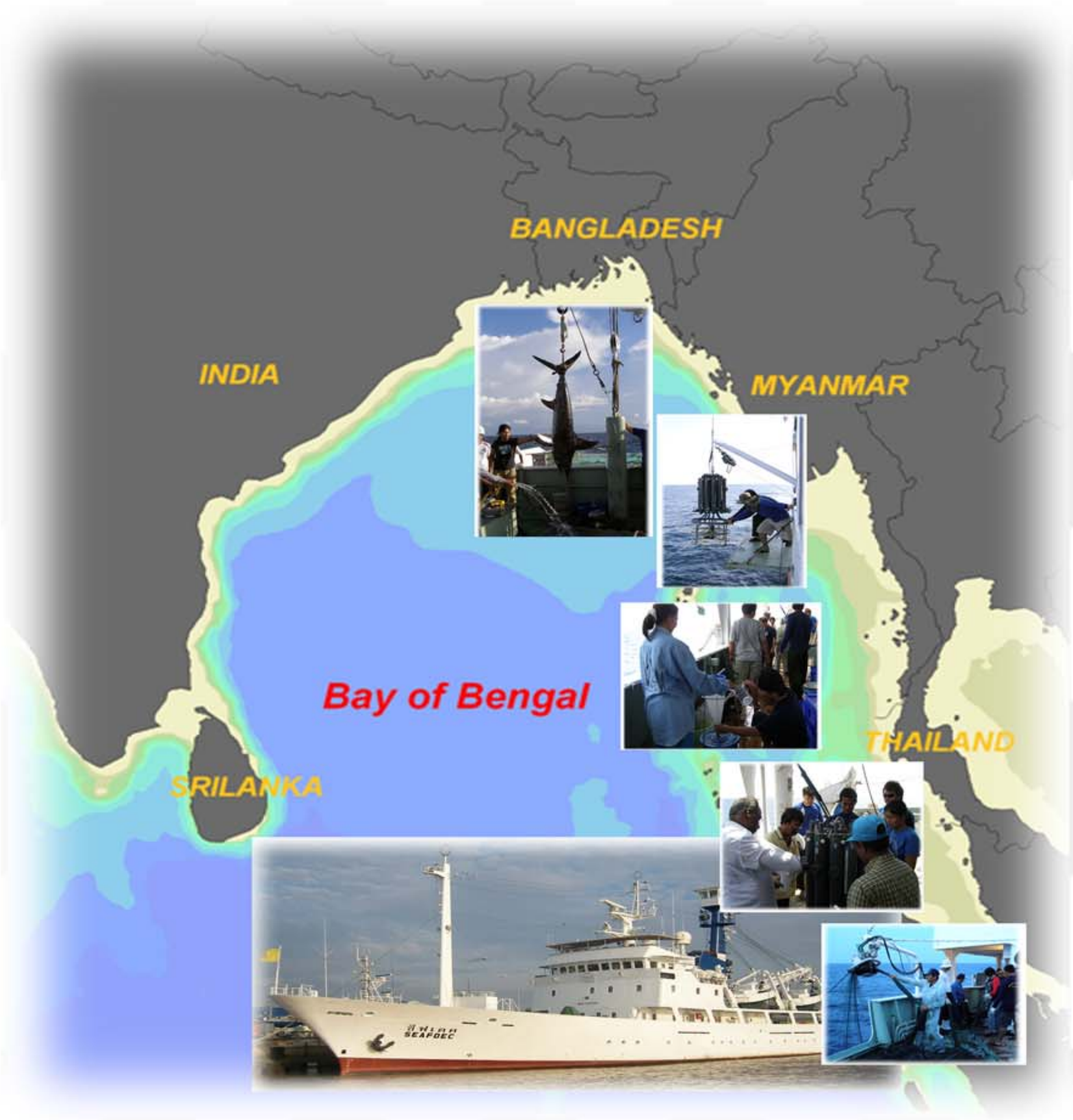
The Ecosystem – Based Fishery Management in the Bay of Bengal



The Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMESTEC)

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Department of Fisheries, (DOF)
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Executive Summary

1. Introduction

The Ecosystem-Based Fishery Management in the Bay of Bengal is a collaborative fishery research project conducted by members of the Multi-Sectoral Technical and Economic Cooperation (BIMSTEC). The BIMSTEC is an international economic cooperation of a group of countries comprising Bangladesh, India, Sri Lanka, Thailand, Myanmar, Bhutan and Nepal. The economic cooperation initiative was initially formulated Bangladesh, India, Sri Lanka and Thailand in their 6 June 1997 Agreement recognized as the "Bangladesh, India, Sri Lanka and Thailand Economic Cooperation" or BIST-EC. Myanmar attended the inaugural June Meeting as an observer and joined the organization as a full member at a Special Ministerial Meeting held in Bangkok on 22 December 1997, upon which the name of the grouping was changed to BIMST-EC. Nepal was granted observer status by the second Ministerial Meeting in Dhaka in December 1998. Subsequently, full membership has been granted to Nepal and Bhutan in 2004. In the first Summit on 31 July 2004, leaders of the group agreed that the name of the grouping should be known as BIMSTEC or the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation.

BIMSTEC has thirteen priority sectors cover all areas of cooperation. Six priority sectors of cooperation were identified at the 2nd Ministerial Meeting in Dhaka on 19 November 1998. They include the followings:

1. Trade and Investment, led by Bangladesh
2. Transport and Communication, led by India
3. Energy, led by Myanmar
4. Tourism, led by India
5. Technology, led by Sri Lanka
6. Fisheries, led by Thailand

The BIMSTEC member countries recognize the role played by the fisheries sector in food supply and food security for their peoples. The natural resource rents provided by the Bay of Bengal and other inland and coastal bodies of water should be properly managed. In the past decades, the overexploitation of the fishery resources and the overcapacity of fishing fleets are the results of rapid fishing technology development, the ever increasing demands for fish as dictated by population growth and export economic policies, and the open access management of the fisheries. A new and effective management is therefore needed to bail the sub-region out of this economic and technical dilemma.

Around the world, fishery managers are increasingly recognizing ecosystems as natural capital assets. Scientific understanding of ecosystem production functions is improving rapidly but remains a limiting factor in incorporating natural capital into decisions, via systems of national accounting and other mechanisms. It is clear that formal sharing of experience, and defining of priorities for future work, could greatly accelerate the rate of innovation and uptake of new approaches.

The Bay of Bengal is a large marine ecosystem where coastal countries have been fishing. Its geographical and hydrological characteristics support plenitude of a variety of fish and shrimps. Sardines, anchovies, and mackerels are commonly caught whilst yellowfin tuna, bigeye tuna, skipjack tuna and swordfish, other large and precious pelagic fish known in the world market are harvested here. The Bay of Bengal is thus known for the source of employment in fishing and income enjoyed by a large number of people, as well as their countries in terms of foreign currency earning.

Three projects in the fisheries sectors have been approved by the 6th Ministerial Meeting in 2004. These are: 1) Ecosystem-based fisheries management in the Bay of Bengal (proposed by Thailand); 2) Impact of offshore oil and gas drilling on the marine fishery resources in the Bay of Bengal (proposed by Bangladesh); and 3) marine fish stock assessment, management and development of new fisheries in the Bay of Bengal (proposed by Bangladesh). Further discussion was made on these three projects during the BIMSTEC Technical Meeting in 2005. For the first project, the Technical Meeting suggested that a focus should be made on the straddling and highly migratory fish stocks and the survey of deep sea areas beyond the EEZ.

2. The Overall Objectives

The overall objectives of this project are as follows:

1) To understand the physical and chemical oceanographic and hydrological conditions of the Bay of Bengal.
2) To investigate the biological data of economic fish in terms of species, abundance, distribution, maturity size, feeding etc.
3) To assess the potential of fishery resources in the Bay of Bengal.
4) To strengthen capability in research work and knowledge exchange by training on the job on board the Thai research vessel.
5) To improve understanding and collaboration among researchers of the member countries during on board surveys.

3. The Project Output

It is expected that the obtained scientific data and information from all sub-projects will be highly beneficial for States bordering the Bay of Bengal to eventually draft the policy on sustainable utilization of fishery resources and achieve the effective fisheries management in the Bay of Bengal.

4. The Findings

The project spent a total of 58 days (from 25 October to 21 December 2007) in the survey, using a SEAFDEC research vessel, in the following maritime areas:

Area A (latitude 16°N -19°N, longitude 88°E -91°E)
Area B (latitude 09°N -14°N, longitude 82°E -85°E)
Area C (latitude 09°N -13°N, longitude 95°E -97°E)

Three types of fishing methods were used during the whole period of the surveys: pelagic long line, drift gill net and automatic squid jigging.

The results of the studies are summarized as follow:

4.1 The Oceanographic and Hydrobiological Conditions

a) The Oceanographic Condition

The oceanographic survey found the western side (area B) of the Bay with higher salinity than the north (area A) and the eastern (area C) boundaries. The water circulation in the Bay, as exhibited by the surface salinity in three spatial areas, was density-driven. Two core cold eddies were observed in the north area of the Bay. The large volume of freshwater discharge by the major rivers plays an important role in inducing lower salinity and higher temperature of the mixed layer (between 14 and 49 m) in the western and eastern areas of the Bay. Hypoxia (where dissolved oxygen was <0.5 ml/l) was found 200 m and deeper in the northern side of the Bay. Surface water shallower than 400 m was occupied by three water masses: Bay of Bengal water (salinity 32-34 psu), Andaman Sea water (salinity 31-33 psu), and Indian Central water (salinity more than 35 psu). The Indian central water occupied all deepest layers of all survey areas.

Distribution of nutrients: nitrite + nitrate, silicate and phosphate were found to correlate positively with depth at all sampling stations. The concentrations of nutrients in the mixed layer depth were low and undetectable in several sampling stations but distinctly high at western station (station 23) of the north of the Bay where chlorophyll-a concentration was also high. In the thermocline layer, a strong nutricline concentration was noticed to be rapidly increasing with depth. Until about 200-250 m the nutrient values were nearly constant or slightly changed. The differentiated pattern of depth profiles of both total phosphorus and total alkalinity together with the relationship between total alkalinity and total phosphorus indicate that sea water characteristic in the enclosed Andaman Sea is different from the entire Bay of Bengal.

Spatial distribution of chlorophyll-a displayed a pattern similar to that of salinity. Most of the low latitude stations exhibited somewhat higher chlorophyll-a concentrations than in those of high latitude stations.

b) Hydrobiological Conditions

A total of 135 phytoplankton species identified belong to the groups of cyanobacteria, diatom, dinoflagellates and silicoflagellates. The northern side of the Bay was inhabited by the highest phytoplankton densities due to the blooms of *Pseudo-nitzschia pseudodelicatissima* in the western part (station 23) of this area.

Similar to phytoplankton, a high concentration of zooplankton was found in the northern area of the Bay. The zooplankton community consisted of 205 species. Copepod was the most prevalent group both in terms of the number of species and biomass. Thirteen families of cephalopod paralarvae were found during the survey period. Family Ommastrephidae was widely distributed in the Bay.

Of the fifty-two families of fish larvae identified, those belong to Family Photichthyidae were the most abundant. The majority of these fishes belong to the inshore reef-fish and oceanic fish groups. In overall, the east of the Bay or the Andaman Sea harbours the richest ichthyodiversity and the highest biomass of fish larvae compared to other study areas.

4.2 The Fishery Resources

From the fishery surveys with 3 types of fishing gear; drift gill net (DGN), pelagic longline (PLL) and automatic squid jigging machine (ASJ), DGN and PLL were satisfactorily effective in catching pelagic fishes and were ideally appropriate tools for sustainable exploitation of the pelagic fishery resources in the Bay of Bengal. It was low catch per unit of effort (CPUE) from ASJ. The overall CPUEs from each type of fishing gear operated in the entire survey areas were DGN 0.84 no/hr (1.27 kg/hr), PLL 1.23 no/100 hooks (27.96 kg/100 hooks) and ASJ 0.19 no/line/hr (0.03 kg/line/hr)

In all fishing areas and with all types of fishing gear, the sum total of five most abundant species captured by number were in the following order: skipjack tuna (*Katsuwonus pelamis*, 22.94%), swordfish (*Xiphias gladius*, 12.94%), silky shark (*Carcharhinus falsiformis*, 8.82%), frigate tuna (*Auxis thazard*, 8.24%) and bigeye thresher shark (*Alopias supersiliosus*, 6.47%).

In terms of weight, the swordfish (34.82%) ranked first of the top-five species followed by bigeye thresher shark (33.88%), silky shark (8.21%) black marlin (*Makaira indica* 4.23%) and yellowfin tuna (*Thunnus albacares*, 3.98%), respectively.

Considering the fishing areas where fish were found in great abundance, the top-five pelagic species were mostly found in area A and C. It can be said that area A is a fertile fishing ground for DGN fishery targeting at tunas particularly skipjack tuna whereas area C is a good fishing ground for billfish fishing with PLL. Although DGN and PLL were operated successfully, their lower CPUEs were achieved when comparing to that of commercial fishing vessels. This could attribute to seasonal variation as the survey period may not fall into a high fishing season. Moreover, the fishing operations were not as intensive as those exerted by commercial fishing vessels.

It was found that the sizes of the fishes captured by these types of fishing gear were mostly sexually mature. The mean total lengths of skipjack tuna, frigate tuna, dolphinfish, swordfish, bigeye thresher shark and silky shark were 41.46, 35.14, 72.94, 211.00, 271.00 and 111.33 cm, respectively. Sex ratios of these species, except that of skipjack tuna, were approximately 1:1. The schools of skipjack tuna were male dominant. Although there were high percentages of sexually mature individuals of both sexes during the survey period, it still insufficient to determine the spawning ground and spawning season. It was considered that the survey duration was rather short, approximately 2 months, and so the acquired biological data concerned with reproductive cycle were insufficient to clarify such items.

Regarding the squids caught by automatic squid jigging machine, the total catches were represented by only one species of Ommastrephidae, purpleback flying squid (*Sthenoteuthis oualaniensis*) which was noticeable more concentrated in area C than in areas A and B. The mean length of the cephalopod was 104 mm for males and 169 mm for females. Sex ratio was 1 male to 4.57 females. At present purpleback flying squid is not regarded as a target species in commercial fishery because of its gristle and low quality for human consumption.

5. Heavy Metal Contamination

The Bay of Bengal's purpleback squid (*Sthenoteuthis oualaniensis*) contained mercury (Hg), lead (Pb) and Zinc (Zn) concentrations in both edible parts and visceral mass were within the safety limits. The mean copper (Cu) concentration in visceral (but not edible) tissues of the squid from every station was higher than the safety limit. The mean cadmium (Cd) concentrations in both edible part and visceral mass of the squid from every station are higher than those of the proposed safety limit. This concluded that Hg, Pb, Zn and Cu concentration in the edible body part of the purpleback squid from the Bay of Bengal are lower than safety limit except Cd. At the same time the study of Hg concentration in fish tissues caught from the same area were also carried out. Most fish analyzed still had Hg concentration in the tissue within the EU and CODEX limit of 0.5µg/g, particularly when fish size not exceeding approximately 15 kg in weight or 150 cm in length. The Hg burden in the tissue of both bigeye thresher shark and swordfish reported in this study were the highest. Swordfish which weighed more than 40 kg accumulated very high Hg content in their flesh exceeding 1 µg./g wet weight which was over the upper limit of the CODEX and EU guideline levels.

6. Acknowledgements

We are grateful to the Ministry of Foreign Affairs who provided the financial support to the survey. The Southeast Asian Fisheries Development Center (SEAFDEC) is generous in providing its research facilities and research vessels for all surveys. Thanks to all researchers from member countries and all crew to help in data collection and services. Finally the documentation edits with fruitful and wider vision by the members of the Technical Committee are great.

Figure 1 Fisheries Research Vessel M.V. SEAFDEC.

Specification

Length over all	65.02 m
Length between perpendiculars	57.00 m
Breadth, molded	12.00 m
Depth to super structure deck, molded	7.10 m
Draft, molded	4.658 m
Service speed at 4.50m draft	14.3 knots
Maximum sea trial speed	16.64 knots
Deadweight	744.42 t
Classification	NK, NS, MNS, Fisheries Training and Research Vessel
Official sign	HSHE
Flag	Kingdom of Thailand
Port of registry	Bangkok, Thailand
Gross tonnage	1178 t
Net tonnage	354 t
Fish hold capacity	145.38 m^3
Tank capacity fuel oil	428.96 m^3
Delivery	10^{th} Feb. 1993
Builder	Miho Shipyard Co., Ltd.

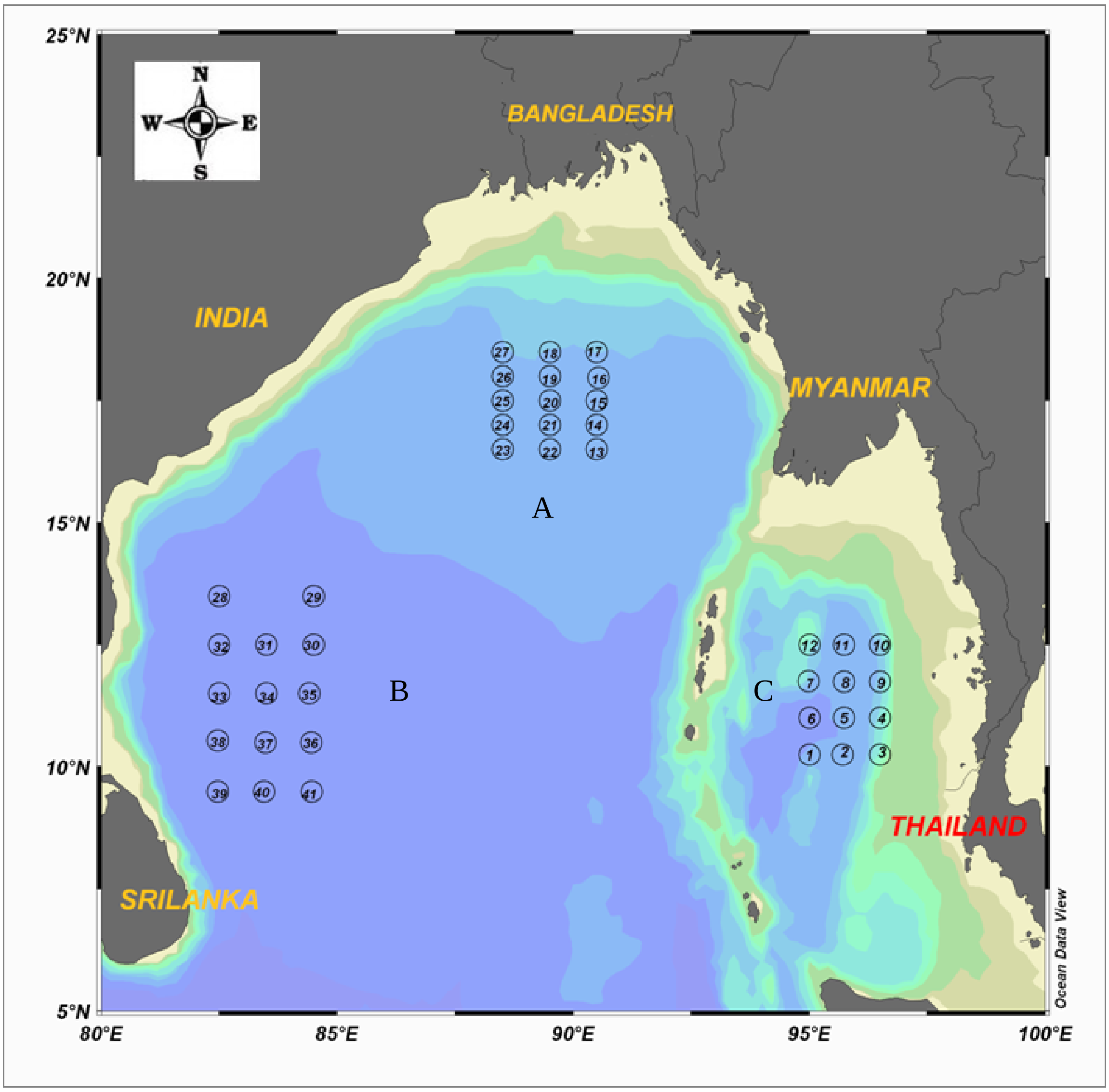

Figure 2 Map showing the survey stations.

Survey Areas

The survey area A, B and C

Area A (latitude 16˚N -19˚N, longitude 88˚E -91˚E)

Area B (latitude 09˚N -14˚N, longitude 82˚E -85˚E)

Area C (latitude 09˚N -13˚N, longitude 95˚E -97˚E)

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Oceanographic Condition of the Bay of Bengal during November-December 2007

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Abstract

Three sub areas of the Bay of Bengal: northern, eastern and western parts were studied for oceanographic condition. Vertical profiles of temperature, salinity were retrieved from CTD cast while dissolved oxygen and pH were measured from water sample collected at the standard depth. Two core-cold eddies were observed in the north of the Bay. Huge fresh water discharge from main rivers in the Bay plays an important role to shallowness of mixed layer depth of 14-49 m depth and resulting low saline and high temperature water in the north and the east of the Bay. Dissolved oxygen in the east was higher than in the north. The oxygen minimum zone (<0.5 m/l) was also observed at depth greater than 200 m in the north of the Bay. Surface water shallower than 400 m was occupied by three water masses: the Bay of Bengal water (salinity 32-34 psu), the Andaman Sea water (salinity 31-33 psu) and the Indian Central water (temperature 10-15°C, salinity more than 35 psu). The Indian Central water occupied all deepest layer of all survey areas.

Key Words: Bay of Bengal, oceanographic condition

Introduction

The study on oceanographic condition of the Bay of Bengal was conducted with the aim to support the Ecosystem-Based Fishery Management in the Bay of Bengal which is a collaborative survey project of the BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation) member countries; Bangladesh, India, Myanmar, Sri Lanka, Nepal and Thailand. The survey was initiated by Thailand, leading country for fishery sector, to observe and collect scientific data concerning to fishery and oceanographic aspects in the Bay of Bengal.

The Bay of Bengal situates in the eastern part of the north Indian Ocean. It is land locked in the North, there is the Andaman and Nicobar Island that separate the Andaman Sea to the East from the Indian Ocean. The shape of the Bay is resemble to a triangle which bordered by member countries of BIMSTEC. There are many large river including the

Ganges, Brahmaputra, Irrawaddy, Godavari, Mahanadi, Krishna and Kaveri emptying freshwater into the Bay.

The Bay of Bengal is influenced by a semi-annually reversing monsoonal wind system. During winter monsoon (November-February), the winds are weak (~5 m/s) and from the Northeast. These trade winds bring cool and dry continental air to the Bay of Bengal. In contrast, during the summer monsoon the strong (~10 m/s) southwest winds bring humid maritime air into the Bay of Bengal. The unique feature of the Bay of Bengal is the large seasonal freshwater pulse, which makes the waters of the upper layers less saline and highly stratified (Narvekar and Prasanna Kumar, 2006).

Materials and Methods

Oceanographic condition of the Bay of Bengal was studied as a part of Ecosystem-Based Fishery Management in the Bay of Bengal. The surveys were planed to collect data from three areas: area A (latitude 16°N-19°N, longitude 88°E-91°E) in the north of the Bay of Bengal, area B (latitude 09°N-14°N, longitude 82°E-85°E) in the western part of the Bay of Bengal and area C (latitude 10°N-12°N, longitude 95°E-97°E) in the Andaman sea (Fig. 1). Due to the influence of cyclone SIDR during the survey period, station 33 to 41 were canceled because of safety reason (Fig. 2). Total survey period was 58 days, which was from 25 October to 21 December 2007.

Data were collected using Falmouth Integrated CTD instrument attached with twelve 2.5 liter Niskin bottles onboard M.V.SEAFDEC. Temperature and salinity were recorded continuously from the surface to the depth of 400 m, which is the maximum length of M.V.SEAFDEC CTD system. The recorded data were then averaged to every one meter depth.

During up cast of CTD operation, water samples were taken at standard depths from surface to 400 m depth. Water samples were then immediately taken for dissolved oxygen determination and pH measurement. Dissolved oxygen was determined by Whinkle titration procedure while pH was measure using Fisher Accumet 1002 pH meter. Please note that dissolved oxygen and pH data were analyzed only in area A and C, because of few data were available. Data were analyzed using Ocean Data View software (Schlitzer, 2005).

The mixed layer depth (MLD), the depth at which the sigma-t value exceeds surface value by 0.2 is defined following Narvekar and Kumar, 2006.

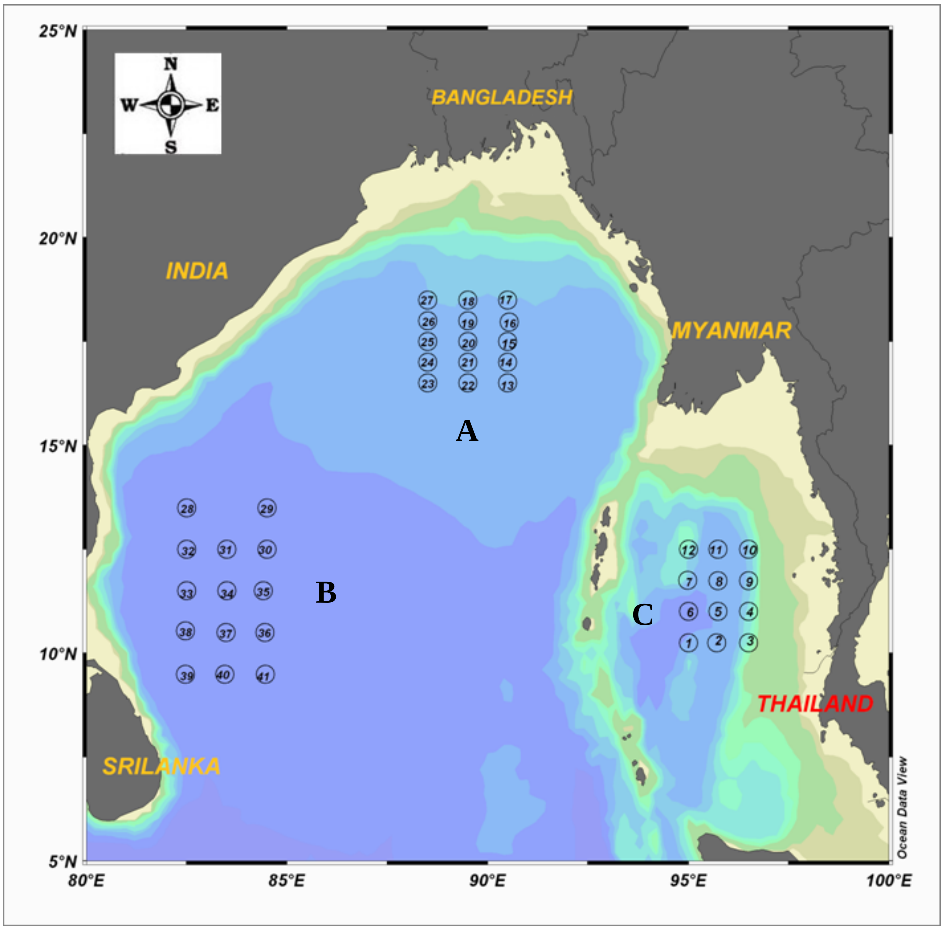


Figure 1 Map showing the survey stations.

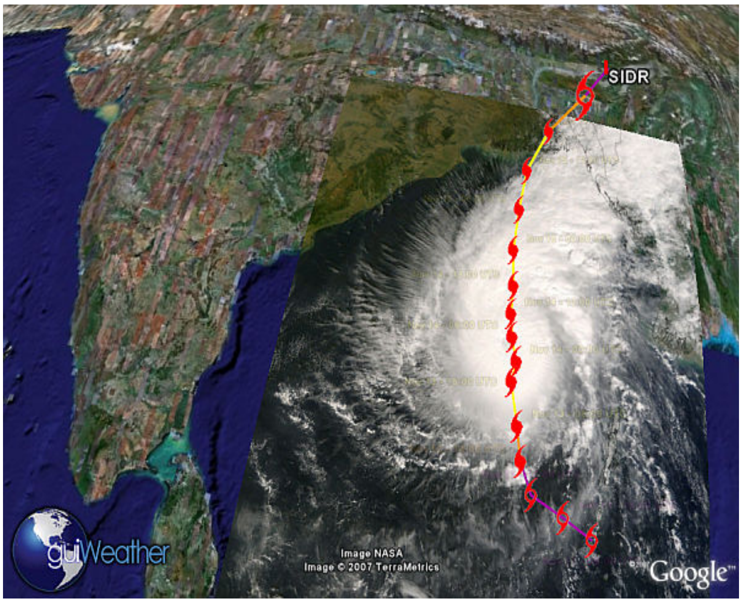


Figure 2 Tropical Cyclone SIDR which formed on November 11, 2007 and dissipated on November 16, 2007 (source: http://www.gearthblog.com/blog/archives/2007 /11/tropical_cyclone_sidr.html).

Results

Area A

Sea surface temperature (SST) and sea surface salinity (SSS) of area A were between 27.8 to 29.7 $^{\circ}$C and 31.5-33.6 psu, respectively. The higher SST was observed in the eastern part of area A which coincides with the area of low salinity.

There were two cold core eddied with high salinity observed at the surface layer of area A. One of which was located in the Southwest (along of longitude 88° $30'$E) where the 27.5 $^{\circ}$C isotherm shoaled from 60 m at latitude 17° $30'$N to 20 m at latitude 16° $30'$N (Fig. 4). The other cold core was observed in the North where 27.5 $^{\circ}$C isotherm shoaled from 50 meters at latitude 18°N to 30 m at latitude 18° $30'$N in the section plots along of longitude 89° $30'$E (Fig. 5).

The average MLD, of area A was 31.3 m depth. The shallowest MLD (19 m) was observed in the areas that occupied by cold-core and high saline water.

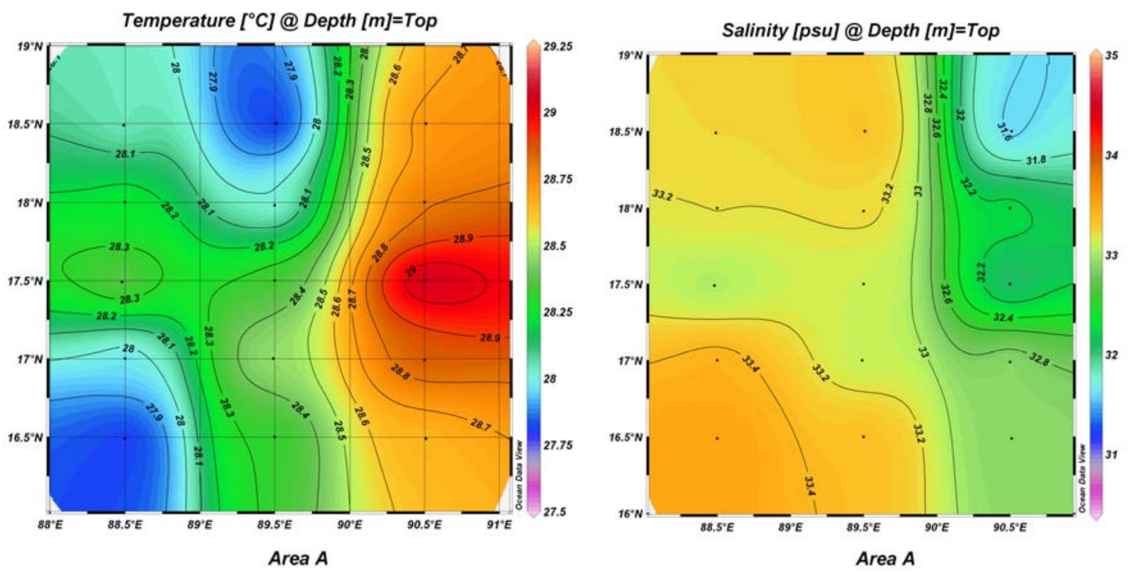


Figure 3 Horizontal plots of temperature ($^{\circ}$C) and salinity (psu) at surface layer of area A. (Dots indicate data location)

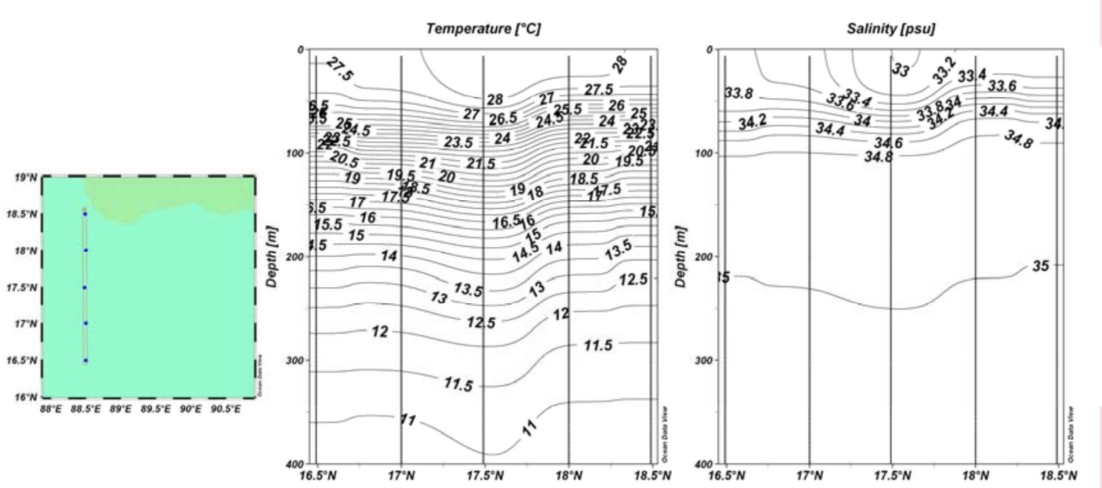


Figure 4 Section plots of temperature (°C) and salinity (psu) of survey stations along longitude 88° 30′E of area A (stations 23-27).

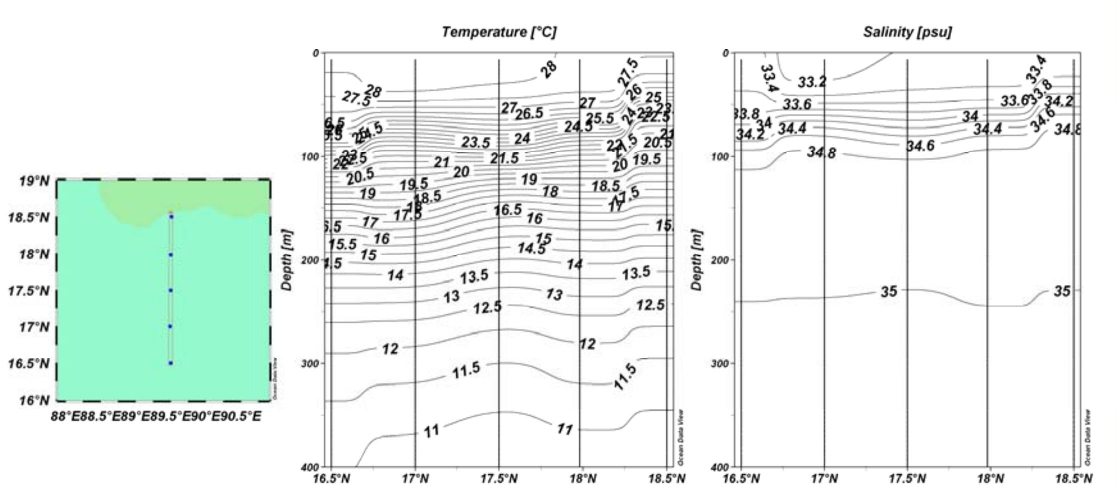


Figure 5 Section plots of temperature (°C) and salinity (psu) of survey stations along longitude 89° 30′E of area A (station 18-22).

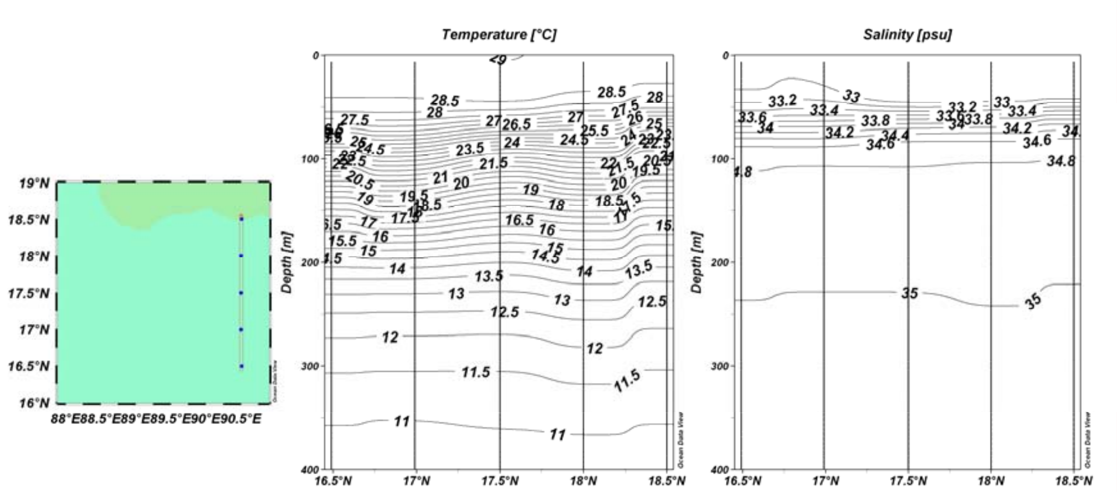


Figure 6 Section plots of temperature (°C) and salinity (psu) of survey station along longitude 90° 30′E of area A (station 13-17).

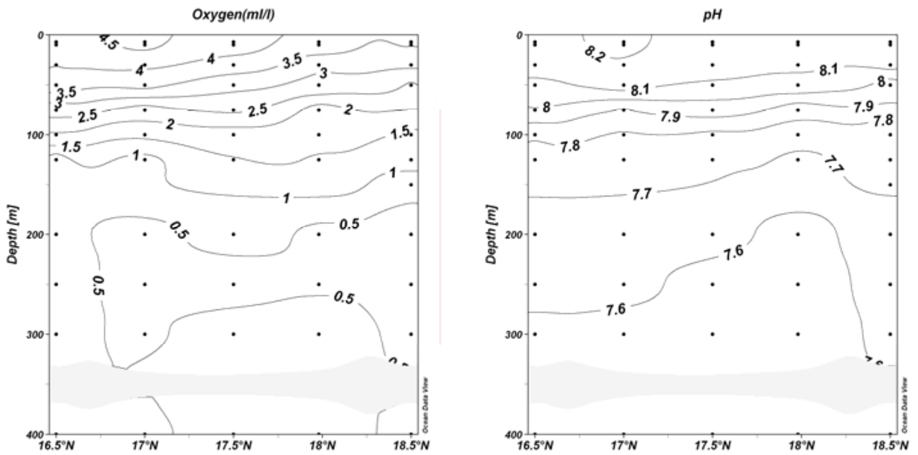


Figure 7 Section plots of oxygen (ml/l) and pH of survey stations along longitude 89° 30′E of area A (station 18-22).
(Dots indicate data location)

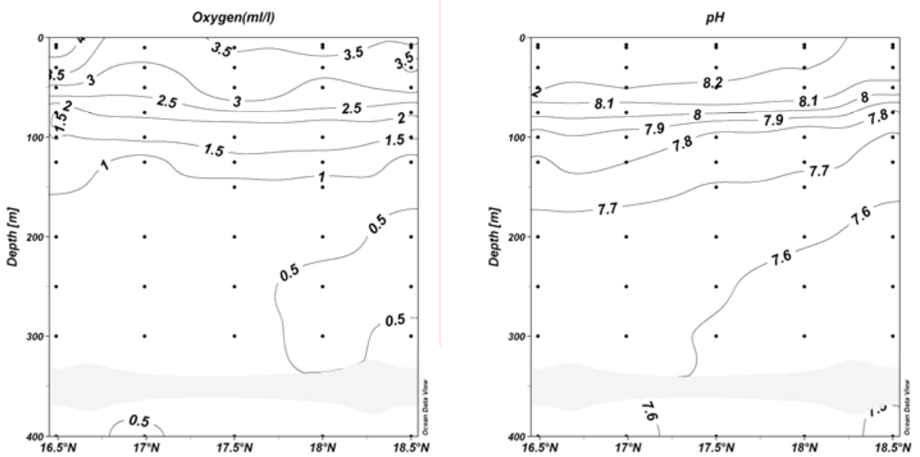


Figure 8 Section plots of oxygen (ml/l) and pH of survey stations along longitude 90° 30′E of area A (station 13-17).
(Dots indicate data location)

Dissolved oxygen concentration of surface water of area A was between 3.94-5.02 ml/l. The changing of dissolved oxygen and pH by depth was observed in surface layer shallower than 150 m, ranges from about 4 to 5 ml/l and 8.2-8.3 to 1 ml/l and 7.7, respectively. Dissolved oxygen and pH were homogeneously below 150 m depth. The tongue like of water mass, whose dissolved oxygen is less than 0.5 ml/l and pH less than 7.6 was observed at depth below 200 m in the north of area A (Fig. 7 and 8).

Area B

SST and SSS patterns of area B are quite homogeneous. The SST ranges between 28.3-28.7°C while SSS ranges between 33.3-34 psu (Fig. 9).

Section plots in Fig.10 show that high salinity gradient occurred only at the upper 100 m depth. There was a strange pattern of salinity at the station 31 where 34.8 psu isohaline was observed at 150 m depth while the other stations were at about 80 m depth.

