Research Seminar 1998. Fisheries Research Institute, Penang. (in press)

Annala, J. H. 1993. Fishery assessment approaches in New Zealand's ITQ system. pp. 791-804. In Proceedings of the International Symposium on Management strategies for exploited fish populations. Alaska Sea Grant AK-SG-93-02, 824 pp.

Anon. 1987. Deep Sea Fisheries Resource Survey Within the Malaysian Exclusive Economic Zone. Vol. 2. Department of Fisheries, Ministry of Agriculture Malaysia, 101p.

Anon. 1996. Annual Fisheries Statistics. Department of Marine Fisheries, Sarawak.

Anon. 1997. Annual Fisheries Statistics. Department of Marine Fisheries,Sarawak.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Hum. Biol. 10:181-213.

Beddington, J. R. and J. G. Cooke. 1983. The potential yield of fish stocks. FAO Fish Tec. Pap. 242:47 p.

Boonyapiwat, S. 1998. Distribution, abundance and species composition of phytoplankton in the South China Sea. In Proceedings of the SEAFDEC Techinical Seminar on the Interdepartmental Collaborative Research Program in the South China Sea, Area II: Sarawak, Sabah, and Brunei Darussalam.Kuala Lumpur, Malaysia 14th15thDecember 1998.

Chua, T.E. and K. J. Charles. 1980. Coastal resources of east coast of Peninsular Malaysia-An Assessment in relation to potential oil spill. Penang: Universiti Sains Association.

Department of Fisheries Malaysia. 1996. Annual Fisheries Statistics 1995. Ministry of Agriculture, Malaysia.

Dwiponggo, A., T. Hariati, S. Banon, M. L. Palmores, and D. Pauly. 1986. Groth, mortality, and recuitment of commercially important fishes and penaeid shrimps in Indonesian waters. ICLARM Tech. Rep. 17.

FAO Fisheries Department. 1993. Reference points for fishery management:their potential application to straddling and highly migratory resources. FAO Fish. Cir. 864.52pp.

Fox, W. W. 1970. An exponential yield model for optimizing exploited fish populations. Trans. Am. Fish. Soc.99:80-88.

Furusawa, M. 1990. Study on Echo Sounder for Estimating Fisheries Resources. Bull. National Res. Institute of Fish. Engineering. 11: 173-249.

Gulland, J. A. 1971. The fish resources of the ocean. West by-fleet, Surrey, Fishing News (Books), Ltd., for FAO.255p.

Hoenig., J. M.. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 81(4):898-903.

Ingles, J. and D. Pauly. 1984. An atlas of the growth, mortality and recuitment of Philippine fishes. ICLARM Tech. Pap. 13.

Jivaluk, J. 1998. Distribution, abundance and composition and zooplankton in the South China Sea. In Proceedings of the SEAFDEC Techinical Seminar on the Interdepartmental Collaborative Research Program in the South China Sea, Area II: Sarawak, Sabah, and Brunei Darussalam. Kuala Lumpur, Malaysia 14th15thDecember 1998.

Liong, P. C. 1974. Hydroacoustic conditions off the east coast of the Peninsular Malaysia during August 1972. Malay. Agri. J. 4(4):492-573.

Mohsin, A. K. M. 1996. Marine fishes and fisheries of Malaysia and neighbouring countries. Universiti Pertanian Malaysia Press, Malaysia. 744p.

Pauly, D. 1980. On the interrelationship between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. CIEM.39(2):175-192

Pititgas, P. 1993. Geostatistics for fish stock assessments:a review and an acoustic application. ICES J. mar Sci.50:285-298.

Richard, R., A. Daud, M. Jamil, and R. Biusing. 1998. Distribution,abundance and biological studies of economically important fishes in the South China Sea, Area II: Sarawak, Sabah, and Brunei Darussalam. In Proceedings of the SEAFDEC Techinical Seminar on the Interdepartmental Collaborative Research Program in the South China Sea, Area II: Sarawak, Sabah, and Brunei Darussalam.Kuala Lumpur, Malaysia 14th15thDecember 1998.

Rosidi, A., A. C. Gambang, R. Hadil, R. H. Raja Bidin, B. Samsudin, K. Shiomi, and S. Fujiwara. 1998. Application of the acoustic method in biomass estimation of multi-species fish in the South China Sea. J. Korean Fish.Soc. Res. 1:157-167.

Saadon, M. N. 1998. Physical characteristics of watermass in the South China Sea. In Proceedings of the SEAFDEC Techinical Seminar on the Interdepartmental Collaborative Research Program in the South China Sea, Area II: Sarawak, Sabah, and Brunei Darussalam. Kuala Lumpur, Malaysia 14th15thDecember 1998.

Schaefer, M.. 1954. Some aspects of the dynamics of populations important to the management of thecommercial marine fisheries. Bull. Inte-Am. Trop. Tune Comm. 1(2):27-56.

Snidvong, A. Geostropic current, divergence and convergence in the South China Sea. In Proceedings of the SEAFDEC Techinical Seminar on the Interdepartmental Collaborative Research Program in the South China Sea, Area II: Sarawak, Sabah, and Brunei Darussalam.Kuala Lumpur, Malaysia 14th15thDecember 1998.

Termvidehakorn, A. 1998. Kind, abundance and distribution of fish larvae in the South China Sea. In Proceedings of the SEAFDEC Techinical Seminar on the Interdepartmental Collaborative Research Program in the South China Sea, Area II: Sarawak, Sabah, and Brunei

Darussalam.Kuala Lumpur, Malaysia 14th15thDecember 1998.
Troadec, J. P.. 1977. Méthod semi-quantitative d'évaluation. FAO Circ., Pêches. 701:131-141.
Vidthayanon, C. 1998. Species composition and diversity of trawled fishes in the South China Sea. In Proceedings of the SEAFDEC Techinical Seminar on the Interdepartmental Collaborative Research Program in the South China Sea, Area II: Sarawak, Sabah, and Brunei Darussalam.Kuala Lumpur, Malaysia 14th15thDecember 1998.
Theparoonrat, Y. Biomass estimation by hydro-acoustic method in the South China Sea. In Proceedings of the SEAFDEC Techinical Seminar on the Interdepartmental Collaborative Research Program in the South China Sea, Area II: Sarawak, Sabah, and Brunei Darussalam.Kuala Lumpur, Malaysia 14th15thDecember 1998.

Distribution, Abundance and Biological Studies of Economically Important Fishes in the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters.

Richard Rumpet, Daud Awang, Jamil Musel and Rooney Biusing*

Fisheries Research Institute, Sarawak Branch, Department of Fisheries Malaysia,
P.O. Box 2243, 93744 Kuching, Sarawak, Malaysia.
* Fisheries Research Center, 89400 Likas, Kota Kinabalu, Sabah, Malaysia.

ABSTRACT

The studies were carried out between 9th July and 3rd August 1996 (3rd cruise) and 30th April and 30th May, 1997 (4th cruise) in the Exclusive Economic Zone of Sarawak and the western part of Sabah. The species distribution, abundance, composition and length-weight relationships of some commercially important fish were investigated and compared for both cruises. The results indicates that the overall catch rate ranged from 3.5 to 194 kg/hr and averaged at 55.9 kg/hr during the 3rd cruise. For the 4th cruise, it ranged from 10.9 to 90.5 kg/hr and averaged at 50.2 kg/hr. During the 3rd cruise, 46.9% of the catch were dominated by demersal fish followed by 41.6% trash fish, 7.8% pelagic fish and 3.1% cephalopod. Priacanthidae was the most dominant family, which made up of 14.1% of the catch followed by Nemipteridae (10.8%), Carangidae (5.0%), Lutjanidae (3.7%) and Mullidae (2.1%). The ten most dominant species found during the 3rd cruise were 1. *Priacanthus macracanthus* (13.2%), 2. *Nemipterus bathybius* (3.3%), 3. *Abalistes stellaris* (2.8%), 4. *Arius spp*.(2.5%), 5. *N. nematophorus* (2.2%), 6. *Gymnocranius griseus* (1.9%), 7. *N. marginatus* (1.7%), 8. *Sepia spp*. (1.7%), 9. *Decapterus spp*. (1.6%) and 10. *Carcharhinus spp* (1.3%). During the 4th cruise, the family Nemipteridae (12.7%) formed the most dominant fish family followed by Carangidae (8.7%), Mullidae (7.1%), Lutjanidae (4.9%) and Priacanthidae (2.2%). The ten most dominant species were: 1. Loligo *spp*. (5.7%), 2. *Nemipterus bathybius* (4.2%), 3. *Abalistes stellaris* (4.0%), 4. *Upeneus moluccensi* (3.8%), 5. *Nemipterus nemurus* (3.8%), 6. *Gymnocranius griseus* (3.2%), 7. *Carangoides malabaricus* (3.2%), 8. *Plectorhynchus pictus* (3.1%), 9. *Upeneus bensasi* (2.4%) and 10. *Arius spp*. (1.8%). The morphometric study shows that the population of fish are normally distributed.

Key words: Distribution, abundance, biological, fish, Sarawak, Sabah, Brunei Darussalam

Introduction

In 1995, a total of 1,108,436 m.t. of marine fish was landed in Malaysia and valued at RM2.71 billion. Out of this total landings, 99,255 m.t. were landed in Sarawak and 166,462 m.t. in Sabah (Anon., 1995). Demersal fish was considered as one of the important fish resources in Sarawak and Sabah. The total landings by trawl net (which consisted mainly of demersal fish) were estimated at 61,958 m.t in Sarawak and 49,106 m.t. in Sabah. Pelagic fish production in Sarawak was very low (about 1,313 m.t. only) as compared to the landings in Sabah i.e. 28,875 m.t.

This paper compares the distribution, abundance, species composition and biological parameters of some commercially important fish species following the two surveys conducted using a research vessel, KK MANCHONG in the Exclusive Economic Zone (EEZ) of Sarawak and the western part of Sabah. The sampling stations selected were based on the acoustic stations which were surveyed by MV SEAFDEC.

Materials and Methods

Two surveys were conducted using KK MANCHONG, a research vessel of the Fisheries Research Institute (FRI), Sarawak Branch, Department of Fisheries, Malaysia on 9th July until 3rd August 1996 (3rd cruise) and 30th April until 30th May 1997 (4th cruise) respectively. The principal characteristics of KK MANCHONG are given as follows:

Type/Hull : Fibre Reinforced Plastic (FRP)
Length : 27.50 m
Breadth : 6.40 m
Depth : 3.00 m
Draft : 2.20 m
Gross tonnage : 150 tons
Registered tonnage : 45 tons
Main engine : 900 hp Yanmar diesel engine
Speed (trial max.): 12.48 knots
Complement (crew and scientists): 22 persons

The sampling gear used in these studies was a high opening otter trawl net as shown in Figure 1 with a horizontal net opening of 20.5 m and a cod-end mesh size of 38 m. A diagrammatic presentation of the net is shown in Figure 1. The net was towed at 3.5 knots for a one-hour duration at a specific station which coincides with its acoustic station (Figure 2).

During the surveys the total catch of each haul was sorted out according to commercial fish and trash fish without considering size categories. Subsequently the commercial fish species were sorted according to demersal fish, pelagic fish, cephalopods, shrimps, crabs, shells and true trash fish i.e. those which have no commercial values.

The dominant fish species from each sampling station were kept frozen and brought back to the laboratory of the FRI, Sarawak Branch for further biological examinations. The measurements on total length (L)an total body weight (W) of individual fish to the nearest millimeter and gram respectively were made in the laboratory.

The frequency distribution patterns for a number of fish species in the combined samples from entire samplings stations were examined. Length-weight relationships were determined separately for each fish species. Equation of the form $W=aL^b$, where a and b are constants of regression, were fitted by transforming the data into logarithms and deriving the regression line by the least square method (Sparre and Venema, 1992).

Results

Overall catch rate

Altogether 17 stations were sampled successfully with one haul per station during the 3rd cruise. During the 4th cruise, only 12 stations were successfully trawled. Appendix 1 and 2 shows the overall catch rate of the various species caught from individual stations of the two cruises. The total catch (inclusive of both commercial and trash fish) from individual stations ranged from 3.5 kg to 194.0 kg for the 3rd cruise and 10.9 to 90.5 kg for the 4th cruise. The overall average catch rate for 3rd cruise was 55.9 kg/hr. Of this, 32.6 kg (58.3%) were commercial fish and 23.3 kg (41.7%) trash fish (Table 1). During the 4th cruise, the overall average catch rate was 50.2 kg/hr. It comprised of about 34.4 kg (68.7%) commercial fish and 15.8 kg (31.3%) trash fish (Table 2).

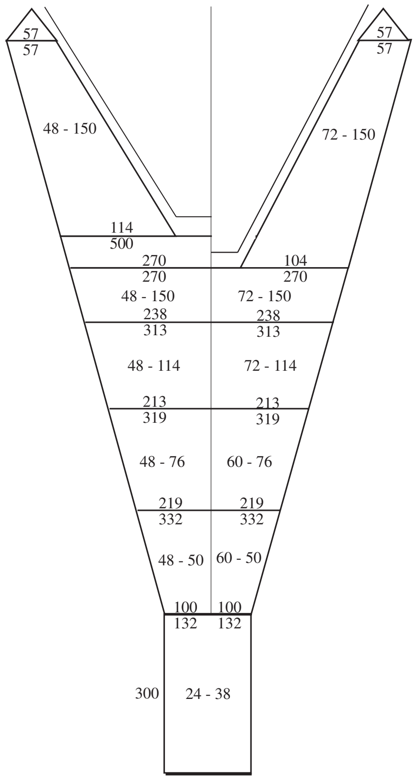

Fig. 1 Design of the high opening trawl net used by KK Manchong

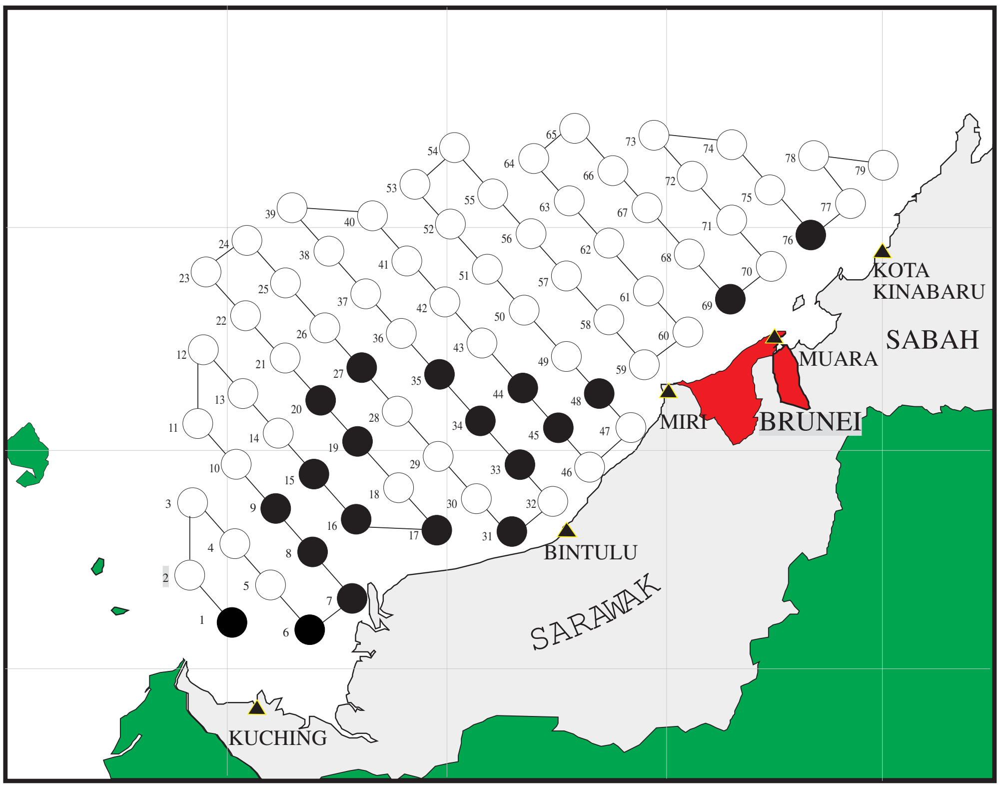

Fig. 2 Trawling stations of KK Manchong

Species composition

Catch percentage by weight of each species and family caught during both cruises were shown in Table 1 and 2 respectively. During the 3rd cruise, commercial fish formed 58.5% of the total catch while the remaining 41.5% made up of trash fish. Among the commercial fish, demersal fish group was the most dominant category making up 46.9% of the total catch followed by pelagic fish, 7.8% and cephalopods, 3.1%.

During the 4th cruise, commercial fish made up of 68.7% of the total catch and the remaining 31.4% was trash fish. The most dominant commercial fish group was demersal fish (44.6%), followed by cephalopods (11.3%) and pelagic fish (10.8%). Table 3 below shows the summarized catch composition of the major fishery group from the entire sampling stations of the cruises.

Numerous species, genera and families of fish were caught during the surveys. Some of these were much more dominant than the others in terms of catch percentage by weight. During the 3rd cruise (Table 1), the family Priacanthidae appeared to be the most dominant fish family (14.1%), followed by Nemipteridae (10.8%), Carangidae (5.0%), Lutjanidae (3.7%), and Mullidae (2.1%). On the other hand, the family Nemipteridae (12.7%) formed the most dominant fish family during the 4th cruise (Table 2) followed by Carangidae (8.7%), Mullidae (7.1%), Lutjanidae (4.9%) and Priacanthidae (2.2%).

Ten most dominant species caught during the 3rd cruise were: 1. *Priacanthus macracanthus* (13.2%), 2. *Nemipterus bathybius* (3.3%), 3. *Abalistes stellaris* (2.8%), 4. *Arius spp*. (2.5%), 5. *Nemipterus nematophorus* (2.2*%), 6. Gymnocranius griseus* (1.9%), *7. Nemipterus marginatus* (1.7%), 8. *Sepia spp*. (1.7%), 9. *Decapterus spp*. (1.6%) and 10. *Carcharhinus spp*. (1.3%).

During the 4th cruise, the ten most dominant species were: 1. Loligo *spp*. (5.7%), 2. *Nemipterus bathybius* (4.2%), 3. *Abalistes stellaris* (4.0%), 4. *Upeneus moluccensi* (3.8%), 5. *Nemipterus nemurus* (3.8%), 6. *Gymnocranius griseus* (3.2%), 7. *Carangoides malabaricus* (3.2%), 8. *Plectorhynchus pictus* (3.1%), 9. *Upeneus bensasi* (2.4%) and 10. *Arius spp*. (1.8%).

Abundance

The highest overall catch rate during the 3rd cruise was recorded at station 44 (193.7 kg/hr) and station 33 (160.2 kg/hr). The lowest catch rate was at station 35 (3.5 kg/hr) and station 10 (9.7 kg/hr). During the 4th cruise, the highest overall catch rate was attained at station 31 (90.46 kg/hr) and station 7 (82.0 kg/hr). Meanwhile, the lowest overall catch rate was registered at station 16 (12.5 kg/hr) and station 9 (22.4 kg/hr).

Commercial fish have an average catch rate of 32.6 kg/hr during the 3rd cruise. The highest catch rate was at station 44, (119.3 kg/hr) and station 33 (94.2 kg/hr) as shown in Figure 3. Demersal fish which was the most dominant among the fish group registered an average catch rate of 26.1 kg/hr and appeared to be most abundant at station 44 with catch rate of 106.7 kg/hr and station 33 (75.6 kg/hr). Pelagic fish which have an average catch rate of 4.4 kg/hr was more abundant at station 33 and 44 with catch rate of 16.1 kg/hr and 11.0 kg/hr respectively. Cephalopods attained an average catch rate of 1.7 kg/hr and were more abundant at station 69 with catch rate of 10.2 kg/hr.

During the 4th cruise, commercial fish registered an average catch rate of 34.4 kg/hr. The highest catch rate was at station 27, (62.9 kg/hr) and station 6, (51.0 kg/hr) as shown in Figure 4. Demersal fish attained an average catch rate of 22.4 kg/hr and the highest catch rate was at station 27 (57.5 kg/hr). Pelagic fish have an average catch rate of 5.4 kg/hr and was most abundant at station 7 and 6 with catch rate of 16.5 kg/hr 13.9 kg/hr. Cephalopods have an average catch rate of 5.6 kg/hr and were more abundant at station 6 (16.6 kg/hr).