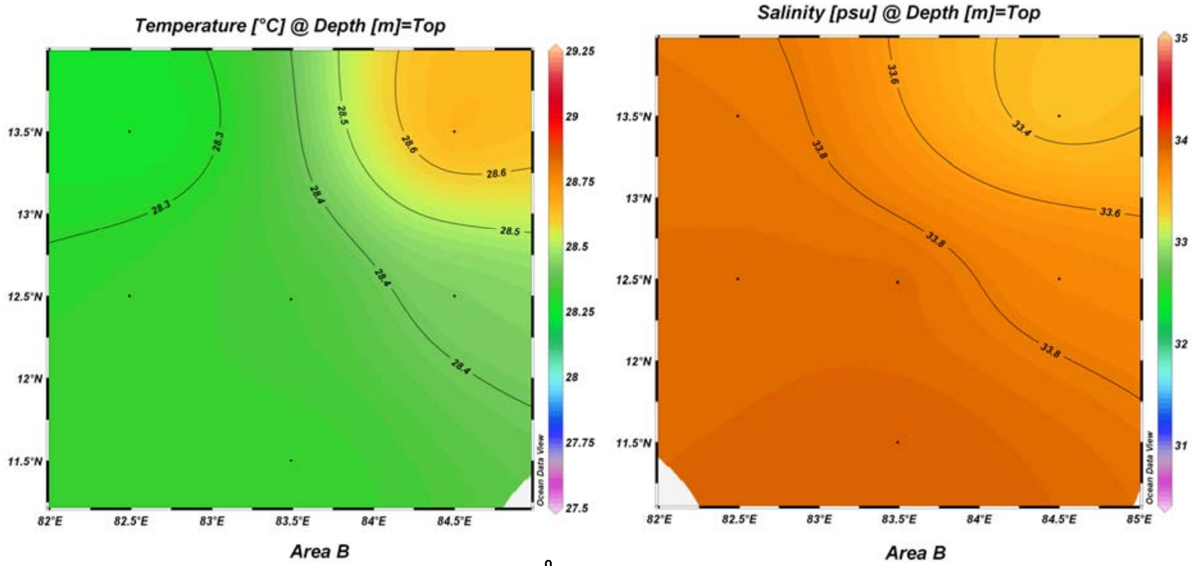


Figure 9 Horizontal plots of temperature (°C) and salinity (psu) at surface of area B. (Dots indicate data location)

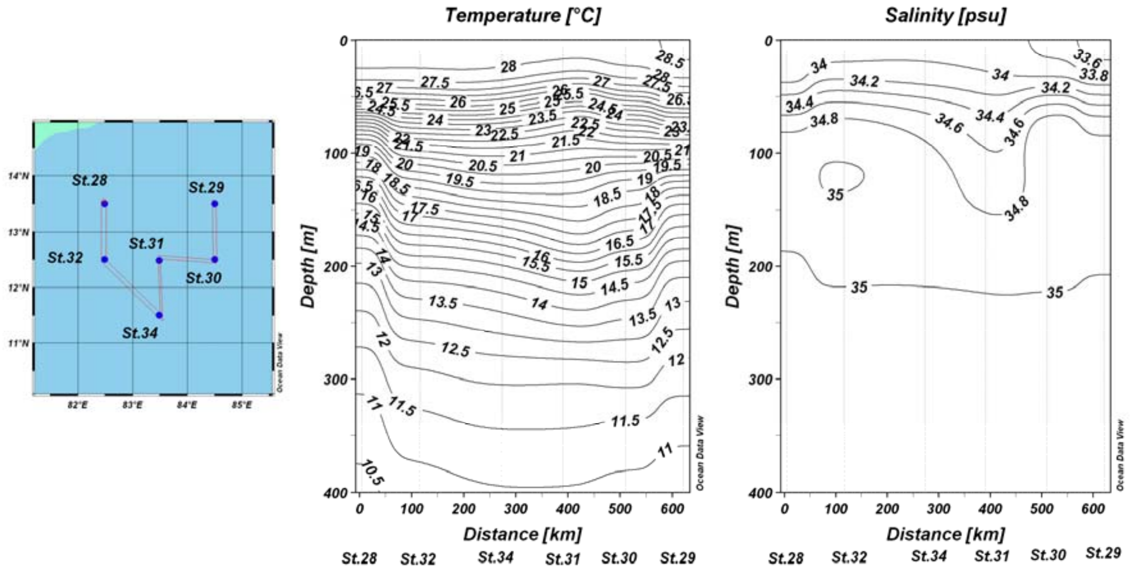


Figure 10 Section plots of temperature (°C) and salinity (psu) of all stations in area B. (Dots indicate data location)

The average mix layer depth of area B was 37.8 m depth. The shallowest MLD was observed in the east side of area B.

Due to the bad weather condition during the survey period of area B, water samples from just a few stations could be collected to determine dissolved oxygen and pH. Therefore, the analyses of these two parameters were not possible.

Area C

The surface salinity of area C, ranges 30.78-32.9 psu, was lower than the others. Lower saline water was observed at the north and the east of the area, indicating the influence of outflow from the rivers from the northern part of the area.

SST of area C ranges from 27.99-28.93°C. The highest SST was observed in the southwest of the area (Fig. 11).

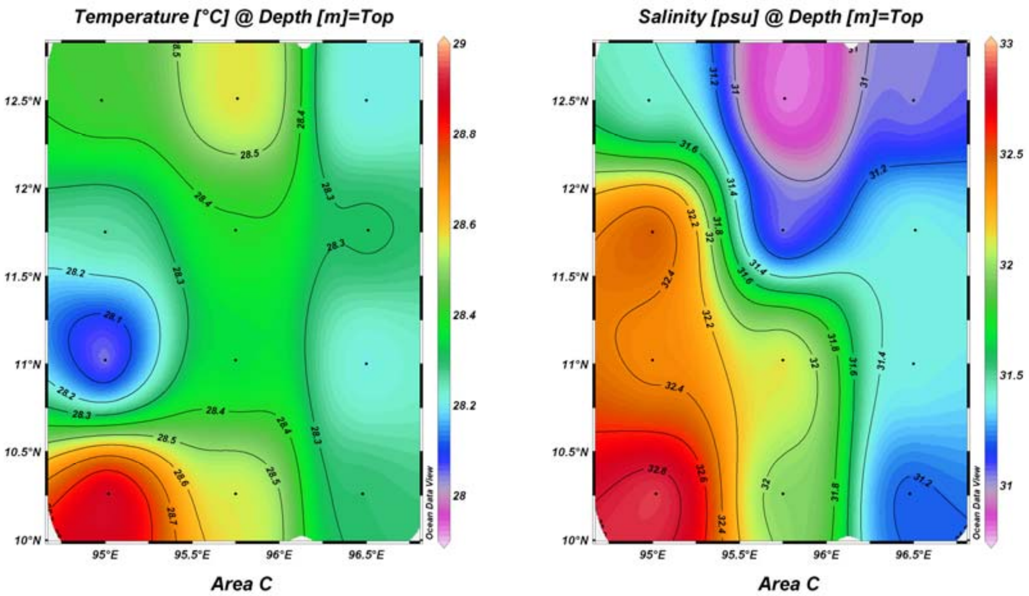


Figure 11 Horizontal plots of temperature (°C) and salinity (psu) at surface of area C. (Dots indicate data location)

Section plots of temperature and salinity along longitude 95°E, 95° 45′E and 96° 30′E show that strong gradient of temperature and salinity occurred from the surface to about 150 m depth, which was deeper than in the area A and B (Figs. 12, 13 and 14). Only in the most northern stations, higher temperature and lower salinity were observed at the same depth (Fig.12). Salinity and temperature of this station were more similar to those of the stations in the eastern part of the area.

MLD was about 19 to 34 m depth. Average MLD of area C was 24 m, which was the shallowest among three survey areas.

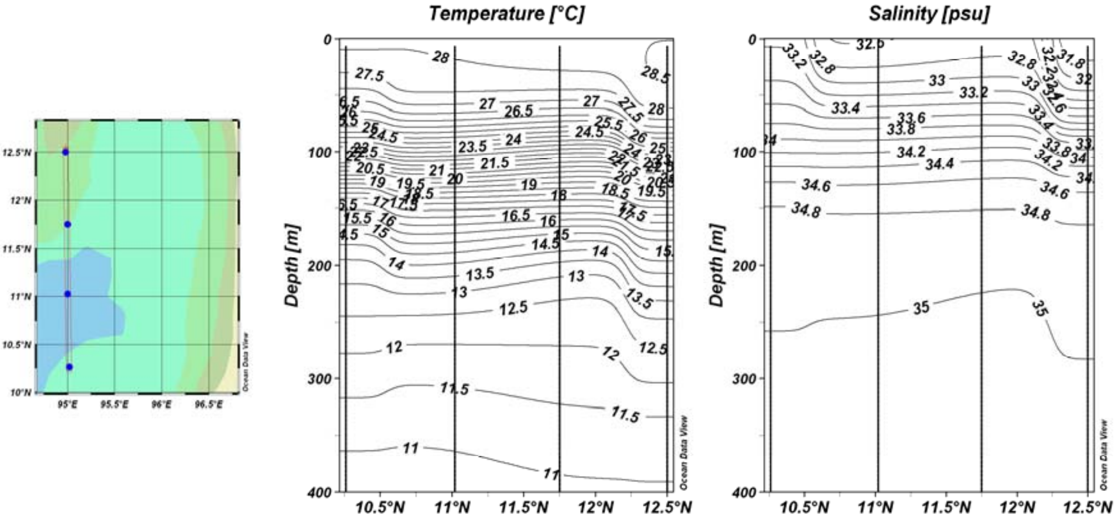


Figure 12 Section plots of temperature (°C) and salinity (psu) of stations along longitude 95°E in area C (station 1, 6, 7 and 12).
(Dots indicate data location)

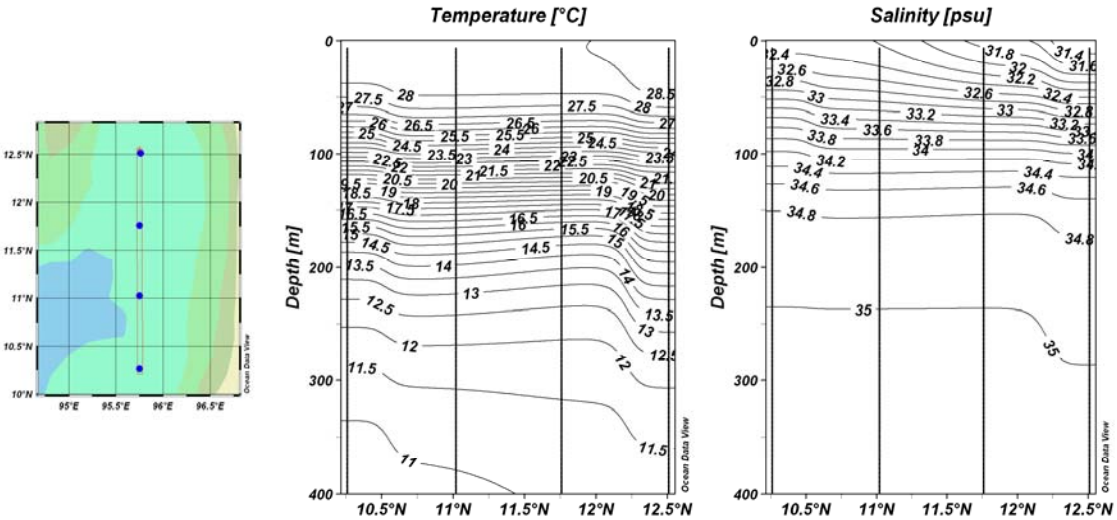


Figure 13 Section plots of temperature (°C) and salinity (psu) of stations along longitude 95° 45′E in area C (station 2, 5, 8 and 11).
(Dots indicate data location)

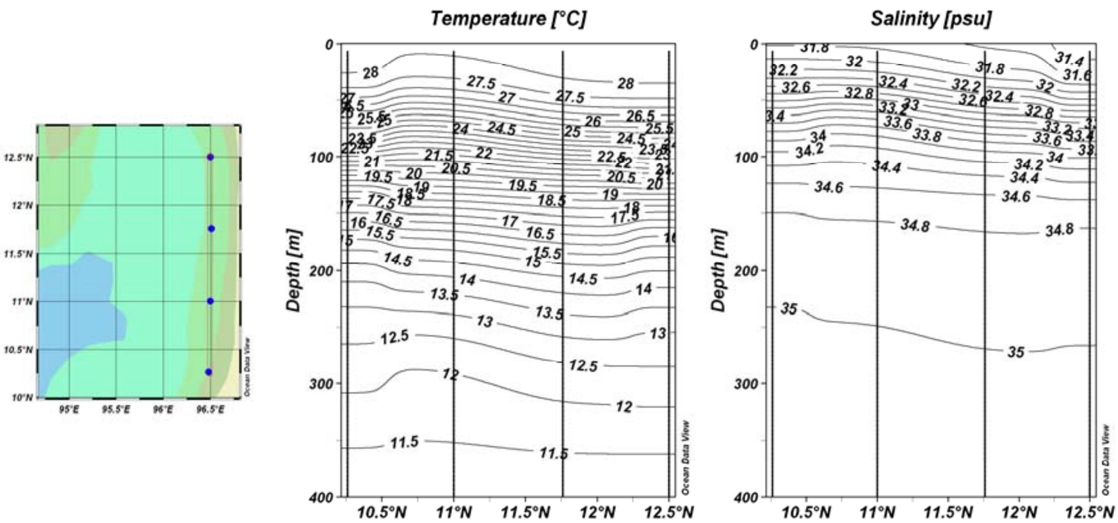


Figure 14 Section plots of temperature (°C) and salinity (psu) of stations along longitude 96° 30′E in area C (station 3, 4, 9 and 10).
(Dots indicate data location)

Section plots of dissolved oxygen and pH along longitude 95°E, 95° 45′E and 96° 30′E also show strong gradient from the surface to 150 m depth. Below that water are homogeneous. Surface dissolved oxygen ranges from 4.97-5.01 ml/l. At the same depth, dissolved oxygen concentration in area C was higher than area A by 0.5 to 1 ml/l. The lowest dissolved oxygen line (0.5 ml/l), observed in area A, did not occur in area C. The pH also shows similar pattern. Surface pH ranges from 8.21-8.27.

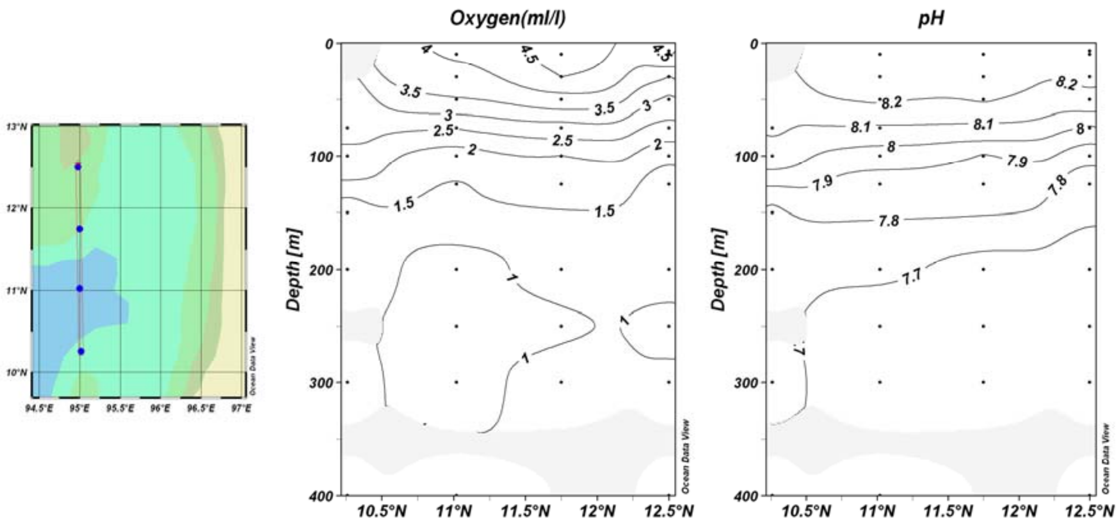


Figure 15 Section plots of dissolved oxygen (ml/l) and pH of stations along longitude 95°E in area C (station 1, 6, 7 and 12).
(Dots indicate data location)

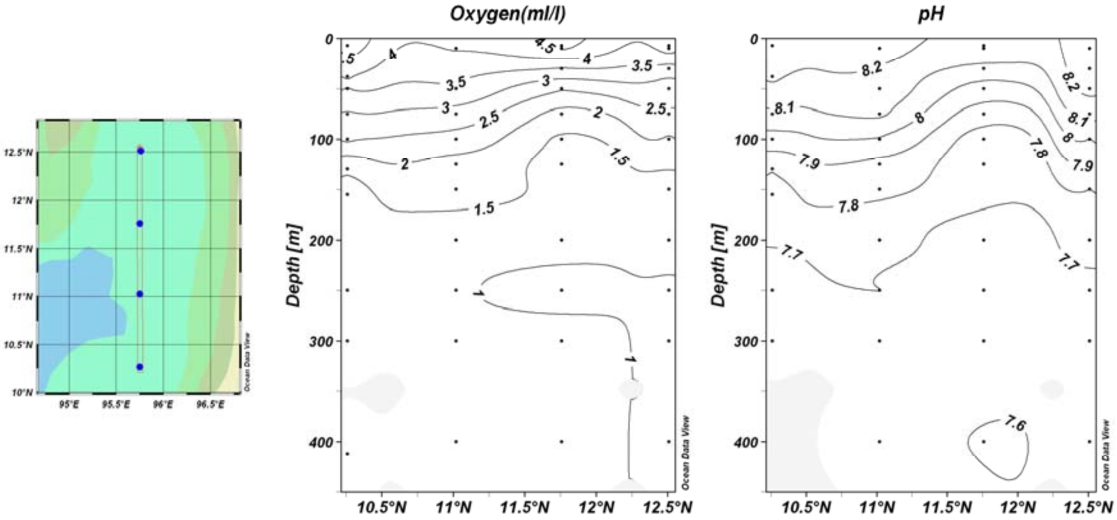


Figure 16 Section plots of dissolved oxygen (ml/l) and pH of stations along longitude 95° 45′E in area C (station 2, 5, 8 and 11).
(Dots indicate data location)

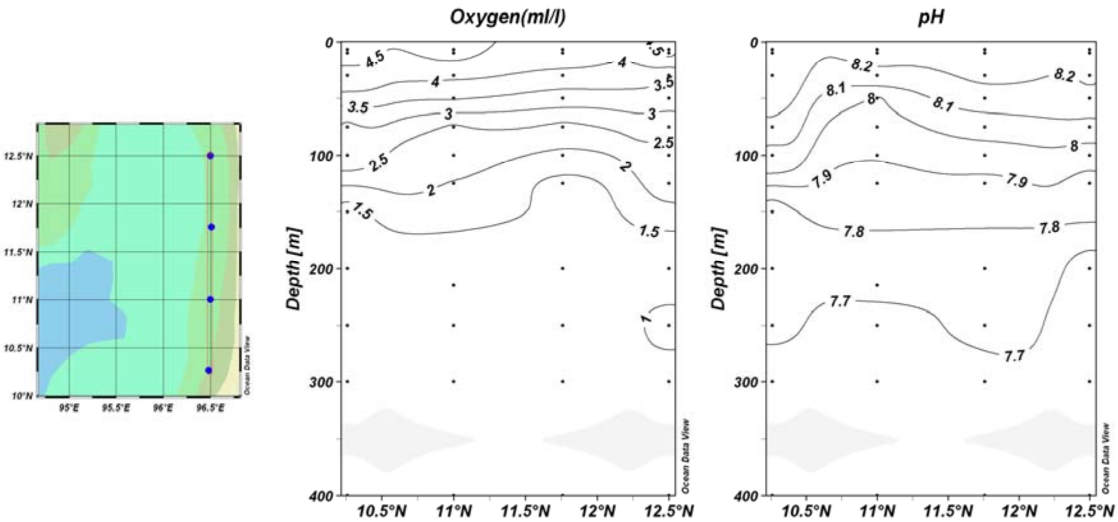


Figure 17 Section plots of dissolved oxygen (ml/l) and pH of stations along longitude 96° 30′E in area C (station 3, 4, 9 and 10).
(Dots indicate data location)

Temperature-Salinity Diagram

Three water masses were observed during the survey (Fig. 18, 19 and 20). Surface layers ranges down to nearly 100 m thick of area A and B were occupied by low salinity water (32-34 psu). This water is known as the "Bay of Bengal water" (BBW). At the surface layer of area C, salinity is lower than that in area A and B by about 1 psu (31-33 psu). Surface water thickness in area C was nearly 150 m. This water mass may be originated in the Andaman Sea from the outflow of large rivers in the area.

The deepest layer in all survey areas, was occupied by low temperature (10-15°C) and high salinity water (more than 35psu), which its property is resemble to the Indian Central Water (ICW) (Rao, 1965 and Tomczak and Godfrey, 2001). It was noted that data of station 31 in area B show a strange characteristic, which could not be explained here.

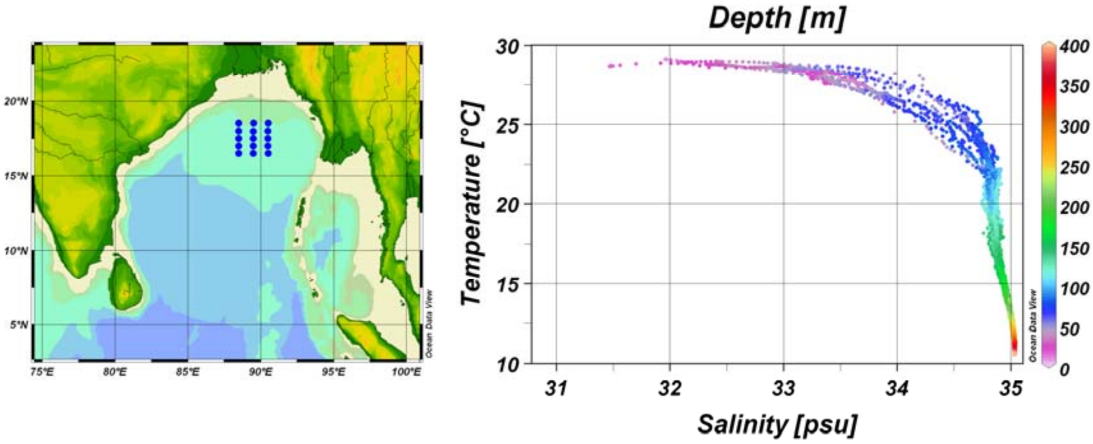


Figure 18 TS diagram of water mass in area A. (colors indicate water depth)

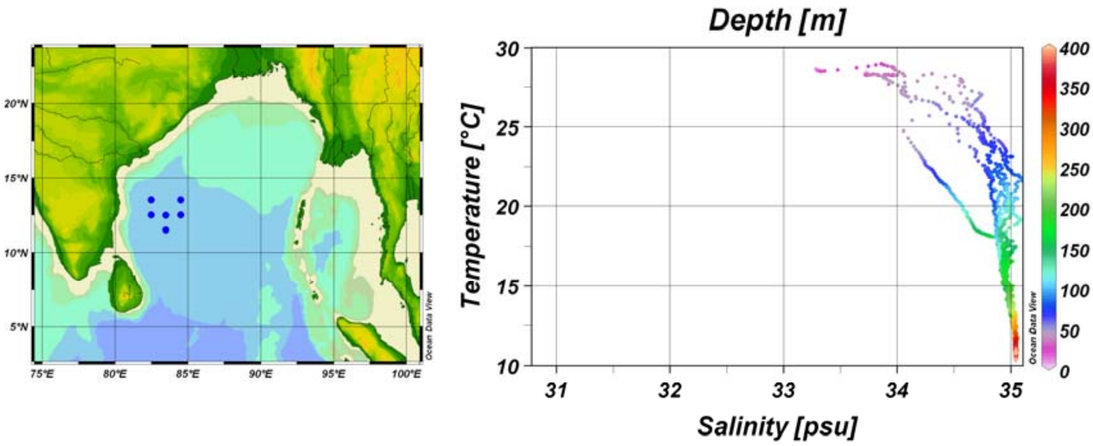


Figure 19 TS diagram of water mass in area B. (colors indicate water depth)

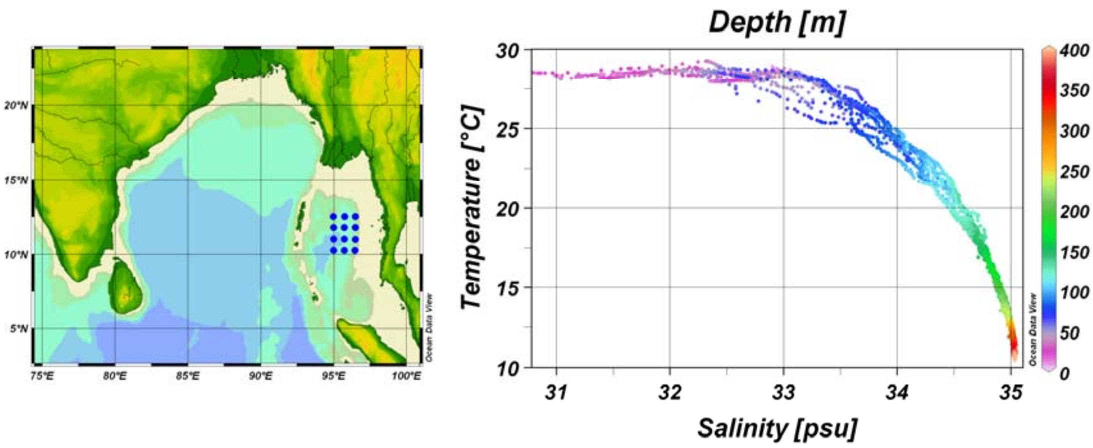
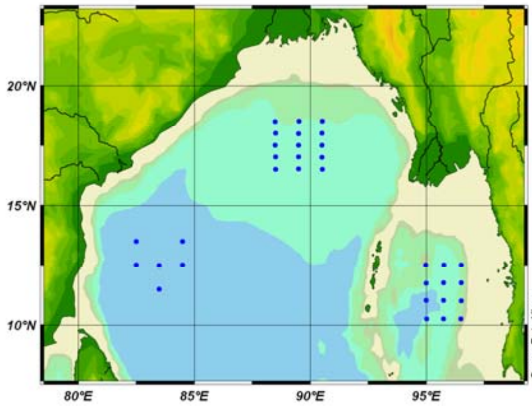


Figure 20 TS diagram of water mass in area C. (colors indicate water depth)



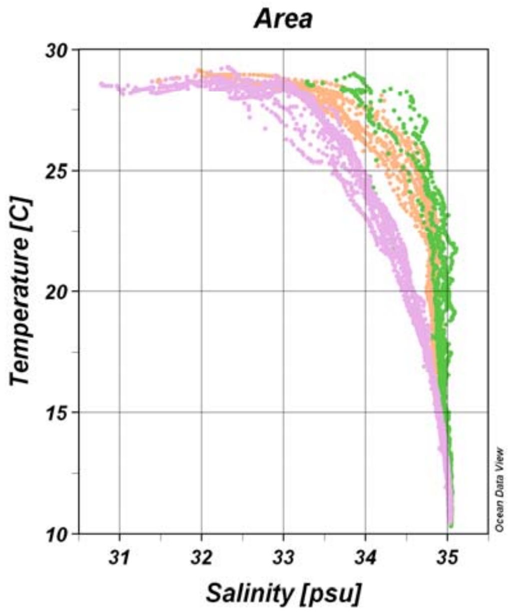


Figure 21 TS diagram of all survey areas.
(colors denote survey area; orange, green and pink represent data from area A, B and C respectively)

Discussions

Salinity of water in the west of the Bay was higher than that in the north and the eastern boundary. Wind direction (Fig. 22) and surface current direction (Fig. 23) explain the observational results that high saline water flows into the Bay from the South, then flows northward and eastward by wind driven current. At the west of the Bay wind direction was northeastward. At the North, wind flowed northward except at the station along longitude $88^{o}30'$E that wind flowed eastward. And at the east of the Bay, wind flowed southeastward and eastward. Due to the influence of cyclone during the survey period, wind directions were not resemble to general wind pattern that during November to December where the Northeast Monsoon prevails in the Bay of Bengal (Tomczak and Godfrey, 2001).

Surface salinity of three areas also shows that water circulation of the Bay was influenced by density driven. At the north and the east of the Bay, large rivers supply huge amount of fresh water that can lead salinity in this area to be lower than at the west by 2-3 psu.

Two cold core eddies were discernible from a low temperature and high salinity water mass in the surface plot and the upheaval of isotherms below the surface in the vertical plot. The occurrence of eddy was reported by Kumar *et al*. (2004). This phenomenon plays as an important mechanism of vertical transfer of nutrients across the halocline to the oligotrophic euphotic zone when the Bay of Bengal is highly stratified.

MLD of area A in this study (31 m) is deeper than in the study of Narvekar and Kumar, (2006) who studied seasonal variability of MLD in the central Bay of Bengal from a long term data set (1900-2004). Their results showed that from the north of latitude 15^{o}N, MLD remained shallow at about 20 m for the most of the year without any appreciable seasonality. The stability of shallow MLD in the north of latitude 15^{o}N was explained by low salinity water, perennially presenting in the northern Bay.

The deeper MLD of this study, compared to that from the average long term data set, may be due to the influence of SIDR cyclone that induces MLD to be deeper than normal situation.

MLD of area B was the deepest (37.8 m) in this study, similar to the results study from long term dataset (Narvekar and Kumar, 2006). The deep MLD is due to moderate to rough sea condition during the survey.

The average shallowest MLD (24 m) was observed in area C. It was coincided with its characteristic that lowest saline area (30.78-32.9 psu). Low surface salinity, influenced from river outflow, may intensify stratification of the water column and decrease vertical mixing in area C.

Dissolve oxygen in this study was low in the North. The concentration was 0.5 to 1 ml/l lower than in the east of the Bay. It was explained in the study of Naqvi (2006) that the distinguishing feature of the Indian Ocean that Asian land mass restrict its northern expanse to the tropic, not allowing adequate ventilation of the thermocline from the North and, to a small extent, a porous eastern boundary (opening between the Indonesian Islands), which facilitates exchange of water with the Pacific Ocean at the low latitudes. The oxygen minimum zone (OMZ) which dissolved oxygen <0.5 ml/l was observed only occurred in area A at depth greater than 200 m. Due to the limitation of wire length, the depth range of OMZ cannot be specified. However, the OMZ depth of this study is within ranges mentioned in the study of Sardessai *et al*. (2007) that OMZ in the Bay of Bengal occurs at intermediate depth (60-800 m). It was suggested that the circulation of the water mass, under the influence of season, and the geochemical processes play a significant role to regenerative processes and OMZ regulation in the Bay of Bengal.

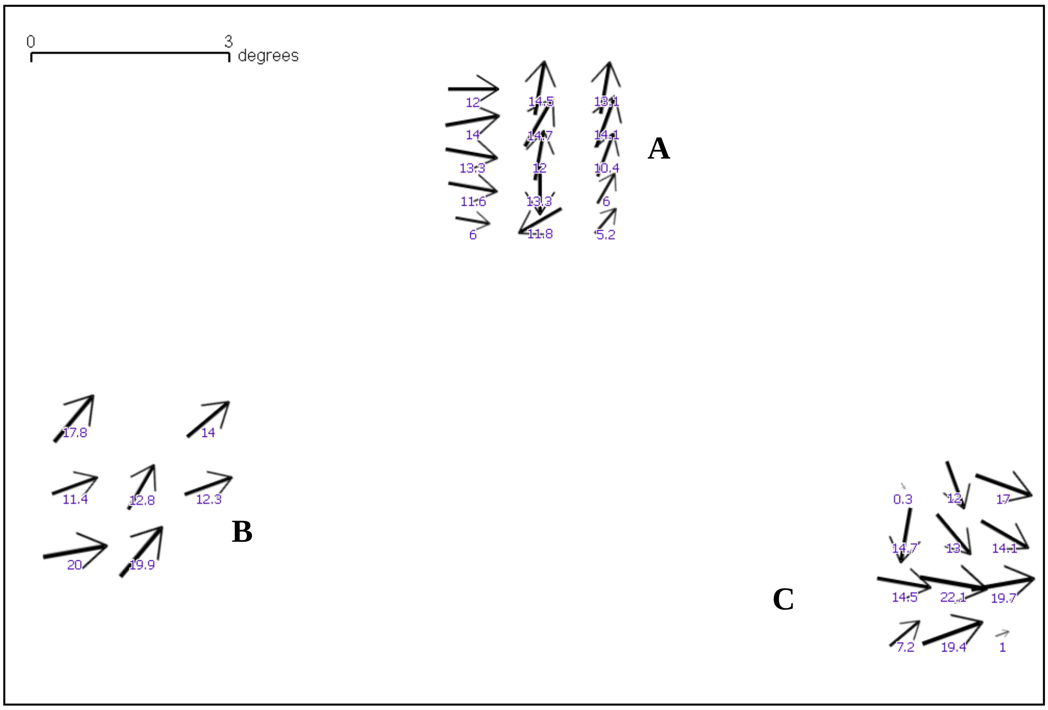


Figure 22 Wind speed and direction recorded from wind indictor during the survey period.

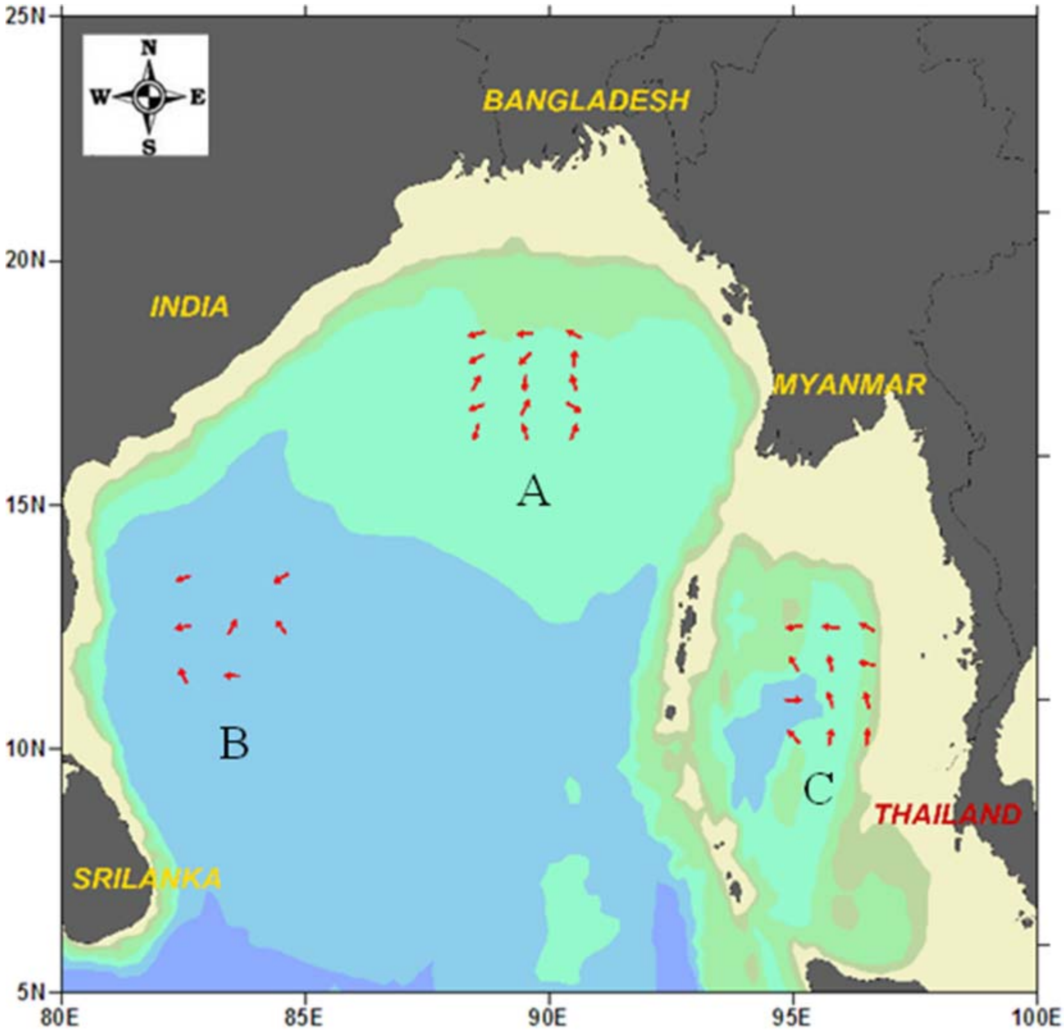


Figure 23 Surface current directions during the survey period.

Conclusions

Two core-cold eddies were observed in the north of the Bay. Huge amount of fresh water supply from main rivers in the Bay plays an important role to mixed layer depth shallowness at the north and the east of the Bay. Dissolved oxygen in the East was higher than in the North. OMZ (<0.5 m/l) was also observed at depth greater than 200 m in the north of the Bay. Surface water beyond 400 m was occupied by three water masses: the Bay of Bengal water (salinity 32-34 psu), the Andaman sea water (salinity 31-33 psu) and the Indian central water (temperature 10-15°C, salinity more than 35 psu). The Indian central water occupied all the deepest layer of all survey areas.

Acknowledgement

Authors would like to thank to all cruise participants (scientists from Bangladesh, India, Myanmar, Sri Lanka, Nepal and Thailand and all SEAFDEC crews) for their kind cooperation during cruise preparation and survey. Special thanks to Dr. Natinee Sukramongkol and Mr. Ritthirong Prommas for help on data collection. We thank Dr. Anukul Buranapratheprat for his reviews and comments. We also appreciate all effort of Mrs. Pattira Lirdwitayaprasit (chief scientist) result in the successful of this survey.

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Comparison of Total Phosphorus Contents and Total Alkalinity in Seawater of Different Area in the Bay of Bengal

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Abstract

Total phosphorus and total alkalinity at different depth throughout the water column (400 m depth, salinity ca. 34 psu) in three areas of the Bay of Bengal were investigated in order to compare their distribution in different areas of the Bay of Bengal. It was found that pattern of depth profile of both total phosphorus and total alkalinity in area C (the Andaman Sea) is different from the other two areas of the Bay of Bengal. Together with the relationship between total alkalinity and total phosphorus, it can be indicated that the characteristics of seawater in the enclosed Andaman Sea are different from the entire Bay of Bengal. In comparison with the other two areas, lower total alkalinity in the surface water and higher total alkalinity but lower total phosphorus in the deeper water was observed in the Andaman Sea.

Key words: total phosphorus, total alkalinity, Bay of Bengal

Introduction

Primary producer in the sea, phytoplankton, require dissolved inorganic nutrients for their growth. The free orthophosphate ion component is a vital nutrient for sustaining marine productivity (e.g., Codispoti, 1989; Tyrrell, 1999). It is well known as the limiting nutrient for primary productivity in marine systems. Regeneration of phosphorus from both particulate and dissolved forms of organic phosphorus is a potentially important source of bioavailable P for marine primary and secondary producers (Ammerman and Azam, 1985; Bjorkman and Karl, 1994; Jackson and Williams, 1985; Karl *et al.*, 1993; Monaghan and Ruttenberg, 1999). Within pools of dissolved and particulate phosphorus or so-called total phosphorus, turnover rates of organic phosphorus are rapid and seasonal, enabling low inorganic phosphorus concentrations to support high primary productivity (Benitez-Nelson and Buesseler, 1999).

Total alkalinity, a measurement of buffering capacity of the marine systems, is known to be a conservative parameter of water masses, therefore its measurements act as a water mass tracer (Schiettecatte *et al.*, 2003, Watanabe *et al.*, 2004). However, the oceans act as a natural reservoir for carbon dioxide (CO_2). Atmospheric CO_2 dissolves naturally in the ocean, forming carbonic acid (H_2CO_3), a weak acid. It is estimated that the world ocean is taking up 1.7 GtC per year, which is almost 30% of the CO_2 released anthropogenically into the atmosphere (Prentice *et a*l., 2001). The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic, with an average decrease in pH of 0.1 units (UNEP, 2008).

Although the coastal ocean is only a small fraction (8%) of the total ocean area, several studies have suggested the importance of the CO_2 dynamics in this area. Between 15% and 50% of the oceanic primary production is now attributed to coastal ocean (Walsh, 1991; Muller-Karger, 2000). Recent studies have concluded that some continental shelves, in general the zone shallower than 200 m, act as a sink for atmospheric CO_2 (Tsunogai *et al*., 1999; Frankignoulle and Borges, 2001), of up to 0.6 GtC per year worldwide (Yool and Fasham, 2001), which is about 30% of the oceanic CO_2 uptake. Another reason that we care about alkalinity is that when organisms build calcium carbonate skeletons, they effectively remove calcium and carbonate from the water column. Progressive acidification of the oceans due to increasing atmospheric CO_2 is expected to reduce biocalcification of the shells; bones and skeletons most marine organisms possess (UNEP, 2008).

In this study, total phosphorus and total alkalinity at different depth throughout the water column (400 m depth, salinity ca. 34 psu) in three areas of the Bay of Bengal were investigated in order to compare their distribution in different areas of the Bay of Bengal.

Material and Methods

Sample collection was conducted onboard M.V. SEAFDEC from 25 October to 21 December 2007 under an Ecosystem-Based Fishery Management Project in the Bay of Bengal in collaborative among the BIMSTEC members (Bangladesh, India, Myanmar, Nepal, Sri Lanka, and Thailand).

Seawater samples were collected at selected depth, using a iCTD system couple with Carousel water sample (Niskin Bottles), from 28 oceanographic stations in the Bay of Bengal 12 stations in area A (upper part of the Bay of Bengal covered international waters and the EEZ of Bangladesh and India), 4 stations in area B (western area of the Bay of Bengal, offshore of India and Sri Lanka waters) and 12 stations in area C (central part of the Andaman Sea covered the EEZ of Myanmar and the Andaman Island of India) (Fig. 1).

Sea water samples for total phosphorus analysis were filled in pre-cleaned 60 ml plastic bottles and immediately kept frozen (-45ºC) until analyzed. Sea water samples for total alkalinity analysis were filled in 125 ml plastic bottles which pre-added a few drops of $HgCl_2$ and then store at room temperature until analysis.

Since total phosphorus defined as all forms of phosphorus, all bound fractions were liberated by persulfate oxidation prior the measurement of the orthophosphate form by ascorbic acid-colorimetric method (Menzel and Corwin, 1965; Grasshoff *et al*., 1983; Strickland and Parsons, 1972)

The amount of total alkalinity in seawater was measured by carrying out a potentiometric titration of a known volume of sea water in a vessel which is sealed from the atmosphere. This is accomplished by adding precise amounts of 0.1 N HCl to the vessel in small increments, and measuring the change in the electromotive potential of the water caused by this addition. The data were used to calculate the total alkalinity by the modified Gran method.