Trash fish have an average catch rate of 23.3 kg/hr and were more abundant at station 44 (74.4 kg/hr) and station 7 (71.0 kg/hr) during the 3rd cruise. The trash fish was dominated by *Pentaprion*

Table 1 Average catch rate (kg/hr) and percentage composition from entire sampling stations (3rd Cruise)

COMMERCIAL FISH	Total	Mean	%
Selar crumenophthalmus	18.68	1.17	1.05
Atule mate	1.68	0.11	0.11
Megalaspis cordyla	0.01	0.00	0.00
Decapterus spp.	33.71	2.11	1.64
Atropus atropus	1.55	0.10	0.09
Alepes kalla	0.12	0.01	0.01
Alectis cilliaris	0.04	0.00	0.00
Carangoides armatus	0.22	0.01	0.01
C. hedlandensis	0.21	0.05	0.01
C. malabaricus	21.11	1.32	1.16
C. talamparoides	1.23	0.08	0.06
Carangoides sp.	2.90	0.18	0.14
Selar sp.	0.43	0.03	0.02
Seriolina nigrofasciata	8.38	0.52	0.44
Uraspis uraspis	4.33	0.27	0.21
Carangidae	**94.52**	**5.91**	**4.94**
Pellona sp.	0.47	0.03	0.04
Amblygaster sp.	26.01	1.63	1.26
Clupeidae	**26.47**	**1.65**	**1.30**
Rastrelliger kanagurta	0.93	0.06	0.05
Scomber australascicus	0.17	0.01	0.01
Scombridae	**1.10**	**0.07**	**0.05**
Sphyraena forsteri	20.10	1.26	0.98
Sphyraena langsar	0.56	0.04	0.03
Sphyraena jello	1.08	0.07	0.05
Sphyraenidae	**21.75**	**1.36**	**1.06**
Chirocentrus dorab	0.91	0.06	0.04
Parastromateus niger	2.18	0.14	0.12
Dussumieria sp.	5.73	0.64	0.27
Pelagic fish	**152.56**	**9.54**	**7.79**
Abalistes stellaris	55.44	3.47	2.78
Argyrops spinifer	1.30	0.08	0.06
Arius spp.	32.12	2.01	2.51
Ariomma indica	16.16	1.01	0.79
Bothidae	0.35	0.02	0.02
Carcharhinus spp.	28.34	1.77	1.56
Dasyatis sp.	15.94	1.00	0.86
Drepane longimana	2.76	0.17	0.22
Epinephelus areolatus	0.09	0.01	0.00
Epinephelus coioides	12.98	0.81	0.63
Epinephelus diacanthus	0.06	0.00	0.00
Epinephelus heniochus	1.23	0.08	0.06
Epinephelus sexfasciatus	2.45	0.15	0.12
Serranidae	**16.81**	**1.05**	**0.82**
Gymnocranius griseus	34.44	2.15	1.92
Gymnura sp.	3.03	0.19	0.15
Lactarius lactarius	0.43	0.03	0.02
Lutjanus malabaricus	21.35	1.33	1.06
Lutjanus lineolatus	11.53	0.72	0.91
Lutjanus lutjanus	3.79	0.24	0.21
Lutjanus sebae	1.37	0.27	0.05
Lutjanus vitta	18.31	1.22	0.89
Pristipomoides multidens	10.37	0.65	0.53
Pristipomoides typus	0.13	0.01	0.01
Lutjanidae	**66.40**	**4.15**	**3.66**
Parupeneus cinnabarinus	13.73	0.86	0.74
Upeneus bensasi	1.85	0.12	0.16
Upeneus moluccensis	23.44	1.47	1.17
Mullidae	**39.03**	**2.44**	**2.07**
Nemipterus bathybius	61.02	3.81	3.31
N. isacanthus	2.80	0.18	0.15
N. japonicus	9.73	1.08	0.48
N. marginatus	35.30	2.52	1.68
N. mesoprion	13.94	0.87	0.68
N. nematophorus	42.02	2.63	2.16
N. nemurus	12.10	0.76	0.65
N. oveniides	0.04	0.01	0.00
N. peronii	17.76	1.18	0.96
N. virgatus	14.83	0.93	0.72
Nemipteridae	**208.48**	**13.03**	**10.80**
Platax sp.	2.38	0.15	0.12
Plectorhynchus pictus	11.39	0.71	0.86
Pomadasys hasta	0.47	0.03	0.04
Psenopsis anomala	0.06	0.00	0.00
Psettodes erumei	16.21	1.01	0.81
Priacanthus macracanthus	268.24	16.76	13.19
P. tayenus	9.37	0.59	0.85
Priacanthus sp.	0.65	0.04	0.03
Priacanthidae	278.26	17.39	14.07
Rhynchobatus djeddensis	10.33	0.65	0.60
Saurida micropectoralis	17.68	1.11	0.87
Sciaenidae	13.00	0.81	0.91
Scolopsis taeniopterus	4.82	0.30	0.26
Sphyrna mokarran	3.99	0.50	0.19
Demersal fish	**879.51**	**54.97**	**46.96**
Shells	0.70	0.05	0.06
Trichiurus lepturus	4.39	0.27	0.21
Loligo duvauceli	17.26	1.08	0.89
Loligo chinensis	7.34	0.46	0.38
Sepioteuthis lessoniana	2.54	0.16	0.17
Sepia spp.	33.65	2.10	1.67
Cephalopods	**60.79**	**3.80**	**3.11**
Metapenaeus ensis	0.15	0.01	0.01
Metapenaeopsis stridulans	0.39	0.02	0.02
Parapenaeopsis sp.	0.04	0.00	0.00
Solenocera subnuda	0.02	0.00	0.00
Trachypenaeus fulvus	0.45	0.03	0.02
Shrimps	**1.06**	**0.07**	**0.05**
Panulirus polyphagus	1.34	0.08	0.07
Thenus orientalis	2.53	0.17	0.14
Crabs	1.15	0.08	0.06
TOTAL (COMMERCIAL)	**1104.02**	**69.00**	**58.45**
Trash fish			
Aluterus monoceros	6.29	0.39	0.33
Anthiidae	12.12	0.76	0.59
Apogon spp.	14.69	0.92	0.71
Argyrops spinifer	0.30	0.02	0.01
Bothidae	3.59	0.22	0.17
Callionymidae	0.19	0.01	0.01
Canthigaster sp.	1.97	0.12	0.10
Carangoides equala	0.02	0.00	0.00
Coradion chrysozonus	0.06	0.00	0.01
Crabs	0.06	0.00	0.00
Dactyloptena sp.	5.28	0.33	0.26
Decapterus spp.	1.17	0.07	0.06
Diodon holocanthus	13.75	0.86	0.79
Dipterygonotus balteatus	0.02	0.00	0.00
Echeneis naucrates	1.04	0.06	0.05
Eutherapon theraps	1.19	0.07	0.11
Fistularia petimba	26.08	1.63	1.28
Heterodontus sp.	4.07	0.25	0.20
Holocentrus sp.	0.35	0.02	0.02
Inimicus sinensis	0.13	0.01	0.01
Lagocephalus spp.	12.47	0.78	0.86
Leiognathus spp.	129.98	8.12	6.63
Lepidotrigla sp.	5.01	0.31	0.25
Loligo duvauceli	3.12	0.19	0.15
Nemipterus marginatus	0.65	0.04	0.03
Nemipterus nematophorus	1.54	0.10	0.07
Octopus sp.	1.23	0.08	0.06
Paramonacanthus spp.	0.66	0.04	0.04
Parascolpsis eriomma	1.82	0.11	0.09
Parupeneus cinnabarinus	0.32	0.02	0.02
Pentaprion longimanus	146.45	9.15	7.13
Platycephalus spp.	1.15	0.07	0.06
Pleuronectes spp.	3.07	0.19	0.15
Priacanthus macracanthus	4.54	0.28	0.22
Priacanthus tayenus	29.31	1.83	1.43
Pristotis jerdoni	1.21	0.08	0.11
Pterois sp.	0.61	0.04	0.03
Pterocaesio chrysozona	0.61	0.04	0.03
Rays	0.55	0.03	0.05
Rhynchostracion nasus	0.47	0.03	0.04
Round sponges	15.99	1.00	0.78
Saurida micropectoralis	82.11	5.13	4.18
Saurida undosquamis	46.35	2.90	2.27
Saurida hoshinonis	0.28	0.02	0.01
Saurida spp.	36.40	2.27	1.77
Scolopsis spp.	0.00	0.00	0.00
Sea cucumber	0.23	0.01	0.02
Sepia spp.	4.91	0.31	0.24
Shells	0.06	0.00	0.00
Stolephorus sp.	0.24	0.01	0.01
Scorpaena scabra	4.39	0.27	0.21
Starfish	0.28	0.02	0.01
Tetrosomus sp.	4.16	0.26	0.22
Torquigener sp.	2.29	0.14	0.11
Triacanthus spp.	0.76	0.05	0.04
Upeneus sulphureus	17.96	1.12	0.87
Upeneus moluccensis	49.44	3.09	2.42
Upeneus spp.	68.90	4.31	6.22
Uranoscopus sp.	0.80	0.05	0.04
TOTAL (Trash)	**772.71**	**48.29**	**41.55**
TOTAL CATCH	**1876.73**	**117.30**	**100.00**

Table 2 Average catch rate (kg/hr) and percentage composition from entire sampling stations (4th Cruise)