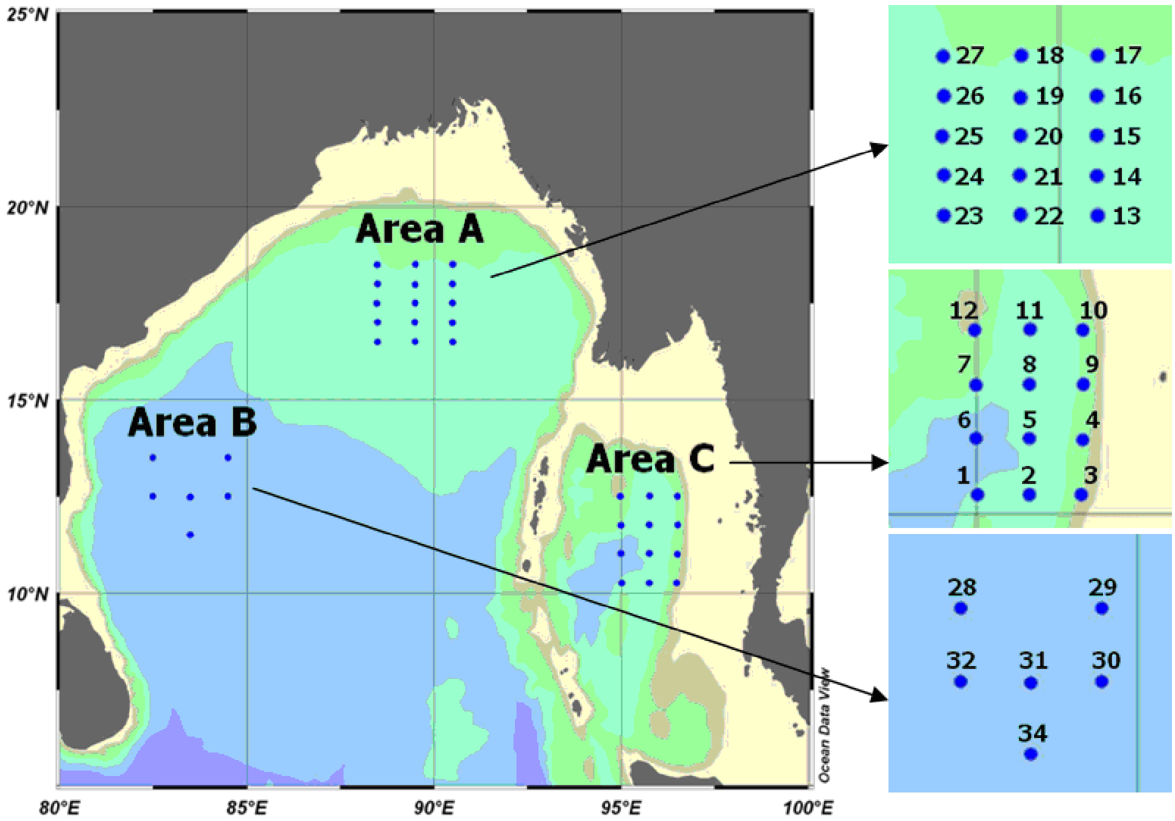
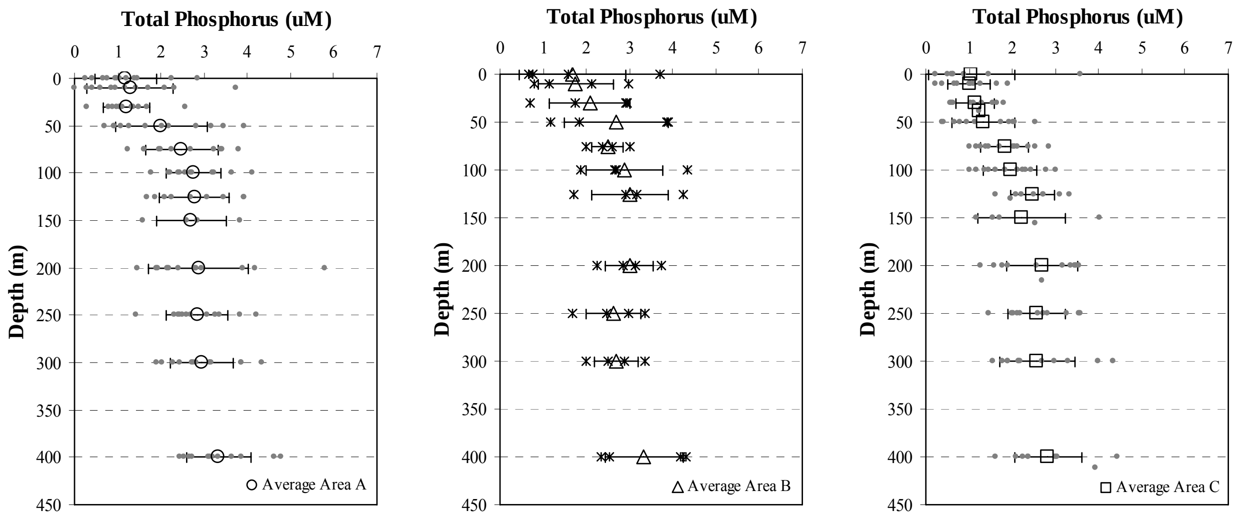


Figure 1 Location map of seawater sampling sites in the Bay of Bengal there was no water sampling in the EEZ Indian waters of area A and B (stations 25, 26, 27, 28 and 32).

Results and Discussions

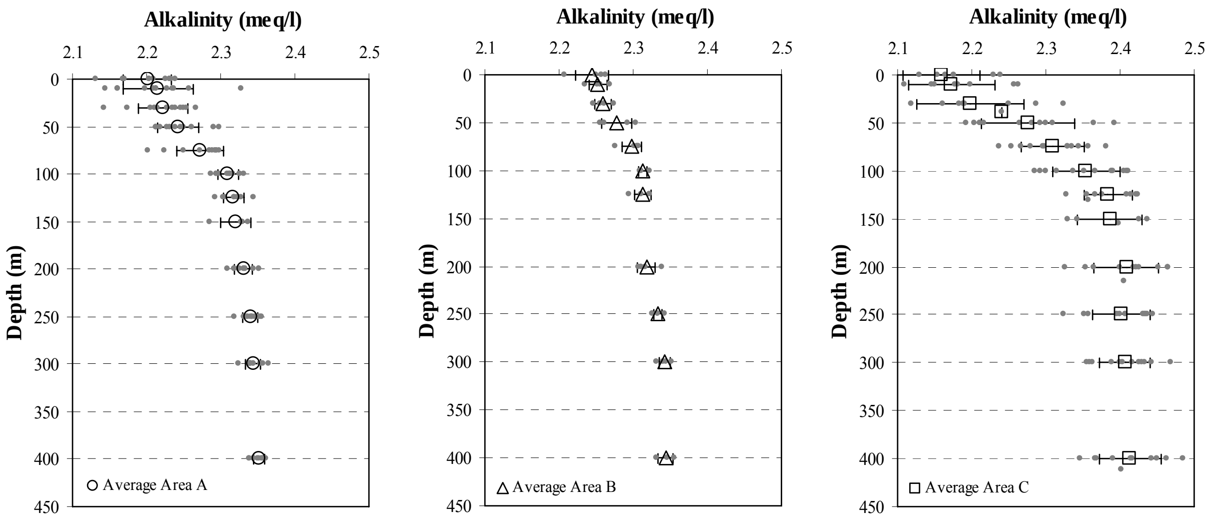
Vertical profiles of total phosphorus concentration and total alkalinity values at various depths of the sampling stations in the different area of the Bay of Bengal are presented in fig. 2 and 3, respectively. The average (± standard deviation), minimum and maximum values of total phosphorus and total alkalinity at various depths of different area in the Bay of Bengal are presented in tables 1 and 2, respectively.

The results showed an increasing of total phosphorus and total alkalinity with depth to about 100 m depth, and then both values remain fairly constant. Average total phosphorus was found to be the lowest in surface layer (above 100 m) of the Andaman Sea (Figs. 2 and 4). High variation of total alkalinity was found throughout the water column in the Andaman Sea, while the total alkalinity of deeper water (below 100 m) of areas A and B were relatively constant (Fig. 3). The lower values and high variation of total alkalinity in surface water of areas A and C (Fig. 3) indicated an influence of freshwater discharged to these coastal areas.



Area A **Area B** **Area C**

Figure 2 Vertical distribution of total phosphorus at each sampling stations (•), and average total phosphorus values (± SD) in area A (○), area B (△) and area C (□).



Area A **Area B** **Area C**

Figure 3 Vertical distribution of total alkalinity at each sampling stations (•), and average total alkalinity values (± SD) in area A (○), area B (△) and area C (□).

Table 1 Average concentration of total phosphorus (µM) in different areas of the Bay of Bengal (average±SD).

Depth (m)	Area A		Area B		Area C	
	Average	Min.-max	Average	Min.-max	Average	min.-max
Surface	1.18±0.71	0.40-2.84	1.68±1.23	0.75-3.72	1.06±1.00	0.21-3.56
10	1.29±1.00	0.005-3.73	1.76±0.86	1.13-2.98	1.00±0.50	0.24-1.91
30	1.21±0.53	0.28-2.55	2.08±0.93	1.75-2.96	1.14±0.44	0.57-1.81
50	2.01±1.06	0.69-3.94	2.69±1.21	1.17-3.90	1.33±0.72	0.39-2.52
75	2.47±0.84	1.23-3.81	2.49±0.38	1.98-3.02	1.83±0.56	1.01-2.85
100	2.77±0.64	1.78-4.13	2.88±0.90	1.85-4.32	1.95±0.61	1.02-3.02
125	2.77±0.81	1.67-3.92	3.00±0.89	1.72-4.23	2.47±0.52	1.61-3.32
150	2.70±0.80	1.57-3.82	-	-	2.21±1.01	1.18-4.03
200	2.87±1.17	1.46-5.78	2.99±0.54	2.24-3.75	2.69±0.82	1.27-3.55
250	2.84±0.72	1.42-4.21	2.63±0.63	1.68-3.37	2.57±0.66	1.44-3.57
300	2.94±0.73	1.90-4.33	2.68±0.51	1.98-3.37	2.58±0.87	1.55-4.34
400	3.34±0.73	2.45-4.77	3.34±0.91	2.34-4.32	2.83±0.78	1.60-4.42

Table 2 Average concentration of total alkalinity (meq/l) in different areas of the Bay of Bengal
(average±SD).

Depth (m)	Area A		Area B		Area C	
	Average	min.-max	Average	min.-max	Average	min.-max
Surface	2.20±0.03	2.13-2.24	2.24±0.02	2.21-2.26	2.16±0.05	2.08-2.24
10	2.22±0.05	2.14-2.33	2.25±0.01	2.24-2.27	2.17±0.06	2.07-2.26
30	2.22±0.03	2.14-2.27	2.26±0.01	2.25-2.27	2.20±0.07	2.08-2.32
50	2.24±0.03	2.21-2.30	2.28±0.02	2.25-2.30	2.28±0.06	2.19-2.39
75	2.27±0.03	2.20-2.30	2.30±0.01	2.28-2.31	2.31±0.04	2.24-2.38
100	2.31±0.01	2.29-2.33	2.31±0.01	2.31-2.32	2.35±0.05	2.29-2.41
125	2.32±0.01	2.29-2.34	2.31±0.01	2.29-2.32	2.38±0.03	2.33-2.42
150	2.32±0.02	2.28-2.34	-	-	2.39±0.04	2.33-2.44
200	2.33±0.01	2.31-2.35	2.32±0.01	2.31-2.34	2.41±0.04	2.33-2.47
250	2.34±0.01	2.32-2.35	2.33±0.01	2.33-2.34	2.40±0.04	2.32-2.44
300	2.34±0.01	2.32-2.36	2.34±0.01	2.33-2.35	2.41±0.03	2.35-2.47
400	2.35±0.01	2.34-2.36	2.34±0.01	2.33-2.36	2.41±0.04	2.35-2.49

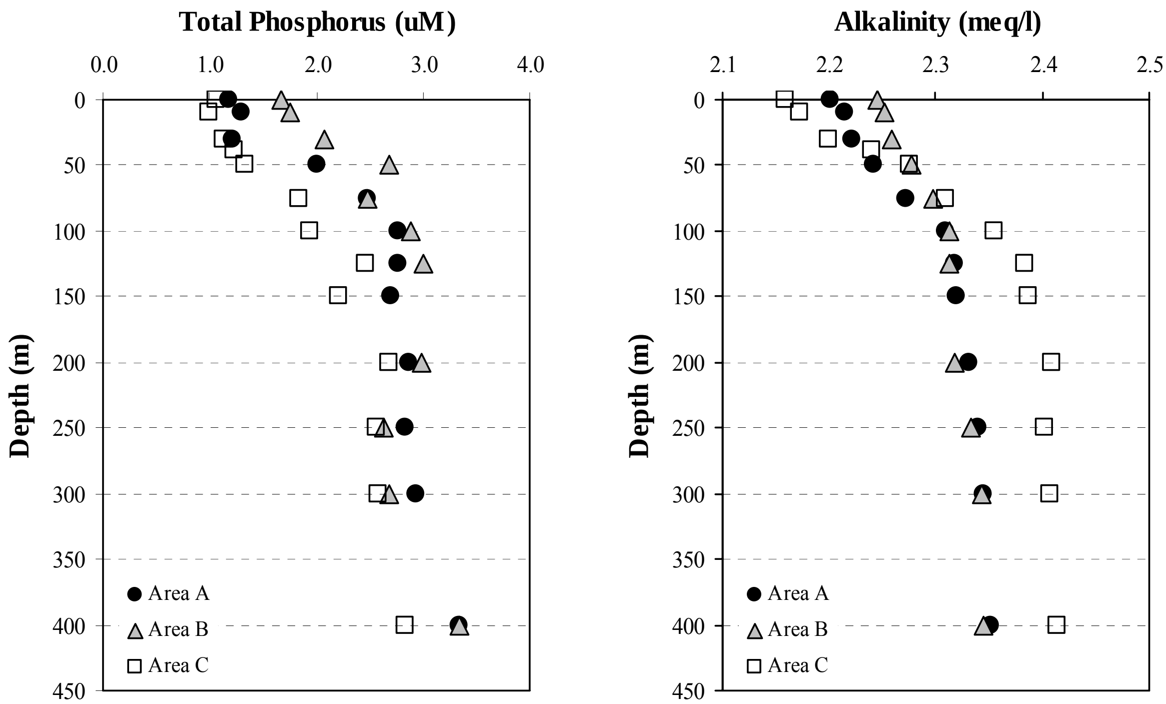


Figure 4 Comparison of average total phosphorus (left) and average total alkalinity (right) depth profiles from different area in the Bay of Bengal.

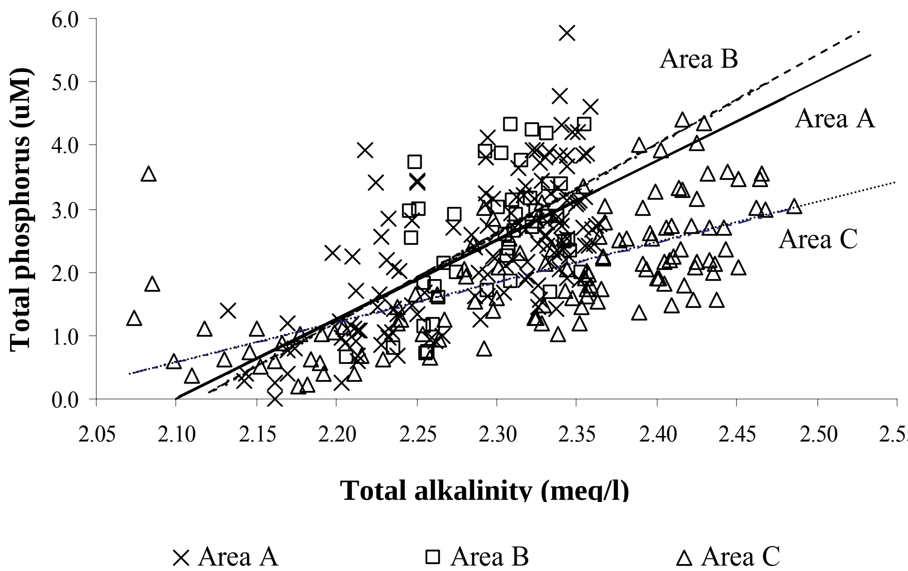


Figure 5 Total phosphorus with total alkalinity relationships in the three study areas in the Bay of Bengal.
(Each individual line represents the trend of each area)

It is clearly seen in fig. 4 that the characteristics of the Andaman seawater is differentiated from the entire Bay of Bengal by having low total phosphorus and low total alkalinity in surface water and high total alkalinity in deeper water. The relationships between total phosphorus and total alkalinity of samples taken from area A and B give similar trend lines, whereas those from area C (the Andaman Sea) show a dissimilar trend (Fig. 5). High variation of total alkalinity values throughout the water column down to 400 m depth in the Andaman Sea may be affected from internal waves. It is believed that the internal waves in the Andaman Sea occur all year round (Jackson, 2004). The amplitudes of internal waves in the Andaman Sea may be up to 70-80 m and can propagate over several hundred kilometers, which lead to transport of water mass and induce turbulence and mixing in the water column (Osborne and Burch, 1980; Jackson, 2004).

Fig. 6 and 7 illustrate horizontal distribution of total phosphorus and total alkalinity, respectively, at different depth. These two figures indicate that the eastern part of the Bay of Bengal is a low total phosphorus region. The distribution of total alkalinity and total phosphorus along north-south section in the area C (the Andaman Sea) and area A (the upper part of the Bay of Bengal) are illustrated in figs. 8 and 9, respectively, and the east-west section of area A is shown in fig. 10.

Conclusion

The total alkalinity in surface water of area C (the Andaman Sea) is lower than those of areas A and B, however, but is higher at the depths below 100 down to 400 m. The vertical distribution of total phosphorus and total alkalinity in areas A and B of the Bay of Bengal are similar. The differentiated pattern of depth profiles of both total phosphorus and total alkalinity together with the relationship between total alkalinity and total phosphorus indicate that sea water characteristics in the enclosed Andaman Sea is different from the entire Bay of Bengal.

Unfortunately, analyses of organic carbon and total nitrogen in these seawater samples are not yet finished. Total alkalinity coupled with pH and temperature data, amount of dissolved inorganic carbon (DIC) species and dissolved carbon dioxide gas (pCO_2) in seawater can be calculated. Interpretation of this data set will provide clearer understanding of biogeochemical processes occurring in these three areas of the Bay of Bengal.

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We gratefully acknowledge Miss Sopana Boonyapiwat and Ms. Pattira Lirdwitayaprasit for their kind cooperation of this collaborative work. We would also like to thank the officers and crew of M.V. SEAFDEC for assisting in sample collection.

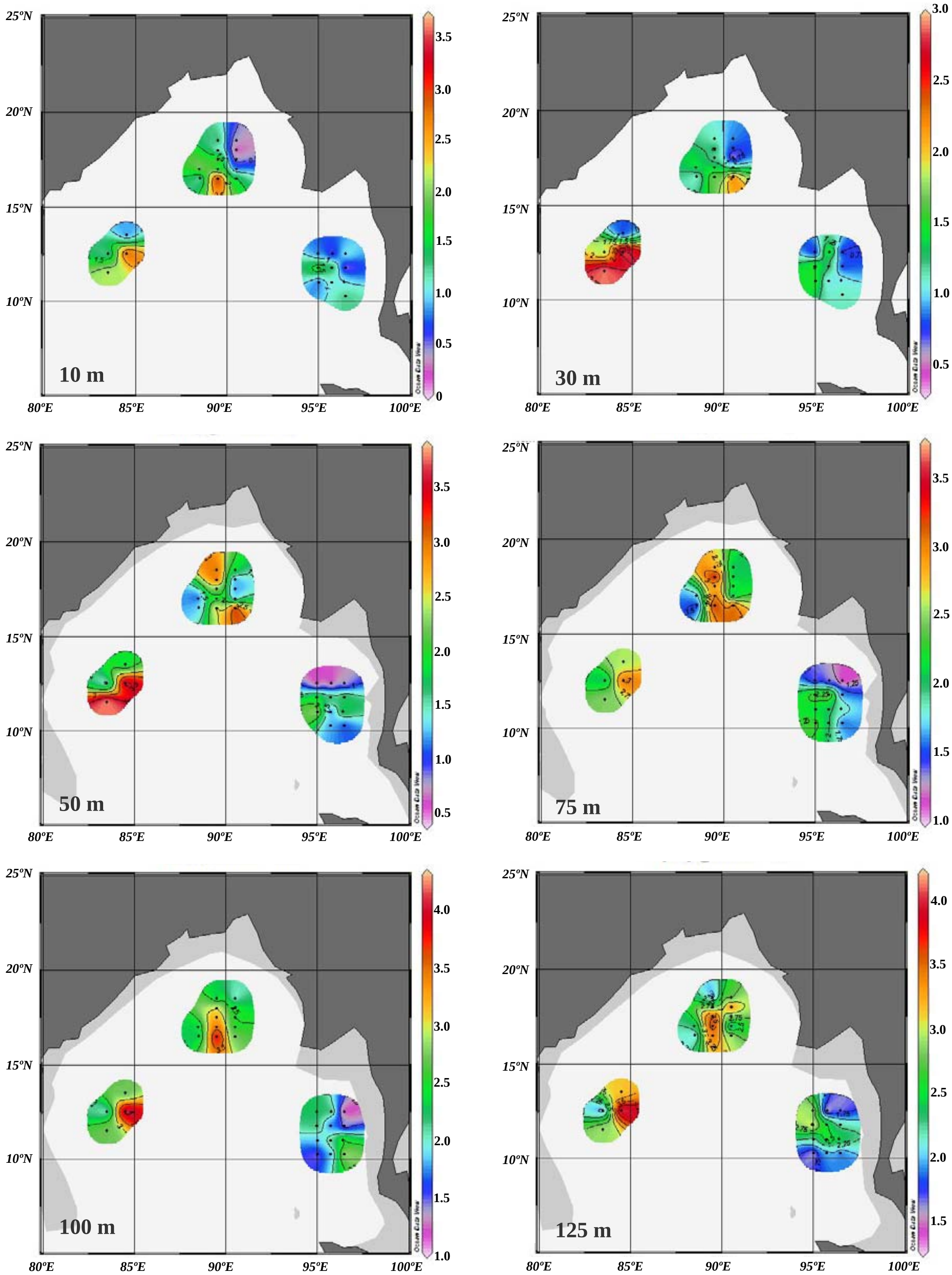

Figure 6 Horizontal distribution of total phosphorus (μM) at 10, 30, 50, 75, 100, 125, 200, 250
and 400 m depth.

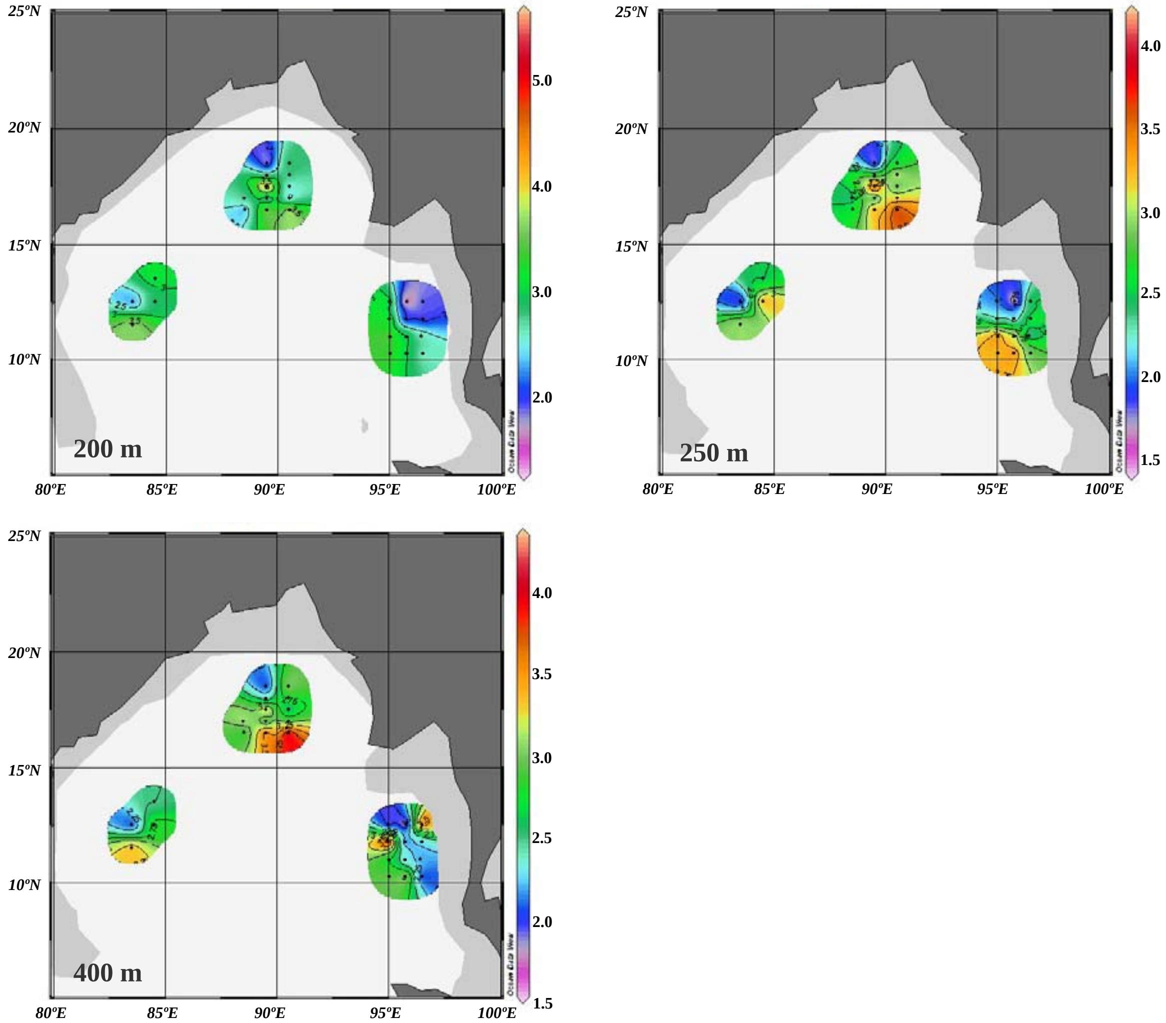

Figure 6 (cont.)

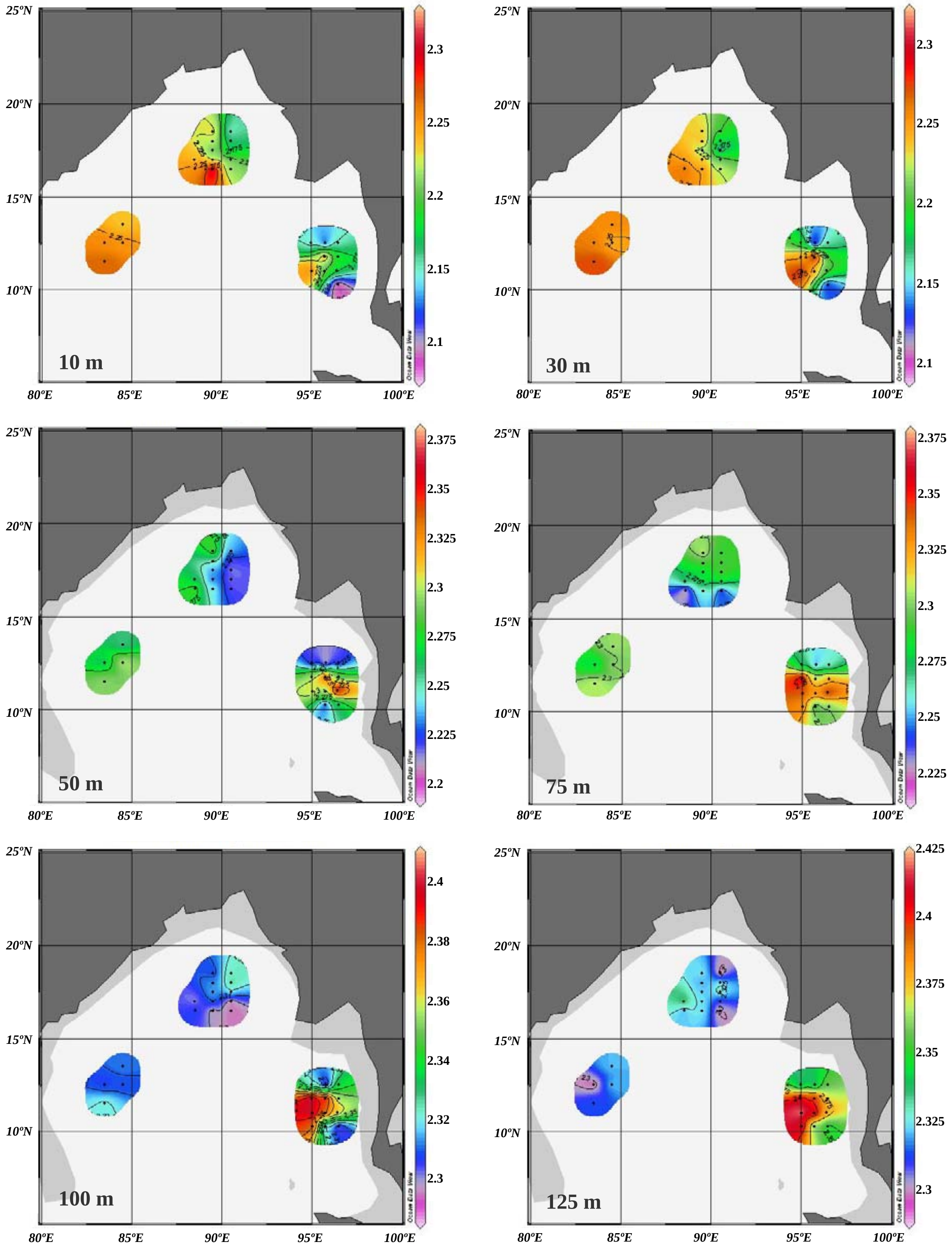

Figure 7 Horizontal distribution of total alkalinity (meq/l) at 10, 30, 50, 75, 100, 125, 200, 250 and 400 m depth.

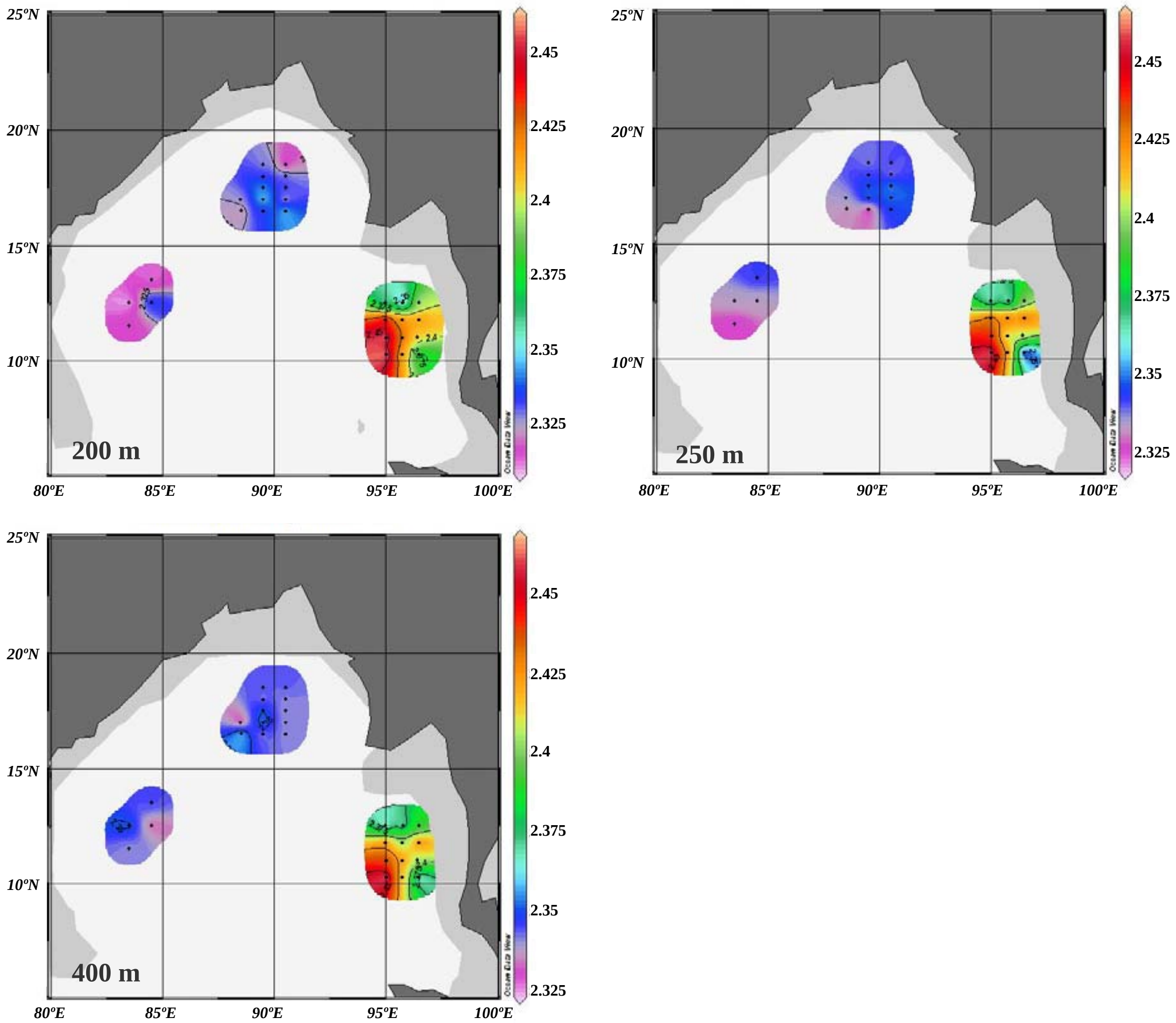

Figure 7 (cont.)

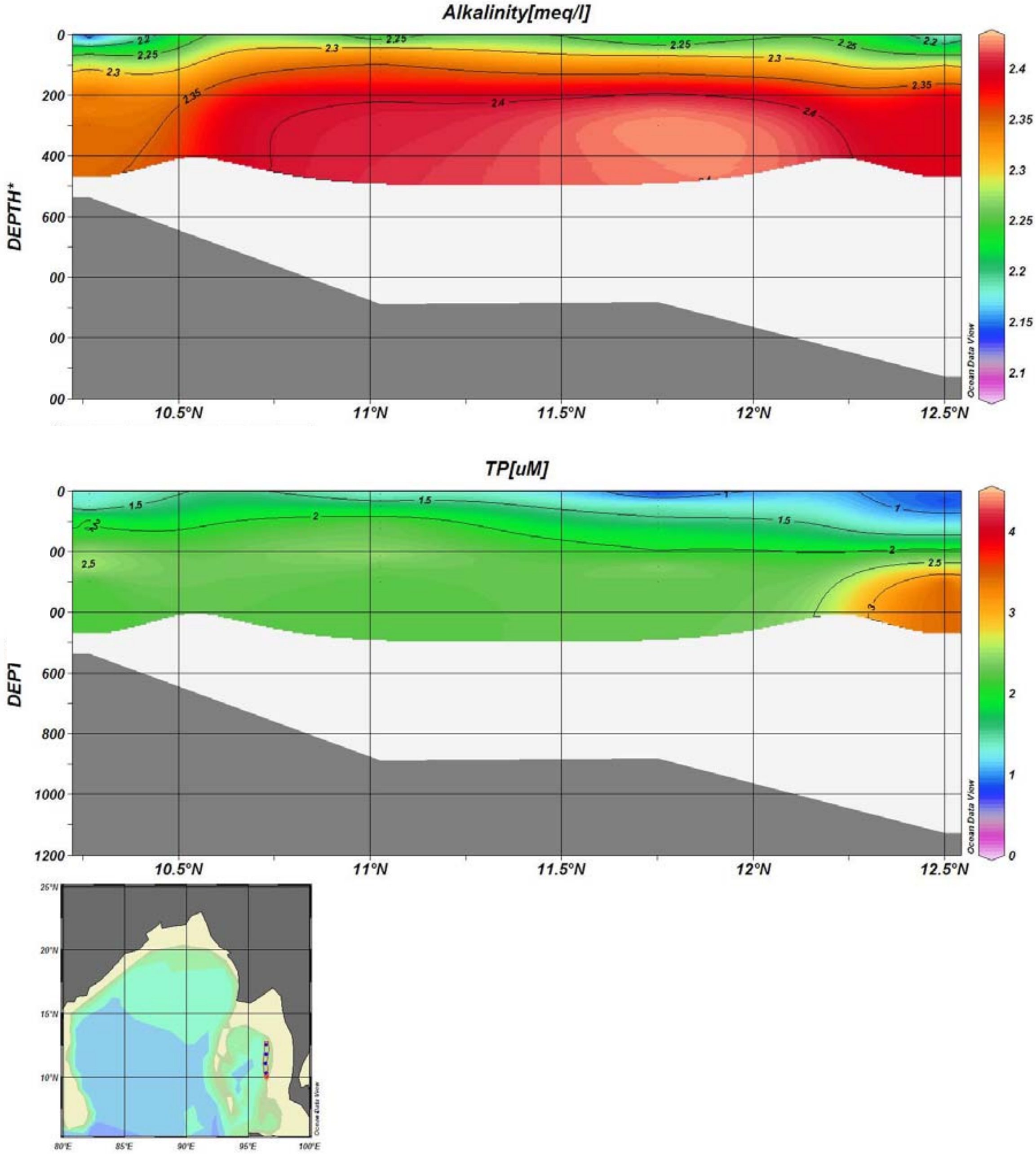

Figure 8 Distribution of total alkalinity (upper) and total phosphorus (lower) along N-S section in area C (the Andaman Sea).

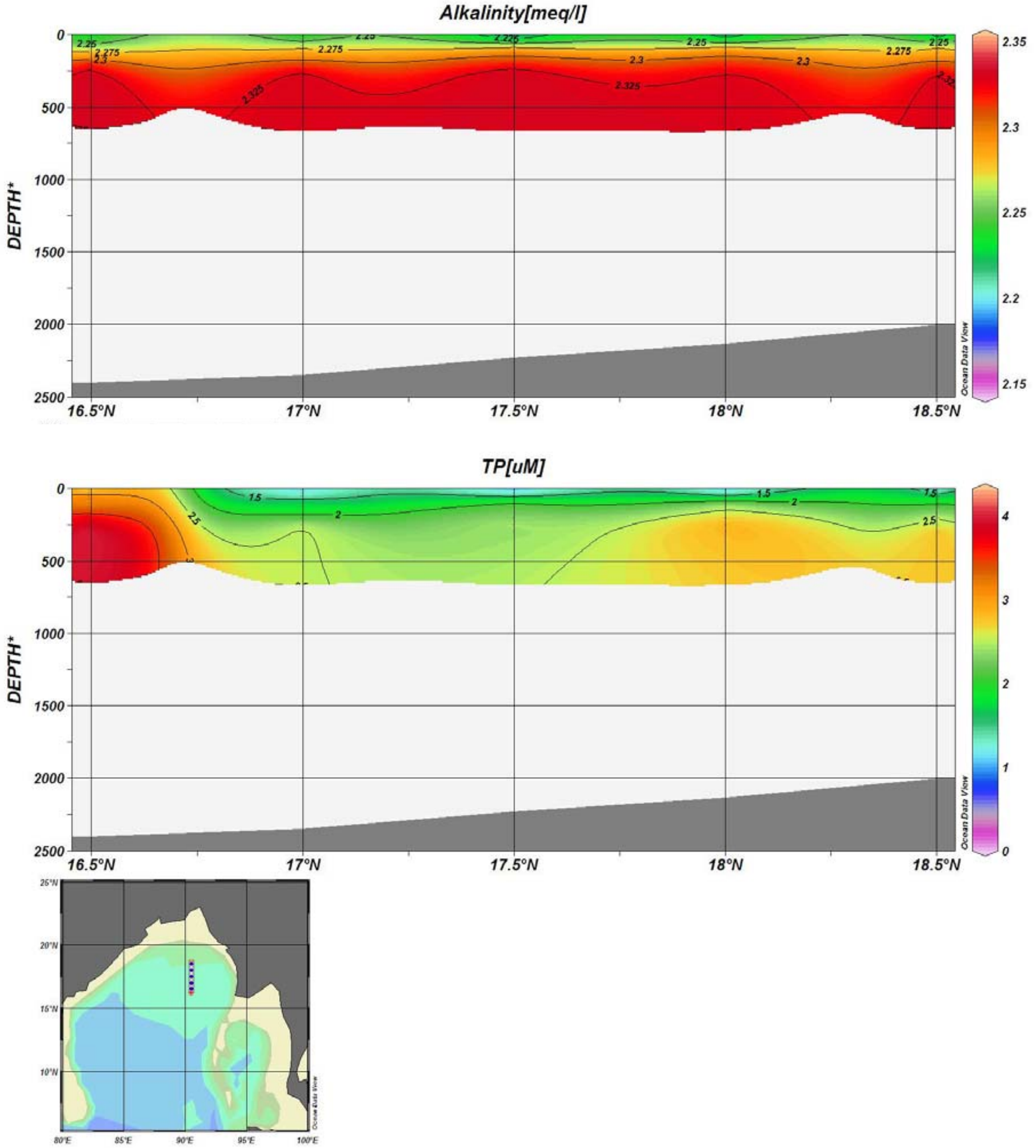

Figure 9 Distribution of total alkalinity (upper) and total phosphorus (lower) along N-S section in area A (the upper part of the Bay of Bengal).

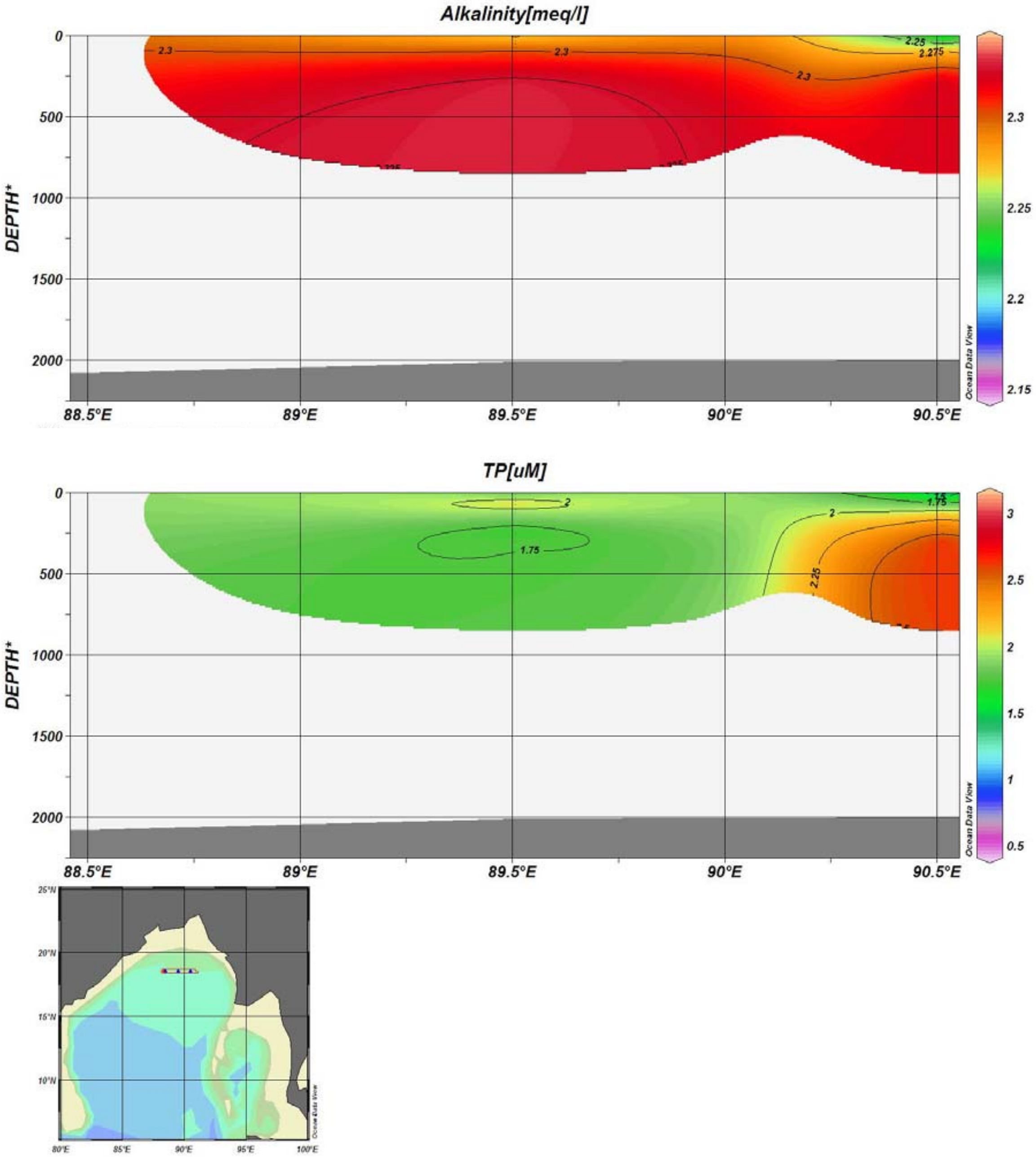

Figure 10 Distribution of total alkalinity (upper) and total phosphorus (lower) along E-W section in area A (the upper part of the Bay of Bengal).