COMMERCIAL FISH	Total	Mean	%
Selar crumenophthalmus	0.00	0.00	0.00
Atule mate	10.46	0.87	1.74
Megalaspis cordyla	0.91	0.08	0.15
Decapterus spp.	2.60	0.22	0.43
Atropus atropus	1.20	0.10	0.20
Alepes kalla	0.00	0.00	0.00
Alepes djedaba	0.16	0.01	0.03
Alepes melanoptera	0.52	0.04	0.09
Alectis cilliaris	0.00	0.00	0.00
Carangoides armatus	0.00	0.00	0.00
C. hedlandensis	0.00	0.00	0.00
C. malabaricus	19.01	1.58	3.16
C. talamparoides	0.00	0.00	0.00
Carangoides sp.	0.10	0.01	0.02
Caranx sexfasciatus	1.00	0.08	0.17
Selar sp.	0.00	0.00	0.00
Seriolina nigrofasciata	2.64	0.22	0.44
Uraspis uraspis	0.00	0.00	0.00
R. djedeba	2.60	0.22	0.43
Selaroides leptolepis	10.96	0.91	1.82
Carangidae	52.16	4.35	8.66
Pellona sp.	0.00	0.00	0.00
Amblygaster sp.	0.00	0.00	0.00
Clupids	0.32	0.03	0.05
Clupeidae	0.32	0.03	0.05
Rastrelliger kanagurta	4.80	0.40	0.80
Scomber australascicus	0.00	0.00	0.00
Scombridae	4.80	0.40	0.80
Sphyraena forsteri	6.51	0.54	1.08
Sphyraena langsar	0.00	0.00	0.00
Sphyraena jello	0.00	0.00	0.00
Sphyraenidae	6.51	0.54	1.08
Chirocentrus dorab	0.40	0.03	0.07
Parastromateus niger	0.40	0.03	0.07
Dussumieria sp.	0.45	0.04	0.07
Pelagic fish	65.04	5.42	10.80
Abalistes stellaris	24.25	2.02	4.03
Argyrops spinifer	0.00	0.00	0.00
Arius spp.	10.70	0.89	1.78
Ariomma indica	0.00	0.00	0.00
Bothidae	1.49	0.12	0.25
Carcharhinus spp.	1.40	0.12	0.23
Dasyatis sp.	0.00	0.00	0.00
Drepane longimana	0.00	0.00	0.00
Ephippus orbis	4.40	0.37	0.73
Epinephelus areolatus	1.75	0.15	0.29
Epinephelus coioides	4.50	0.38	0.75
Epinephelus diacanthus	0.00	0.00	0.00
Epinephelus heniochus	0.00	0.00	0.00
Epinephelus sexfasciatus	0.14	0.01	0.02
Epinephelus spp.	0.12	0.01	0.02
Serranidae	6.51	0.54	1.08
Gymnocranius griseus	19.55	1.63	3.25
Gymnura sp.	1.70	0.14	0.28
Lactarius lactarius	0.20	0.02	0.03
Lutjanus malabaricus	10.34	0.86	1.72
Lutjanus lineolatus	0.90	0.08	0.15
Lutjanus lutjanus	1.70	0.14	0.28
Lutjanus sebae	0.70	0.06	0.12
Lutjanus vitta	1.04	0.09	0.17
Pristipomoides multidens	6.70	0.56	1.11
Pristipomoides typus	0.00	0.00	0.00
Pristipomoides spp	0.35	0.03	0.06
Pristipomoides pleurospilus	7.70	0.64	1.28
Lutjanidae	29.43	2.45	4.89
Parupeneus cinnabarinus	0.00	0.00	0.00
Parupeneus pleurospilus	5.23	0.44	0.87
Upeneus bensasi	14.60	1.22	2.43
Upeneus moluccensis	22.62	1.89	3.76
Mullidae	42.45	3.54	7.05
Muraenesox sp	4.10	0.34	0.68
Nemipterus bathybius	25.40	2.12	4.22
N. hexadon	0.60	0.05	0.10
N. isacanthus	0.00	0.00	0.00
N. japonicus	7.50	0.63	1.25
N. marginatus	2.67	0.22	0.44
N. mesoprion	3.87	0.32	0.64
N. nematophorus	0.00	0.00	0.00
N. nemurus	22.62	1.89	3.76
N. oveniides	0.00	0.00	0.00
N. peronii	7.80	0.65	1.30
N. tolu	0.20	0.02	0.03
N. virgatus	1.40	0.12	0.23
Parascolopsis inermis	0.95	0.08	0.16
Pentapodus setosus	3.70	0.31	0.61
Nemipteridae	76.71	6.39	12.74
Platax sp.	2.80	0.23	0.47
Plectorhynchus pictus	18.80	1.57	3.12
Pomadasys hasta	0.26	0.02	0.04
Pomadasys argenteus	0.12	0.01	0.02
Psenopsis anomala	0.00	0.00	0.00
Psettodes erumei	2.70	0.23	0.45
Priacanthus macracanthus	8.65	0.72	1.44
P. tayenus	4.33	0.36	0.72
Priacanthus sp.	0.00	0.00	0.00
Priacanthidae	12.98	1.08	2.16
Rhynchobatus djeddensis	0.00	0.00	0.00
Saurida micropectoralis	0.00	0.00	0.00
Sciaenidae	1.67	0.14	0.28
Scolopsis taeniopterus	6.10	0.51	1.01
Sphyrna mokarran	0.00	0.00	0.00

Demersal fish	268.32	22.36	44.57
Shells	0.00	0.00	0.00
Trichiurus lepturus	0.00	0.00	0.00
Loligo duvauceli	15.24	1.27	2.53
Loligo chinensis	14.34	1.20	2.38
Loligo sp	34.14	2.85	5.67
Sepioteuthis lessoniana	1.06	0.09	0.18
Sepia spp.	2.94	0.25	0.49
Cephalopods	67.72	5.64	11.25
Metapenaeus ensis	0.10	0.01	0.02
Metapenaeopsis stridulans	0.00	0.00	0.00
Parapenaeopsis sp.	0.00	0.00	0.00
Penaeus japonicus	0.06	0.01	0.01
Solenocera subnuda	0.00	0.00	0.00
Trachypenaeus fulvus	0.05	0.00	0.01
T. haumela	0.87	0.07	0.14
T. myops	1.31	0.11	0.22
Shrimps	2.39	0.20	0.40
Panulirus polyphagus	0.49	0.04	0.08
Thenus orientalis	8.56	0.71	1.42
Crabs	0.75	0.06	0.12
TOTAL (COMMERCIAL)	413.27	34.44	68.65
Trash fish			
Aluterus monoceros	0.53	0.04	0.09
Alutera	0.19	0.02	0.03
Anthiidae	0.00	0.00	0.00
Apogon spp.	1.76	0.15	0.29
Argyrops spinifer	0.00	0.00	0.00
Arothron sp.	1.10	0.09	0.18
Bothidae	0.00	0.00	0.00
Callionymidae	0.00	0.00	0.00
Canthigaster sp.	0.00	0.00	0.00
Carangoides equala	0.00	0.00	0.00
Coradion chrysozonus	0.00	0.00	0.00
Crabs	0.00	0.00	0.00
Dactyloptena sp.	0.20	0.02	0.03
Decapterus spp.	1.99	0.17	0.33
Diodon holocanthus	2.14	0.18	0.36
Diodon spp.	0.92	0.08	0.15
Dipterygonotus balteatus	0.12	0.01	0.02
Echeneis naucrates	0.00	0.00	0.00
Eutherapon theraps	0.00	0.00	0.00
Fistularia petimba	1.23	0.10	0.20
Fistularia spp	1.94	0.16	0.32
Heterodontus sp.	0.00	0.00	0.00
Holocentrus sp.	9.50	0.79	1.58
Inimicus sinensis	0.00	0.00	0.00
Labridae	0.20	0.02	0.03
Lagocephalus spp.	3.81	0.32	0.63
Leiognathus spp.	2.32	0.19	0.39
Lepidotrigla sp.	0.28	0.02	0.05
Loligo duvauceli	0.00	0.00	0.00
Lophodiodon	0.38	0.03	0.06
Nemipterus marginatus	0.00	0.00	0.00
Nemipterus nematophorus	0.00	0.00	0.00
Octopus sp.	0.00	0.00	0.00
Ostracion sp	0.19	0.02	0.03
Paramonacanthus spp.	0.00	0.00	0.00
Parascolpsis eriomma	0.00	0.00	0.00
Parapercids	0.28	0.02	0.05
Parupeneus cinnabarinus	0.00	0.00	0.00
Pentaprion longimanus	18.26	1.52	3.03
Platycephalus spp.	0.26	0.02	0.04
Pleuronectes spp.	3.76	0.31	0.62
Priacanthus macracanthus	0.00	0.00	0.00
Priacanthus tayenus	0.00	0.00	0.00
Pristotis jerdoni	14.40	1.20	2.39
Pseudomonocanthus sp	0.03	0.00	0.00
Pterois sp.	0.00	0.00	0.00
Pterocaesio chrysozona	0.00	0.00	0.00
Pterocaesis	1.07	0.09	0.18
Rays	27.05	2.25	4.49
Rhynchostracion	0.90	0.08	0.15
Rhynchostracion nasus	0.15	0.01	0.02
Round sponges	0.00	0.00	0.00
Saurida micropectoralis	0.00	0.00	0.00
Saurida undosquamis	15.12	1.26	2.51
Saurida hoshinonis	0.00	0.00	0.00
Saurida elongata	5.55	0.46	0.92
Saurida spp.	14.60	1.22	2.43
Saurida tumbil	10.60	0.88	1.76
Scolopsis spp.	0.00	0.00	0.00
Sea cucumber	0.00	0.00	0.00
Sepia spp.	0.00	0.00	0.00
Shells	0.00	0.00	0.00
Stolephorus sp.	0.10	0.01	0.02
Scorpaena scabra	0.00	0.00	0.00
Siganus oramin	0.20	0.02	0.03
Sillago	3.00	0.25	0.50
Sillago sihama	5.50	0.46	0.91
Starfish	0.00	0.00	0.00
Synodous hoshinonis	0.19	0.02	0.03
Tetrosomus sp.	1.19	0.10	0.20
Therapon theraps	12.00	1.00	1.99
Torquigener sp.	0.00	0.00	0.00
Triacanthus spp.	0.13	0.01	0.02
Upeneus sulphureus	25.00	2.08	4.15
Upeneus moluccensis	0.00	0.00	0.00
Upeneus spp.	0.60	0.05	0.10
Uranoscopus sp.	0.00	0.00	0.00
TOTAL (Trash)	188.74	15.73	31.35
TOTAL CATCH	602.01	50.17	100.00

Table 3 Summary of the catch composition of the major fish group

Fishery group	Total (kg)		Average catch (kg/hr)		Percentage (%)	
	3rd cruise	4th cruise	3rd cruise	4th cruise	3rd cruise	4th cruise
Demersal fish	444.72	268.32	26.16	22.36	46.96	44.57
Pelagic fish	74.18	65.04	4.36	5.42	7.79	10.8
Cephalopods	29.32	67.72	1.72	5.64	3.11	11.25
Shrimps	0.49	2.39	0.03	0.2	0.05	0.40
Crab	0.54	0.75	0.04	0.06	0.06	0.12
Shell fish	0.60	0.00	0.04	0.00	0.06	0.00
Trash fish	395.81	188.74	23.28	15.73	41.55	31.35
Others	3.98	9.05	0.24	0.75	0.42	1.51
Total catch	949.63	602.01	55.86	50.16	100.00	100.00

longimanus, *Leiognatus spp*., *Upeneus spp*.and *Saurida micropectoralis*. During the 4th cruise, trash fish registered an average catch rate of 15.7 kg/hr. Most trash fish were caught at station 31 (53.1 kg/hr) followed by station 7 (41.1 kg/hr). The trash fish were dominated by *Upeneus sulphureus*, *Pentaprion longimanus* and *Saurida spp*.

Priacanthids, the most dominant among the fish family in the 3rd cruise have an average catch rate of 7.9 kg/hr. The highest catch rate was at station 44, (100.0 kg/hr) and was recorded only by *Priacanthus macracanthus*. Nemipterids attained an average catch rate of 6.1 kg/hr. *Nemipterus bathybius* recorded the highest average catch rate of 1.9 kg/hr. Nemipterids were most abundant at station 33 with catch rate of 22.2 kg/hr. Carangidae, the third most dominant fish family registered an average catch rate of 2.8 kg/hr. In terms of individual species within the family, *Decapterus spp*. attained the highest average catch rate (1.0 kg/hr) and the others recorded an average catch rate of less than 1.0 kg/hr. Carangidae was most abundant at station 34 with catch rate of 8.7 kg/hr.