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Distribution of Nutrients in the Bay of Bengal

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Abstract

The spatial distribution of nutrients (nitrite + nitrate, silicate and phosphate) was determined during the joint research survey on the Ecosystem-Based Fishery Management in the Bay of Bengal by M.V. SEAFDEC between 25 October to 21 December 2007. Water samples from twenty-eight stations were analyzed onboard by the Integral Futura Continuous Flow Automated Analysis. The detectable ranges of nitrite + nitrate, silicate and phosphate in the northern Bay of Bengal were 0.07-37.87, 0.01-48.56 and 0.10-3.13 µM; in the western Bay of Bengal 2.06-35.23, 2.89-46.03 and 0.15-3.16 µM; and in the eastern Bay of Bengal 0.35-36.63, 0.05-46.63 and 0.36-2.76 µM, respectively. The vertical section profiles indicated that the concentrations of nutrients in the mixed layer depth were very low and undetectable in several sampling stations. In the thermocline layer, a strong nutricline concentration was noticed to be rapidly increasing with depth but below 200-250 m, it tended to be constant. Furthermore, several near shore stations were observed to have higher concentrations of nutrients than the stations in the open sea.

Key words: nutrient, nitrite + nitrate, silicate, phosphate, Bay of Bengal

Introduction

Nutrient is functionally involved in the process of living organisms. Traditionally, in chemical oceanography the term has been applied almost exclusively to silicate, phosphate and inorganic nitrogen. The role of nutrients in the ocean is to support the ocean food chains. Phytoplanktons are primary food producers in the sea and through photosynthesis, they produce food for zooplanktons which are then consumed by organisms higher up in the food chain (Spencer, 1975).

Generally, nutrient is also present in sea water in very small amounts, but only minute quantities of these are required by living organisms. Nutrient is essential for phytoplankton growth as it is taken up by phytoplankton cells and built in as atoms in amino acids, proteins, nucleic acids, fats, etc. Among the nutrient elements, silicate is essential for diatoms to build up their skeletons which consist of biogenic silicate (Baretta-Bekker *et al*., 1998).

When phytoplankton, zooplankton or higher organisms are dead, these are decomposed by marine bacteria. This in turn takes a particle form of nutrient and in a dissolved form so that phytoplankton can use it more easily. Distribution of nutrients is useful for predicting the phytoplankton abundance and assemblages. Moreover, it could also be used as indicator of the status of nutrient loading or to predict productivity (De-Pauw and Naessens, 1991).

With the importance of nutrients as mentioned above, this study aimed to measure the nutrient level (nitrite + nitrate, silicate and phosphate) and to illustrate the nutrients distribution in the Bay of Bengal.

Materials and Methods

Site Location

From the 42 oceanographic observation stations, station 25-28, 32-33, 35-45 were cancelled because of the influence of Northeast Monsoon and rough sea conditions. Water samples were collected using the M.V. SEAFDEC from 28 stations in the Bay of Bengal covering three areas, namely: the northern Bay of Bengal (area A: latitude 16°N-19°N, longitude 88°E-91°E); the western Bay of Bengal (area B: latitude 09°N-14°N, longitude 82°E-85°E); and the eastern Bay of Bengal (area C: latitude 10°N-12°N, longitude 95°E-97°E) from 25 October to 21 December 2007. Fig. 1 illustrates the map of the sampling locations.

Water Collection

At each station, the top 400 m of the water column was divided into 12 levels of standard depths (0, 10, 30, 50, 75, 100, 125, 150, 200, 250, 300, and 400 m). Water samples from each depth were collected with 2.5 l Go-Flo Niskin bottle on a 12 bottle rosette. Replicate nutrient samples were sub-sampled from the Niskin bottles then filtered through Whatman GF/C filter papers and were collected into 60 ml polypropylene bottles which were then rinsed three times with the sample before storing at -20°C until analysis.

Analysis of Water Samples

Nitrite + nitrate (NO_2+NO_3-N), silicate (SiO_4-Si) and phosphate (PO_4-P) were analyzed in 3 replicates using standard colorimetric methods as adapted for auto-analyzers according to Gordon *et al*. (1995). The Integral Futura Continuous Flow Automated Analysis was used to analyze the samples onboard. Nutrient concentrations were determined from the mean peak heights and calculated using linear regression achieved from a seven point standard curve prepared in low nutrient seawater matrix. The vertical profile of nutrients and environmental data were prepared using Ocean Data View (ODV) software (Schlitzer, 2006).

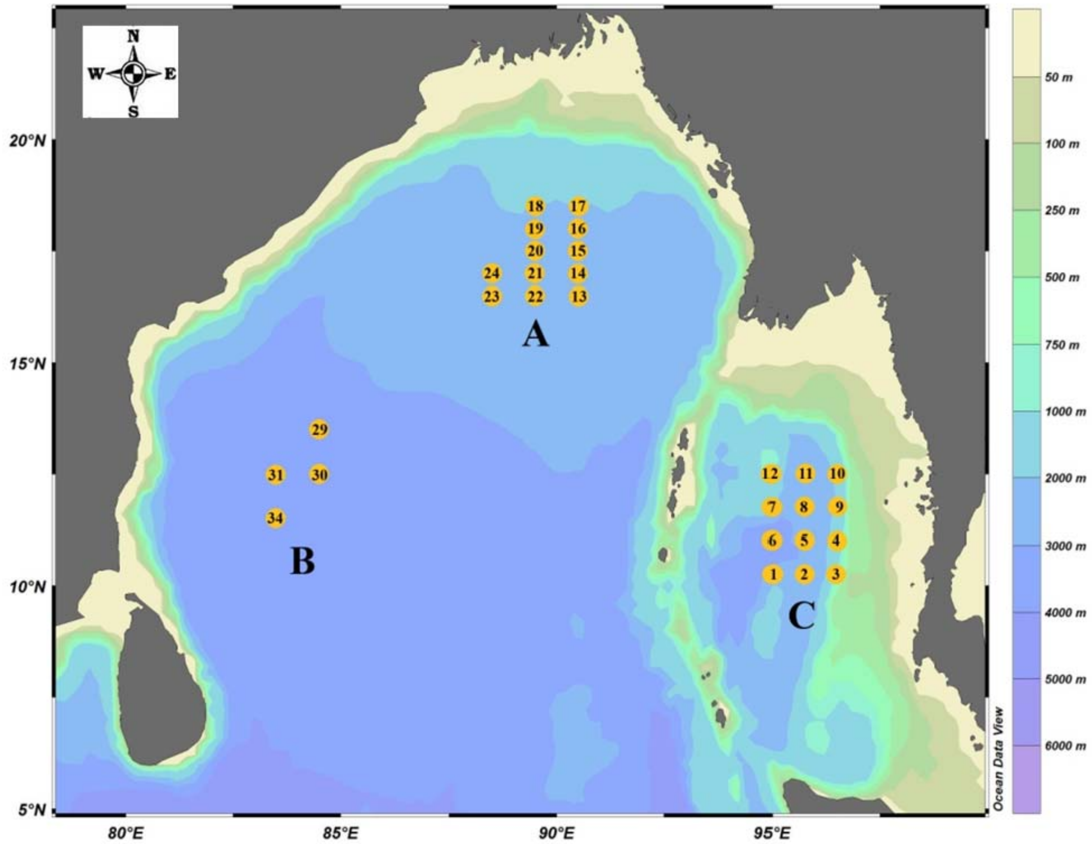


Figure 1 Map of survey area showing the water sampling stations.

Results and Discussions

Water samples from the three areas that included 28 sampling stations were analyzed. The results of sample analysis are shown in tables 1, 2 and 3.

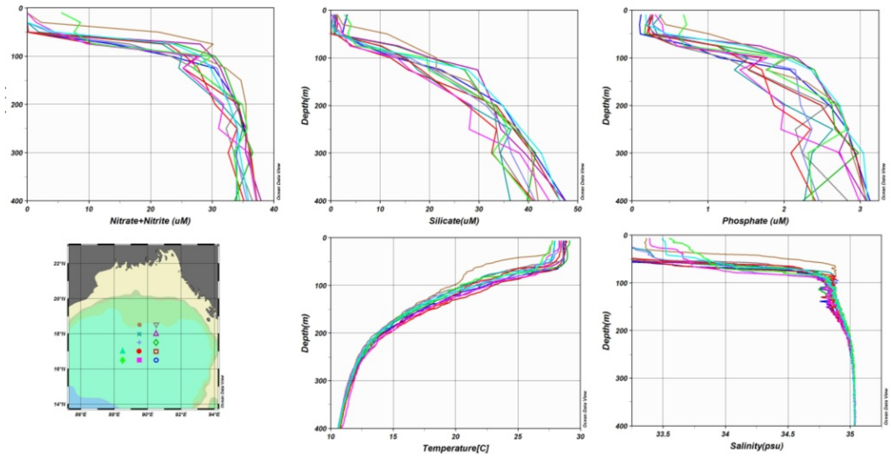
Nutrients in Area A: the Northern Bay of Bengal

Fig. 2a shows the vertical profiles of nutrients and environmental data in the northern Bay of Bengal. The mixed layer depth (MLD) and thermocline layer determined by temperature profile are identified with depths 0-50 m and 51-250 m, respectively. The vertical sections profile of the nutrient in this area was divided into two sections: section A1 (Fig. 3a) includes station 18-22 and section A2 (Fig. 3b) includes station 13-17. In this area A, the nitrite + nitrate concentration (Table 1, Figs. 3a and 3b) in the MLD layer ranged between undetectable (N.D.) to 21.31 µM. Although the concentration was extremely low and could be detectable only in few stations, the observation was consistent with many similar studies conducted in the Bay of Bengal (Kumar *et al.*, 2002; Madhupratap *et al.*, 2003), Except for the high concentration in station 18 and 23 which nearly located the cold-core eddy area (Kumar *et al.*, 2004). Thereby it was possible that the influence of cold-core eddy bring nutrients into this area between our study period. In the thermocline layer, the nitrite + nitrate concentration ranged between 9.82 and 35.70 µM. Fig. 2a shows a strong nitricline level which was noticed to increase rapidly with depth, however until below 250 m, it tended to be constant. At the sub-thermocline layer, the values ranged from 32.55 to 37.87 µM with maximum value of 37.87 µM observed in station 16 at 400 m depth.

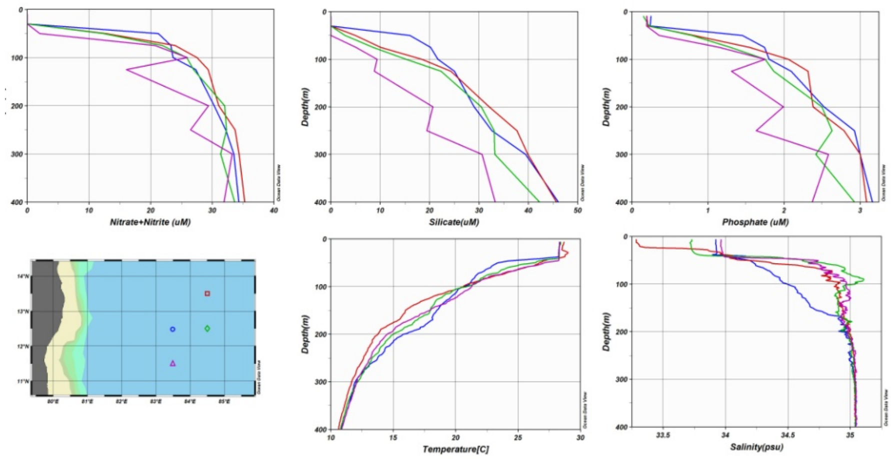
Table 1 Concentration of nitrite + nitrate at standard depths.

Area	Station	Concentration (µM)											
		Depth (m)											
		0	10	30	50	75	100	125	150	200	250	300	400
A	13	-	N.D.	N.D.	N.D.	13.78	23.30	30.34	-	34.20	35.20	36.10	37.21
	14	-	N.D.	N.D.	N.D.	11.04	27.55	25.30	-	34.24	35.01	36.20	37.24
	15	-	N.D.	N.D.	N.D.	24.35	30.39	31.91	-	34.08	34.94	36.54	33.62
	16	-	N.D.	N.D.	0.07	28.02	29.92	31.31	-	33.71	35.50	35.37	37.87
	17	-	N.D.	N.D.	0.27	16.58	23.26	27.10	-	34.51	32.20	33.53	36.49
	18	-	N.D.	2.30	21.31	-	30.14	27.93	32.18	34.62	35.52	35.94	37.29
	19	-	N.D.	N.D.	1.87	21.83	25.02	24.60	-	31.46	34.91	33.95	33.97
	20	-	N.D.	N.D.	3.64	14.56	26.17	30.84	-	32.73	34.02	33.80	35.57
	21	-	N.D.	N.D.	N.D.	22.81	25.63	27.70	-	30.46	34.03	32.55	35.10
	22	-	N.D.	1.47	4.53	9.82	28.03	25.20	-	31.81	31.00	35.77	37.10
	23	N.D.	5.58	8.66	7.60	10.57	29.91	26.97	-	34.85	35.70	33.48	34.41
	24	N.D.	N.D.	N.D.	4.56	23.70	28.21	29.73	-	32.76	34.10	34.42	35.84
B	29	N.D.	N.D.	N.D.	12.76	23.96	27.52	29.30	-	31.06	33.70	34.33	35.23
	30	N.D.	N.D.	N.D.	12.38	21.89	25.85	27.02	-	31.99	32.32	31.36	33.62
	31	N.D.	N.D.	N.D.	21.25	23.29	23.62	27.30	-	30.31	32.11	33.47	34.28
	34	N.D.	N.D.	N.D.	2.06	20.72	25.96	16.11	-	29.37	26.51	33.22	31.87
C	1	-	-	-	-	8.28	20.30	-	32.32	34.42	-	35.32	35.43
	2	N.D.	-	N.D.	N.D.	6.43	20.72	-	30	30.55	35.30	32.65	32.98
	3	N.D.	N.D.	N.D.	N.D.	14.83	22.42	-	30.06	33.91	32.14	33.21	35.71
	4	-	N.D.	N.D.	23.32	17.00	23.90	25.04	-	34.17	34.20	31.28	31.56
	5	-	N.D.	-	N.D.	1.29	16.98	30.10	29.61	34.49	35.60	35.89	36.29
	6	-	N.D.	N.D.	N.D.	10.45	22.74	30.70	-	34.97	34.41	35.98	36.49
	7	N.D.	N.D.	N.D.	N.D.	10.19	28.87	30.63	-	34.95	35.85	35.49	-
	8	N.D.	N.D.	8.28	23.52	29.35	33.15	35.00	-	36.09	35.70	36.59	36.32
	9	N.D.	N.D.	N.D.	0.35	9.83	20.23	24.45	-	30.14	29.53	30.35	32.68
	10	N.D.	N.D.	N.D.	N.D.	10.57	20.26	27.40	-	33.12	35.30	35.74	36.07
	11	N.D.	N.D.	N.D.	N.D.	3.14	20.34	-	30.61	33.58	35.60	36.33	36.63
	12	N.D.	N.D.	N.D.	3.48	17.33	16.38	23.20	-	34.33	35.80	36.40	36.54

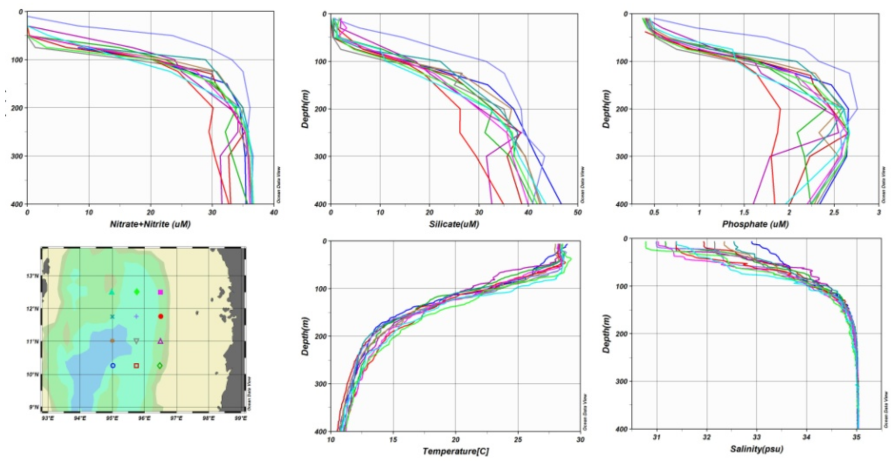
"-"= samples not collected, "N.D." = not detected



(a)



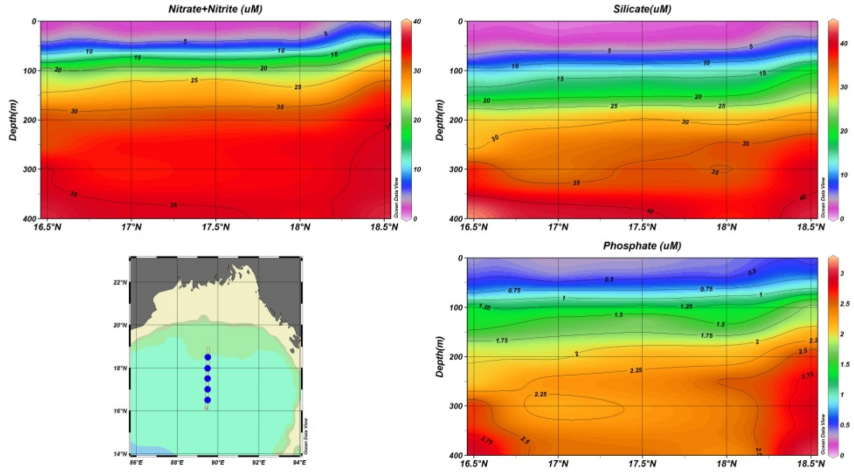
(b)



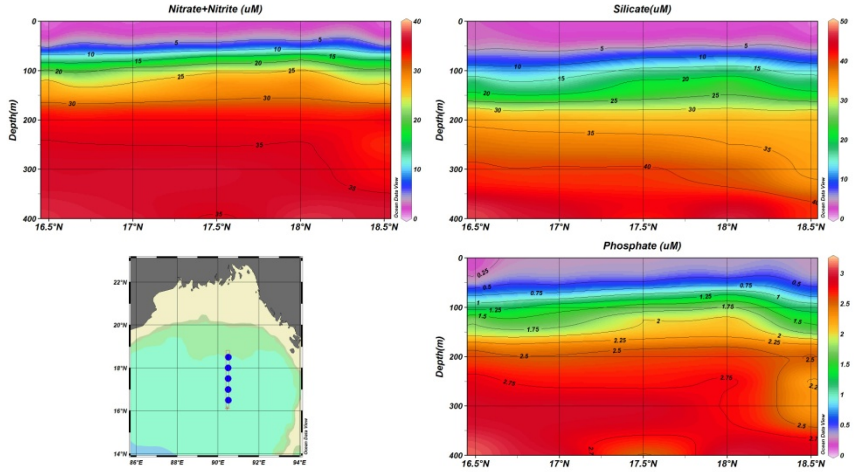
(c)

Figure 2 Vertical profile of nutrients (nitrate + nitrite, silicate and phosphate) (µM), temperature (°C) and salinity (psu) in upper 400 m, 25 Oct.-21 Dec. 2007.

(a) area A: station 13-24
(b) area B: station 29-31 and 34
(c) area C: station 1-12



(a)



(b)

Figure 3 The vertical section profiles of nitrite + nitrate, silicate and phosphate in area A.
(a) section A1: station 18, 19, 20, 21 and 22
(b) section A2: station 13, 14, 15, 16 and 17

The silicate distribution (Table 2, Figs. 3a and 3b) was also similar to that of the nitrite + nitrate. The concentration of silicate at the MLD ranged between undetectable (N.D.) to 10.87 µM. Thus, the area was generally devoid of silicate except for a noticeable high concentration in station 13, 18 and 23, which indicated that the nutrient must have originated from the river discharge around the area (Subramanian, 1993; Kumar, *et al.*, 2002 and Madhupratap *et al.*, 2003). In the thermocline layer, a strong nutricline was also noticed to have silicate concentration rapidly increasing with depth, ranging from 2.98 to 38.70 µM. Silicate concentration at the sub-thermocline layer ranged between 39.78 and 48.56 µM, The highest silicate concentration of 48.56 µM was found in station 13 at 400 m depth.

Phosphate values (Table 3) in the MLD were also low and gradually increasing with depth. The values were between 0.10-1.02 µM and the distinctly value also found in station 18 and 23. In the thermocline layer, a strong nutricline was also noticed to have phosphate concentration rapidly increasing with depth, ranging from 0.58 to 2.85 µM. At the sub-thermocline layer, phosphate values ranged between 2.09 to 3.13 µM, with the highest concentration of 3.13 µM at 400 m depth in station 13.

Table 2 Concentration of silicate at standard depths.

Area	station	Concentration (µM)											
		Depth (m)											
		0	10	30	50	75	100	125	150	200	250	300	400
A	13	-	2.24	1.64	1.32	5.82	12.65	-	22.2	35.06	38.70	42.22	48.56
	14	-	0.14	0.26	N.D.	3.46	12.92	14.91	-	33.81	37.63	41.55	47.42
	15	-	0.38	N.D.	N.D.	13.17	22.03	26.80	-	33.91	37.43	41.86	40.02
	16	-	N.D.	N.D.	N.D.	14.51	20.15	29.20	-	33.52	36.70	38.53	48.44
	17	-	N.D.	N.D.	1.45	7.40	14.23	20.80	-	34.88	33.42	35.79	44.62
	18	-	0.43	1.44	10.87	-	20.78	21.54	27.8	33.72	38.33	41.01	47.03
	19	-	N.D.	N.D.	0.01	9.17	14.94	16.92	-	28.19	37.00	35.34	39.78
	20	-	N.D.	N.D.	1.1	5.21	15.52	21.90	-	31.78	35.44	37.24	42.80
	21	-	N.D.	N.D.	N.D.	9.07	14.32	17.23	-	27.81	33.71	33.64	40.60
	22	-	N.D.	0.86	1.44	2.98	12.45	15.42	-	28.87	28.30	38.55	44.69
	23	-	1.94	3.24	2.6	4.32	19.29	19.72	-	32.97	35.71	34.43	41.28
	24	N.D.	N.D.	N.D.	1.17	7.94	17.21	27.80	-	34.73	38.50	42.57	46.34
B	29	N.D.	N.D.	N.D.	4.98	10.07	18.43	24.30	-	32.03	37.71	39.86	45.67
	30	N.D.	N.D.	N.D.	2.89	8.58	15.23	22.34	-	30.43	33.11	33.17	42.23
	31	N.D.	N.D.	N.D.	16.00	20.21	21.66	25.00	-	28.99	32.61	39.39	46.03
	34	N.D.	N.D.	N.D.	N.D.	5.12	9.35	8.81	-	20.65	19.44	30.59	33.28
C	1	-	-	-	-	6.63	15.86	-	-	31.81	37.04	41.59	46.63
	2	-	-	0.32	0.39	5.11	13.71	24.40	26.92	-	38.44	35.69	38.66
	3	5.18	0.52	0.56	1.71	10.49	16.41	-	26.93	32.77	31.22	36.19	40.98
	4	-	2.11	1.92	18.40	11.57	17.10	19.93	-	32.27	38.61	31.49	32.59
	5	-	0.9	-	0.49	2.00	11.48	26.62	24.97	34.99	36.42	39.26	42.60
	6	-	0.66	1.59	1.96	7.85	15.19	26.12	-	36.57	35.62	39.35	42.29
	7	0.05	N.D.	0.42	0.63	6.77	22.14	24.91	-	34.11	37.81	37.01	-
	8	0.43	0.49	5.86	14.64	22.6	31.42	35.13	-	38.52	38.94	43.26	40.81
	9	0.61	0.67	1.22	3.47	6.54	14.65	18.74	-	26.15	26.10	29.43	34.93
	10	-	1.69	3.19	1.32	7.79	14.93	-	20.93	29.82	35.60	36.72	39.92
	11	2.03	1.73	1.29	1.10	4.67	12.69	-	23.95	32.2	36.72	37.15	41.78
	12	1.15	0.69	1.24	1.38	9.97	11.15	16.80	-	32.18	36.30	38.08	43.51

"-"= not collected sample, "N.D." = not detected

Nutrients in Area B: the Western Bay of Bengal

Fig. 2b shows the vertical profiles of nutrients and environmental data in the western Bay of Bengal. The mixed layer depth (MLD) and thermocline layer are similar to that described for area A, i.e. 0-50 m and 51-250 m, respectively. The vertical sections of the nutrients are illustrated in fig. 4. The nitrite + nitrate concentration (Table 1, Fig. 4) at MLD layer was between undetectable (N.D.) to 21.25 µM. In the upper 30 m layer, it was undetectable in all stations and gradually increasing with depth. The thermocline layer showed a strong nitricline and was noticed to show concentration that is rapidly increasing with depth, ranging from 16.11 to 33.70 µM, and at the sub-thermocline layer between 31.36 and 35.23 µM. Maximum value of 35.23 µM was found at 400 m in station 29.

The silicate concentration in the MLD and thermocline layer (Table 2, Fig. 4) was similar to that of the nitrite + nitrate concentration. In the MLD layer, the range was between undetectable (N.D.) to 16.00 µM. The high concentration was also found at station 31. In the thermocline layer, the value was between 5.12 and 37.71 µM, while at the sub-thermocline layer it was between 30.59 and 46.03 µM. A maximum value of 46.03 µM was found at 400 m in station 31.

Table 3 Concentration of phosphate at standard depths.

Area	Station	Concentration (μM)											
		Depth (m)											
		0	10	30	50	75	100	125	150	200	250	300	400
A	13	-	0.12	0.10	0.11	0.78	1.16	2.08	-	2.60	2.83	2.93	3.13
	14	-	0.28	0.23	0.2	0.58	1.71	1.53	-	2.49	2.70	2.94	3.08
	15	-	0.28	0.18	0.17	1.16	2.10	2.40	-	2.63	2.67	2.98	2.25
	16	-	0.25	0.19	0.30	1.68	2.17	2.36	-	2.68	2.85	2.72	3.08
	17	-	0.27	0.22	0.28	0.58	1.24	1.55	-	2.58	2.15	2.24	2.84
	18	-	0.36	0.44	1.02	-	2.06	1.76	2.29	2.73	2.84	2.89	3.09
	19	-	0.39	0.28	0.33	1.13	1.53	1.35	-	2.03	2.64	2.37	2.27
	20	-	0.28	0.27	0.45	0.80	1.49	2.15	-	2.22	2.37	2.24	2.46
	21	-	0.27	0.22	0.23	1.12	1.40	1.71	-	1.87	2.35	2.09	2.41
	22	-	0.31	0.40	0.42	0.60	1.78	1.42	-	2.00	1.96	2.74	2.99
	23	-	0.68	0.72	0.62	0.69	2.00	1.78	-	2.71	2.83	2.32	2.38
	24	0.21	0.18	0.19	0.47	1.48	2.00	2.36	-	2.74	2.81	3.04	3.10
B	29	0.24	0.19	0.21	0.81	1.55	2.06	2.32	-	2.38	2.79	3.00	3.09
	30	0.18	0.15	0.23	0.79	1.30	1.75	1.87	-	2.50	2.63	2.41	2.93
	31	0.34	0.25	0.24	1.45	1.74	1.81	2.09	-	2.53	2.93	3.00	3.16
	34	0.26	0.20	0.19	0.36	1.15	1.75	1.31	-	1.99	1.63	2.59	2.37
C	1	-	-	-	-	0.99	1.65	-	2.47	2.66	-	2.64	2.34
	2	0.37	-	0.40	0.55	0.93	1.66	2.24	2.27	-	2.67	2.23	2.01
	3	0.36	0.37	0.42	0.57	1.25	1.65	-	2.08	2.41	2.09	2.17	2.24
	4	-	0.41	0.59	1.38	1.19	1.61	1.69	-	2.51	2.55	1.79	1.60
	5	-	0.42	-	0.51	0.75	1.38	2.06	2.13	2.61	2.67	2.62	2.31
	6	-	0.44	0.48	0.66	1.13	1.76	2.29	-	2.58	2.33	2.55	2.28
	7	0.40	0.41	0.45	0.60	1.12	2.08	2.25	-	2.61	2.46	2.19	-
	8	0.42	0.5	0.97	1.75	2.17	2.33	2.67	-	2.76	2.57	2.59	2.24
	9	0.41	0.42	0.62	0.89	1.44	1.63	1.90	-	1.87	1.80	1.84	-
	10	-	0.40	0.43	0.57	1.02	1.54	2.06		2.46	2.64	2.57	2.20
	11	0.39	0.39	0.42	0.54	0.86	1.60	-	2.28	2.54	2.66	2.63	2.25
	12	0.42	0.45	0.50	0.74	1.37	1.41	1.61	-	2.60	2.67	2.51	1.96

"-"= not collected sample, "N.D." = not detected

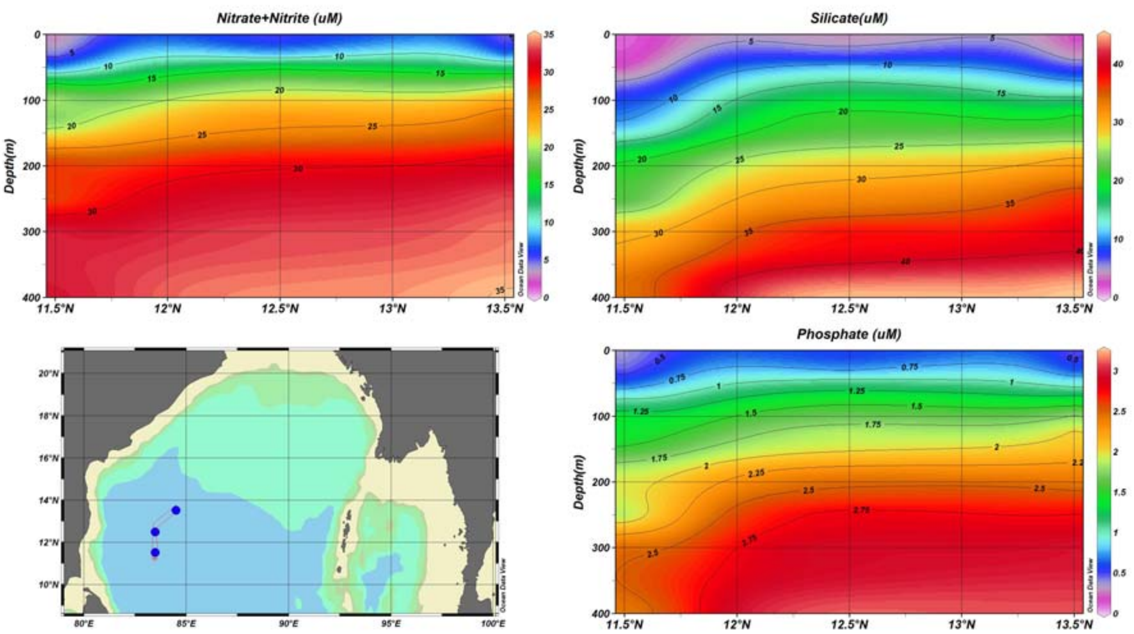


Figure 4 The vertical section profiles of nitrite + nitrate, silicate and phosphate in area B, station 29, 31 and 34.

For the phosphate concentration (Table 3, Fig. 4) in the MLD layer, the range was between 0.15 and 1.45 µM, the highest concentration was in station 31 at 50 m depth. In the thermocline layer, the value was between 1.15 and 2.93 µM, and 2.37-3.16 µM at the sub-thermocline layer. The highest concentration of 3.16 µM was also found at 400 m in station 31.

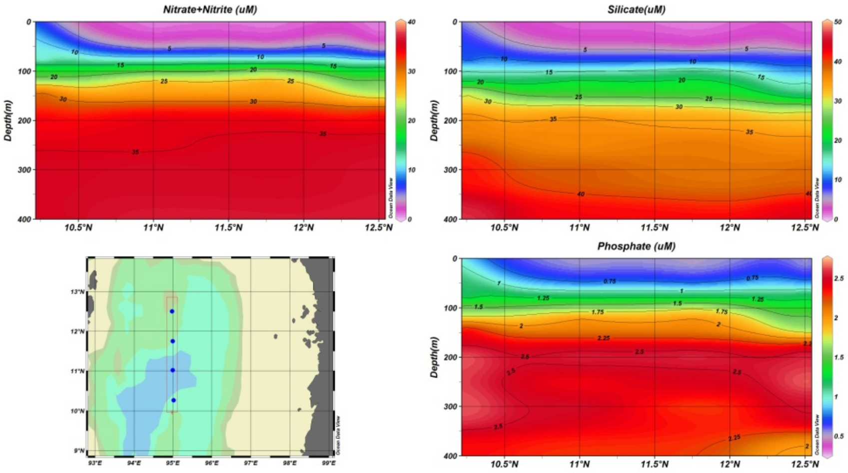
Nutrients in Area C: the Eastern Bay of Bengal

Fig. 2c shows the vertical profiles of nutrients and environmental data in the eastern Bay of Bengal. The MLD and thermocline layer are also described at depths 0-50 m and 51-200 m, respectively. The vertical sections of the nutrients in this area were divided into three sections: section C1 (Fig. 5a) included station 1, 6, 7, 12; section C2 (Fig. 5b) consist of station 2, 5, 8, 11 and section C3 (Fig. 5c) with station 3, 4, 9, 10.

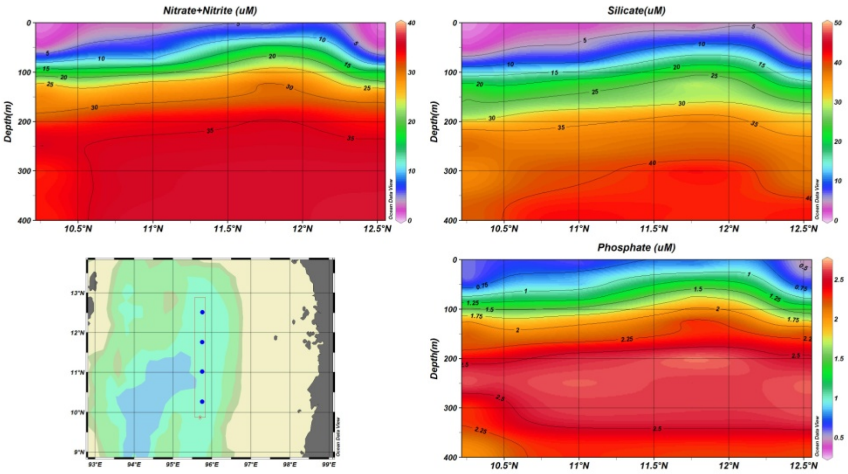
The nitrite + nitrate concentration (Table 1) ranged between undetectable (N.D.) to 3.52 µM in the MLD. Most of them were undectable. The low salinity in the surface waters in the North of this area and near shore section (Fig. 5c) suggests that there was influence of river inputs from the land to the open ocean. However, there was no significant input of nitrite + nitrate in the water mass. It is possible that the nitrate transported by the river runoffs is biologically consumed within the estuarine and coastal regions (Kumar *et al.*, 2002). However, in station 8 of section C2 (Fig. 5b) located at the center of area C, a remarkable high value of nitrite + nitrate. In the thermocline layer the concentration of nitrite + nitrate ranged between 1.29 and 36.09 µM. A strong nitricline concentration was noticed to be rapidly increasing with depth until below 200 m when it tended to be constant (Fig. 5 a-5 c). While in the sub-thermocline layer, the range was 29.53-36.63 µM with the maximum value of 36.63 µM found at 400 m in station 11. The concentration of nitrite + nitrate in this area was also similar to other studies in the Bay of Bengal (Obromwan, 2006 and Kumar *et al*., 2007).

In all stations in area C, the concentration of silicate also increased with depth. The silicate value (Table 2) was also low at the MLD layer, between 0.05-18.40 µM except in station 8 which had high value similar to that of the nitrite + nitrate value (Fig. 5b). In the thermocline layer, a strong nutricline was also noticed to have silicate concentration rapidly increasing with depth similar to that in areas A and B, ranging from 2.00 to 38.52 µM. At the sub-thermocline layer, the range was between 26.10 and 46.63 µM and the highest value (46.63 µM) was found at depth 400 m of station 1. Comparing the silicate concentration in section C3 located near shore with that in section C1 and C2 which are in the open sea, the concentration at surface layer (section C3) was slightly higher than in C1 and C2 (Fig. 5a-5c). This suggests that there was influence of river runoff of silicate from the rivers such as the Irrawady river, etc. (Subramanian, 1993).

As for the phosphate concentration, at MLD layer the range was between 0.36 and 1.75 µM. In thermocline layer, it was between 0.75 and 2.76 µM. A strong nutricline showed a trend of phosphate concentration increasing with depth until approximately 200 m. Station 8 at MLD and thermocline layer had high value similar to nitrite + nitrate and silicate. At the sub-thermocline layer, the range was between 1.60 and 2.67 µM. The concentration of phosphate in this study was also in the same range as that observed by Obromwan (2006).



(a)



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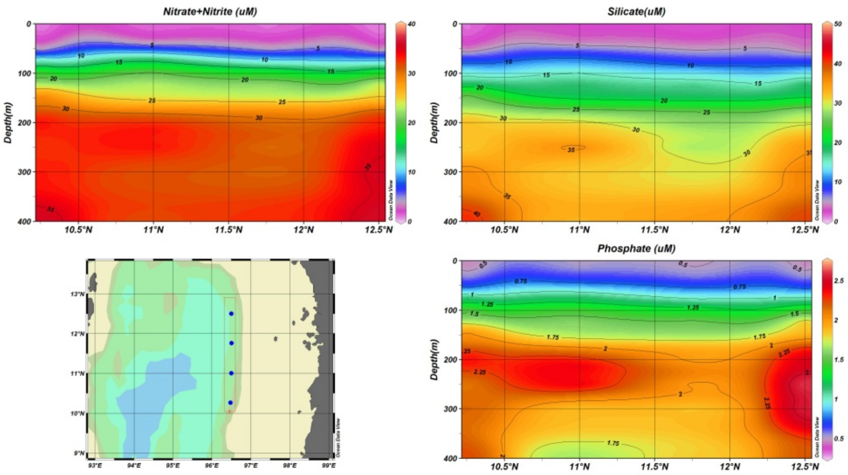

(c)

Figure 5 The vertical section profiles of nitrite + nitrate, silicate and phosphate in area C.
(a) section C1: station 1, 6, 7 and 12
(b) section C2: station 2, 5, 8 and 11
(c) section C3: station 3, 4, 9 and 10

Conclusions

The result of this study showed that the distribution of the nutrients: nitrite + nitrate, silicate and phosphate uniformly increased with depth at all sampling stations. Generally, the MLD layer in the Bay of Bengal had very low nutrient concentrations or sometimes even undetectable. In addition, there were several near shore stations that had nutrient concentration higher than those in stations in the open sea. Nutricline concentration was noticed to be rapidly increasing with depth beyond 50 m. Until about 200-250 m, the nutrient values were nearly constant or slightly changed. Finally, spatial distribution of nutrient studies will certainly provide better scientific basis to understand the ecosystem of the Bay of Bengal.

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Distribution of Chlorophyll-a in the Bay of Bengal

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Abstract

The distribution of chlorophyll in the Bay of Bengal was determined between 25 October to 21 December 2007, during the joint research survey on the Ecosystem-Based Fishery Management in the Bay of Bengal by the M.V. SEAFDEC. Chlorophyll-a from twenty-four stations in the study area were investigated using spectrophotometer. Results showed that the concentrations of chlorophyll-a in the eastern Bay of Bengal was 0.0375-0.5207 mg m^{-3}. In the northern Bay of Bengal it was 0.0365-1.1162 mg m^{-3}. While in the western Bay of Bengal the range was 0.0357-0.1839 mg m^{-3}. The spatial distribution of chlorophyll-a was similar pattern to the salinity and the highest concentration mostly confined at 10 m. The surface layer taken at the low latitude stations had higher concentrations than at the high latitude stations. Furthermore, river discharge with high turbidity may impede photosynthesis activity of phytoplankton in this area.

Key words: chlorophyll-a, primary productivity, Bay of Bengal

Introduction

Phytoplankton is a primary producer which converts inorganic matters into organic compounds through photosynthesis, enabling the transfer of energy and nutrients to the zooplankton. Considering that plankton organisms have short life cycles and can quickly respond to changing environments such as in the case of water pollution, some phytoplankton species can thus be used as index for monitoring water quality.

Chlorophyll is a principal pigment which phytoplankton use in photosynthesis to convert nutrients and carbon dioxide, which are dissolved in sea water into plant materials. Chlorophyll-a,b,c and Phaeophytin are the most commonly occurring pigment in seawater. Their concentrations showed wide fluctuation. Chlorophyll-a is the major photosynthetic pigment of marine phytoplankton that has been used as an indicator of biomass or primary productivity in the oceans (Beebe, 2008). The aim of this study is to collect information on the distribution of chlorophyll-a in the Bay of Bengal as they reflect the primary productivity.

Materials and Methods

Site Location

From the 42 oceanographic observation stations, station 25-28, 32-33, 35-45 were cancelled because of the influence of the northeast monsoon and rough sea conditions. Furthermore, the samples extracted from station 1, 2, 3 and 31 had decomposed before these could be analyzed due to the repair of the spectrophotometer. In this study, the water samples were collected from 24 stations in the Bay of Bengal covering three areas, namely: in the northern Bay of Bengal (area A: latitude 16°N-19°N, longitude 88°E-91°E); in the western Bay of Bengal (area B: latitude 09°N-14°N, longitude 82°E-85°E); and in the eastern Bay of Bengal (area C: latitude 10°N-12°N, longitude 95°E-97°E) from 25 October to 21 December 2007 using the M.V. SEAFDEC. The map of the sampling locations is shown in fig. 1.

Sample Collection

Most of the water samples were collected using the 10 l Vandorn water sampler. The 12 fold rosette with 2.5 l Niskin bottle was used when the sea condition was rough. Water samples were taken from four depths: 2 m, 10 m, 100-150 m and 200-300 m. Four to twelve liters of water samples were vacuum filtered onboard through the Whatman GF/F (pore size *ca.* 0.45 µ, diameter 47 mm) in the dark laboratory. Then the filters were dropped with suspension of magnesium carbonate and stored in desiccant bottle at -20°C until extraction.

Sample Extraction and Analysis

The filters were cut into small pieces and placed in a 50 ml centrifuge tube, then 15 ml of 90% acetone was added and allowed to stand overnight in a refrigerator. Then, these were centrifuged at room temperature for 10 min at 3000 RPM. The supernatants were decanted into a 50 mm path length spectrophotometer cuvette. The methods employed for algal absorption measurements and calculations are described in detail by Parsons *et al.*, (1984). The horizontal profile of chlorophyll and salinity were analyzed using the Ocean Data View (ODV) software (Schlitzer, 2006).

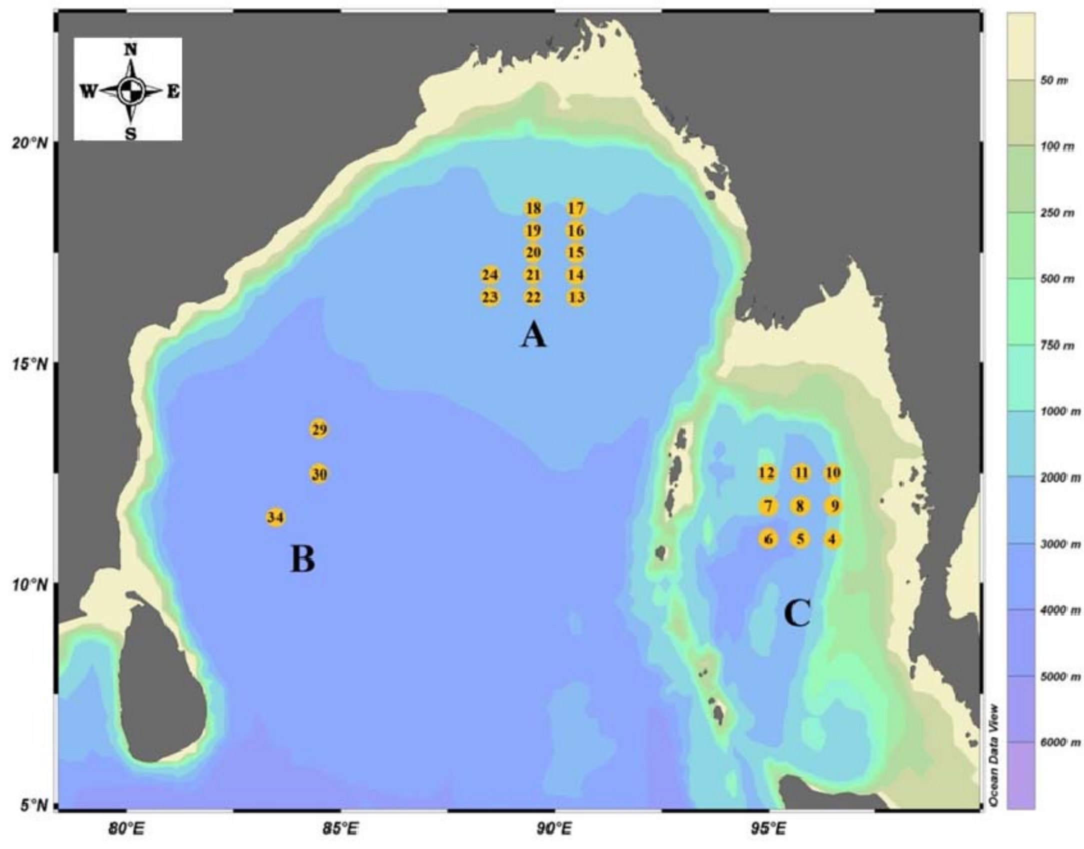

Figure 1 Chlorophyll sampling stations in the Bay of Bengal.

Table 1 Bottom depths and sampling depth (m) of chlorophyll samples.

Area	Station	Bottom depth	1st depth	2nd depth	3rd depth	4th depth
A	13	2,430	2	10	125	250
	14	2,353	2	10	125	200
	15	2,231	2	10	125	250
	16	2,136	2	10	125	250
	17	2,005	2	10	125	200
	18	2,012	2	10	150	250
	19	2,146	2	10	125	200
	20	2,249	2	10	125	250
	21	2,402	2	10	125	200
	22	2,511	2	10	125	200
	23	2,633	2	10	125	200
	24	2,530	2	10	125	200
B	29	3,412	2	10	125	200
	30	3,329	2	10	125	250
	34	3,470	2	-	-	-
C	4	890	2	10	115	215
	5	513	2	10	125	250
	6	3,526	2	10	125	200
	7	2,841	2	10	100	200
	8	2,556	2	10	125	300
	9	883	2	10	125	200
	10	1,128	2	10	125	200
	11	2,551	2	10	150	250
	12	1,418	2	10	125	250

“-”= samples were not collected

Results and Discussions

The bottom depth and sampling depth of the stations where chlorophyll samples were collected are shown in table 1. The concentrations of chlorophyll-a at various depths in the Bay of Bengal observed from this study are shown in table 2 and illustrated in figs. 2 and 4.

Table 2 Concentrations of chlorophyll-a (mg m^{-3}) observed at various depths.

Area	Station	Chlorophyll-a			
		1st depth	2nd depth	3rd depth	4th depth
A	13	0.4229	0.3951	0.1346	0.0415
	14	0.2224	0.2700	0.2562	0.0610
	15	0.1113	0.1388	0.0704	0.0856
	16	0.2314	0.2360	0.3184	0.0813
	17	0.1790	0.2045	0.1939	0.0851
	18	0.3130	0.3539	0.0618	0.0560
	19	0.4032	0.3560	0.0527	0.0365
	20	0.5074	0.6084	0.0686	0.0597
	21	0.2965	0.3737	0.0886	0.3003
	22	0.7147	0.7475	0.1061	0.0725
	23	0.7902	1.1162	0.0967	0.0538
	24	0.2742	0.2904	0.2100	0.0502
B	29	0.1397	0.1839	0.0502	0.0517
	30	0.1223	0.1319	0.0645	0.0357
	34	0.1533	-	-	0.0390
C	4	0.5207	0.2143	0.0830	0.0375
	5	0.1674	0.1519	0.1291	0.0458
	6	0.4738	0.2498	0.0898	0.0574
	7	0.2704	N.D.	N.D.	-
	8	0.1599	0.1852	0.1031	0.0414
	9	0.2187	0.2142	0.0817	0.0418
	10	0.2544	0.3218	0.0974	0.0522
	11	0.0433	0.1943	0.0453	0.1812
	12	0.1604	0.1812	0.0799	0.0422

"-"=samples not collected, "N.D." = not detected

Chlorophyll in area A: the northern Bay of Bengal (Fig. 2)

Distribution of chlorophyll-a at 2 m and 10 m are similar that low latitude stations had higher chlorophyll-a concentration than in the high latitude stations. The plume of chlorophyll-a distribution seemed to come from the Southeast. The surface chlorophyll-a concentration at the Southwest was higher than that in the northeast area by 0.5-0.7 mg m^{-3}. The chlorophyll-a concentrations at 2 m and 10 m ranged from 0.1113 to 0.7902, and 0.1388 to 1.1162 mg m^{-3}, respectively. Most of stations had higher concentration at 10 m more than at 2 m depth. Almost all stations that deeper than 100 m had lower concentration of chlorophyll-a.

In this study, the southwest of area A had the highest concentration of chlorophyll-a, which perhaps could be assumed, as influenced by the nutrients from deeper water lead by cold-core eddy which was consistently reported by Kumar *et al.* (2004). Distribution of chlorophyll-a was similar pattern to the salinity (Fig.3). Therefore, river discharge with high turbidity may impede photosynthesis activity of phytoplankton in the high latitude of this area.

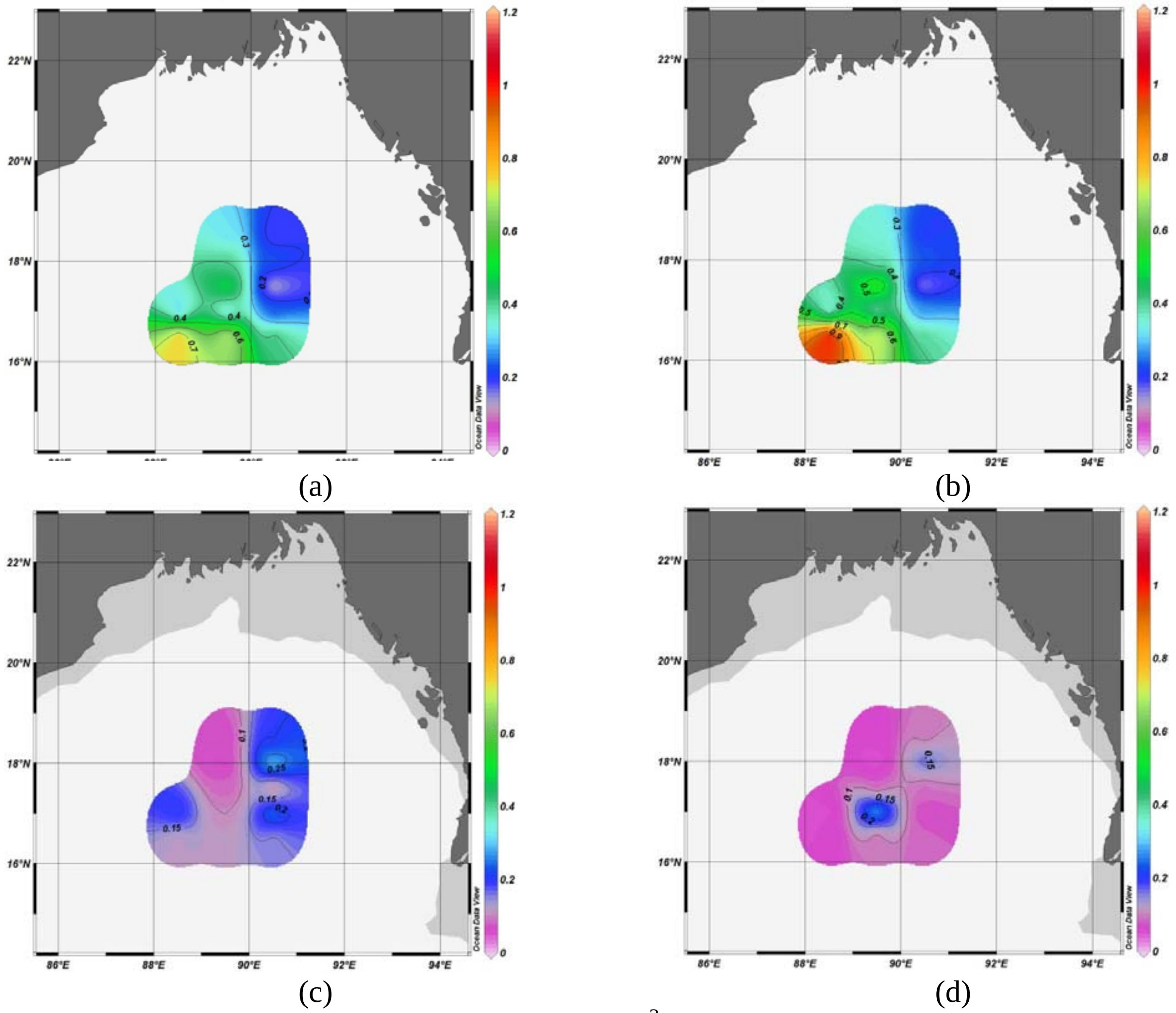

Figure 2 Concentration of chlorophyll-a (mg m^{-3}) in area A of the Bay of Bengal.
(a) 1st depth (b) 2nd depth (c) 3rd depth (d) 4th depth

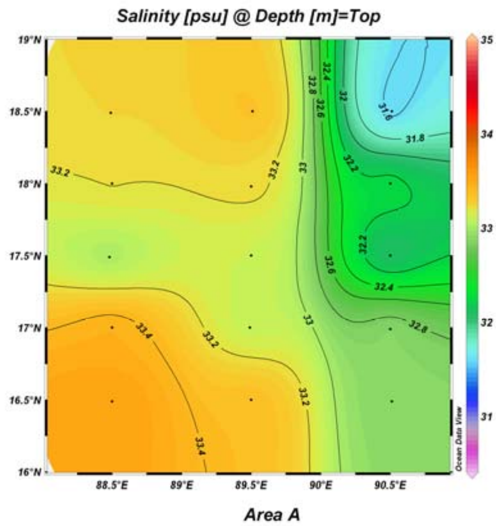

Figure 3 Horizontal plots of salinity (psu) at surface layer in area A.
(Dots indicate data location)

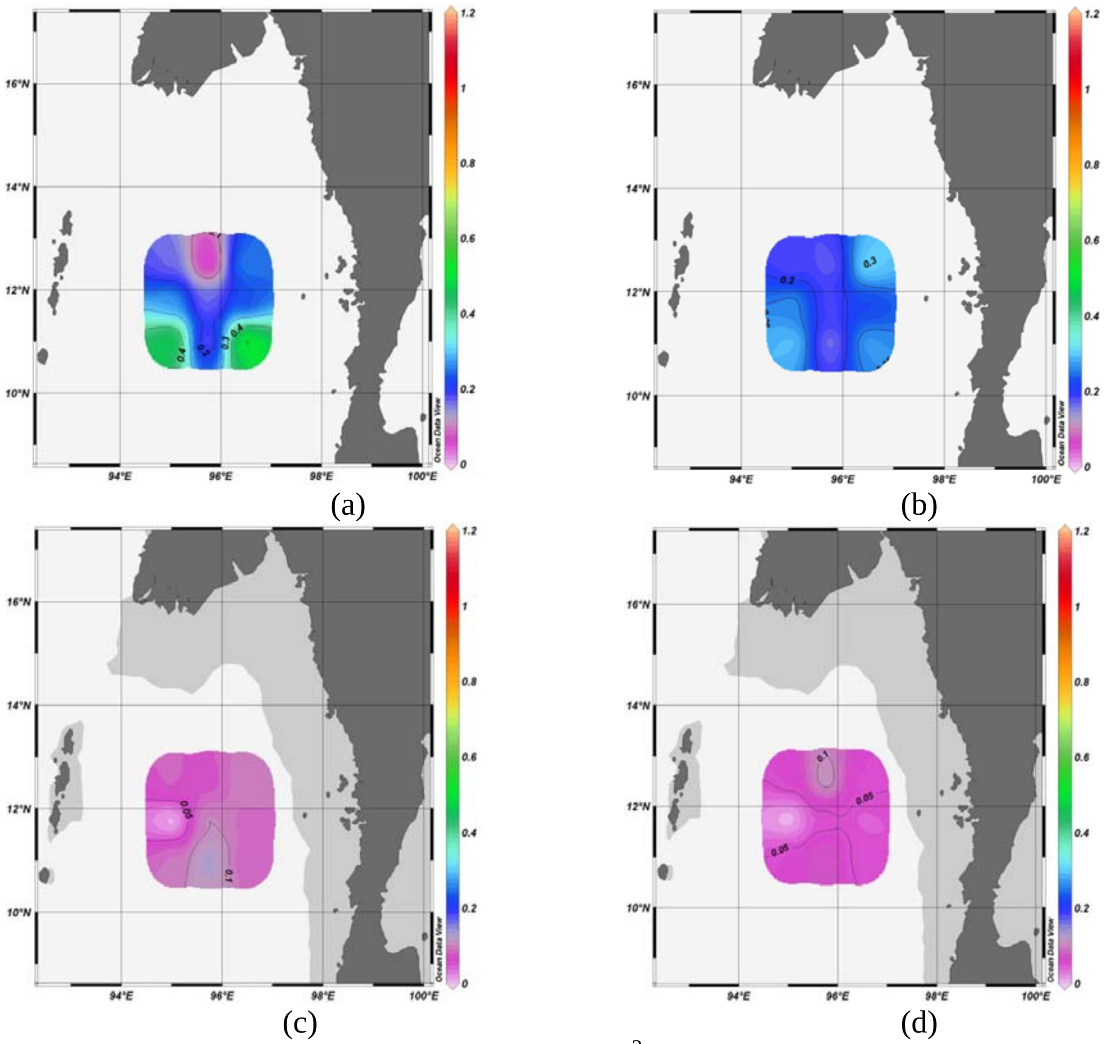

Figure 4 Concentration of chlorophyll-a (mg m^{-3}) in area C of the Bay of Bengal.
(a) 1st depth (b) 2nd depth (c) 3rd depth (d) 4th depth

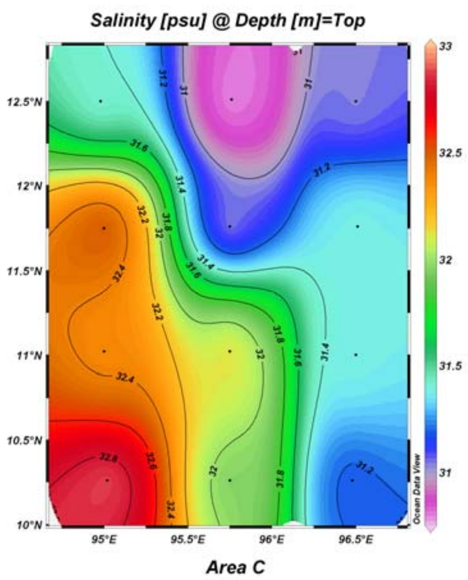

Figure 5 Horizontal plots of salinity (psu) at surface layer in area C.
(Dots indicate data location)

Chlorophyll in Area B: the Western Bay of Bengal

During the period when area B was surveyed, many of the survey stations were canceled because of the Northeast Monsoon and rough sea conditions. The data in area B were therefore not enough to make a conclusion. However, the chlorophyll-a concentrations observed from this area are indicated in table 2.

Chlorophyll in Area C: the Eastern Bay of Bengal (Fig. 4)

Spatial distribution of chlorophyll-a is shown in fig. 4. The chlorophyll-a concentrations at 2 m and 10 m ranged from 0.0433-0.5207 mg m^{-3} and 0.1519 to 0.3218 mg m^{-3}, respectively. The distributions of chlorophyll-a at 2 m and 10 m are same pattern. It was also observed that the low latitude stations had higher chlorophyll-a than the high latitude stations, similar to that in area A. Distribution of chlorophyll-a was also similar pattern to the salinity (Fig.5). Especially at surface layer of station 11, the salinity was low, because influence of the Irrawadee river discharge with high turbidity may effect to decreasing of chlorophyll-a concentration. At deeper than 100 m, chlorophyll-a concentrations were lower than above and homogeneous.

The observed range of chlorophyll-a at 2 m ranged between 0.04-0.52 mg m^{-3}, which were higher than in earlier reports by Wisespongpand *et al.* (2006) that the concentrations of chlorophyll-a in the Andaman Sea covering the waters of Thailand and Myanmar between 06° 45´N, 096° 15´E and 12° 45´N, 096° 45´E, were 0.03-0.11 mg m^{-3} . In this study, the highest concentrations of chlorophyll-a in several stations were observed at 10 m depth similar to area A.

Conclusions

It was observed during the survey that most of the low latitude stations in the Bay of Bengal exhibited somewhat higher chlorophyll-a concentrations than in the high latitude stations. The highest chlorophyll concentration was mostly confined at 10 m of most of the survey stations. Distribution of chlorophyll-a was similar pattern to the salinity. Furthermore, river discharge with high turbidity may impede photosynthesis activity of phytoplankton.

Acknowledgements

The authors wish to express their sincere thanks to all the scientists from Bangladesh, India, Myanmar, Sri Lanka, Nepal and Thailand for their cooperation during the BIMSTEC project survey, 75-1/2007 cruise of the M.V. SEAFDEC. The successful completion of this project would have not also been possible without the dedication of the officers from the Department of Fisheries of Thailand as well as the captain, officers and crew of the M.V. SEAFDEC. Our special thanks are also extended to Ms. Suree Satapoomin (Phuket Marine Biological Center), Ms. Puntip Wisespongpand (Department of Marine Science, Kasetsart University) and Ms. Virgilia T. Sulit (SEAFDEC) for their constructive and critical comments and suggestions.

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Species Composition, Abundance and Distribution of Phytoplankton in the Bay of Bengal

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Abstract

Species composition, abundance and distribution of phytoplankton were studied from water samples collected at surface layer of 24 stations in 3 areas (north, west and east) in the Bay of Bengal in November 2007. A total of 135 phytoplankton species belonging to 2 species of cyanobacteria, 78 species of diatoms, 53 species of dinoflagellates and 1 species of silicoflagellate were identified. The occurrence of species in each area was recorded. *Oscillatoria erythraea* and *Proboscia alata* were the dominant species in all areas. *Pseudo-nitzschia pseudodelicatissima* presented with high densities causing the blooms in the Northern Bay. The highest phytoplankton density was 133,790 cells/L. Dinoflagellate did not dominate phytoplankton population during this survey.

Key words : phytoplankton, Bay of Bengal, species composition, abundance, distribution

Introduction

This study is a part of the project on “The Ecosystem-Based Fishery Management in the Bay of Bengal” which is a collaborative survey project of the BIMSTEC member countries.

The Bay of Bengal is characterized as a large marine ecosystem bounded by territory of many countries. It is a semi-enclosed tropical ocean basin under strong influence of tropical monsoons and receives large volume of freshwater from both river discharge and rainfall (Vinayachandran and Mathew, 2003).The northern part of the Bay of Bengal is an area where storm surges and cyclones frequently occur. These cyclones cause turbulence in coastal and nearshore areas (Dwivedi and Choubey, 1998).

The information on phytoplankton in the offshore waters of the Bay of Bengal is scanty and inadequate for understanding the dynamics of the Bay ecosystem. Most studies have been carried out in the coastal areas. The International Indian Ocean Expedition was the prominent survey conducted both in the coastal areas and open sea of the Indian Ocean including the Bay of Bengal in 1963. Dinoflagellate species collected during this survey were recorded by Taylor (1974). Except for this expedition, the present study is the first investigation of phytoplankton in the offshore areas around the Bay. The purpose of this study is to describe species composition, abundance and distribution in the surface layer in the Bay of Bengal. The results will benefit for marine fishery studies of the BIMSTEC member countries.

Materials and Methods

Phytoplankton sampling was carried out on board M.V.SEAFDEC at 24 stations during November 2007. The study area was divided into three areas: area A or the Northern Bay, area B or the Western Bay and area C locates in the Eastern Bay of Bengal (Fig. 1). Seawater samples were collected by Van Dorn water sampler at 2-4 m below the sea surface. Forty to sixty liters of the water samples were filtered onto a 20 µm mesh phytoplankton net and preserved with 2% formalin/seawater mixture immediately. The samples were concentrated by sedimentation. Phytoplankton in the concentrated samples was count and identified by using a 0.5 ml counting slide, compound microscope fitted with a phase contrast device. Filamentous cyanobacteria was counted as one unit or filament.

Results

Identification

A total of 58 genera with 135 species were identified from the samples collected in the surface layer during this survey. The identified phytoplankton consisted of 2 genera with 2 species of cyanobacteria, 36 genera with 78 species of diatoms, 19 genera with 53 species of dinoflagellates and 1genus with 1 species of silicoflagellate. There were 52 genera with 103 species, 29 genera with 46 species and 48 genera with 95 species observed in the area A,B, and C, respectively. A taxonomic list and occurrence were recorded in Table1.

Phytoplankton Abundance

Phytoplankton densities in 3 areas of the Bay of Bengal are shown in Fig.2 and Table 2. The cell densities in the area A, B and C were in the range of 261-133,790, 509-722 and 171-11,178 cells/L, respectively. The maximum cell count was found at station 23 which is located in the northwestern part of the Bay. The cell densities examined from 3 stations in the area B were rather low similar to most stations in the area C but high cell densities were observed near coastal area of Myanmar.

Species Composition and Distribution

One species of cyanobacteria and 5 species of diatoms dominated phytoplankton population in the surface layer during the survey period in the Bay of Bengal. The composition of 6 dominant species and 15 associated species are shown in Table 2. *Oscillatoria erythraea* and *Proboscia alata* occurred as dominant species distributed in all areas (area A, B and C).

Phytoplankton population at 6 western stations of the area A were dominated by *Pseudo-nitzscia pseudodelicatissima* (Fig.3) and presented with highest percentage of abundance (68.12%) at station 20. The massive blooms of *Pseudo-nitzsci pseudodelicatissima* as dominant species and *Chaetoceros messanensis* as associated species, with of 27.67 % and 20.62 % contribution to total phytoplankton density, respectively, led to distinct phytoplankton bloom at station 23 in which total phytoplankton density reached 133,790 cells/l. Phytoplankton communities in 4 stations in area A were distinguished from other areas due to their lower abundance and the dominance (in term of percentage of abundance) of a cyanobacteria, *Oscillatoria erythraea*. There was no distinct bloom of phytoplankton in the area B and C. The dominant species and associated species of 3 stations in the area B occurred with low percentage of abundance of low total phytoplankton densities.

High percentage of abundance of dominant species were observed with low densities in some stations in the area C, and on the contrary, very low percentage of abundance of *Chaetoceros compressus* which presented as dominant species was found from high total phytoplankton density in station 10 (Table 2).

Discussion and Conclusion

Phytoplankton species of the present survey were mostly similar to those recorded from the Andaman Sea in November 2004 (Boonyapiwat, 2006) and Myanmar waters in February 2007 (Boonyapiwat, in press) but the species number was lower than other studies. This might due to the differences in sampling depths since only surface phytoplankton samples were reported in this study while other studies covered both surface and sub-surface samples. It is also widely recognized that phytoplankton species in the surface layer and deeper layer are different (Boonyapiwat, 1999, 2000; Furuya and Marumo,1983).

From this study, it is obvious that the Northern Bay of Bengal were productive with high phytoplankton densities during the northeast monsoon. Naik *et al.* (2006) noted that surface phytoplankton population in the Bay of Bengal showed seasonal variations and the abundance peaked during the beginning of northeast monsoon (November). However, Paul *et al.* (2007) collected sample during southwest monsoon and revealed that microphytoplankton were abundant in the Northern Bay. Then this area might be the most productive area compared to the other areas in the Bay of Bengal during both northeast and southwest monsoons. The present study showed the abundance at the western part of the Northern Bay that might be resulted from the nutrient-rich water discharge from the rivers at the west coast of India to the Bay of Bengal. The great bloom occurred at station 23 where Prommas *et al.* (in press) also found highest phosphate and nitrite+ nitrate concentrations.

Thallassionema frauenfeldii and *Thalassiothrix longissima* were the dominant species recorded by Paul *et al.* (2007) and they were abundant as associated species in the Northern and Western Bay of Bengal. *Oscillatoria erythraea* was dominant in the Eastern Bay which closed to Myanmar waters where Boonyapiwat (2006) and Boonyapiwat (in press) reported that this species also dominate phytoplankton population.

It is concluded that the Northern Bay of Bengal was productive during the survey period. *Psuedo-nitzscia pseudodelicatissima* occurred as bloom throughout the western part of the Northern Bay. *Oscillatoria erythrare* and *Proboscia alta* were the major dominant species in the Bay because they distributed predominantly in all areas of the Bay.

Acknowledgement

We extend our thanks to the officers and crew of the M.V.SEAFDEC and scientists on board for their assistance. A special thank to Dr. Ajcharaporn Piumsomboon for her useful suggestion and edition this paper.

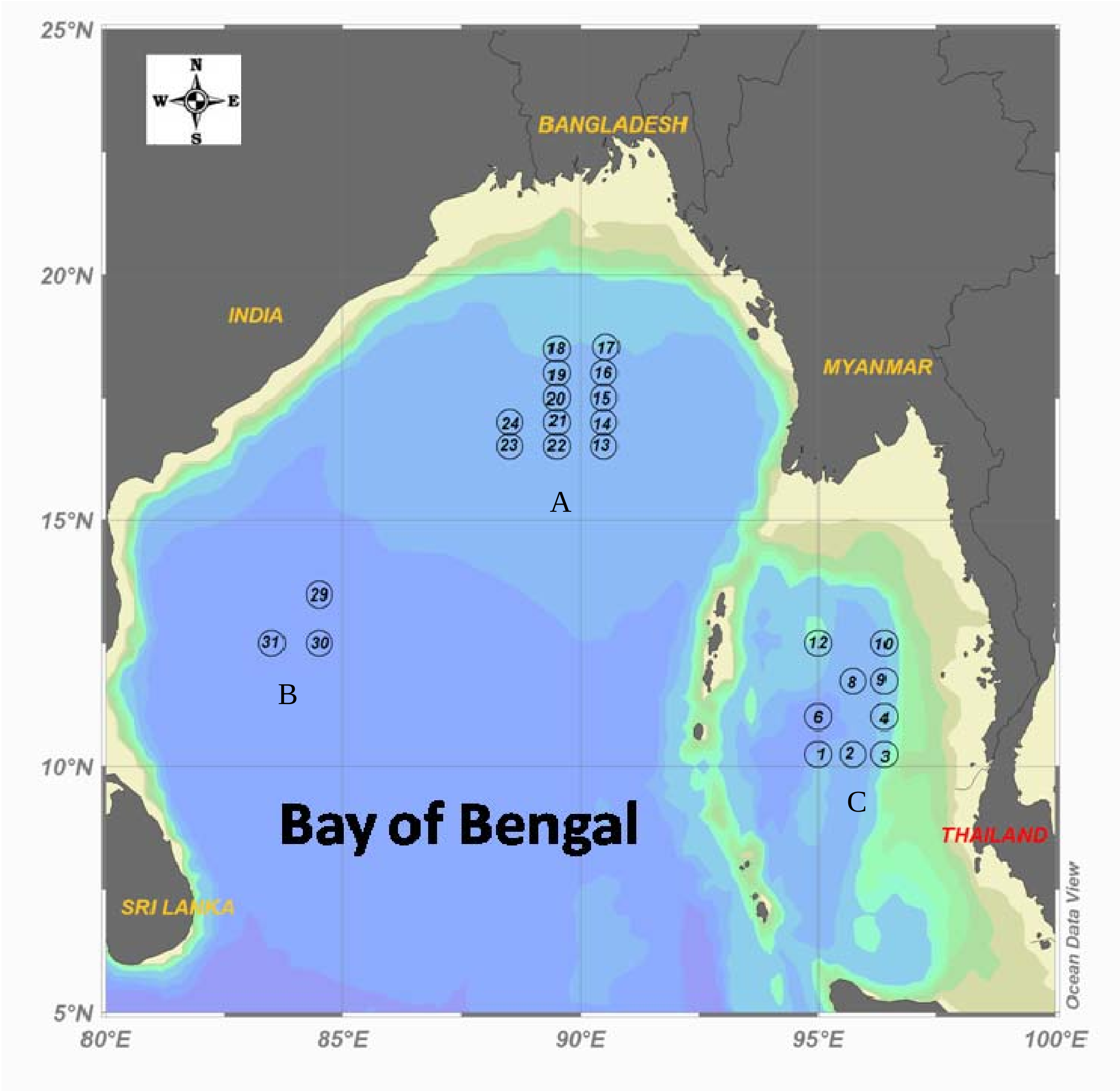

Figure 1 Sampling station of Phytoplankton in the Bay of Bengal.

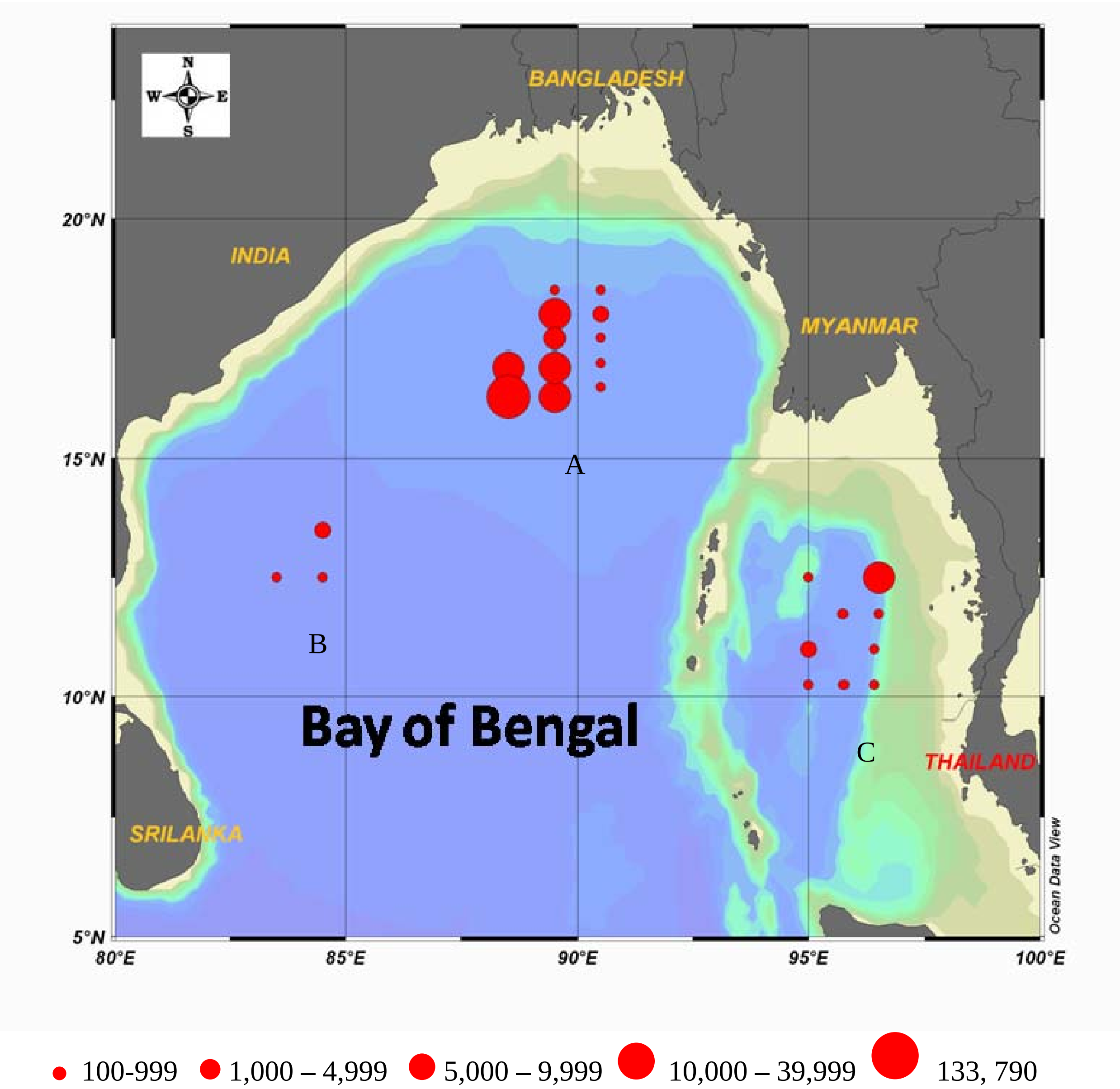

Figure 2 Phytoplankton density (cells/liter) in the surface layer.

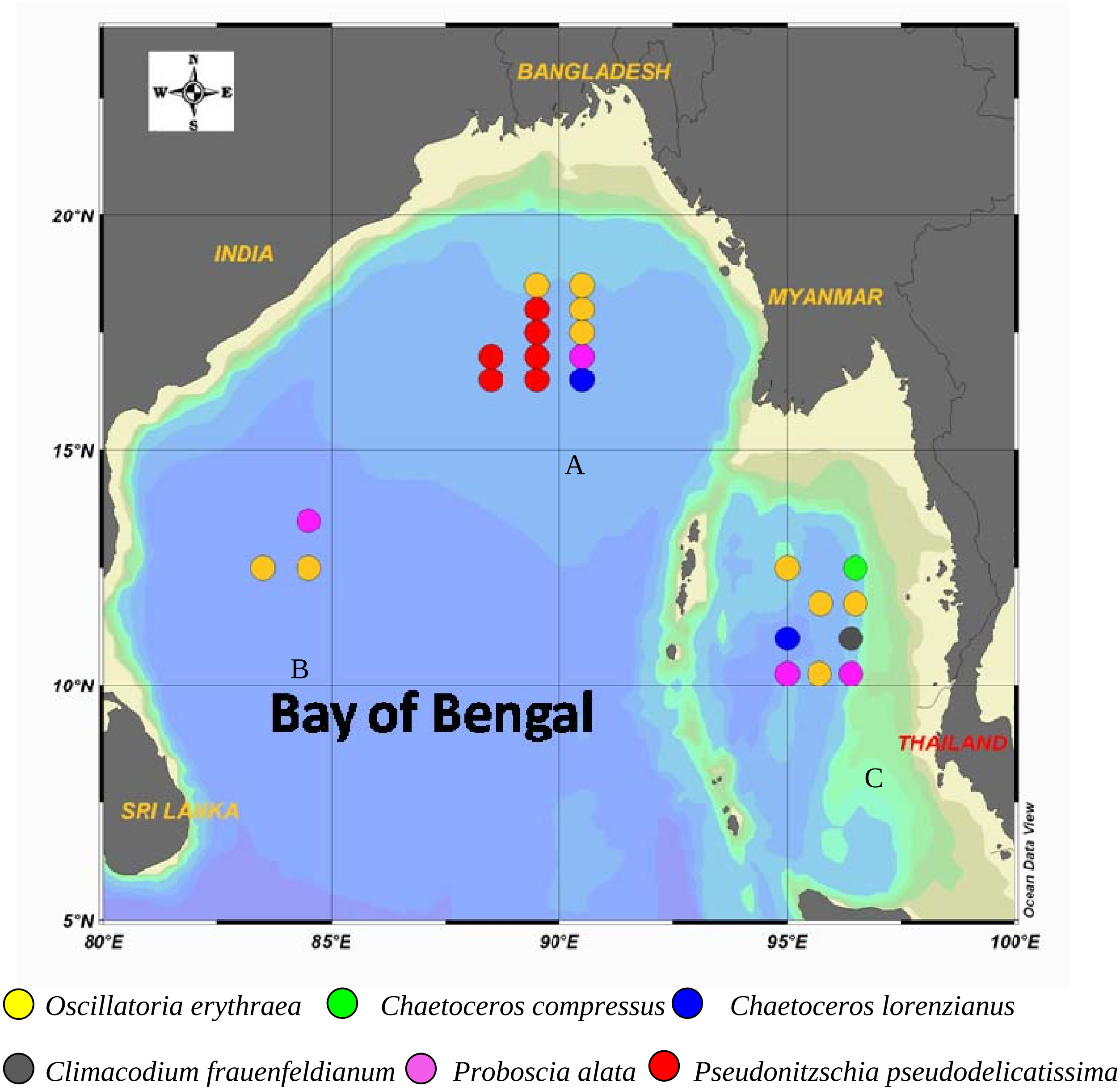

Figure 3 Dominant phytoplankton species in the Bay of Bengal.

Table 1 List of species occurred in 3 areas and range of their densities (cells/l).

Taxa	Area A	Area B	Area C
Division Cyanophyta			
Class Cyanophyceae (Cyanobacteria or Blue-green algae)			
Calothrix crustacea Schousboe & Thuret	0-416	3-26	0-5
Oscillatoria erythraea (Ehrenberg) Geitler	0-1,109	69-131	0-555
Division Chromophyta			
Class Bacillariophyceae (Diatom)			
Actinocyclus spp.	0-35	0	0-5
Asterolampra marylandica Ehrenberg	0-35	0	0
Asteromphalus flabellatus (Bre'bisson) Greville	0	0-1	0-17
A. roperianus (Greville)	0	0	0-5
A. sarcophagus Wallich	0	0	0-3
Asteromphalus spp.	0	0	0-2
Azpeitia nodulifera (A. Schmidt) G. Fryxell & P.A. Sims	0-4	0-26	0-35
Bacteriastrum comosum (O.F. Muller) Hendey	0-416	0	0-381
B. delicatulum Cleve	0-5,963	0-26	0-589
B. elongatum Cleve	0--607	0	0-18
B. minus Karsten	0	0	0-26
Bacteriastrum sp.	0-21	0	0-11
Cerataulina bicornis (Ehrenberg) Hasle	3-1,109	0	0-399
C. pelagica (Cleve) Hendey	0-5,963	0	0-36
Chaetoceros aequatorialis Cleve	0-104	0-7	0
C. affinis Lauder	0-2,496	0-113	0-849
C. atlanticus Cleve	0-8,736	0-26	0
C. borealis Bailey	0-320	0	0
C. brevis Schütt	0-503	0	0
C. coarctatus Lauder	0-1,127	0-165	0-121
C. compressus Lauder	0-27	0	0-1,30
C. curvisetus Cleve	0-3,328	0	0
C. dadayi Pavillard	0-815	0-24	0
C. densus (Cleve) Cleve	0-867	0	0-26
C. denticulatus Lauder	0-1387	0	0
C. diadema (Ehrenberg) Gran	0-32	0	0
C. didymus Ehrenberg	0	0	0-243
C. diversus Cleve	0-17	0-61	0-260
C. laevis Leuduger-Fortmorel	0	0	0-919
C. lauderii Ralfs in Lander	0-1,803	0	0
C. lorenzianus Grunow	0-2,635	0-113	0-1,109
C. messanensis Castracane	0-27,595	0	0-96
C. peruvianus Brightwell	0-1,803	0-61	0-86
C. pseudodichaeta Ikari	0	0	0-19
C. rostratus Lauder	0-2,912	0	0
C. socialis Lauder	0-589	0	0-399

0 = not found

Table 1 (Cont.)