During the 4th cruise, the most dominant family i.e Nemipteridae have an average catch rate of 6.4 kg/hr. The highest catch rate was at station 27 with catch rate of 14.62 kg/hr. Carangidae attained an average catch rate of 4.3 kg/hr and the highest catch rate was recorded at station 7 (15.9 kg/hr). Among the carangids, *Atule mate* registered the highest catch rate (9.5 kg/hr) at station 6.

Table 4 Length-weight relationship of selected species

Species	n	a	b	r^2
Selar crumenophthalmus	123	0.0057	3.4063	0.92
Decapterus kurroides	56	0.0067	3.1937	0.88
Decapterus ruselli	204	0.0053	3.2989	0.91
Decapterus macrosoma	85	0.0076	3.1082	0.86
C. malabaricus	144	0.0104	3.2704	0.96
Carangoides equala	54	0.0323	2.8953	0.92
Dussumieria spp.	198	0.0095	3.0511	0.67
Ariomma indica	53	0.0244	3.0545	0.63
Nemipterus bathybius	250	0.0172	3.0350	0.98
Nemipterus marginatus	96	0.0152	3.1071	0.98
Nemipterus mesoprion	143	0.0139	3.1161	0.99
Nemipterus nematophorus	186	0.0194	2.9862	0.98
Nemipterus nemurus	79	0.0188	2.9585	0.90
Nemipterus virgatus	55	0.0212	2.9414	0.98
Priacanthus macracanthus	151	0.0142	2.9997	0.98

The b values obtained ranged from 2.89 to 3.40.

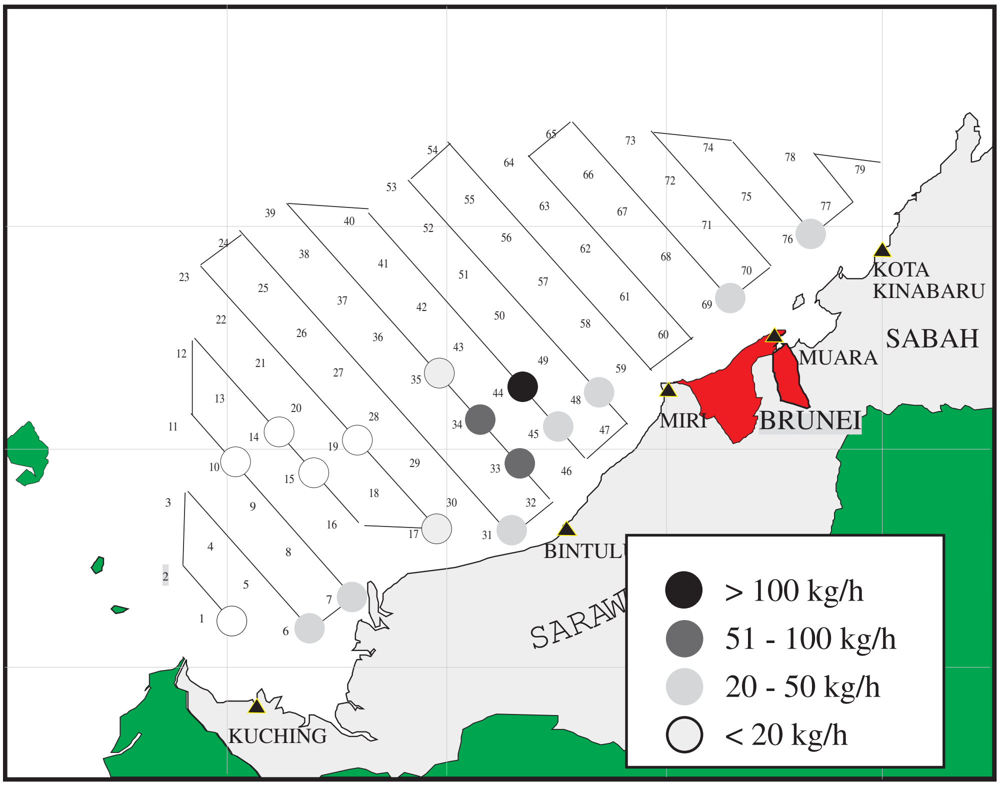

Fig. 3 Catch rate of commercial fish of individual station during 3rd cruise (9th - 3rd August 1996)

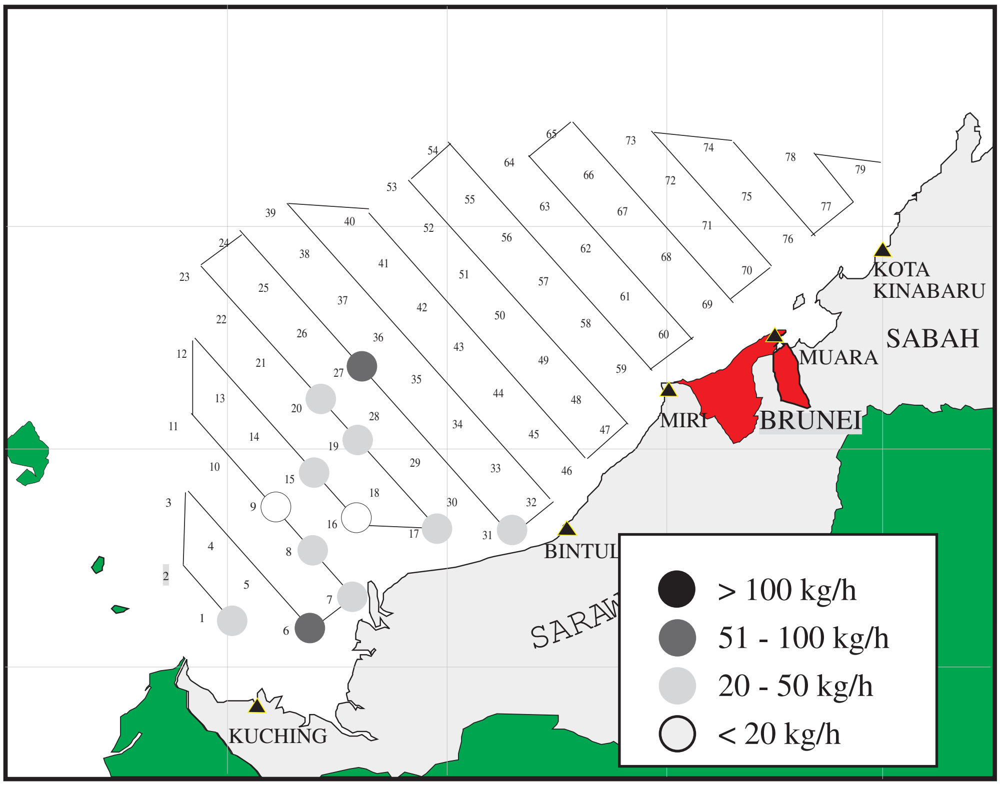

Fig. 4 Catch rate of commercial fish of individual station during 4th cruise (30th April - 30th May 1997)

Length-Weight Relationship

The length-weight relationship of the selected species are as shown in Table 4 below:

Discussions

The overall average catch rate from individual stations during 3rd cruise (55.9 kg/hr) and 4th cruise (50.2 kg/hr) is very low compared to 318 kg/hr and 210 kg/hr obtained from previous surveys within the same areas in 1972 (Mohammed Shaari et al, 1976a) and 1973 (Mohammed Shaari et al, 1976b) respectively. However, in the present survey, the number of hauls is very small in number (i.e. 17 and 12 hauls for 3rd and 4th cruise respectively) as compared to 118 hauls during the previous survey (Mohammed Shaari et al, 1976b).

The other factor that might contributed to the low overall average catch rate of commercial fish after 17 and 12 hours trawling respectively is the openning of the trawl net. It could be that the net mouth did not open properly.

For an ideal fish which maintains the same shape, b=3, and this has occasionally been observed (Allen, 1938). In the present study, it seemed that the cube law is being obeyed as most of the b values lies close to 3. In general, the fish are also normally distributed. This was based on the findings by Carlender (1969) that fish with b values equal to 3 are more representative of the population. It was found that the b values for nemipterids varies excepts for 3 species (*N. nematophorus, N. nemurus and N. virgatus*). This suggests that the nemipterids have different growth rate. The lower values of b can be considered to be the result of biological features of the species.

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References

Allen, K.R. (1938). Some observations on the biology of the trout (*Salma trutta*) in Windermert. *J. Anim. Ecol*. 7:333-49.

Anon. 1995. Annual Fisheries Statistics. Marine Fisheries Department of Sarawak. Ministry of Agriculture Malaysia.

Carlender, K. 1969. Handbook of freshwater fishery biology. Vol. 1. Iowa State University press, Annos.

Mohammed Shaari bin Sam Abdul Latiff, W. Weber, Lee Aik Kean, Lam Wah Chang. 1976a. Demersal Fish Resources in Malaysian Waters - 6. Trawl survey off the coasts of Sarawak, Brunei and the west coast of Sabah. (29th March 1972-1st May 1972). *Fisheries Bulletin* No. 8. Ministry of Agriculture and Rural Development, Malaysia: 1-64.

Mohammed Shaari bin Sam Abdul Latiff, W. Weber, Lee Aik Kean. 1976b. Demersal Fish Resources in Malaysian Waters - 9. Second trawl survey off the coasts of Sarawak. (17th August 1973-18th September 1973). *Fisheries Bulletin* No. 11. Ministry of Agriculture Malaysia: 1-28.

Sparre, P. and Venema, S.C. 1992. Introduction to tropical fish stock assessment. Part I.Manual Fish. Tech. Pap. 306/1, Rev.1, FAO, Rome. 337 pp.

Biomass Estimation by Hydro-acoustic Methods in the South China Sea, Area II : Sarawak, Sabah and Brunei Darussalam.

Yuttana Theparoonrat
Training Department, Southest Asian Fisheries Development Center.

ABSTRACT

The abundance of fisheries resources and their structure off shore of Sarawak, Sabah and Brunei Darussalam were investigated under the SEAFDEC Collaborative Research Survey. Hydro-acoustic surveying by using a scientific echo sounder model FQ-70 was conducted for estimating the fish abundance and biomass. Two survey cruises were carried out by M.V. SEAFDEC during 10 July to 2 August 1996 and 1 to 24 May 1997 for pre and post-northeast monsoon seasons, respectively. The scientific echo-sounder was equipped with an echo-integrator and two quasi-ideal beam transducers with operating frequencies of 50 and 200 kHz. For pre and post-northeast monsoon season was 1,717,852 tons and 956,397 tons, respectively. The maximum fish abundance were found at the water depth between 100 to 200 m was 92.4% and 49.8% of total abundance for pre and post-northeast monsoon season, respectively.