Taxa	Area A	Area B	Area C
Chaetoceros subtilis Cleve	0	0	0-36
C. tetrastichon Cleve	0-225	0	0-5
Chaetoceros spp.	0-1,560	17-61	0-27
Climacodium biconcavum Cleve	0-156	0	0-108
C. frauenfeldianum Grunow	0-520	17-65	0-243
Corethron criophilum Castracane	0	0	0-35
Coscinodiscus asteromphalus Ehrenberg	0	0	0-4
C. radiatus Ehrenberg	0-3	0	0
Coscinodiscus spp.	0-4	0-4	0-3
Cylindrotheca closterium (Ehrenberg) Reimann & Lewin	0-104	0	0
Dactyliosolen blavyanus (H. Peragallo) Hasle	0-1	0	0
D. fragilissima (Bergon) Hasle	0-1	0	0-2
D. phuketensis (Sundstrom) Hasle	0-87	0	0-8
Detonula pumila (Castracane) Gran	0	0	0-1,179
Ditylum sol Grunow	0	0	35
Ethmodiscus spp.	0-2	0	0
Eucampia cornuta (Cleve) Grunow	0-1,248	0	2
Fragilariopsis doliolus (Wallich) Medlin & Sims	0-329	0	0-329
Fragillaria spp.	0-139	0	0-13
Guinardia cylindrus (Cleve) Hasle	0-87	0	0-2
G. flaccida (Castracane) H. Peragallo	0	0	0-17
G. striata (Stolterfoth) Hasle	0-52	0-26	0-64
Halicotheca thamensis (Shrubsole) Ricard	0-13	0	0
Haslea gigantea (Hustedt) Simonsen	0-1,109	0-19	0-11
H. wawrikae (Hustedt) Simonsen	0-35	0-26	0-8
Hemiaulus hauckii Grunow	0	0	0-66
H. membranacea Cleve	0	0	0-29
H. sinensis Greville	0-156	0-26	0-503
Lauderia annulata Gran	0-1	0	0-104
Leptocylindrus danicus Cleve	0-416	0	0-225
L. mediterraneus (H. Peragallo) Hasle	0-416	0-9	0-30
Lioloma delicatulum (Cupp) Hasle	0-69	0	0-17
Meuniera membranacea (Cleve) P. C. Silva	0-52	0-17	0-2
Navicula spp.	0-3	0	0-2
Nitzschia spp.	0-5	0	0
Planktoniella sol (Wallich) Schütt	0-832	0	0
Proboscia alata (Brightwell) Sundstrom	0-3,883	44-243	0-192
Pseudo-nitzchia pseudodelicatissima (Hasle) Hasle	0-37,024	0	0-68
P. pungens (Grunow&Cleve) Hasle	0-17,472	0	0
Pseudo-nitzschia spp.	0-65	0	0-96
Pseudosolenia calcar-avis (Chultz) Sundstrom	0-1,803	49-116	0-8
Rhizosolenia bergonii H. Peragallo	0-9	0-832	0

0 = not found

Table 1 (Cont.)

Taxa	Area A	Area B	Area C
Rhizosolenia clevei Ostenfeld	0-17	0-5	0-6
R. formosa H. Peragallo	0	0-4	0-8
R. hyalina Ostenfeld	0-10	0	0-2
R. imbricata Brightwell	0-173	0	0-52
R. robusta Norman	0	0	0-2
R. setigera Brightwell	0-35	0	0-329
R. styliformis Brightwell	0-139	0-9	0
Thalassionema frauenfeldii (Grunow) Hallegraeff	0-1,109	0-17	0-329
Thalassionema nitzschioides (Grunow) Mereschkowski	0	0	0-32
Thalassiosira eccentrica (Ehrenberg) Cleve	0-17	0	0-6
Thalassiosira spp.	0-953	0-12	0-8
Thalassiothrix longissima Cleve Grunow	0-1,248	0-52	0-1
Class Dinophyceae (Dinoflagellate)			
Alexandrium spp.	0-17	3-17	0
Amphisolenia bidentata Schroder	0-17	0-9	0-3
Ceratium azorium Cleve	0-17	0	0
C. biceps Claparede Lachmann	0	0	2
C. bilone Cleve	0	0-9	0
C. carriense Gourret	0-17	0	0-2
C. contortum Gourret	0-1	0	0
C. declinatum (Karsten) Jörgensen	0-87	0-3	0
C. deflexum (Kofoid) Jörgensen	0-1	0-1	0-1
C. dens Ostenfeld & Schmidt	0-35	0	0-1
C. furca (Ehrenberg) Claparede Lachmann	0-416	0-9	0-17
C. fusus (Ehrenberg) Dujardin	1-81	0-9	0-5
C. gravidum Gourret	0	0	0-2
C. gibberum Gourret	0-3	0	0
C. hexacanthum Gourret	0	0-1	0
C. horridum (Cleve) Hran	0	0-1	0
C. kofoidii Jörgensen	0-17	0	0-17
C. massiliense (Gouttet) Karsten	0-17	0	0
C. praelongum (Lemmermann) Kofoid	0-17	0	0
C. pulchellum Schroder	0-1	0	0
C. teres Kofoid	0-139	0-4	0-8
C. trichoceros (Ehrenberg) Kofdoid	0-17	0-1	0-2
C. tripos (O.F. Muller) Nitzsch	0-139	0-1	0-2
Ceratium spp.	0	0	0-2
Ceratocorys horrida Stein	0-17	0	0
Dinophysis acuminata Claparede & Lachmann	0	0	0-35
Dinophysis spp.	0-1	0	0
Diplopsalis lenticulata Berg	0-17	0	0-2
Goniodoma polyedricum (Pouchet) Jörgensen	0-139	0	0-2

0 = not found

Table 1 (Cont.)

Taxa	Area A	Area B	Area C
Gonyaulax glyptorhynchus Murry & Whitting	0	0	0-2
G. spinifera (Claparede & Lachmann) Diesing	0-17	0	0-6
Gonyaulax spp.	0	0-4	0
Gymnodinium sanguineum Hirasaka	0	0	0-4
Gymnodinium spp.	0-13	0	0-8
Ornithocercus magnificus Stein	0-1	0	0-35
O. thumii (A. Schmidt) Kofoid & Skogsberg	0-1	0	0-35
Oxytoxum scolopax Stein	0-7	0	0
Phalacroma doryphorum Stein	0-1	0	0-2
P. rotundatum (Claparede & Lachmann) Kofoid & Michener	0-1	0	0-5
Podolampas palmipes Stein	0-3	0-3	0-2
P. spinifera Okamura	0	0-1	0-1
Pronoctiluca spp.	0	0	0-2
Prorocentrum compressum (Bailey) Abe' & Dodge	0-1	0-1	0-1
P. graclie Schütt	0	0	0-1
P. mexicanum Tafall	0-1	0	0
P. micans Ehrenberg	0	0	0-5
Protoperidinium angustum (Dangeard) Balech	0-17	0	0
P. conicum (Gran) Balech	0-277	0	0-2
P. crassipes (Kofoid) Balech	0-1	0-1	0
P. divergens (Ehrenberg) Balech	0-2	0	0
P. grande (Kofoid) Balech	0	0	0-2
P. latispinum (Mangin) Balech	0-3	0-1	0
P. oceanicum (Vanhoff) Balech	0-17	0	0-17
P. pacificum Kofoid & Michener	0-2	0	0-17
P. pallidum (Ostenfeld) Balech	0-1	0	0
Protoperidinium spp.	0-35	0-1	0-10
Pyrocystis hamulus Cleve	0-1	0	0
P. lunula species complex	0-69	0-1	2
P. noctiluca Murray ex Haeckel	0-17	0	0
Pyrophacus horologium Stein	0	0	0-17
Scripsiella spp.	0-3	0-5	0-5
Class Dictyochophyceae			
(Silicoflagelate)			
Dictyocha speculum Ehrenberg	0-35	0	0
Dictyocha sp.	0	0	0-1

0 = not found

Table 2 Percentage of abundance of phytoplankton species in the Bay of Bengal.

Area	Station	Total (cells/l)	Dominant species	%	Associated species	%
C	1	171	*Proboscia alata*	40.94	*Climacodium frauenfeldianum*	12.28
	2	191	*Oscillatoria erythraea*	26.70	*Climacodium frauenfeldianum*	10.99
	3	649	*Proboscia alata*	29.58	*Oscillatoria erythraea*	14.79
	4	564	*Climacodium frauenfeldianum*	19.15	*Chaetoceros peruvianus*	15.25
	6	1,266	*Chaetoceros lorenzianus*	14.06	*Chaetoceros socialis*	12.12
	8	730	*Oscillatoria erythraea*	65.07	*Proboscia alata*	10.68
	9	328	*Oscillatoria erythraea*	62.80	*Chaetoceros lorenzianus*	5.79
	10	11,178	*Chaetoceros compressus*	12.41	*Detonula pumila*	10.55
	12	299	*Oscillatoria erythraea*	48.83	*Proboscia alata*	8.36
A	13	473	*Chaetoceros lorenzianus*	13.95	*Chaetoceros peruvianus*	9.72
	14	429	*Proboscia alata*	24.48	*Oscillatoria erythraea*	5.83
	15	716	*Oscillatoria erythraea*	21.23	*Thalassionema frauenfeldii*	17.18
	16	1,321	*Oscillatoria erythraea*	16.65	*Thalassionema frauenfeldii*	13.63
	17	661	*Oscillatoria erythraea*	18.00	*Thalassionema frauenfeldii*	16.79
	18	261	*Oscillatoria erythraea*	14.17	*Chaetoceros lorenzianus*	4.21
	19	11,691	*Pseudo-nitzschia pseudodelicatissima*	30.83	*Cerataulina bicornis*	7.26
	20	8,767	*Pseudo-nitzschia pseudodelicatissima*	68.12	*Cerataulina bicornis*	10.48
	21	14,613	*Pseudo-nitzschia pseudodelicatissima*	22.18	*Pseudo-nitzschia pungens*	13.52
	22	21,153	*Pseudo-nitzschia pseudodelicatissima*	14.5	*Chaetoceros messanensis*	10.82
	23	133,790	*Pseudo-nitzschia pseudodelicatissima*	27.67	*Chaetoceros messanensis*	20.62
	24	33,573	*Pseudo-nitzschia pseudodelicatissima*	33.04	*Pseudo-nitzschia pungens*	15.23
B	29	1,497	*Proboscia alata*	16.23	*Chaetoceros coarctatus*	11.02
	30	509	*Oscillatoria erythraea*	24.50	*Thalassiothrix longissima*	10.22
	31	722	*Oscillatoria erythraea*	18.14	*Pseudosolenia calcar-avis*	16.07

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Composition, Abundance and Distribution of Zooplankton in the Bay of Bengal

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Abstract

A 58 days-collaborative survey (25 October-21 December, 2007) of the BIMSTEC member countries (Bangladesh, India, Myanmar, Sri Lanka, Nepal and Thailand) was carried on in the Bay of Bengal in order to elucidate the fertility of the area as a new fishery ground. The purpose of this study was to determine the composition, abundance and distribution of zooplankton in 3 areas (area A; the northern part, area C; the eastern part and area B; the western part) of the Bay of Bengal. All samples were collected by oblique towing with Bongo net of 330 µm mesh size. The zooplankton community consisted of 205 species, 119 genera. Copepoda was the most important group both in term of species number and abundance. Widely distributed groups in this study were: copepods, protozoan zooplankton, arrow worms, larvaceans, cnidarians, ostracods and thaliaceans. The distribution pattern of major constituents of zooplankton community indicated the most productive nature of area A in comparison to other areas.

Keywords: zooplankton, Bay of Bengal, composition, abundance, distribution

Introduction

The Bay of Bengal locates in the northeastern part of the Indian Ocean. It resembles a triangle in shape and is bordered by India and Sri Lanka to the West, Bangladesh and the Indian state of West Bengal to the North and Myanmar, southern part of Thailand and the Andaman and Nicobar Islands to the East.

Zooplankton includes both planktonic or microscopic invertebrates and larval stages of some marine fishes that rely on water currents to move any great distance. Zooplankton is a broad categorization spanning a range of organism sizes that includes both small protozoans and large metazoans. Zooplankton includes holoplanktonic organisms whose complete life cycle lies within the plankton, and meroplanktonic organisms that spend part of their life cycle in the plankton before metamorphosis to either nekton or sessile, benthic existence. (wapedia, 2008) Through it consumption and processing of phytoplankton (and other food sources), zooplankton plays an important role in aquatic food webs, both as a resource for consumers on higher trophic levels and as a conduit for packaging the organic material in the biological pump (wikipedia, 2008). The importance of zooplankton as the first food for the post larval fish has been documented. Therefore, knowledges on diversity or species composition, abundance and distribution of zooplankton are of significance for fishery management. In addition, prediction of fish abundance based on only zooplankton in natural environment should be based on multiple components or food-web structure of the study area.

This study aims to present species composition, abundance of zooplankton including their distribution in the Bay of Bengal. The qualitative and quantitative data were analyzed from 33 samples taken from 3 areas in the Bay of Bengal. This is a collaborative survey project of the BIMSTEC member countries (Bangladesh, India, Myanmar, Sri Lanka, Nepal and Thailand). The main purpose of BIMSTEC is to manage fishery resources in the Bay of Bengal.

Material and Methods

Zooplankton samples were collected from 33 stations during the cruise of fisheries research vessel M.V. SEAFDEC between 25 October to 21 December 2007 (Table 1 and Fig. 1) in the Bay of Bengal. The sampling stations were divided into 3 areas: area A (latitude 16°N-19°N, longitude 88°E-91°E) covered 15 stations (station 13-27), area B (latitude 09°N-14°N, longitude 82°E-85°E) included 7 stations (station 13-27) and area C (latitude 10°N-12°N, longitude 95°E-97°E) included 11 stations (station 1-6 and 8-12).

Zooplankton samples were collected using a Bongo net, 45 cm. in diameter and 330 µm mesh size, equipped with a flow meter and obliquely towed at a vessel speed of 2 knots. The towing depth of each haul was 150 meters. The samples were immediately preserved in 5% buffered formaldehyde sea water for further analyses.

Zooplankton samples were counted for larger representatives such as cnidarians, decapods, euphausids, arrow worms, etc. using an open counting chamber of 80 mm X 50 mm X 2 mm size. Counting was made under a binocular dissecting microscope at proper magnification. The examination at a higher magnification under the compound microscope may be used to identify questionable organisms. For dense sample, zooplanktorn fraction of <200 µm were separated from the larger ones by filtration and sub-sampled with a Widebore pipet for an aliquot of 1-5 ml for counting with a Sedgwick-Rafter counting chamber under a compound microscope at 100X magnification.

Report zooplankton as number per cubic meter:

$$\text{No. individuals/ m}^3 = \frac{C \times V_1}{V_2 \times V_3}$$

Where C = number of organisms counted,
V_1 = volume of the concentrated sample (ml),
V_2 = volume of the sample counted (ml),
V_3 = volume of the filtered volume of water (m^3)

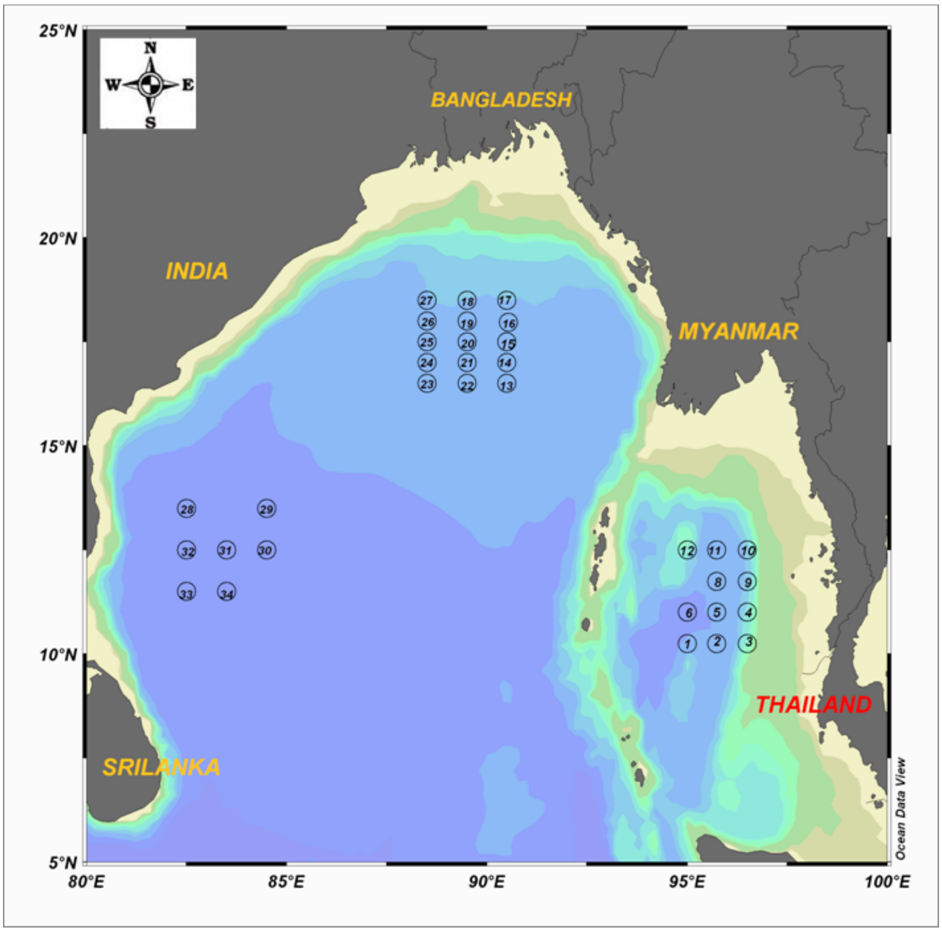

Figure 1 Sampling stations in the Bay of Bengal.

Results

Species Composition

Zooplankton communities in the Bay of Bengal consisted of 205 species, 119 genera and 44 taxa. Copepods were the most diverse group containing the highest number of species (98), followed by Cnidaria (32) and Protozoa (25). The taxa that were not identified to generic or species levels included Polychaeta, mollusk larvae, Mysidacea, decapod larvae, larval stages of Copepoda, Cyphonautes larvae, Echinodermata larva and fish larvae. There was no significant difference in the diversity and the abundance of zooplankton from three studied areas. The diversities in decreasing order were as followed: area A (150 species, 119 genera), area C (147 species, 87 genera), and area B (131 species, 81 genera).

Abundance

Copepoda were so far the most abundant taxon accounting for 45.82% of total zooplankton densities within the copepod communities, the relative abundance of calanoid copepods was 30.68% of total copepods followed by and poecilostomatoids (10.51%) and cyclopoids (6.17%) and harpacticoids (0.07%) in respective order. Major taxa of calanoids included Augaptiliidae, Acartiidae, Centropagidae, Pontellidae, Calanidae, Paracalanidae, Eucalanidae, Euchaetidae and Scolecithricidae. Copepodites were high in number at most stations. Sarcodine protozoans ranked the second in abundance after copepods and made up for 17.52% of total zooplankton density. Other common taxa were arrow worm (8.92%) and larvaceans (6.56%) with Sagitta and Oikopleura as the regular constituents in these areas.

Total zooplankton abundance was ranging from 97-568 individuals/m^3.The highest zooplankton abundance in this study was recorded from area A with 154-568 individuals/m^3 of total abundance followed by area B (97-477 individuals/m^3 of total abundance) and area C (84-344 individuals/m^3 of total abundance). The highest abundance was observed at station 24 in area A with zooplankton density of 568 individuals/m^3, followed by 477 individuals/m^3 at station 29 in area B and 97 individuals/m^3 in station 33 of area B. Copepods, the most abundant taxon in all areas, contributed to 40.10% of total abundance in area B, 43.00% in area A, and 55.22% in area C. Sarcodine protozoans were the second most abundant taxon after copepods in area A and area B. Arrow worms occurred in all areas, and were usually found in moderate numbers ranging from 5.75% to 11.75% of total abundance. Larvaceans were rich in area A and area B with 6.55% of total abundance and 6.41% of total abundance, respectively. Ostracods were abundant only in area B with 8.80% of total abundance. Details of distribution and abundance o zooplankton were shown in table 1 and fig. 2-8.

Distribution and Abundance of Zooplankton Groups

Distribution of zooplankton groups are recorded in terms of percentage of occurrences which were divided into 4 categories: 1-25% = very rare; 26-50% = rare; 51-75% = common and 76-100% = very common/ widely distributed.

1. Sarcodine protozoans

Sarcodine protozoans consisted mainly of planktonic foraminiferans and radiolarians. A total of 24 species from 21 genera were identified. Important sarcodine protozoans species were *Centrocubus cladostylus, Hystrichaspis dorsata, Spongosphaera streptacantha, Acanthochiasma fusiforme* and *Glogigerina bulloides*. Their contributions were 82%, 64%, 55%, 48%, and 45% of occurrences, respectively. Their abundances ranged from 1 individuals/m^3 to 195 individuals/m^3. The highest abundance found at station 20 in area A.

2. Ciliates

This group was very rare in this study area with only 3% occurrence of a single species: *Tintinnopsis mortensii* with 1 individuals/m^3 at station 30 in area B.

3. Cnidarians

Cnidarians includes Hydomedusae and Siphonophores. A total of 32 species from 26 genera were identified in the study area. Cnidarian abundance ranged from 6 to17 individuals/m^3; the maximum value was found at station 19 in area A. Siphonophores were commonly distributed. *Chelophyes contorta* had highest percentage of occurrences with 94% followed by *Bassia bassensia* (85%) and *Enneagonum hyalinum* (79%), respectively**.** Most species of Hydomedusae were rarely distributed. Only two species (*Aglaura hemistoma* and *Liriope tetraphylla*) were widely distributed; with the values of 67% and 36%, respectively.

4. Polychaetes

Nine species belonging to 7 genera were collected in the study area. Polychaetes in this study included both planktonic forms and larval forms (meroplankton). All species were low in numbers and rarely found with the percentage of occurrences were not higher than 21%. Polychaete larvae were widely distributed (55%) in low number ranging from 1 to 4 individuals/m^3. The occurrence of planktonic polychaetes was rare (3-21%).

Pedinosoma curtum was widely distributed. Total abundance ranged from 1 to 4 individuals m^{-3}. The maximum densities was found at stations 22, 23, 25 and 27 in area A and stations 28 and 30 in area B.

5. Mollusks

Mollusks in this study included gastropod larvae, planktonic mollusks and bivalved larvae. Mollusks occurred in low abundances ranging from 1 to 8 individuals m^{-3}. Planktonic mollusks in class Gastropoda found in this study were in subclasses Prosobranchia and Opistobranchia. Among Prosobranchia (heteropods), Atlanta was common in this study. It was commonly distributed (55%) in small numbers (1-7 individuals/m^3). The Opistobranchia (pteropods) in order Thecosomata or shelled pteropods were less diverse, approximately 6 species were identified. The common genus was Creseis. Only *Notobranchaea* sp., the naked pteropods (Order Gymnostomata) was found at stations 25 and 27. Gastropod larvae and bivalved larvae were rarely distributed (3%) in this study.

6. Calanoid copepods

This is one of important taxa in this study. It is the most diverse groups in the area: 64 species 34 genera in 13 groups were identified. Four widely distributed (79-97%) species were *Lucicutia flavicornis, Clausocalanus arcuicornis, Scolecithricella longispinosa* and *Acrocalanus gibber*. Total abundances of calanoid copepod ranged from 18 to 271 individuals/m^3. The maximum value was found at station 24 in area A. Calanoid copepodids were very high at all stations the maximum number was observed at station 24. *Clausocalanus arcuicornis* was high in number at station 22 and 27 in area A. *Scolecithricella longispinosa* and *Paracalanus aculeatus* were also found in moderate abundance. Copepodid stages of calanoid copepods were common all stations particularly copepodites of Subeucalanus and Euchaeta. They were more abundant (148-179 individuals/m^3) and widely distributed (91-100%). However, nauplii stages of all genera were rarely distributed and low number.

7. Cyclopoid copepods

Oithona was the dominant genus in this study. It was widely distributed (100% occurrence) at all station. Their abundances varied greatly from 1 to 32 individuals/m^3. Maximum number was found at station 22 in area A.

8. Harpacticoid copepods

This groups were one of the rare groups in this study with 3-5% occurrence. Only two species (*Macrosetella gracilis* and *Miracia efferata*) were identified and observed in low numbers with 3 and 2 individuals/m^3, respectively. Harpacticoid copepods were not found in area B

9. Poecilostomatoid copepods

Thirty one species belonging to 6 genera were identified. Four widely distributed species (79-100% occurrence) were *Oncaea venusta, O. conifera, Corycaeus catus*, and *Copilia mirabilis*. Among these species *O. venusta* was the dominant species in this study. Total abundances of Poecilostomatoid copepods ranged from 7 to 110 individuals/m^3. Maximum value was found at station 1 in area C.

10. Ostracods

Ostracods were commonly distributed. Two genera: Cypridina and Euconchoecia were found in this study. Total abundances of ostracods ranged from 1 to 116 individuals/m^3.

The maximum value was found at station 29 (116 individuals/m^3) in area B. *Euconchoecia* spp. were widely distributed (97% occurrence) but completely absent station 24. *Cypridina* spp. were very rarely distributed (21% occurrence) and presented in very low to medium number (1-49 individuals/m^3).

11. Hyperiids

Ten species in 7 genera of hyperiid were identified in the study area. They were rarely distributed (3-39% occurrence) in very small numbers (1-6 individuals m^{-3}). The highest abundance found in area B with 21 individuals/m^3. *Lestrigonus macroohthalanus* was common species in the area.

12. Mysids

Mysids was one of the rare groups in this study. Its distribution was 18% occurrence with very low abundance (1-2 individuals/m^3). Mysids was completedly absent in area A.

13. Euphausids

Larval stages were commonly distributed with 70% occurrence. Low abundance values of 1-7 individuals/m^3 were observed. Maximum number was found at station 9 in area C. Adult stages found only *Stylocheiron* sp. was at stations 30 and 31 in area B with abundance values of 1 individuals/m^3

14. Stomatopod larvae

Both larval stages (erichthus and alima) were collected in the area. Alima larvae were more often observed than erichthus larvae (20% and 3% occurrence). They were always found in very low numbers (1-3 individuals/m^3)

15. Planktonic shrimps

This group included larval stages of Penaeid, Caridean and Palinuran shrimps. One genus (Lucifer) was identified in the samples. Early larval stage of Penaeid, Caridean and Palinuran shrimps were very rare (3-15% occurrence) in the samples with abundance values of 1 individuals/m^3. Abundance of Lucifer was very low both in adult forms and larval forms (protozoea and mysis); only 3-39% occurrences were recorded. Its abundance values ranged from 1 to 9 individuals/m^3; the maximum value was found at station 29 in area B.

16. Crab larvae

This group included Anomuran larvae, Porcellanid larvae and zoea stage of Brachyura (true crab). They were very rarely distributed (3-6 % occurrence) with very low abundance values (1-2 individuals/m^3) at only four stations (2,4,25 and 28).

17. Decapod larvae

This is one of the rare groups in this study. Very low abundanc was observed at station 24 in area A (2 individuals/m^3).

18. Arrow worms

A total of 10 species belonging to genera Sagitta were persent in the samples. *Sagitta* was an important genus that was widely distributed (94% occurrence) with abundance value ranged from 1 to 78 individuals/m^3. Maximum value was found at station 31 in area B. *Sagitta enflata* was the most important species occurring at most stations.

19. Bryozoans

Cyphonautes larvae, the larval stage of phylum Ectoprocta were rarely observed (9% occurrence) in this study. Very low abundances (1 individual/m^3) were recorded at three stations (11, 17 and 25). Bryozoans wwas completely absent in Area B.

20. Echinodermata larvae

This group consisted of bipinnaria larvae of class Asteroidea, auricularia larvae of class Holothuroidea, echinopluteus larvae of class Echinoidea and ophiopluteus larvae of class Ophiuroidea. They were very rare in distribution (21%, 3%, 9% and 18% occurrence), respectively. Their abundances varied from 5 to 106 individuals/m^3. Bipinnaria larvae and auricularia larvae were found only in area C. Echinopluteus larvae and Ophiopluteus larvae were found in area A and C. Echinodermata larvae was completely absent in area B.

21. Larvaceans

Only one genus: Oikopleura was found in this study. They were regularly found (18-94%) in the study area. Their abundances ranged from 1 individual/m^3 to 39 individuals/m^3. Two important species were: *O. fusiformis* and *O. longicauda*, and were widely distributed with 94% and 88% occurrences, respectively. The highest abundance found in area A (74 individuals/m^3).

22. Thaliaceans

Two groups of thaliaceans were rare and present in low number. Salps consisted three genera: Pegea, Salpa and Thalia. Only one genus of doliolids (Doliolum) was identified. *Doliolum* spp. were common in distribution (80% occurrence), but occurred in low abundance values (1-7 individuals/m^3). Maximum number of thaliaceans were found at station13 and 27 in area A. Salps were rarely distributed (15-24% occurrence) of low number ranging from 1-4 individuals/m^3

23. Fish eggs and fish larvae

The data recorded here was underestimated; accurate data will be published elsewhere under ichthyoplankton. Fish eggs and fish larvae were separarely collected by a 500 µm plankton net. Eggs and larvae of fish rarely distributed (3-9% occurrence) in low numbers ranging from 1 to 2 individuals/m^3. They were observed in three found only three samples collected from station 13, 23 and 32.

24. Cephalochordates

Amphioxides sp. was only one species collected in the study area. This groups was one of the rare groups in this study with 21% occurrence. Small number (1-4 individuals/m^3) was observed at 7 stations. The maximum value was found at station 20 in area A. Cephalochordates was absent in area C.

Table 1 Distribution of marine zooplankton and abundance (individuals/m^3) of species found at 3 Areas in the Bay of Bengal.
(The number indicated minimum and maximum density in a unit of individuals/m^3)

Taxa/Species	Abundace values		
	Area A	Area B	Area C
PHYLUM PROTOZOA (protozoans)			
Class Sarcodina			
Order Foraminiferida			
Berggrenia (Globerotalia) pumilio (Parker)	0	0	0-1
Candeina nitida d' Orbigny	0-1	0	0
Globigerina bulloides d' Orbigny	0-63	0-15	0
G. falconensis Blow	0-4	0	0-2
Globigerinella siphonifera d' Orbigny	0-2	0	0
Globigerinita minuta (Natland)	0	0	0-1
Globorotalia menardii (Parker,Jones and Brady)	0-1	0-3	0
Hastigerina digitata (Rhumbler)	0-4	0-2	0
Sphaeroidinella dehiscens (Parker and Jones)	0	0-2	0
Tenuitella parkerae (Broennimann and Resig)	0-6	0	0-2
Order Radiolarida			
Family Acanthochiasmidae			
Acanthochiasma fusiforme Haeckel	0-9	0-9	0-3
A. rubescens Haeckel	0-80	0-3	0-1
Family Acanthometridae			
Acanthometra bulbosa Haeckel	0-1	0	0
A. pellucida Müller	0-1	0	0-5
Family Dorataspidae			
Hystrichaspis dorsata Haeckel	0-10	0-6	0-3
Family Spongodiscidae			
Stylodictya sp.	0-3	0	0
Family Castanellidae			
Castanidium variabile Borgert	0-7	0	0-1
Family Actinommidae			
Carposphaera acanthosphora (Popofsky)	0-2	0	0
Centrocubus cladostylus Haeckel	8-93	0-34	0-10
Cromyomma circumtextum Haeckel	0	0	0-1
Heliosoma sp.	0-1	0	0
Spongosphaera streptacantha Haeckel	0-17	0-6	0-4
Family Phyllostauridae			
Acanthostaurus purpurascens (Haeckel)	0-1	0	0

* 0 = not found

Table 1 (Cont.)

Taxa/Species	Abundace values		
	Area A	Area B	Area C
Family Dictycanthidae			
Dictyacantha sp.	0-1	0-1	0
Class Ciliata			
Order Tintinnida			
Family Codonellidae			
Tintinnopsis mortensii Schmidt	0	0-1	0
PHYLUM CNIDARIA (cnidarians)			
Class Hydrozoa			
Order Anthomedusae			
Family Corynidae			
Euphysora bigelowi Maas	0	0	0-1
Sarsia resplendes Bigelow	0-1	0	0-1
Family Bougainvilliidae			
Bougainvillia principis (Steenstrup)	0	0	0-1
Kollikerina fasciculata Péron and Lesueur	0	0	0-1
Order Leptomedusae			
Family Phialuciidae			
Octophialucium medium Kramp	0-1	0-1	0-1
Family Eirenidae			
Eirene hexanemalis (Goette)	0-1	0	0
Eutima gracilis (Forbes and Goodsir)	0-1	0	0
Order Limnomedusae			
Family Proboscidactyla			
Proboscidactyla ornata (McCrady)	0-1	0	0
Order Trachymedusae			
Family Rhopalonematidae			
Amphogona apicata Kramp	0	0-1	0
Family Geryoniidae			
Aglaura hemistoma Péron and Lesueur	0-1	0-1	0-1
Liriope tetraphylla (Chamisso and Eysenhardt)	0-1	0-1	0-1
Order Narcomedusae			
Family Aeginidae			
Solmundella bitentaculata (Quoy and Gaimard)	0-1	0-1	0
Family Cuninidae			
Cunina octonaria McCrady	0-1	0	0-10

* 0 = not found

Table 1 (Cont.)

Taxa/Species	Abundace values		
	Area A	Area B	Area C
Order Siphonophora			
Family Agalmidae			
Agalma haeckeli Bigeloe	0-1	0-1	0-1
Family Prayidae			
Amphicaryon acaule Chun	0	0-1	0-1
A. peltifera Haeckel	0-1	0-1	0-1
Family Hippopodiidae			
Hippopodius hippopus (Forskal)	1-1	0-1	0-1
Family Diphyidae			
Sulculeolaria quadrivalvis Blainville	0-1	0-1	0-1
Diphyes bojani (Eschscholtz)	0-1	0-1	0-1
D. chamissonis (Huxley)	0-1	0	0-1
D. dispar Chamisso and Eysenhardt	0-1	0-1	0-1
Lensia campanella (Moser)	0-1	0-1	0-1
L. challengeri Totton	0-1	0-1	0-1
L. conoidea (Keferstein and Ehlers)	0-1	0-1	0-1
L. subtiloides (Len and van Riemsdijk)	0-1	0-1	0-1
Chelophyes contorta (Lens and van Riemsdijk)	0-1	1-1	0-1
Eudoxoides mitra (Huxley)	0-1	1-1	0-1
Family Abylidae			
Abyla trigona Quoy and Gaimard	0	0-1	0-1
Abylopsis eschscholtzi (Huxley)	0-1	0-1	0-1
A. tetragona (Otto)	0-1	0-1	0-1
Bassia bassensia (Quoy and Gaimard)	0-1	1-1	0-1
Enneagonum hyalinum Quoy and Gaimard	0-1	0-1	0-1
PHYLUM ANNELIDA (segment worms)			
Class Polychaeta			
Polychaete larvae	0-4	0-3	1-3
Order Phyllodocida			
Family Alciopidae			
Alciopina parasitica Clapare'de & Panceri	0	0-3	0-1
Rhynchonerella moebii (Apstein)	0	0	0-2
Family Iospilidae			
Iospilus affinis (Viguier)	0-3	0-1	0
Phalacrophorus pictus Greeff	0-1	0	0

* 0 = not found

Table 1 (Cont.)

Taxa/Species	Abundace values		
	Area A	Area B	Area C
Family Lopadorhynchidae			
Maupasia gracilis Reibisch	0-1	0	0
Pedinosoma curtum Reibisch	0-2	0-1	0-1
Family Tomopteridae			
Tomopteris dunckeri Rosa	0-1	0	0-1
T. elegans Chun	0-1	0-1	0-1
T. nationalis Apstein	0	0	0-1
PHYLUM MOLLUSCA (mollusks)			
Class Gastropoda			
Subclass Prosobranchia (heteropods)			
Order Mesogastropoda			
Family Atlantidae			
Atlanta spp.	0-7	0-5	0-1
Subclass Opistobranchia (pteropods)			
Order Thecosomata (shelled pteropods)			
Family Limacinidae			
Limacina sp.	0	0	0-1
Family Cavoliniidae			
Creseis acicula (Rang)	0-2	0	0-1
C. virgula (Rang)	0-1	0-1	0-2
Cuvierina sp.	0-1	0	0
Family Cymbuliidae			
Cymbulia sp.	0	0	0-1
Order Gymnosomata (naked pteropods)			
Family Notobranchaeidae			
Notobranchaea sp.	0-1	0-1	0
Gastropod larvae (veliger larvae)	0-1	0	0
Class Bivalvia			
Bivalve larvae (veliger larvae)	0	0-1	0
Class Cephalopoda	0-66	0-35	14-108
PHYLUM ARTHROPODA			
SUBPHYLUM CRUSTACEA (CRUSTACEAN)			
Class Maxillopoda			
Subclass Copepoda			
Copepod nauplii	0-2	0-1	0-1

* 0 = not found

Table 1 (Cont.)

Taxa/Species	Abundace values		
	Area A	Area B	Area C
Order Calanoida			
calanoid unidentified species1	0-1	0-1	0
calanoid unidentified species2	0	0-1	0
Calanoid copepodid	5-71	2-33	0-21
Superfamily Arietelloidea			
Family Augaptiliidae			
Euaugaptilus sp.	0	0-1	0-1
Haloptilis longicornis (Claus)	0-2	0-3	0-1
H. mucronatus (Claus)	0	0-1	0-1
H. spiniceps (Giesbrecht)	0-1	0	0
Haloptilus sp.1	0-1	0	0
Haloptilus sp.2	0-1	0	0-1
Haloptilis copepodid	0-1	0-1	0-1
Family Heterorhabdidae			
Heterorhabdus papilliger (Claus)	0-2	0-1	0-1
Family Lucicutiidae			
Lucicutia flavicornis (Claus)	1-9	1-4	0-4
Lucicutia copepodid	0-4	0-3	0-5
Family Metridinidae			
Pleurommama robusta (Dahl)	1-12	0-3	0-1
Superfamily Centropagoidea			
Family Acartiidae			
Acartia amboinensis Carl	0	0-1	0-5
A. danae Giesbrecht	0-1	0	0-1
A. negligens Dana	0-1	0-3	0-2
A. pacifica Steuer	0	0	0-3
Acartia copepodid	0	0-1	0-8
Family Candaciidae			
Candacia catula (Giesbrecht)	0-2	0-1	0-2
C. pachydactyla (Dana)	0	0-1	0-1
Candacia sp.1	0-1	0	0
Candacia sp.2	0-1	0	0
Candacia sp.3	0	0-1	0-1
Paracandacia truncata (Dana)	0-1	0-1	0-2
Candacia copepodid	0-1	0-3	0-5

* 0 = not found

Table 1 (Cont.)

Taxa/Species	Abundace values		
	Area A	Area B	Area C
Family Centropagidae			
Centropages calaninus (Dana)	0-2	0-1	0
C. elongatus Giesbrecht	0-1	0	0-1
C. furcatus (Dana)	0-1	0-1	0-2
C. gracilis (Dana)	0-1	0	0-1
Centropages copepodid	0-1	0	0-1
Family Pontellidae			
Calanopia aurivilli Cleve	0	0-1	0-1
C. minor A. Scott	0	0-1	0-2
Labidocera sp.	0	0-1	0
Pontellina morii Fleminger & Huslemann	0-1	0	0-2
P. plumata (Dana)	0-1	0-1	0
Labidocera copepodid	0	0-1	0
Pontella copepodid	0-1	0	0
Pontellina copepodid	0-3	0-1	0-1
Family Temoridae	3		
Temora discaudata Giesbrecht	0-6	0	0-2
Temora copepodid	0-2	0-1	0-2
Superfamily Megacalanoidea			
Family Calanidae			
Canthocalanus pauper (Giesbrecht)	0-14	0-4	0-2
Cosmocalanus darwinii (Lubbock)	0-2	0-3	0-5
Nannocalanus minor (Claus)	0-2	0-5	0-1
Undinula vulgaris (Dana)	0-1	0-1	0-2
Family Paracalanidae			
Acrocalanus gibber Giesbrecht	0-13	0-5	0-8
A. gracilis Giesbrecht	0-29	0-1	0-1
A. longicornis Giesbrecht	0-8	0-1	0-1
A. monachus Giesbrecht	0-3	0-1	0-1
Paracalanus aculeatus Giesbrecht	0-18	0-6	0-26
Family Calocalanidae			
Calocalanus pavo (Dana)	0-1	0	0-1
C. plumulosus (Claus)	0-3	0-1	0
Calocalanus copepodid	0-26	0-1	0-1

* 0 = not found

Table 1 (Cont.)

Taxa/Species	**Abundace values**		
	Area A	**Area B**	**Area C**
Superfamily Eucalanoidea			
Family Eucalanidae			
Pareucalanus sewelli (Fleminger)	0-1	0-2	0-3
Rhincalanus cornutus Dana	0-2	0-1	0-1
Subeucalanus crassus Giesbrecht	0	0	0-1
S. subcrassus Giesbrecht	0	0	0-1
Subeucalanus sp.	0-5	0	0
Pareucalanus copepodid	0-5	0-12	0-6
Subeucalanus copepodid	1-29	2-6	1-23
Superfamily Clausocalanoidea			
Family Aetideidae			
Aetideus sp.	0-1	0	0-1
Chiridius sp.	0-1	0-1	0
Euchirella bella Giesbrecht	0	0-11	0
Family Clausocalanidae			
Clausocalanus arcuicornis Dana	2-50	0-17	1-13
C. furcatus (Brady)	0-8	0-1	0-2
Family Euchaetidae			
Euchaeta concinna Dana	0-1	0-2	0-2
E. longicornis (Giesbrecht)	0	0-1	0
E. marina (Prestandrea)	0	0-2	0
E. wolfendeni A. Scott	0-1	0-1	0-2
E. rimana Bradford	0-1	0	0
Euchaeta copepodid	1-17	1-15	1-11
Family Phaennidae			
Phaenna spinifera Claus	0	0	0-1
Family Scolecithricidae			
Scolecithricella longispinosa Chen & Zhang	2-17	0-16	0-10
S. ctenopus (Giesbrecht)	0-1	0-2	0-1
Scolecithricella sp.1	0	0	0-1
Scolecithricella sp.2	0-4	0	0
Scolecithrix danae (Lubbock)	0-1	0-1	0-1
Scaphocalanus sp.	0-1	0	0
Order Cyclopoida			
Cyclopoid copepodid	0-1	0	0

* 0 = not found

Table 1 (Cont.)

Taxa/Species	**Abundace values**		
	Area A	**Area B**	**Area C**
Family Oithonidae			
Oithona spp.	1-32	3-24	1-29
Order Harpacticoida			
Family Miraciidae			
Macrosetella gracilis (Dana)	0-1	0	0-1
Miracia efferata Dana	0-1	0	0-1
Order Poecilostomatoida			
Family Corycaeidae			
Corycaeus agilis Dana	0-4	0-2	0-2
C. asiaticus F. Dahl	0-1	0	0-1
C. catus F. Dahl	0-5	0-4	1-9
C. crassiusculus Dana	0-3	0-1	0-3
C. flaccus Giesbrecht	0	0-1	0-2
C. longistylis Dana	0-1	0-1	0-4
C. speciosus Dana	0-2	0-2	0-10
Corycaeus sp.1	0-1	0-1	0-2
Corycaeus sp.2	0	0	0-1
Corycaeus sp.3	0	0	0-1
Corycaeus sp.4	0	0-2	0-1
Corycaeus sp.5	0-1	0-1	0-1
Corycaeus sp.6	0	0	0-1
Corycaeus sp.7	0-1	0	0
Farranula gibbulus Giesbrecht	0-2	0-2	0-2
Farranula sp.	0-4	0-1	0-2
Family Lubbockiidae			
Lubbockia squillimana Claus	0	0	0-1
Family Oncaeidae			
Oncaea conifera Giesbrecht	0-13	1-11	0-18
O. venusta Philippi	1-8	1-24	5-46
Family Sapphirinidae			
Copilia mirabilis Dana	0-6	0-3	0-5
C. quadrata Dana	0-2	0-1	0-2
C. vitrea (Haeckel)	0	0-1	0
Sapphirina gastrica Giesbrecht	0-1	0	0
S. metallina Dana	0	0-1	0-2
S. nigromaculata Claus	0-1	0	0-2

* 0 = not found

Table 1 (Cont.)