Key words: Biomass estimation, Acoustic survey, South China Sea, Sarawak, Sabah, Brunei Darussalam.

Introduction

Marine fisheries resources are migrate according to the change of seasonal and maturity state. The abundance estimation of such migratory species are need to design the survey with cover all that particular area. Southeast Asian Fisheries Development Center (SEAFDEC) was proposed to conduct the Collaborative Research Survey on the marine fisheries resources and the environmental factors in the South China Sea of SEAFDEC member country's waters. Two survey cruise were performed by M.V. SEAFDEC during pre-northeast monsoon season from 10 July to 2 August 1996 and post-northeast monsoon season from 1 to 24 May 1997. The objective of the survey is to estimate the abundance of fisheries resources and their structures at the off shore of Sarawak, Sabah and Brunei Darussalam waters, and to study on the variation of the abundance during pre-northeast monsoon and post-northeast monsoon season.

Materials and Methods

The survey area was divided into 79 oceanographic survey stations (Fig 1). Each station were located at 30 nautical miles apart. The hydro-acoustic survey by using scientific echo-sounder model FQ- 70 are carried out along the parallel cruise track of 30 nautical mile. Scientific echo-sounder was equipped with dual frequency by using two quasi-ideal beam transducers with operated on 50 kHz and 200 kHz. This acoustic survey system were equipped with echo integrator, calibration system and data recorder. The system is designed so that a vast amount of data can be stored onto the floppy disk memory and processed by the data analyzer. The raw data from Furuno FQ-70 software in form of K3 ASCII code are using for the calculation. The volume back scattering strength (SV) of high frequency (200 kHz) was calculated from data recorded from 10 to 200 m.

The calibration of FQ-70 is conducted before the survey cruise is performed at the survey station number 1. M.V. SEAFDEC is anchored at the water depth of 36 meter where the clam sea and weak current of 0.4 knot. The calibration is performed by using standard hydrophone model TW-9103-S attached at 1 meter under the transducer sound beam axis. Both low (50 kHz) and high frequency (200 Attenuation and Gain, Transmitting Sensitivity of Transducer, and Receiving Sensitivity of Transducer.

Hydro-acoustic Data Collection

The hydro-acoustic data of fish school in the area of Sarawak, Sabah and Brunei Darussalam are recorded by using scientific echo sounder (FQ-70). The data of means volume back scattering was recorded by high frequency (200 kHz.) with the transmission rate of 123 ping/min. The ship constant cruising speed is 10 knots. During the survey cruise, the raw data of reflected echo signal from fish school also recorded on to VHS Video tape for data bank reservation. The processed echo information from echo integrator with the distance interval of 0.1 nautical mile were calculated by echo integrator and data analyzer. The integration of volume back scattering strength (SV) of fish school were calculated from the water depth layer of 10 m to 200 m for 8 integration layers. Two bottom integration layers were calculated at 1 m to 5 m to 10 m above the sea bottom. The integrated of SV and density of fish were recorded on the floppy disk as well as printed out on printer and also plotted on the echogram. The recorded data was recalculation for biomass estimation of fisheries resources and their distribution in the survey area. The parameters setting for echo integrator unit are showing below:

The Parameter Setting for Echo Integrator Unit

Range			**Sonar parameter**		
1. REC RANGE		0 - 200 m	1. Calculation	SV-H	SV-L
2. LAYER	1	10 - 20 m	2. SL	220.00	215.10
	2	20 - 40 m	3. ME	-194.90	-185.60
	3	40 - 60 m	4. Absorption	92.70	9.90
	4	60 - 80 m	5. 10 log y	-16.10	-14.50
	5	80 - 100 m	6. AMP Gain	50.30	49.00
	6	100 - 130 m	7. Pulse Length	1.20	1.20
	7	130 - 160 m	8. Sound Velocity		1500.00
	8	160 - 200 m			
	9	B10 -B5 m			
	10	B5 - B1 m			

Calculation of Volume Back Scattering Strength (SV)

The volume back scattering strength (SV) of fish school is obtained from the following equation;

$$SV = 20 \log V_{sv} - (SL + ME) + 20 \log r + (2\alpha r/1000) - 10 \log (\log (c\tau/2) - 10 \log\psi$$

where

SV	:	Volume Back scattering Strength, (dB)	α	:	Absorption Coefficient (dB/km)
Vsv	:	Voltage output (Vrms)	c	:	Underwater Sound speed (m/sec)
SL	:	Source Level, (dB)	τ	:	Pulse duration (ms)
ME	:	Receiving Sensitivity, (dB)	ψ	:	Equivalent beam width

r : Range of target (m)

The scientific echo sounder FQ-70 can be automatically calculated the means volume back scattering strength (SV_{avg}) in particular layer width and log interval of ship cruising. The calculation can be perform with pre-setting parameter by the following equation;

$$SVavg = (\Sigma\Delta_r \Sigma_1 sv_i)/\Delta r1$$

where Δ_r : Layer width
1 : Log interval

During the survey cruise, the layer width and log interval was set at 0.1 nautical mile. The fish density can be calculated as the following formula;

$$N = 10^{(SV-BSV)/10}$$

where N : Density of fish in the integrating layer (n/m^3)
BSV : Back scattering strength of a single fish per unit volume (=TS)

The calculation of SV was performed by average the SV from 1^{st} layer with started at 10 m depth down to 200 m layer. The layer at with sea bottom appear was excluded from the calculation but will be substituted by two bottom layer of layer 9 and 10

Averaging the SV Value in Sections of the Distance Run

The average of SV value in section of distance run can be calculated by using the following equation :

$$SV_{avg} : = 10 \log \left(\frac{\Sigma 10^{(svi/10)}}{K} \right)$$

where SV_{avg} : SV value after averaging
Svi : SV value of each section
K : Number of integral per section of distance run

The integrated average SV from FQ-70 were check and eliminated the high SV value caused by the interference from the ship electronic equipment

Biomass estimation

Biomass is defined as the density of fish (Tones per square nautical mile) in the area surveyed, derived from the integrated echoes. The biomass estimation can be perform by using Algebraic Method (Johannesson and Mitson, 1983). The basic principle is schematically illustrated in Fig. 2. Each sample observation (ai) is assigned to a corresponding rectangular area, here call "Elementary Statistical Sampling Rectangle" (ESSR). For a parallel survey grid with equidistant inter-transect spacing (Dt) (30 nautical mile) all ESSR's will have equal area sizes given by

$$ESSR = Dt \times (ESDU) \ mile^2$$

where ESDU is the selected "Elementary Sampling Distance Unit". When the inter-transect spacing equal one ESDU, it follow that the ESSR becomes a square of size $(ESDU)^2$

The estimation of biomass was calculated by using algebraic Method with estimated the means SV of each Elementary Statistical Sampling Interval (ESSR) with cover area is 30x30 nautical miles. The population density (fish/m^2) was calculated by using the parameter of means SV in each ESSR and fish target strength (TS). The average TS of fish was calculated by the equation (Miyanohana et al, 1987; Furusawa, 1990 as following ;

$$TS = 20 \log 1\text{-}66 \ \text{(dB)}$$

Where 1 is fish length in cm.

Since, the maximum catch of pelagic species in Sarawak, Sabah and Labuan of Malaysia contributed from sardine with annual catch ranging from 16,907 tons to 19,958 tons from 1994 to 1995 (Table.1 (D.O.F. Malaysia, 1994, 1995, 1996), then sardine was selected as the representative species for determine TS of single fish for biomass estimation. The target strength (TS) of sardine (Sadinella gibbosa) with the first capture at body length of 10 cm and weight of 10 gm (Somjaiwong, 1991) is –46.0 dB was using for the calculation. The abundance of biomass in each ESSR in obtained by multiplying the population density in the ESSR to the means weight of sardine.

Table 1 Landing of marine fish by year and species of Sarawak, Sabah and Labuan.

Fish Species	1993	1994	1995
Round Scad	11,650	13,779	15,833
Sadine	7,802	16,907	19,958
Tuna	20,028	14,548	18,050
Mackerel	18,249	15,106	13,092
Spanish Mackerel	12,077	6,871	8,393
Total	69,806	67,211	75,326

Result and Discussion

Fig 3 shows the echogram of pelagic and demersal fish school detected by 200 kHz. And 50 kHz. The echogram also showing the vertical distribution curve (VDC) with scale ranging from –80 dB to –30 dB. The VDC detected by 50 kHz Shows the high reverberation level from surface to bottom. Where as VDC detected by 200 kHz. Showing the less values. The sample of average volume back scattering strength (SV) and density of fish (N) in each depth layer with integrated for each 0.1 nautical mile of 200 kHz And 50 kHz.

Fig. 4 and Fig. 5 showed the biomass distribution presented by means SV at each 0.1 nautical mile measured during pre and post-northeast monsoon season, respectively. The SV showing high value of both season at the shallow water and around the station numbers 25, 26, 27, 36, 41, 42 and 50 where, the stations are between the contour line of 100 m to 200 m. During the survey cruise, the echogram can be recorded a lot of big pelagic fish school.

The summary of biomass estimation by frequency of 200 kHz. During pre-northeast monsoon and post-northeast monsoon season are showing in Table 2 and 3. The total estimated biomass during pre-northeast monsoon season are 1,717,852.38 tons and 956,396.88 tons, respectively. The biomass distribution are showing in Fig. 6 and 7 for pre and post-northeast monsoon season, respectively.