Taxa/Species	Abundace values		
	Area A	Area B	Area C
S. opalina Dana	0	0	0-1
S. stellata Giesbrecht	0	0-1	0-1
Sapphirina sp.1	0-1	0	0
Sapphirina sp.2	0	0	0-1
Sapphirina sp.3	0	0	0-1
Sapphirina sp.4	0-1	0	0
Sapphirina copepodid	0-2	0-2	0-1
Class Ostracoda			
Family Cypridinidae			
Cypridina spp.	0-18	0-49	0
Family Halocypridae			
Euconchoecia spp.	1-15	4-67	1-13
Class Malacostraca			
Superorder Percarida			
Order Amphipoda			
Suborder Hyperiidea			
Family Vibiliidae			
Vibilia australis Stebbing	0	0-1	0
V. propinqua Stebbing	0-1	0	0
Vibilia spp.	0	0	0-1
Family Hyperiidae			
Hyperia macrocephala (Dana)	0-1	0	0-1
Phronimopsis sp.	0	0-1	0
Lestrigonus bengalensis Giles	0-1	0	0-1
L. macrophthalanus (Vosseler)	0-3	0-6	0-2
Family Phronimidae			
Phronima colletti Bovallius	0	0-1	0
Phronimella elongata Claus	0	0-2	0
Family Oxycephalidae			
Calamorhynchus pellucidus Streets	0	0-1	0
Order Mysidacea			
Unidentified mysids	0	1-2	0-1
Order Euphausiacea			
Euphausiid larvae	0-5	0-3	0-7
Euphausiid calyptopis	0-1	0-1	0
Euphausiid Adult	0-4	0-5	0-5

* 0 = not found

Table 1 (Cont.)

Taxa/Species	Abundace values		
	Area A	Area B	Area C
Family Euphausiidae			
Stylocheiron sp.	0	0-1	0
Order Stomatopoda			
Erichthus larvae	0	0	0-1
Alima larvae	0-1	0-3	0-1
Order Decapoda			
Suborder Dendrobranchiata			
Family Penaeidea			
Penaeid larvae	0-1	0-1	0
Penaeid mysis	0	0	0-1
Family Luciferidae			
Lucifer protozoea	0-3	0-9	0-3
Lucifer mysis	0-1	0-1	0-2
Lucifer typus H.M. Edwards	0	0-1	0
Lucifer spp.	0-1	0-3	0-5
Suborder Pleocyemata			
Infraorder Caridea			
Caridean larvae	0-1	0	0
Infraorder Palinura			
Phyllosoma larvae	0-1	0-1	0
Infraorder Anomura			
Anomuran larvae	0-1	0	0
Infraorder Palinuridea			
Porcellanid larvae	0	0	0-1
Infraorder Brachyura			
Brachyuran zoea	0	0-1	0-2
Brachyuran megalopa	0	0-1	0-1
unidentified decapod larvae	0-2	0	0
PHYLUM CHAETOGNATHA (arrow worms)			
Class Sagittodidae			
Subclass Chorismogonata			
Order Aphragmophora			
Family Sagittidae			
Sagitta bedoti Beraneck	0-2	0	0-3
S. enflata Grasse	0-9	0-18	0-11
S. ferox Doncaster	0	0-1	0-2

* 0 = not found

Table 1 (Cont.)

Taxa/Species	Abundace values		
	Area A	Area B	Area C
S. hexaptera d' Orbigny	0-5	0-3	0-2
S. hispida Conant	0-1	0	0-1
S. minima Grassi	0-1	0-6	0-1
S. neglecta Aida	0-7	0-13	0-2
S. pacifica (Tokioka)	0-2	0-4	0-1
S. robusta Doncaster	0	0-1	0
Sagitta spp.	8-24	0-39	1-21
PHYLUM ECTOPROCTA (bryozoans)			
Cyphonautes larvae	0-1	0	0-1
PHYLUM ECHINODERMATA (echinoderms)			
Class Asteroidea			
Bipinnaria larvae	0	0	0-5
Class Holothuroidea			
Auricularia larvae	0	0	0-1
Class Echinoidea			
Echinopluteus larvae	0-1	0	0-1
Class Ophiuroidea			
Ophiopluteus larvae	0-1	0	0-1
PHYLUM CHORDATA (chordates)			
SUBPHYLUM UROCHORDATA			
Class Larvacea			
Family Oikopleuridae			
Oikopleura fusiformis Fol	1-39	0-12	0-6
O. longicauda Vogt	0-35	2-22	0-11
O.intermedia Lohman	0-1	0-2	0-3
Oikopleura spp.	0-2	0-3	0-7
Class Thaliacea			
Order Salpida			
Family Salpidae			
Pegea spp.	0-2	0-1	0
Salpa spp.	0-3	0-1	0-4
Thalia spp.	0-2	0-1	0-2
Order Doliolida			
Family Doliolidae			
Doliolum spp.	1-7	0-3	1-4

* 0 = not found

Table 1 (Cont.)

Taxa/Species	**Abundace values**		
	Area A	**Area B**	**Area C**
Class Pisces			
Fish eggs	0	0-1	0
Fish larvae	0-2	0-1	0
SUBPHYLUM CEPHALOCHORDATA			
Amphioxides sp.	0-4	0-2	0
Total of zooplankton	154-568	97-477	100-451

* 0 = not found

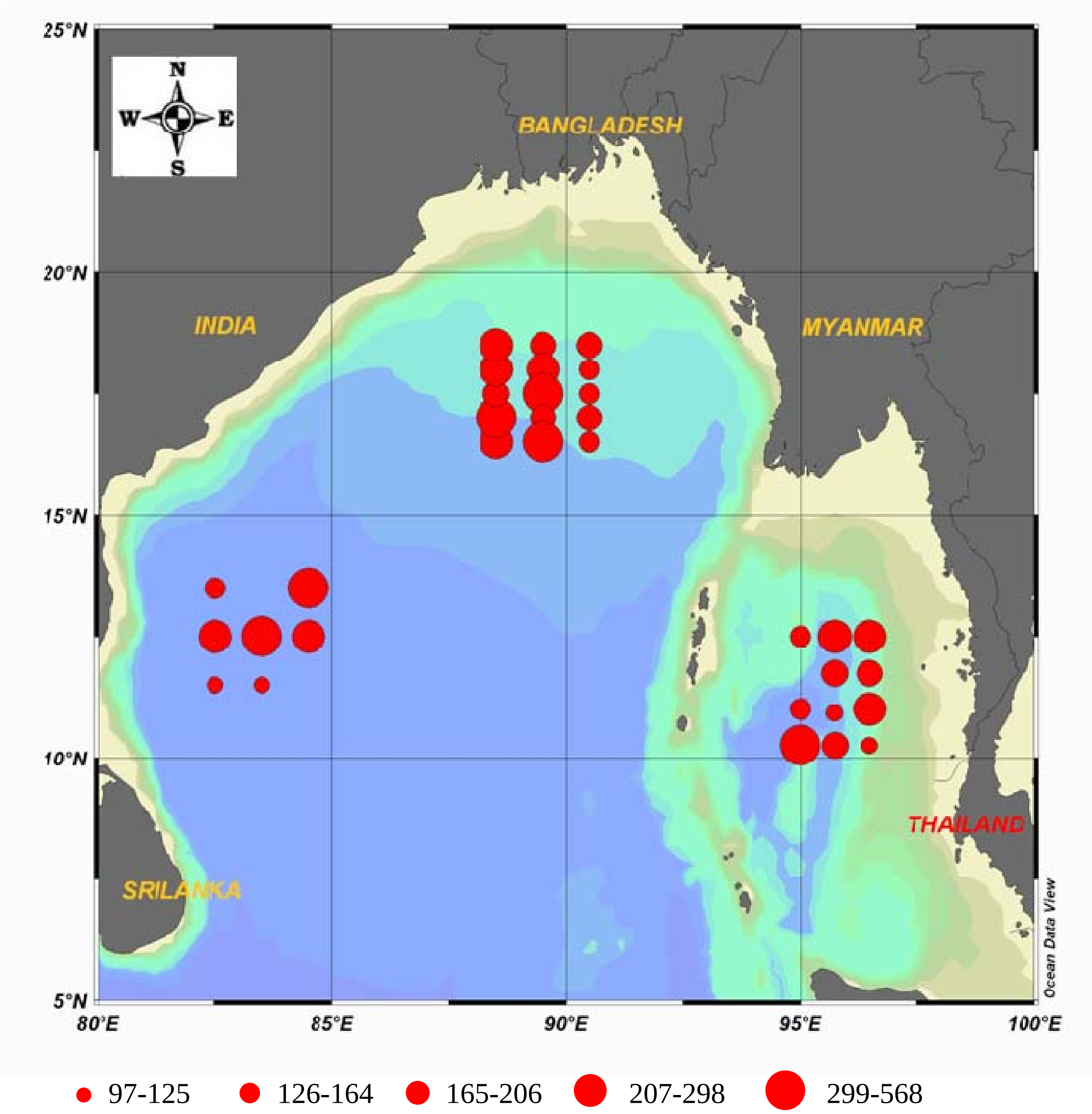

Figure 2 Distribution and abundance of total zooplankton (individuals/m^3) in the Bay of Bengal

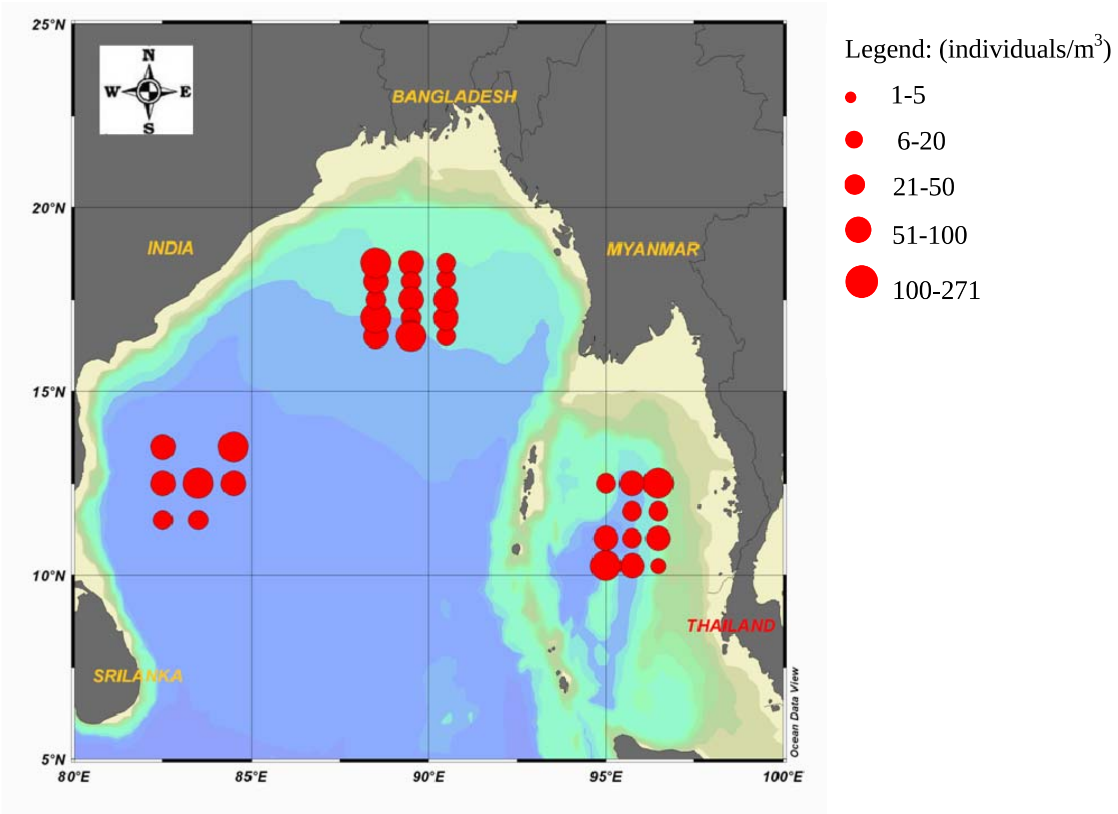

Figure 3 Distribution and abundance of calanoid copepods.

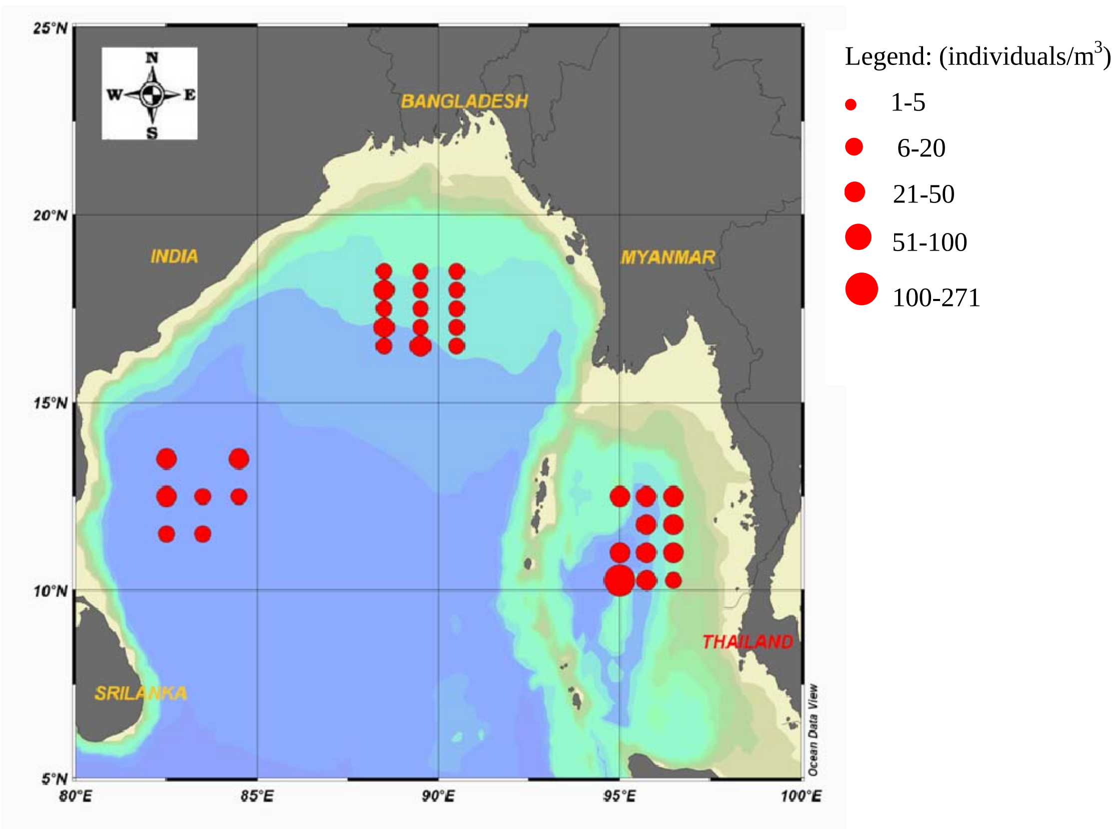

Figure 4 Distribution and abundance of poecilostomatoid copepods.

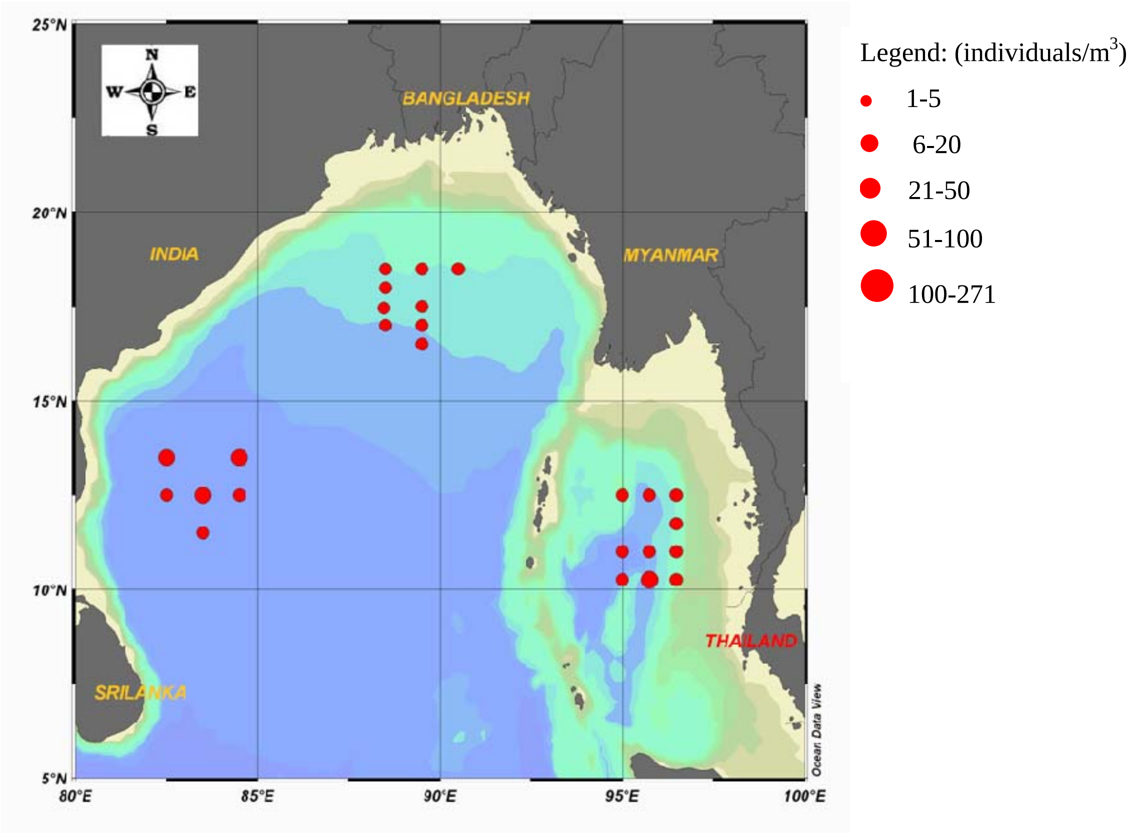

Figure 5 Distribution and abundance of planktonic shrimps.

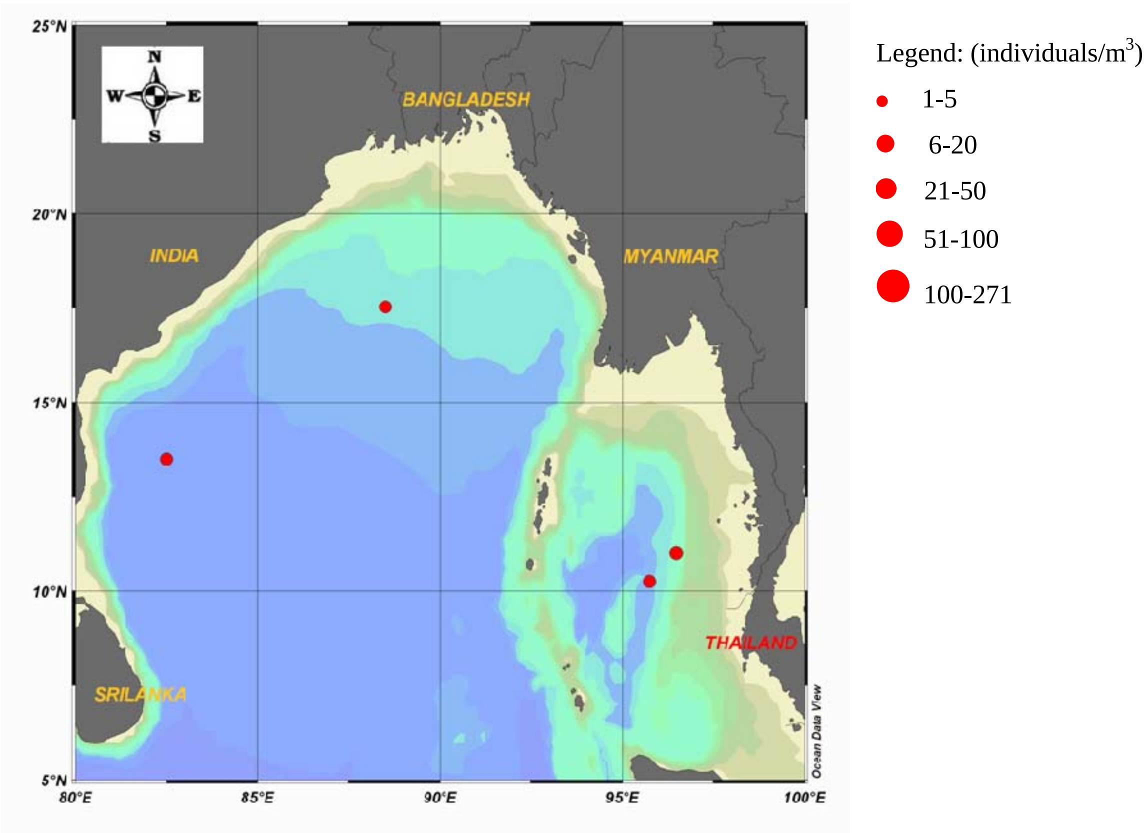

Figure 6 Distribution and abundance of crab larvae.

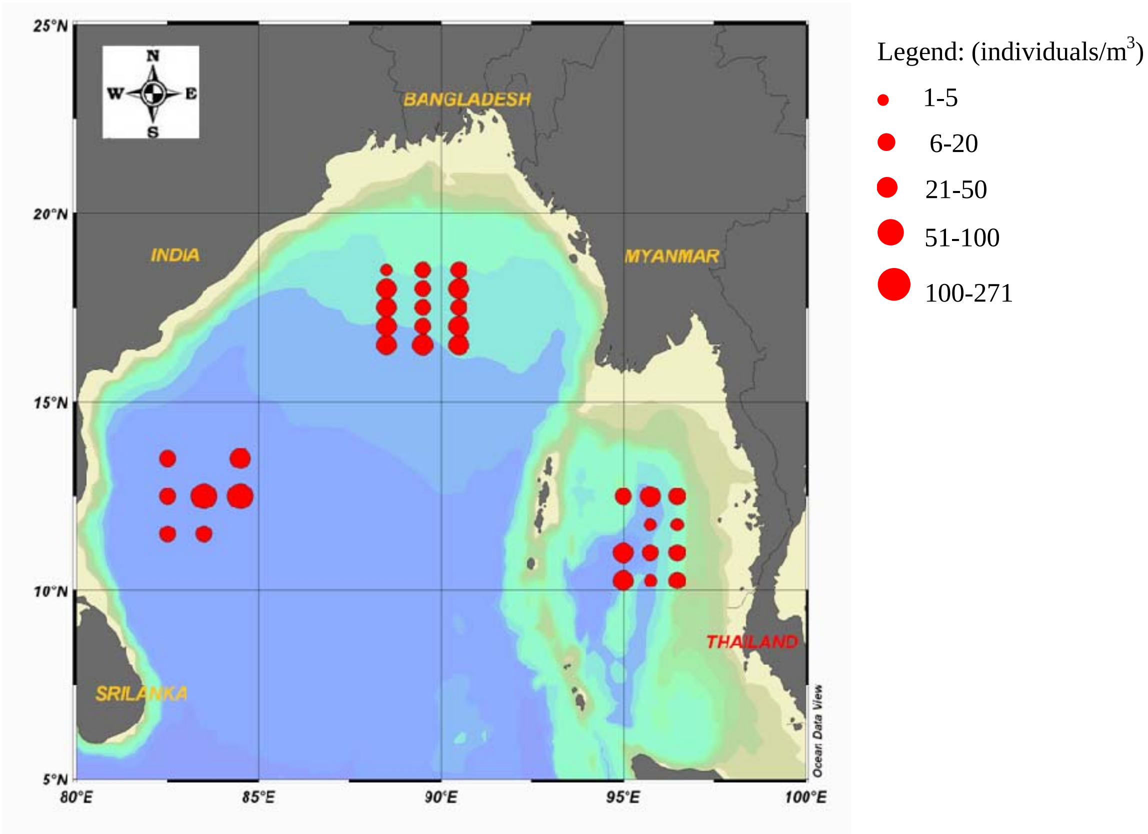

Figure 7 Distribution and abundance of arrow worms.

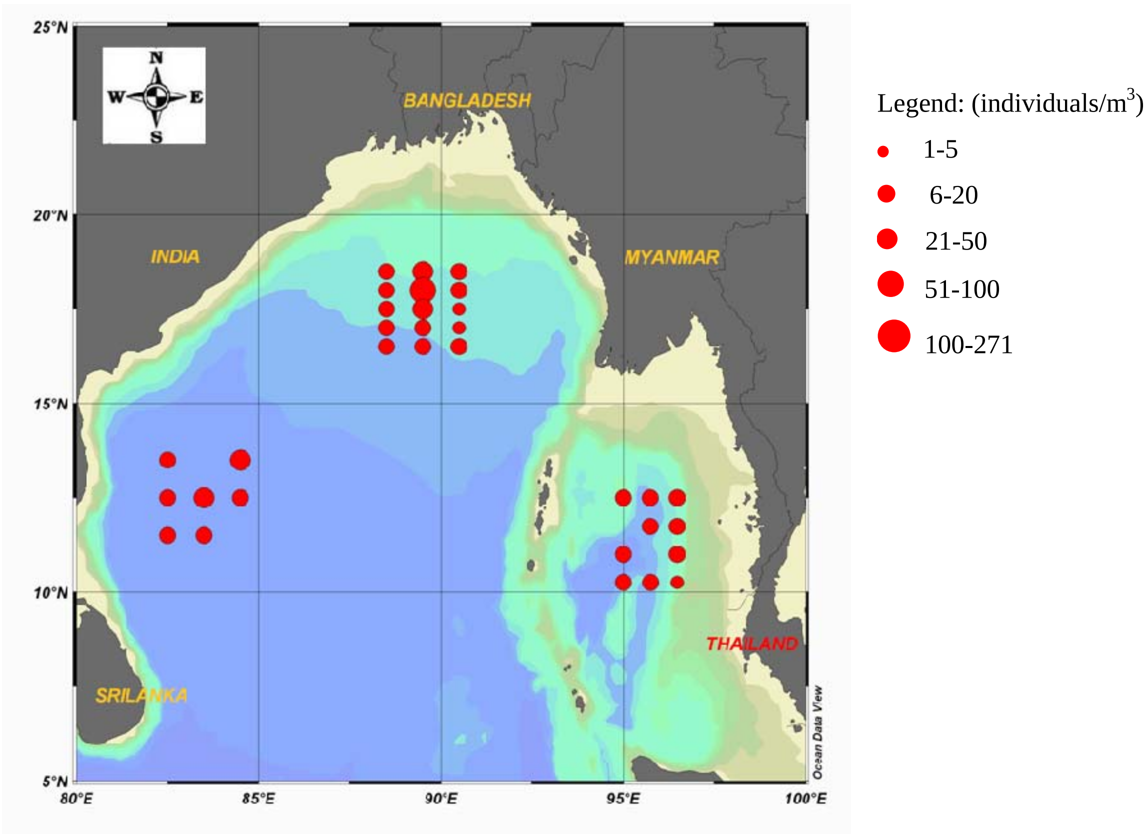

Figure 8 Distribution and abundance of larvaceans.

Discussion

Copepods are the most important group of zooplankton in the Bay of Bengal both in species number and abundance. It also formed the bulk of the zooplankton in other areas such as along the coast of Pakistan (Hag *et al*., 1973) the Red sea, the Persian Gulf and Arabian Sea (Kimor, 1973). The density of copepods was high, particularly in the northern part of the Bay during the SW monsoon, April to October, which was in consistence with the observation of Rao (1973).

Based on the ecological role of copepods reported by Sewell (1947), and Vinogradov and Vorovina (1962), out of 72 species of copepods founding this study, the most abundant copepods were epipelagic and mesopelagic species (copepod that live between surface to above 500 m depth). The bathypelagic species, on the other hand, are relatively few and largely dominanted by *Lucicutia flavicornis, Clausocalanus arcuicornis,* and *Scolecithricella longispinosa.* Other species that were rarely distributed included *Eugaugaptilus* sp., *Heterorhabdus papilliger, Pleuromamma robusta* and *Pareucalanus sewelli.*

Protozoans comprise of free-floating sarcodines (foraminiferans and radiolarians) and ciliates (tintinnids). Its abundance was next to copepods. Tintinnids are lorica-building, planktonic oligotrichid ciliates ranging in size from 20 to 200 µm. They constitute a major component of the microzooplankton in most marine environments (Beers and Stewart, 1967, Alder, 1973). They were collected in low to very low number due to the mesh size (330 µm) used for collection.

The collection includes 10 species of arrow worms. *Sagitta enflata* was the dominant species constituting 44.21% of the total arrow worm which corresponded with Nair (1977) and Nair *et al.* (2000) who described *Sagitta enflata* as being the dominant species in the Indian Ocean. Important species were *S. hexaptera, S. neglecta*, *S. minima* and *S. pacifica*. Among the different species of chaetognaths encountered in the present study, *Sagitta enflata* and *S. hexaptera* are cosmopolitan species of the Atlantic, Indian and Pacific Oceans (Nair *et al*., 1981), while the remaining species were characteristic of Indo-Pacific region.

Oikopleura is an important genus of larvaceans in the Bay of Bengal. According to Fenaux (1973), Oikopleura was the most abundant and frequent encountered in the Red Sea and the Persian Gulf: *Oikopleura longicauda* and *O. fusiformis* were widely distributed with high density. Both species were common during March-April period and October-November in the western part of the Bay of Bengal. Bhavanarayana and Ganapati, 1972. High abundances of larvaceans was recorded at station 19 in area A with the maximum number of 74 individuals/m^3.

Cnidarians in the Bay of Bengal comprise of thirty-two species of hydromedusae and siphonophores, but they are quite low in numerical abundance. Siphonophores were commonly distributed at all stations, but most hydomedusae were rarely distributed and very low in number. *Chelophyes contorta*, *Bassia bassensia* and *Enneagonum hyalinum* were common species of siphonophores. They were also reported elsewhere in the western part of the Bay of Bengal (Nair *et al*., 1981). *Aglaura hemistoma* and *Liriope tetraphylla* were the dominant species of hydomedusae in this study. Vannucci and Navas (1973) reported *Aglaura hemistoma* and *Liriope tetraphylla* were two predominated species in the Indian Ocean. Their abundance in the collection was affected by the geographic distribution of the sampling sites, mostly oceanic and far from land. High abundances of cnidarians were found in area A (northern part of the Bay of Bengal) as other areas (along the south west coast of India, Arabian coast, northern part of the Bay of Bengal, Thailand coast) (Rao, 1973).

Ostracods were fairly abundant in the Bay of Bengal. Only species of *Cypridina* and *Euconchoecia* were found in the area. *Cypridina dentata* and *Euconchoecia aculeate* found in neritic as well as ocenics waters. George and Nair (1980) *Euconchoecia* spp. was dominant at most stations in the Bay of Bengal (Nair *et al*., 1981) but they always presented in low number in this study. High abundances (116 individuals/m^3) of ostracod was observed at station 29 in area B (western part of the Bay of Bengal).

Thaliaceans in the Bay of Bangal comprise of Salps (Pegea, Salpa and Thalia) and only one doliolid genus (Doliolum). *Doliolum* spp. were commonly distributed at all areas. According to Bhavanarayana and Ganapati (1972), they were common during March-April period and October-November in the western part of the Bay of Bengal. Salps were scarcely distributed in this study.

Regarding planktonic shrimps (included larval stages of Penaeid, Caridean and Palinuran shrimps and Lucifer), they were very rarely distributed with low values. Larval stages of euphausids were commonly distributed but in very low number. Only adult stages of Stylocheiron was found in area B (westhern part of the Bay of Bengal). *Stylocheiron insulare* , a coastal species, recurred in the Andaman Sea and south of Java. (Brinton and Gopolakrishnan, 1973). In the case of polycheaetes, there were both planktonic forms and larval forms (meroplankton). Larval forms were widely distributed with low number but planktonic forms occurrence were rarely distributed. Mollusks presented in the area included gastropod larvae, planktonic mollusks and bivalved larvae. Atlanta and Creseis were common in the Bay of Bengal with low number. Planktonic mollusks and bivalved larvae were sparse in this study. *Lestrigonus macroohthalanus* was the dominant species of hyperiid in the Bay of Bengal. Most hyperiids were rarely distributed in small numbers. Fairly high concentration of amphipods were noted towards the northern part of the Bay of Bengal (Nair *et al*.,1981). But the abundance of hyperiids of area B (western part of the Bay of Bengal) was higher thanthose of other areas. Echinoderm larvae, mysids, crab larvae, stomatopod larvae, decapod larva, bryozoans and cephalochordates yielded low abundance in all samples examined. Their detailed results will be published elsewhere.

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Composition, Abundance and Distribution of Fish Larvae in the Bay of Bengal

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Abstract

The study on composition, abundance, and distribution of fish larvae was conducted in the Bay of Bengal (BOB) with the aim to get more scientific data for fishery management in this area. Fish larvae samples were collected in the northern (area A), western (area B) and eastern part (area C) of the BOB during the period of 25 October to 6 December, 2007. Fifty-two families of fish larvae were identified of which Photichthyidae was the most abundance. Fifty one families could be found in area C while only nineteen and eighteen families were observed in area B and A. The highest average density of total fish larvae, 485 larvae/1,000 m^3, was also obtained in area C. A total of twenty-four economic important fish larvae families were found in the studied areas. Almost all economic families were presented in area C while 8 and 7 families were found in area B and A. These results suggested that the Andaman Sea or area C was the richest diversity and most abundant of fish larvae in this study. Regarding to tuna larvae, a small number were recorded during this survey period. Six species of tuna larvae were found in area C, 3 species in area A and 2 species in area B. The relationships between environmental parameters and fish larvae abundance have not been analyzed statistically due to the small sample sizes in this study. However, the spatial changes in temperature indicating that at 75 m depth of three study areas the temperature was obviously fluctuated whereas at the surface and 150 m depth a slightly change was observed. As for the changes in salinity, the results showed the halocline layer of area C was deeper than those of area A and B indicating that these areas were influenced by the river runoff of which the huge nutrients were discharged. Although, this study provided some information about abundance and distribution of fish larvae in the BOB but there are still not enough to understand the clear pattern of fish larvae abundance and distribution of the whole area. The further study on temporal and spatial distribution of fish larvae in relation to oceanographic parameters was also recommended.

Key words: composition, abundance, distribution, fish larvae, Bay of Bengal

Introduction

The Bay of Bengal (BOB) is one of the large marine ecosystem of the world ocean that lacks of large scale seasonal upwelling and defined as moderately productive ecosystem (Madhupratap *et al*., 2003). BOB is land locked ocean in the north and influenced by seasonally reversing monsoon winds. Shankar *et al*. (2002) reported that the low sea surface salinities, particularly in the northern region of BOB were a result of the heavy monsoonal precipitation. The large freshwater are from the Ganga, Brahmaputra and Irrawaddy rivers (UNESCO, 1988). This excess water fluxes is a significant source of freshwater to BOB. The large riverine outflows generates highly stable stratification in the upper layers of the northern BOB and forms a strong “barrier layer” to the re-supply of nutrients from deeper waters during summer monsoon throughout the post-summer periods. The barrier layer in conjunction with hydrographic characteristics will have a profound influence on the biological productivity (Sprintall and Tomczak 1992, Vinayachandran *et al*., 2002)

Generally, BOB is considered to have a lower biological productivity than its western counterpart, the Arabian Sea. Although the rivers may bring nutrients, these are though to be removed in the deeper waters because of the narrow shelf (Qasim, 1970). Most previous biological studies in BOB focused mainly on the seasonal variation in primary production and on the composition and abundance of mesozooplankton (Nair *et al*., 1981; Achuthankutty *et al*., 1980; Madhupratap *et al.,* 2003) but little is known about fish larvae abundance and its composition.

In this present work, the study of larvae is a part of the biological oceanographic survey incorporated in the project Ecosystem-Based Fishery Management in the Bay of Bengal (BOB) which is a collaborative survey project among member countries of BIMSTEC (Bangladesh, India, Myanmar, Sri Lanka, Nepal and Thailand) aimed for fishery management. The understanding of abundance and distribution of fish larvae in conjunction with ecological conditions could fill up the gap in the study of fish life history and be considered as an important information for fishery management. Generally, the larval stage is most vulnerable to ecological changes, any fluctuation either quality or quantity of the ecological conditions will be harmful to larval lives and may probably indicate the onward potential of recruitment (Leis and Rennis, 1983). Although, there was some information of fish larvae in some coastal areas of the Indian Ocean but little is known about the distribution and abundance of fish larvae in offshore areas of the BOB.

To provide more information of fish larvae for fishery management, the study on abundance and distribution of fish larvae in the eastern, northern and western part of the BOB was conducted. The results may be served as the basic information to evaluate the existing of fish stocks and may also be served as the preliminary information for the future investigations in relation to environmental parameters.

Objectives

1. To identify fish larvae composition.
2. To determine abundance and distribution of the total fish larvae and the top five most abundant families.
3. To determine abundance and distribution of tuna larvae in the Bay of Bengal.
4. To compare fish larvae assemblages by stations.

Materials and Methods

1. Study Area

The survey area (Fig. 1) included the upper part of the Bay of Bengal (area A, station 13-27); the western part (area B, station 28-34) and the Andaman Sea (area C, station 1-12). The project survey was conducted by the fishery research vessel M.V. SEAFDEC during 25 October-6 December 2007.

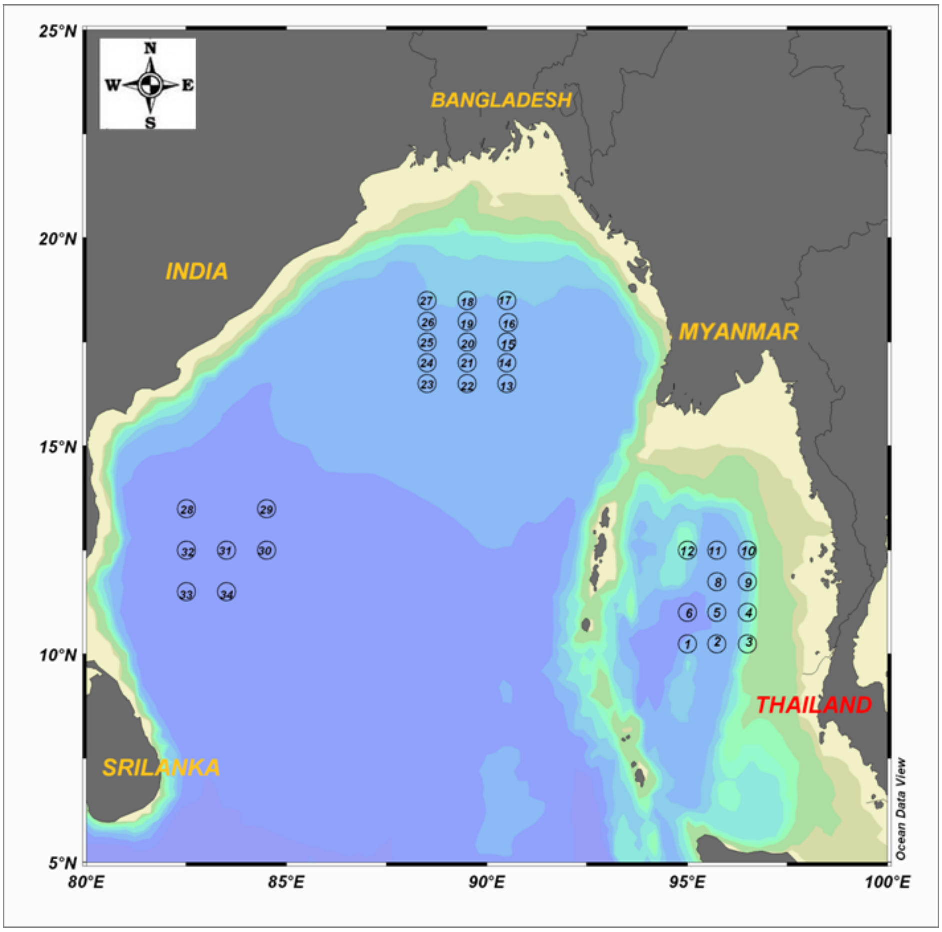

Figure 1 Station for fish larval sampling in the Bay of Bengal.

2. Sampling Procedures

2.1 Fish larvae were collected by bongo net 45 cm in diameter with mesh size 500 micrometer at the mouth and 330 micrometer at the cod end. A flow meter was attached to the mouth of net to determine the volume of sea water filtered during each tow. The sampling period was about 30 minutes with oblique tow at ship speed of 2 knots. The sampling depth was from 150 m to the surface. Collected specimens were preserved in 10% formalin sea water buffered with borax. Each of fish larvae was later sorted out from zooplankton and transferred to 4% formalin sea water solution. Fish larvae samples were standardized to numbers caught per 1,000 m^3 of sea water volume filtered. The details of operations are shown in Appendix 1.

2.2 Environmental factors (temperature, salinity) at 3 levels (surface water, 75 m and 150 m) in each station were measured by CTD at the same time as fish larvae were collected.

3. Laboratory Method

Fish larvae were identified under stereo microscope to family level by using the descriptions of related taxa given in Leis and Rennis (1983), Ozawa (1986), Nishikawa and Rimmer (1987), Matsumoto (1958), Matsumoto (1972), Leis and Carson-Edwart (2000). Unidentified larvae were placed in "unknown" category due to the samples were too small to identify and damaged larvae were placed in "incomplete" category.

4. Data Analysis

The number of total fish larvae and the top five most abundant families which were standardized to number caught per 1,000 m^3 of seawater volume filtered were mapped for spatial distribution.

Determination of the Constancy of Occurrence was based on the ecological index proposed by Dajoz (1983) cited by Schifino *et. al.,* 2004:

$$C = P/Q \times 100$$

Where: C = Constancy of Occurrence of the family (%)
P = Number of samples where the family occurred
Q = Total number of samples

The families were then divided into three categories:

Constants (when $C>50\%$)
Accessories (when $25\%\leq C\leq 50\%$)
Accidental (when $C<25\%$)

Determination for the type of fish larvae which grouped into 5 categories based on the adult habitat (Smith and Heemstra, 1986).