During the post-northeast monsoon season, the maximum biomass is presented between station number 50 to 51 with the water depth of 160 m. in the amount of 1,384,550.oo tons. The minimum biomass is presented between station number 63 to 64 in the amount of 93.06 tons Where the water depth is 1600 m. The total biomass presented at the water depth of <100m, 100 to 200m and

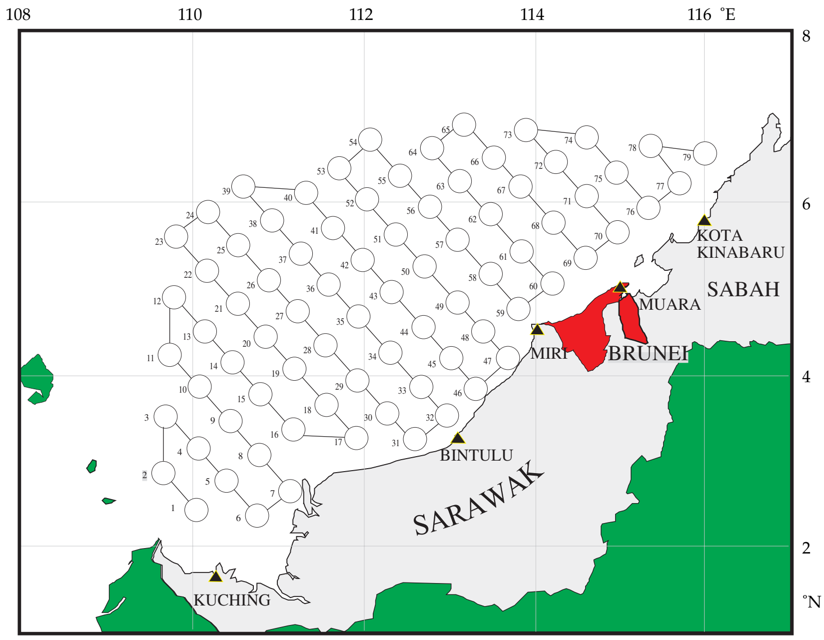
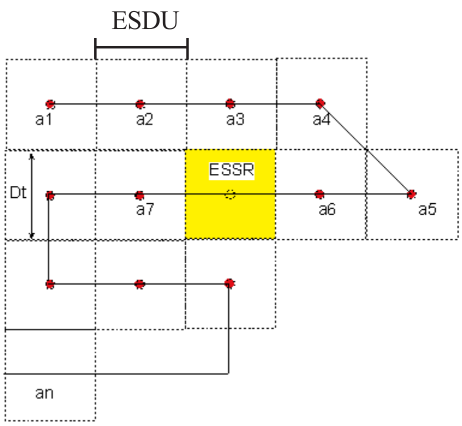


Fig. 1 The survey area

Fig. 2. Elementary statistical sampling interval (ESSR) along the cruise track when the inter-transect (Dt) equals one elementary sampling distance unit (ESDU). Tatal biomass estimation is the summation of all the abundance of the ESSR area.



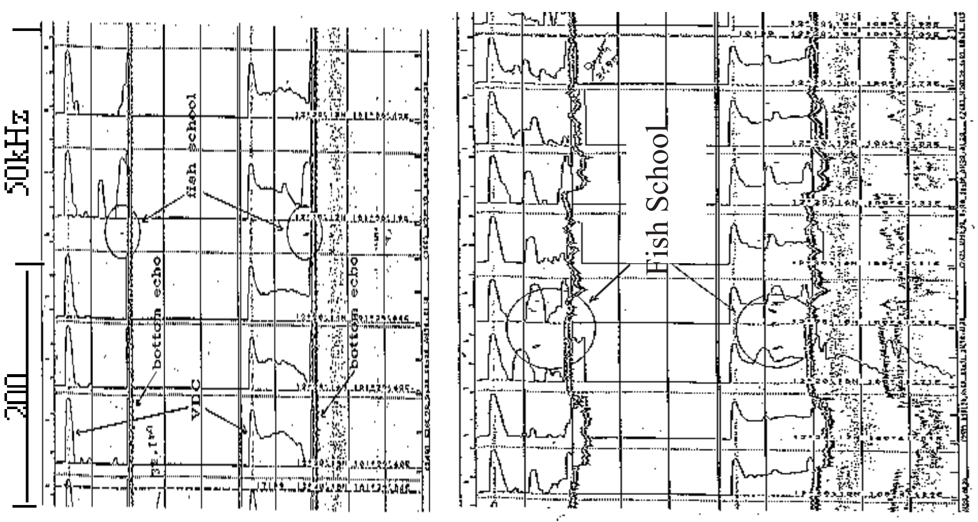


Fig. 3 The echogram of pelagic and demersal fish schools superimposed with Vertical Distribution Curve (VDC) detected by 50 kHz. and 200 kHz.

Table 2 Summary of biomass estimation by high frequency (200kHz)during premonsoon season off shore Sarawak, Sabah and Brunei Darussalam. The table show estimation for each station (ESSR) with cover area is 30x30 nuatical mile

Station	Means SV (dB)	Weight (tons)	Depth (m)	Station	Means SV (dB)	Weight (tons)	Depth (m)
1-2	-72.87	2953.02	46.5	40-41	-90.47	220.47	200.0
2-3	-82.83	424.48	66.2	41-42	-68.77	29489.90	180.6
3-4	-84.37	322.92	71.9	42-43	-68.54	20559.98	119.5
4-5	-76.97	1730.17	70.1	43-44	-76.13	2845.26	95.0
5-6	-74.45	1715.50	38.9	44-45	-83.41	429.57	76.7
6-7	-71.83	2906.67	36.0	45-46	-75.92	1383.76	44.0
7-8	-68.52	5892.31	34.1	46-47	-64.81	10314.61	25.4
8-9	-74.26	2305.88	50.0	47-48	-72.19	4179.90	56.3
9-10	-85.74	260.51	79.5	48-49	-79.40	1314.43	93.2
10-11	-88.88	152.36	95.7	49-50	-72.03	10834.45	140.7
11-12	-68.60	18238.01	107.6	50-51	-51.55	1384550.00	160.9
12-13	-86.25	328.15	112.7	51-52	-86.56	542.54	199.9
13-14	-87.82	204.31	100.6	52-53	-85.01	775.07	200.0
14-15	-82.52	548.99	79.8	53-54	-81.55	1719.86	200.0
15-16	-72.96	3542.96	57.0	54-55	-87.06	484.22	200.0
16-17	-66.01	12012.21	39.0	55-56	-84.98	780.03	200.0
17-18	-71.11	3734.24	39.2	56-57	-93.03	122.22	200.0
18-19	-76.06	1846.91	60.6	57-58	-79.87	2531.68	200.0
19-20	-78.41	1433.26	80.8	58-59	-82.76	1206.11	185.2
20-21	-76.10	3087.13	102.2	59-60	-77.14	4087.36	172.1
21-22	-74.13	6201.32	130.7	60-61	-92.49	138.60	200.0
22-23	-77.60	3106.12	145.4	61-62	-90.41	223.86	200.0
23-24	-77.15	4128.30	174.4	62-63	-81.88	1594.94	200.0
24-25	-82.68	1325.05	200.0	63-64	-94.22	93.06	200.0
25-26	-70.05	18492.92	152.3	64-65	-84.43	886.63	200.0
26-27	-69.11	16483.74	109.4	65-66	-86.44	557.56	200.0
27-28	-67.22	20153.80	86.4	66-67	-78.45	3510.98	200.0
28-29	-76.94	1662.97	66.8	67-68	-90.78	205.45	200.0
29-30	-71.24	4104.37	44.5	68-69	-82.11	1373.12	181.8
30-31	-70.79	2680.09	26.1	69-70	-76.52	2852.94	104.3
31-32	-65.88	9762.12	30.7	70-71	-70.21	23020.09	196.7
32-33	-74.45	1937.49	43.9	71-72	-85.60	677.37	200.0
33-34	-80.59	643.74	60.0	72-73	-81.09	1913.19	200.0
34-35	-80.45	873.43	78.8	73-74	-87.01	489.67	200.0
35-36	-78.06	1882.09	98.0	74-75	-80.63	2126.18	200.0
36-37	-70.29	15615.09	135.7	75-76	-75.11	7235.07	191.0
37-38	-82.76	1300.35	200.0	76-77	-73.94	4985.01	100.5
38-39	-88.99	310.04	200.0	77-78	-80.05	2202.20	181.2
39-40	-80.24	2324.37	200.0	78-79	-74.02	8767.69	180.0
					Total =	**1717852**	

Table 3. Summary of biomass estimation by high frequency (200 kHz) during post-northeast monsoon season off shore of Sarawak, Sabah and Brunei Darussalam. The table show estimation for each station (ESSR) with cover area is 30 x 30 nautical mile.

Station	Means SV (dB)	Weight (tons)	Depth (m)	Station	Means SV (dB)	Weight (tons)	Depth (m)
1-2	-62.73	30475.03	46.5	40-41	-73.28	11544.31	199.9
2-3	-73.22	3901.30	66.6	41-42	-70.87	18149.18	180.5
3-4	-71.76	5959.60	72.8	42-43	-68.17	22378.88	119.4
4-5	-68.99	10906.12	70.3	43-44	-74.53	4107.04	94.9
5-6	-69.81	4966.83	38.6	44-45	-74.11	3672.33	76.9
6-7	-67.90	7283.08	36.5	45-46	-65.60	15003.80	44.3
7-8	-72.96	2165.15	34.7	46-47	-63.93	12804.26	25.7
8-9	-68.89	8018.83	50.5	47-48	-65.69	18732.57	56.4
9-10	-80.16	937.97	79.1	48-49	-75.17	3499.58	93.5
10-11	-77.95	1895.55	96.1	49-50	-68.02	27524.18	142.1
11-12	-65.37	38629.55	108.1	50-51	-69.68	21489.75	162.4
12-13	-74.30	5163.92	113.1	51-52	-69.93	25005.21	200.0
13-14	-76.81	2548.95	99.5	52-53	-76.69	5271.18	200.0
14-15	-72.81	5170.71	80.2	53-54	-68.85	32017.28	200.0
15-16	-74.39	2563.12	57.2	54-55	-80.44	2220.10	200.0
16-17	-62.22	29410.04	39.9	55-56	-82.99	1235.54	200.0
17-18	-68.77	6329.70	38.7	56-57	-75.35	7175.69	200.0
18-19	-69.57	8302.24	61.2	57-58	-71.03	19359.08	200.0
19-20	-75.64	2742.49	81.7	58-59	-71.71	15065.28	181.6
20-21	-74.41	4566.07	102.5	59-60	-66.50	44562.34	162.0
21-22	-74.64	5474.31	129.7	60-61	-82.39	1418.77	200.0
22-23	-67.81	29603.82	145.4	61-62	-71.05	19278.31	200.0
23-24	-76.23	5012.40	171.3	62-63	-78.92	3150.28	200.0
24-25	-72.20	14823.12	199.9	63-64	-83.83	1016.37	200.0
25-26	-68.33	27626.06	152.9	64-65	-89.80	256.87	200.0
26-27	-81.99	850.65	109.5	65-66	-77.60	4274.07	200.0
27-28	-73.48	4784.12	86.8	66-67	-75.46	6992.36	200.0
28-29	-69.23	9861.52	67.2	67-68	-78.56	3421.60	200.0
29-30	-70.61	4755.88	44.5	68-69	-68.36	32650.16	181.9
30-31	-61.99	23392.87	26.1	69-70	-69.69	13898.91	105.4
31-32	-58.10	58311.63	30.7	70-71	-77.63	4185.10	197.5
32-33	-65.59	14907.20	43.9	71-72	-80.30	2295.99	200.0
33-34	-75.17	2253.92	60.2	72-73	-73.85	10120.98	200.0
34-35	-83.11	474.30	78.9	73-74	-78.49	3482.21	200.0
35-36	-78.10	1864.24	97.8	74-75	-85.13	753.75	200.0
36-37	-62.34	95461.97	133.1	75-76	-83.43	1066.63	191.3
37-38	-75.60	6768.21	200.0	76-77	-76.45	2744.86	98.7
38-39	-80.05	2427.10	200.0	77-78	-68.00	35457.60	182.0
39-40	-75.30	7258.02	200.0	78-79	-82.41	1266.92	179.7
					Total =	**956397**	

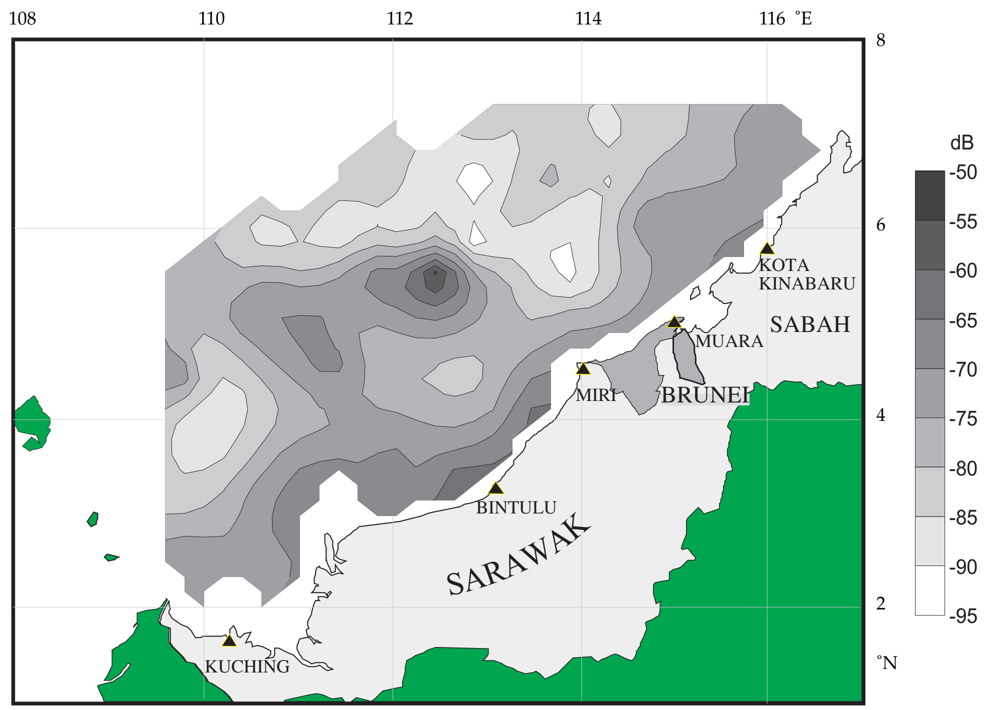


Fig. 4 Distribution of back scattering volume (SV) of fish biomass measured during the pre monsoon season in Sarawak , Sabah and Brunei Darussalam waters.

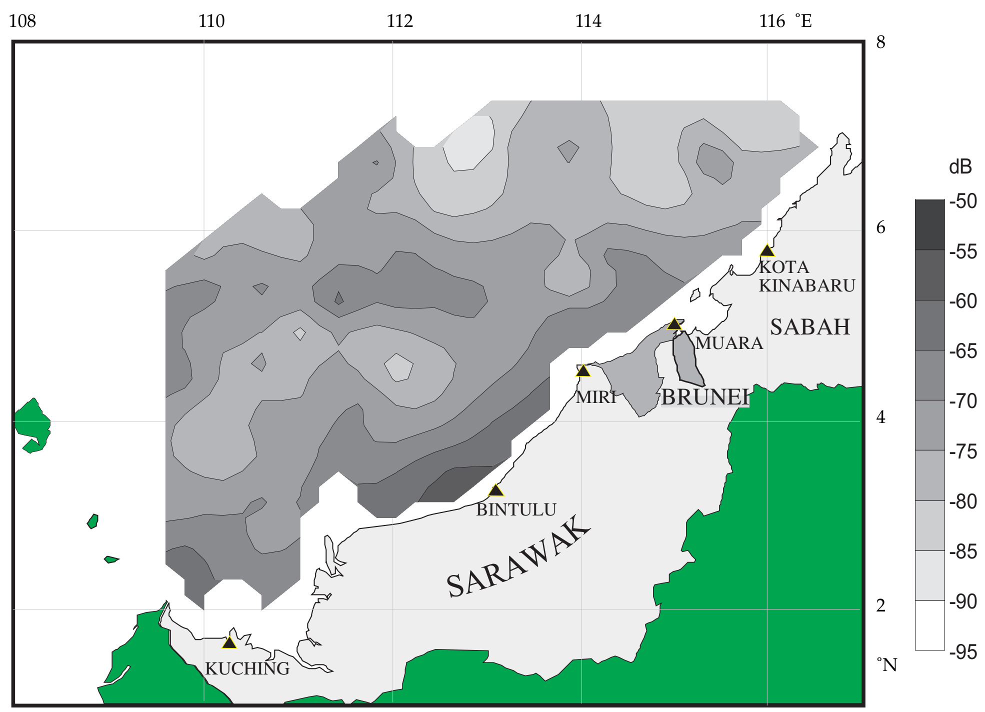


Fig. 5 Distribution of back scattering volume (SV) of fish biomass measured during the post monsoon season in Sarawak , Sabah and Brunei Darussalam waters.

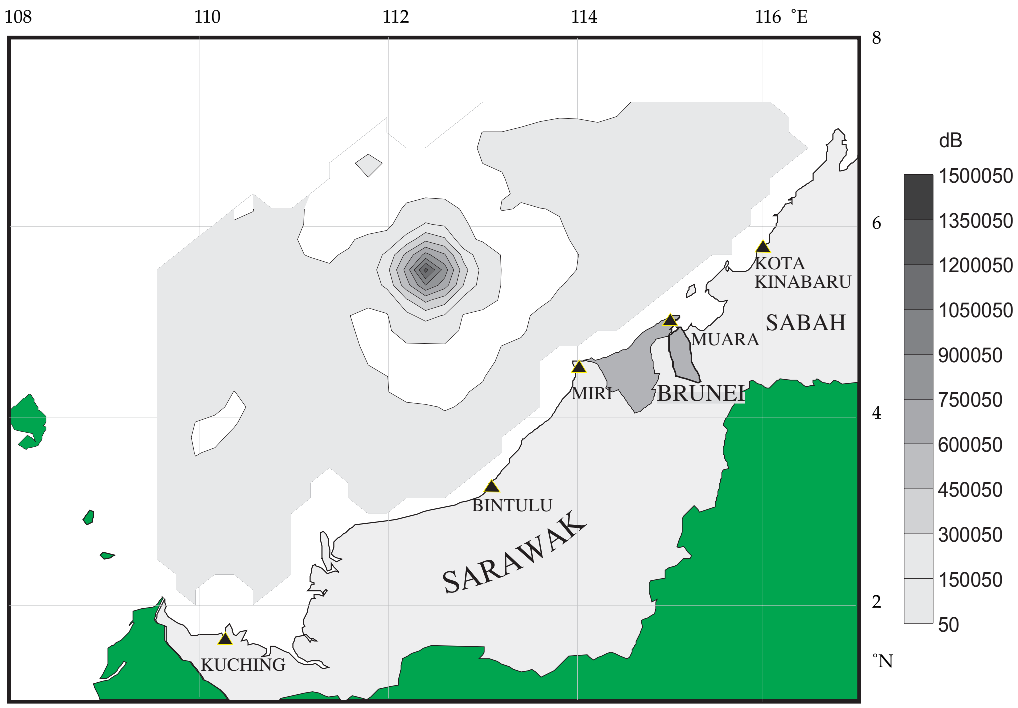


Fig. 6 Distribution of average fish biomass (ton x 900nm) during the pre monsoon season in Sarawak , Sabah and Brunei Darussalam waters.

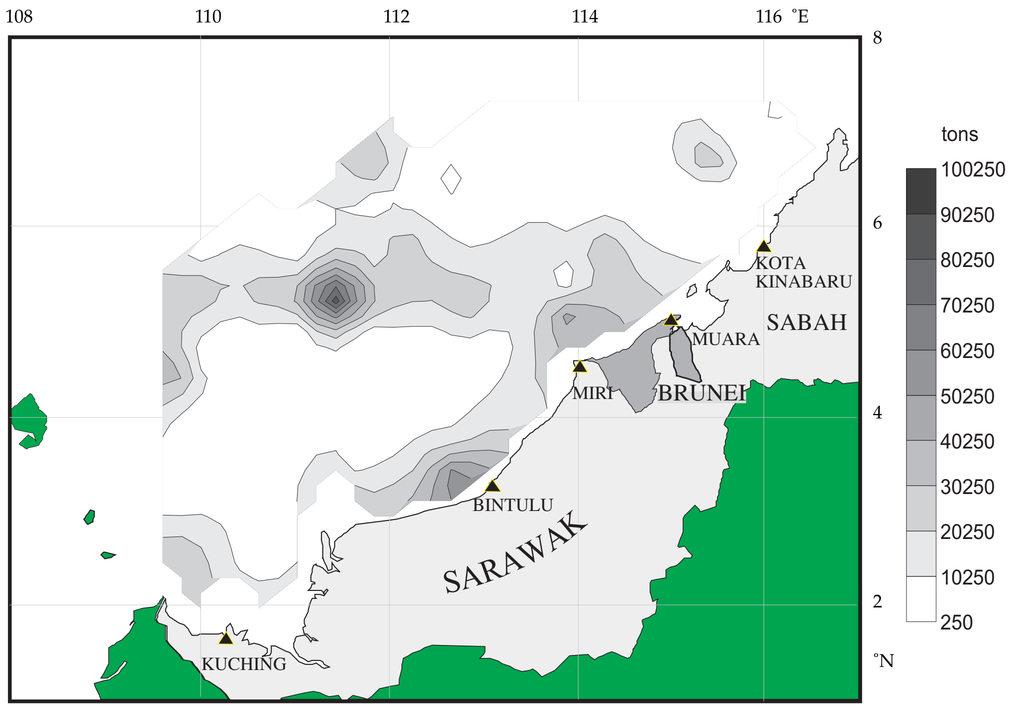


Fig. 7 Distribution of average fish biomass (ton x 900nm) during the post monsoon season in Sarawak , Sabah and Brunei Darussalam waters.