Group 1: fresh water fish
Group 2: neritic fish
Group 3: inshore-reef fish
Group 4: shallow to oceanic fish
Group 5: oceanic fish

For comparing the community structures of fish larvae by station, a cluster analysis was used as shown in the form of a dendrogram. The analysis used a squared Euclidean distance as a measurement of proximity and followed an unweighted pair group method-arithmetic average for linkage as described by Pielou (1984). The software used for cluster analysis was Statistica for Windows 6.0 version (Statsoft, Inc. 1984-2001).

Results

1. Composition, Abundance and Distribution of Fish Larvae in the Bay of Bengal and Top 5 Families in 3 areas.

In the Bay of Bengal

A total of 14,584 specimens of fish larvae consisted of 52 families were found in the study areas. Area C was the richest fish larvae diversity and also the highest average number per station (Table 1 and Fig. 2 and 3). Area B and A were the second and third ranks, respectively. The spatial pattern variation of total fish larvae in the BOB were shown in Figs. 2 and 3.

Twenty-four economic important families of fish larvae were identified in these study areas and all of them found in area C. Only 8 and 7 economic important families were found in area B and A respectively (Table 1).

Twelve families of fish larvae (Photichthyidae, Myctophidae, Bregmacerotidae, Carangidae, Labridae, Callionymidae, Gobiidae, Sphyraenidae, Gempylidae, Scombridae, Bothidae, Cynoglossidae) were obtained in all 3 areas.

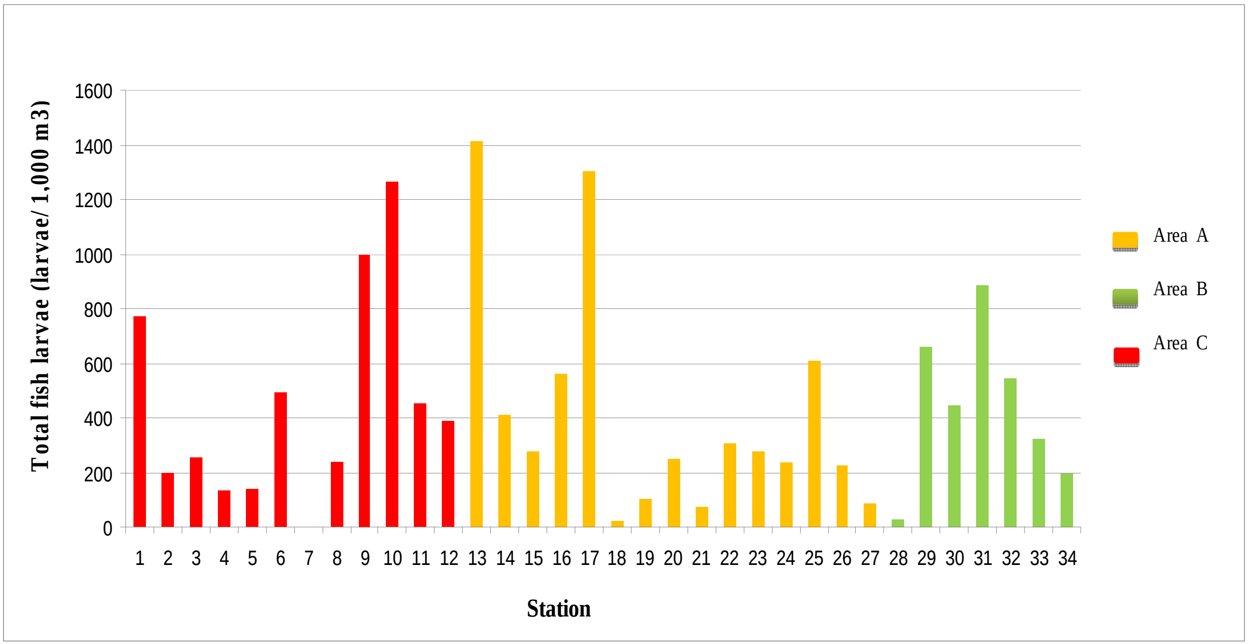

Figure 2 Spatial pattern variation in abundance of total fish larvae in 3 areas.

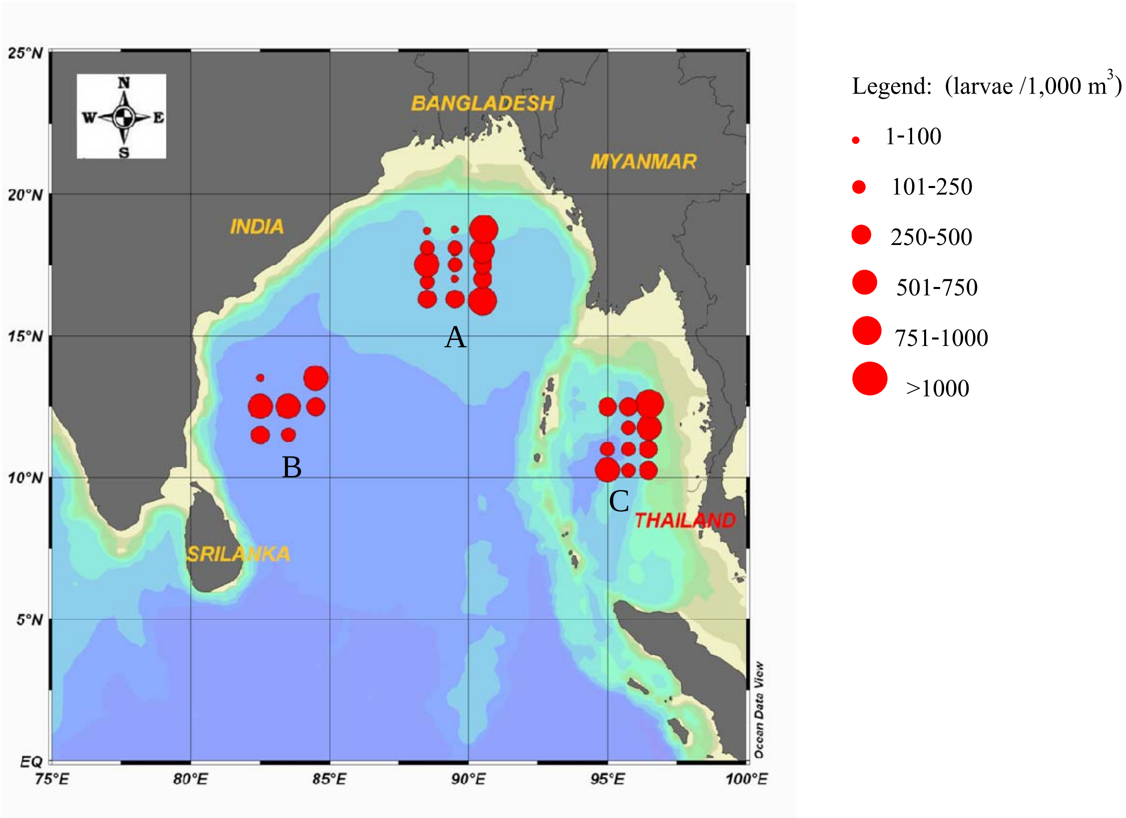

Figure 3 Distribution and abundance of total fish larvae in the Bay of Bengal**.**

1.1 Area A

1.1.1 Total Fish Larvae

6,170 specimens were collected in this area. They belonged to 18 families of which 7 families were the economic important group. These were Hemirhamphidae, Carangidae, Sphyraenidae, Gempylidae, Scombridae, Bothidae and Cynoglossidae. All of them contributed about 5.64% to the total fish larvae. Among them, the most dominant family was Carangidae followed by Scombridae and Gempylidae. As shown in Table 1 and Appendix 2, the average number per station of fish larvae in area A was 411 larvae/1,000 m^3. The highest abundance was observed at station 13 and the lowest was at station 18. The fish larvae in station 13-17 near Myanmar waters, were more abundant and amounted to 56 % of the total fish larvae with mean density of 794 larvae/1,000m^3. This high percentage of fish larvae was composed of top 5 dominant families which were Photichthyidae, Bregmacerotidae, Myctophidae, Callionymidae and Carangidae (Tables 1 and 2; Appendix 2).

Based on the constancy of occurrence, 5 families of Photichthyidae, Myctophidae, Bregmacerotidae, Carangidae and Callionymidae were considered as constant families of which only Carangidae was the economic important family. Four accessory families were Paralepididae, Gobiidae, Gempylidae and Scombridae of which 2 families were economic importance. The rest was 9 accidental families of which 4 economic important families were included (Table 2).

Referring to the category of the adult's habitats, 6 families (Labridae, Callionymidae Gobiidae, Bothidae, Cynoglossidae and Ostraciidae) were inshore-reef fish and 6 families (Photichthyidae, Stomiidae, Myctophidae Gempylidae, Exocoetidae and Paralepididae) represented oceanic fish (Table 3).

Table 1 Total number of fish larvae in the Bay of Bengal.

Total number of fish larvae (larvae /1,000 m^3)			
Family	Area A	Area B	Area C
Ophichthyidae	14		42
Engraulidae*			3
Gonostomatidae		60	255
Photichthyidae	3,310	830	316
Stomiidae	7	7	42
Chlorophthalmidae			16
Scopelarchidae		3	17
Synodontidae*		6	44
Paralepididae	27		165
Evermannellidae		3	9
Myctophidae	483	1,109	2,348
Carapidae			6
Ophidiidae			9
Exocoetidae	7		
Bregmacerotidae	1,530	849	431
Ceratiidae			5
Hemirhamphidae*	11		96
Holocentridae			4
Scorpaenidae			44
Liparidae			8
Acropomatidae*			3
Serranidae*			34
Priacanthidae*			68
Apogonidae		12	89
Coryphaenidae*			13
Carangidae*	231	53	59
Menidae*			3
Bramidae*			29
Lutjanidae*			35
Gerreidae*			3
Lethrinidae*			4
Nemipteridae*			3
Mullidae*			3
Teraponidae*			3
Labridae	6	11	36
Champsodontidae*			35
Ammodytidae			6
Blenniidae			10
Callionymidae	325	24	242
Gobiidae	27	16	101
Schindleriidae			3
Sphyraenidae*	3	6	6
Gempylidae*	38	7	41
Trichiuridae*		3	3
Scombridae*	42	3	25
Bothidae*	13	33	178
Pleuronectidae			3
Cynoglossidae*	18	19	33
Triacanthidae			6
Balistidae*			6
Ostraciidae	3		8
Tetraodontidae			6
Unknown	24	23	118
Incomplete	59	32	255
Total fish larvae	6170	3093	5321
Average mean	411	445	485

* Economic fish

Table 2 Number of fish larvae (larvae/1,000 m^3) in the upper part of the Bay of Bengal (area A).

Family	Total number of larvae	Mean number of larvae	SD	Percentage of total catch	Rank	Frequency of Occurrence (%)	Classification according to Constance of Occurrence (1)	(2)	(3)
Ophichthyidae	14	0.92	0.58	0.22	10	20.00			x
Photichthyidae	3310	220.67	117.81	53.66	1	93.33	x		
Stomiidae	7	0.46	-	0.11	14	6.67			x
Paralepididae	27	1.81	2.45	0.44	8	26.67		x	
Myctophidae	483	32.17	11.61	7.82	3	86.67	x		
Bregmacerotidae	1530	101.99	57.80	24.80	2	93.33	x		
Exocoetidae	7	0.44	0.71	0.11	14	13.33			x
Hemirhamphidae	11	0.76	2.12	0.19	12	13.33			x
Carangidae	231	15.38	4.54	3.74	5	80.00	x		
Labridae	6	0.42	0.00	0.10	15	13.33			x
Callionymidae	325	21.68	4.22	5.27	4	100.00	x		
Gobiidae	27	1.77	0.55	0.43	9	33.33		x	
Sphyraenidae	3	0.17	-	0.04	17	6.67			x
Gempylidae	38	2.55	1.26	0.62	7	40.00		x	
Scombridae	42	2.77	0.71	0.67	6	46.67		x	
Bothidae	13	0.90	1.73	0.22	11	20.00			x
Cynoglossidae	10	0.63	0.71	0.15	13	13.33			x
Ostraciidae	3	0.17	-	0.04	16	6.67			x
Unknown	24	1.61	1.10	0.39					
Incomplete	59	3.91	2.70	0.95					
Total fish larvae	6170			100.00					

(1): constant family
(2): accessories family
(3): accidental family

Table 3 Fish grouping based on adult habitat in the upper part of the Bay of Bengal (area A).

Group 1 Freshwater fish	Group 2 Neritic fish	Group 3 Inshore-reef fish	Group 4 Shallow to oceanic fish	Group 5 Oceanic fish
Ophichthyidae	Carangidae	Bothidae	Champsodontidae	Exocoetidae
	Hemirhamphidae	Callionymidae	Scombridae	Gempylidae
		Cynoglossidae	Sphyraenidae	Myctophidae
		Gobiidae		Paralepididae
		Labridae		Photichthyidae
		Ostraciidae		Stomiidae

1.1.2 Top Five Dominant Families

1.1.2.1 Photichthyidae

Photichthyid larvae were the most abundant family of total fish larvae.They contributed 53.66% to the total fish larvae and were found in almost all stations except in station 18. The mean density was 220.67 larvae/1,000 m^3. The highest density 967 larvae/1,000 m^3 was found in station 17. Photichthyidae larvae were concentrated at station 13-17 (Table 2, Figs. 4, 5 and Appendix 2).

1.1.2.2 Bregmacerotidae

Bregmacerotid larvae were the second abundant family. They were 24.80 % of the total fish larvae and were found in almost all stations except in station 18.The mean density was 220.67 larvae/1,000 m^3 (Table 2, Figs. 4, 5 and Appendix 2).

1.1.2.3 Myctophidae

Myctophid larvae were the third abundant family. They constituted 7.82% of the total fish larvae. Myctophid larvae were collected from 14 stations and were found the highest density in station 17. None was found at station 18. The mean density was 32.17 larvae/1,000 m^3 (Table 2, Figs. 4, 5 and Appendix 2).

1.1.2.4 Callionymidae

Callionymid larvae contributed 5.27% to the total number. They occurred in all stations with the most abundance in station 27 (75 larvae/1,000 m^3). The mean density was 21.68 larvae/1,000 m^3 (Table 2, Figs. 4, 5 and Appendix 2).

1.1.2.5 Carangidae

Carangid larvae ranked the fifth abundance of the total fish larvae. They were the economically important fish larvae having least abundance and constituted only 3.74% of the total fish larvae. They occurred in 12 stations from 15 stations. The mean density was 15.38 larvae/1,000 m^3 (Table 2, Figs. 4, 5 and Appendix 2).

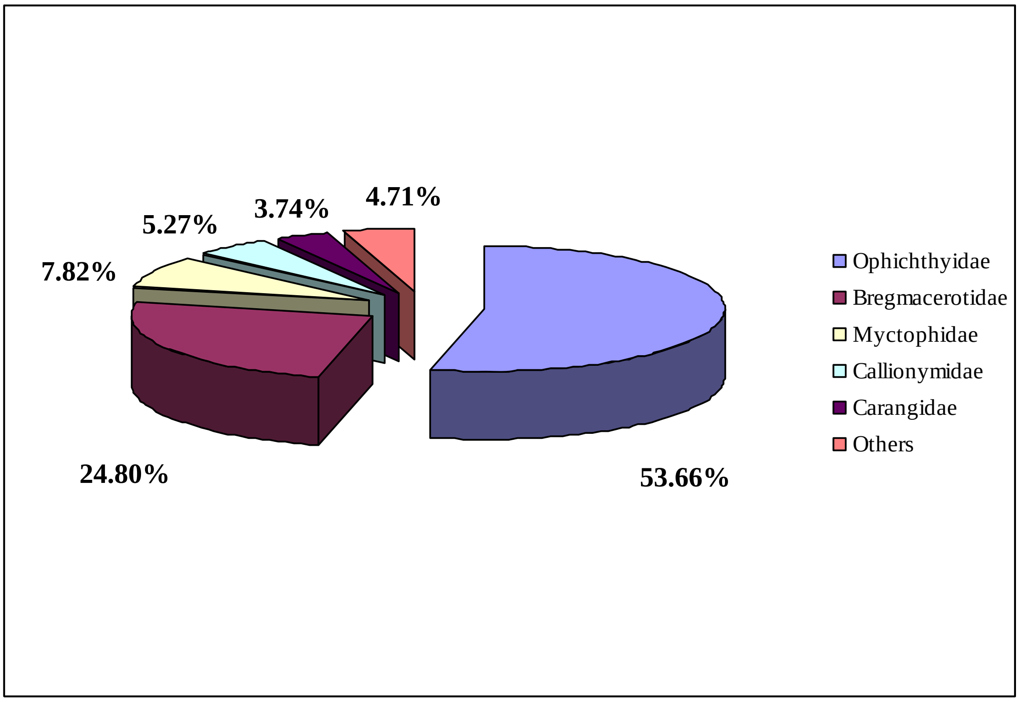

Figure 4 Top five most abundant composition of total collection (%) in area A.

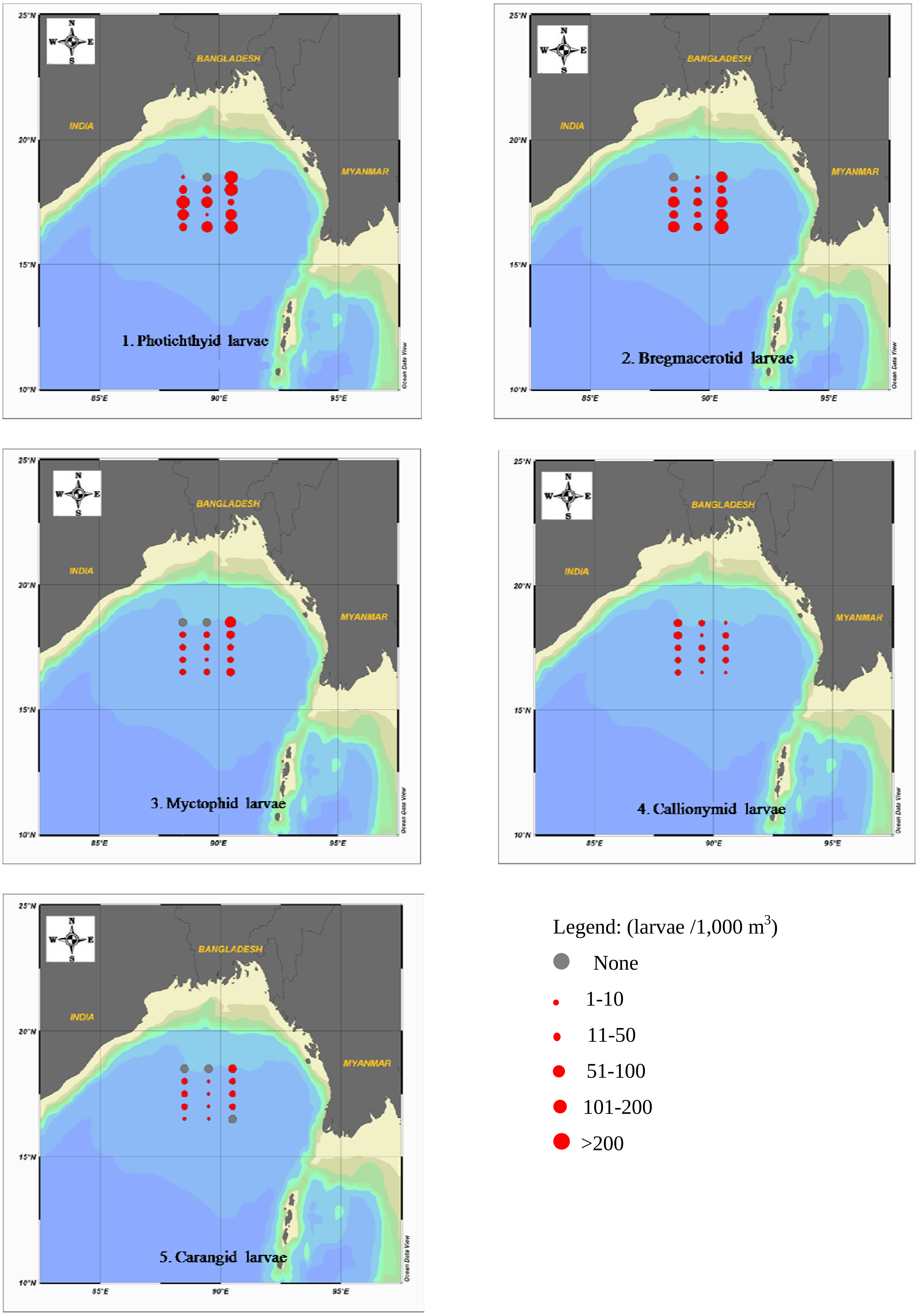

Figure 5 Distribution and abundance of top five most fish larvae in the upper part of the Bay of Bengal (area A).

1.2 Area B

1.2.1 Total Fish Larvae

Nineteen families were identified from 3,093 specimens and 8 families were economic groups. These were Synodontidae, Carangidae, Sphyraenidae, Gempylidae, Trichiuridae Scombridae, Bothidae and Cynoglossidae which constituted about 2% of the total fish larvae. Among them, Carangidae was the most dominant followed by Bothidae and Gempylidae. The average number of fish larvae per station was 445 larvae/1,000 m^3 (Tables 1 and 4; Appendix 3).

Based on the constancy of occurrence of the fish families, among the 19 families, 6 were considered as constants. The others were 4 accessories and 9 accidental families. The constants families were Gonostomatidae, Photichthyidae, Myctophidae, Bregmacerotidae and Carangidae and Bothidae. Synodontidae, Apogonidae, Labridae and Callionymidae were accessory families and the rest were accidental families (Table 4).

Regarding to the adult's habitat, this study area was dominated by families included in group 5 for oceanic fish (Gonostomatidae, Photichthyidae, Myctophidae, Gempylidae Trichiuridae, Stomiidae, Scopelarchidae, Evermannellidae) followed by Group 3 for inshore-reef fish (Apogonidae, Labridae, Callionymidae, Gobiidae, Bothidae and Cynoglossidae) (Table 5).

Table 4 Number of fish larvae (larvae /1,000 m^3) in the western part of the Bay of Bengal (area B).

Family	Total number of larvae	Mean number of larvae	SD	Percentage of total catch	Rank	Frequency of Occurrence (%)	Classification according to Constance of Occurrence		
							(1)	(2)	(3)
Gonostomatidae	60	8.58	2.608	1.94	4	85.71	x		
Photichthyidae	830	118.59	20.67	26.85	3	100.00	x		
Stomiidae	7	0.95	-	0.22	11	14.29			x
Scopelarchidae	3	0.48	-	0.00	13	14.29			x
Synodontidae	6	0.92	0	0.21	12	28.57		x	
Evermannellidae	3	0.48	-	0.11	13	14.29			x
Myctophidae	1109	158.42	31.7	35.86	1	100.00	x		
Bregmacerotidae	849	121.35	56.56	27.47	2	85.71	x		
Apogonidae	12	1.67	1.414	0.38	9	28.57		x	
Carangidae	53	7.50	1.049	1.70	5	85.71	x		
Labridae	11	1.58	0	0.36	10	42.86		x	
Callionymidae	24	3.38	1.414	0.77	7	28.57		x	
Gobiidae	16	2.24	-	0.51	8	14.29			x
Sphyraenidae	6	0.82	-	0.18	12	14.29			x
Gempylidae	7	0.95	-	0.22	11	14.29			x
Trichiuridae	3	0.41	-	0.11	13	14.29			x
Scombridae	3	0.48	-	0.11	13	14.29			x
Bothidae	33	4.71	3	1.07	6	57.14	x		
Cynoglossidae	3	0.45	-	0.10	13	14.29			x
Unknown	23	3.27	1.414	0.74					
Incomplete	32	4.52	0.816	1.02					
Total fish larvae	3093			100.00					

(1): constant family (2): accessories family (3): accidental family

1.2.2 Top Five Dominant Families

1.2.2.1 Myctophidae

Myctophid larvae were the most abundant family in this area. They contributed 35.86% to the total fish larvae and distributed in all stations.The mean density was 158.42 larvae/1,000 m^3 and the highest density 255 larvae/1,000 m^3 was found in station 31 (Table 4, Figs. 6, 7 and Appendix 3).

1.2.2.2 Bregmacerotidae

Bregmacerotid larvae were the second abundant family. They contributed 27.47% to the total fish larvae and were found almost every station, except station 28, with mean density 121.35 larvae/1,000 m^3 (Table 4, Figs. 6, 7 and Appendix 3).

1.2.2.3 Photichthyidae

Photichthyid larvae ranked the third in abundance. They were 26.85% of the total fish larvae and could be found in all stations. They were distributed widely over all the study area. The highest density 24 larvae/1,000 m^3 was observed in station 32 and the mean number was 118.59 larvae/1,000 m^3 (Table 4, Figs. 6, 7 and Appendix 3).

1.2.2.4 Gonostomatidae

Gonostomatid fish larvae were the fourth abundance. They constituted 1.94% to the total larvae and were found almost every station except station 29. Mean density of bristle mouth fish larvae was 8.58 larvae/1,000 m^3 (Table 4, Figs. 6, 7 and Appendix 3).

1.2.2.5 Carangidae

Carangid larvae were the fifth abundance. They were the economically important fish larvae having least abundance. They constituted 1.70 % of the total fish larvae and occurred in 6 stations from 7 stations.The mean density was 7.50 larvae/1,000 m^3 (Table 4, Figs. 6, 7 and Appendix 3).

Table 5 Fish grouping based on adult habitat in the western part of the Bay of Bengal (area B).

Group 1 Freshwater fish	Group 2 Neritic fish	Group 3 Inshore-reef fish	Group 4 Shallow to oceanic fish	Group 5 Oceanic fish
_	Carangidae	Apogonidae	Bregmacerotidae	Evermannellidae
		Bothidae	Scombridae	Gempylidae
		Callionymidae	Sphyraenidae	Gonostomatidae
		Cynoglossidae	Synodontidae	Myctophidae
		Gobiidae		Photichthyidae
		Labridae		Scopelarchidae
				Stomiidae
				Trichiuridae

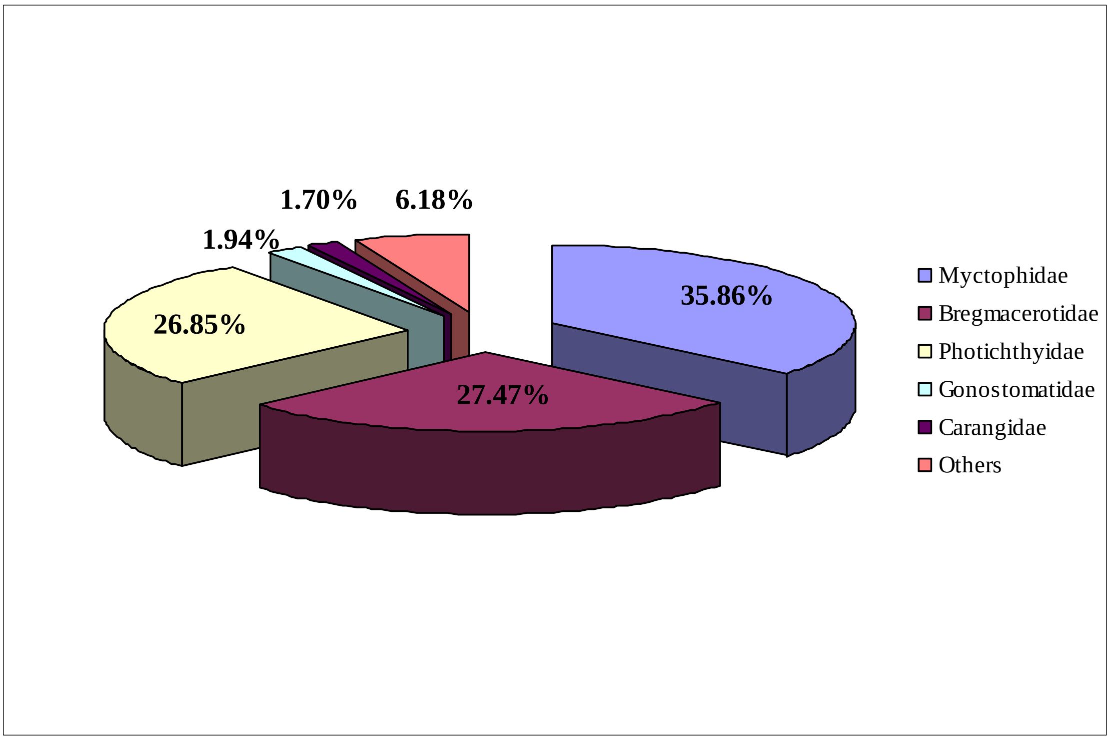

Figure 6 Top five most abundant composition of total collection (%) in area B.

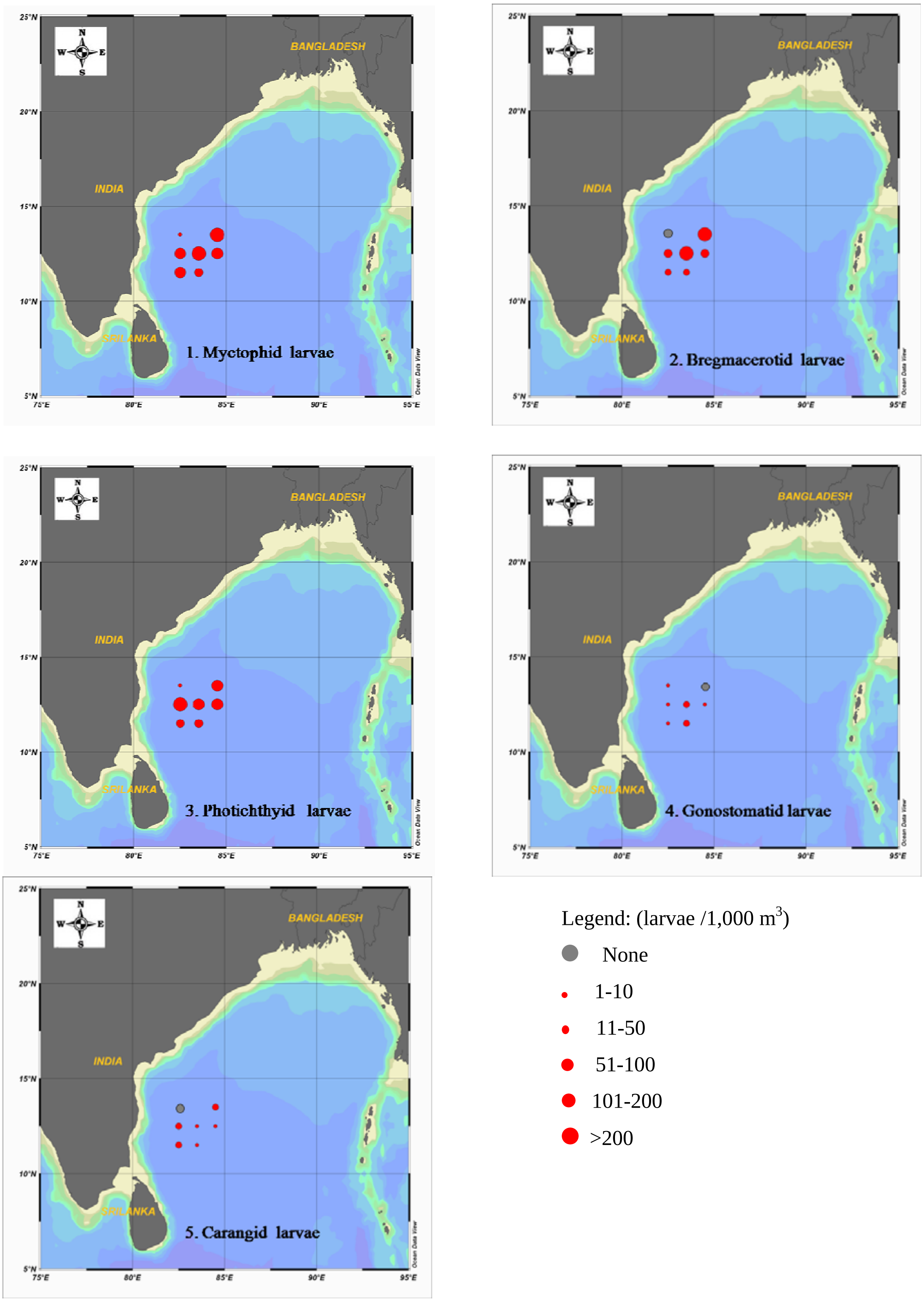

Figure 7 Distribution and abundance of top five most fish larvae in the western part of the Bay of Bengal (area B).

1.3 Area C

1.3.1 Total Fish Larvae

A total of 5,321 specimens of 51 families were recorded in this area. The average number per station was 485 larvae/1,000 m^3 and 24 economic important families were identified. Among them, the most dominant family was Bothidae followed by Hemirhamphidae and Carangidae. All of the economic fish families contributed 14% to the total fish larvae. (Tables 1 and 6) the highest density was observed in station 10 and the lowest was in station 4. However, most of the fish larvae distributed around station 6 to 12, with mean density 639 larvae/1,000 m^3, and contributed 71.91% to the total abundance. This high percentage was mainly produced by top 5 families which were Myctophidae, Bregmacerotidae, Photichthyidae, Gonostomatidae and Callionymidae. They constituted 67.43% of the total fish larvae.

According to the constancy of occurrence (Table 6), fourteen families were considered as constant families. The other 14 and 23 families were accessories and accidental families. Fourteen families representing accessories were Scopelarchidae, Ophidiidae Hemirhamphidae, Priacanthidae, Coryphaenidae, Carangidae, Bramidae, Lutjanidae, Labridae, Chamsodontidae, Blennidae, Gempylidae, Scombridae and Cynoglossidae. The rest belonged to constant and accidental group.

Based on the adult's habitat 22 families were in Group 3 for inshore-reef fish (Holocentridae, Serranidae, Priacanthidae, Apogonidae, Menidae, Lutjanidae, Gerreidae, Lethrinidae, Nemipteridae, Mullidae, Teraponidae Labridae , Ammodytidae, Blenniidae, Callionymidae, Gobiidae, Bothidae , Pleuronectidae, Cynoglossidae, Triacanthidae, Balistidae, Ostraciidae and Tetraodontidae) followed by group 5 for oceanic fish (Gonostomatidae, Photichthyidae, Stomiidae, Chlorophthalmidae, Scopelarchidae, Paralepididae, Evermannellidae, Myctophidae, Ceratiidae , Liparidae, Acropomatidae, Coryphaenidae, Bramidae, Schindleriidae, Gempylidae, Trichiuridae) (Table 7).

1.3.2 Top Five Dominant Families

1.3.2.1 Myctophidae

Myctophid larvae were the most abundant family. They contributed 44.05% to the total fish larvae and were found at all stations in this area.The mean density was 213.43 larvae/1,000 m^3 and the highest number 490 larvae/1,000 m^3 was observed at station 1 followed by stations 10, 9 and 6 (Table 6, Figs. 8, 9 and Appendix 4).

1.3.2.2 Bregmacerotidae

Bregmacerotid larvae were the second abundant family. They contributed 8.01% to the total fish larvae and were found in 8 of 11 sampling stations. The highest number of Bregmacerotid larvae occurred at station 10. The mean density was 208 larvae/1,000 m^3 (Table 6, Figs. 8, 9 and Appendix 4).

1.3.2.3 Photichthyidae

Photichthyid larvae were widely distributed over the study area. The highest number of larvae were found at station 9 with density 74 larvae/1,000 m^3.The mean density was 28.71 larvae/1,000 m^3 (Table 6, Figs. 8, 9 and Appendix 4).

Table 6 Number of fish larvae (larvae /1,000 m^3) in the Andaman Sea (area C).

Family	Total number of larvae	Mean number of larvae	SD	Percentage of total catch	Rank	Frequency of Occurrence (%)	Classification according to Constance of Occurrence		
							(1)	(2)	(3)
Ophichthyidae	42	3.78	1.46	0.78	14	72.73	x		
Engraulidae	3	0.25	-	0.05	32	9.09			x
Gonostomatidae	255	23.23	4.61	4.80	4	100.00	x		
Photichthyidae	316	28.71	8.17	5.93	3	100.00	x		
Stomiidae	42	3.86	0.71	0.80	14	72.73	x		
Chlorophthalmidae	16	1.41	-	0.29	24	9.09			x
Scopelarchidae	17	1.59	0.00	0.33	23	27.27		x	
Synodontidae	44	3.99	1.46	0.82	13	63.64	x		
Paralepididae	165	15.01	2.91	3.10	7	100.00	x		
Evermannellidae	9	0.78	0.71	0.16	27	18.18			x
Myctophidae	2348	213.43	43.30	44.07	1	100.00	x		
Carapidae	6	0.52	0.00	0.11	29	18.18			x
Ophidiidae	9	0.78	0.00	0.16	27	27.27		x	
Bregmacerotidae	431	39.19	29.22	8.09	2	72.73	x		
Ceratiidae	5	0.46	-	0.10	30	9.09			x
Hemirhamphidae	96	8.74	15.84	1.80	9	36.36		x	
Holocentridae	4	0.35	-	0.07	31	9.09			x
Scorpaenidae	44	4.04	1.46	0.83	13	63.64	x		
Liparidae	8	0.76	-	0.16	28	9.09			x
Acropomatidae	3	0.23	-	0.05	32	9.09			x
Serranidae	34	3.05	1.17	0.63	19	54.55	x		
Priacanthidae	68	6.15	3.92	1.27	11	36.36		x	
Apogonidae	89	8.10	5.82	1.67	10	54.55	x		
Coryphaenidae	13	1.20	0.58	0.25	25	27.27		x	
Carangidae	59	5.39	7.94	1.11	12	27.27		x	
Menidae	3	0.26	-	0.05	32	9.09			x
Bramidae	29	2.65	3.50	0.55	21	36.36		x	
Lutjanidae	35	3.21	5.20	0.66	18	27.27		x	
Gerreidae	3	0.25	-	0.05	32	9.09			x
Lethrinidae	4	0.35	-	0.07	31	9.09			x
Nemipteridae	3	0.26	-	0.05	32	9.09			x
Mullidae	3	0.23	-	0.05	32	9.09			x
Teraponidae	3	0.23	-	0.05	32	9.09			x
Labridae	36	3.28	2.08	0.68	16	27.27		x	
Champsodontidae	35	3.21	2.87	0.66	17	36.36		x	
Ammodytidae	6	0.53	-	0.11	29	9.09			x
Blenniidae	10	0.88	0.00	0.18	26	27.27		x	
Callionymidae	242	21.99	11.84	4.54	5	90.91	x		
Gobiidae	101	9.15	3.76	1.89	8	63.64	x		
Schindleriidae	3	0.26	-	0.05	32	9.09			x
Sphyraenidae	6	0.54	0.00	0.11	29	18.18			x
Gempylidae	41	3.74	2.24	0.77	15	45.45		x	
Trichiuridae	3	0.25	-	0.05	32	9.09			x
Scombridae	25	2.27	1.26	0.47	22	36.36		x	
Bothidae	178	16.19	8.97	3.34	6	63.64	x		
Pleuronectidae	3	0.26	-	0.05	32	9.09			x
Cynoglossidae	33	3.02	0.82	0.62	20	36.36		x	
Triacanthidae	6	0.54	0.00	0.11	29	18.18			x
Balistidae	6	0.57	-	0.12	29	9.09			x
Ostraciidae	8	0.71	-	0.15	28	9.09			x
Tetraodontidae	6	0.57	0.00	0.12	29	18.18			x
Unknown	118	10.73	2.64	2.21					
Incomplete	255	23.14	8.10	4.78					
Total fish larvae	5330			100.00					

(1): constant family, (2): accessories family, (3): accidental family

Table 7 Fish grouping based on adult habitat in the Andaman Sea (area C).

Group 1 Freshwater fish	Group 2 Neritic fish	Group 3 Inshore-reef fish	Group 4 Shallow to oceanic fish	Group 5 Oceanic fish
Ophichthyidae	Carangidae	Ammodytidae	Bregmacerotidae	Acropomatidae
	Engraulidae	Apogonidae	Carapidae	Bramidae
	Hemirhamphidae	Balistidae	Champsodontidae	Ceratiidae
		Blenniidae	Scombridae	Chlorophthalmidae
		Bothidae	Scorpaenidae	Coryphaenidae
		Callionymidae	Sphyraenidae	Evermannellidae
		Cynoglossidae	Synodontidae	Exocoetidae
		Gerreidae		Gempylidae
		Gobiidae		Gonostomatidae
		Holocentridae		Liparidae
		Labridae		Myctophidae
				Ophidiidae
		Lethrinidae		Paralepididae
		Lutjanidae		Photichthyidae
		Menidae		Schindleriidae
		Mullidae		Scopelarchidae
		Nemipteridae		Stomiidae
		Ostraciidae		Trichiuridae
		Pleuronectidae		
		Priacanthidae		
		Serranidae		
		Teraponidae		
		Tetraodontidae		

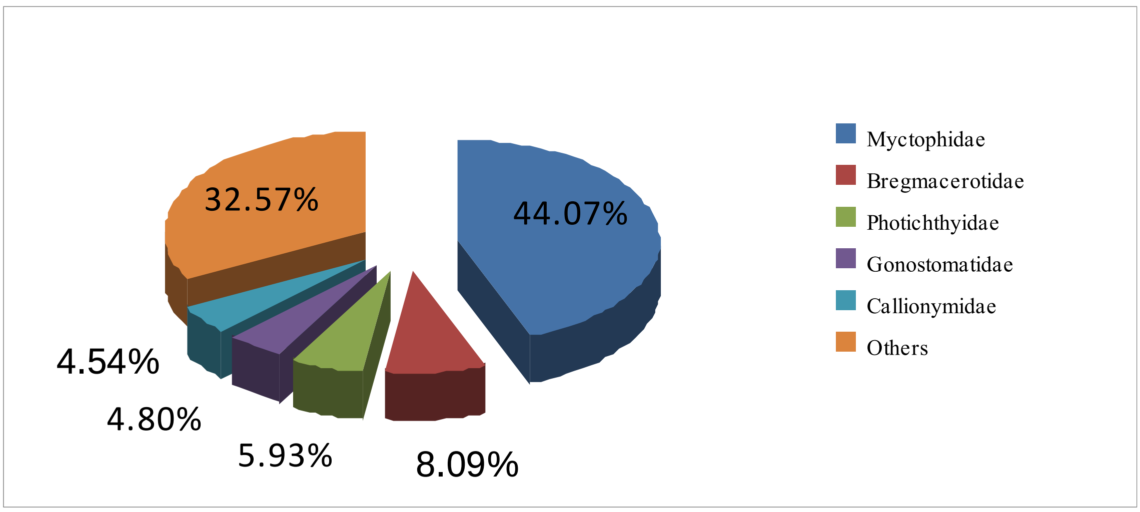

Figure 8 Top five most abundant composition of total collection (%) in area C.

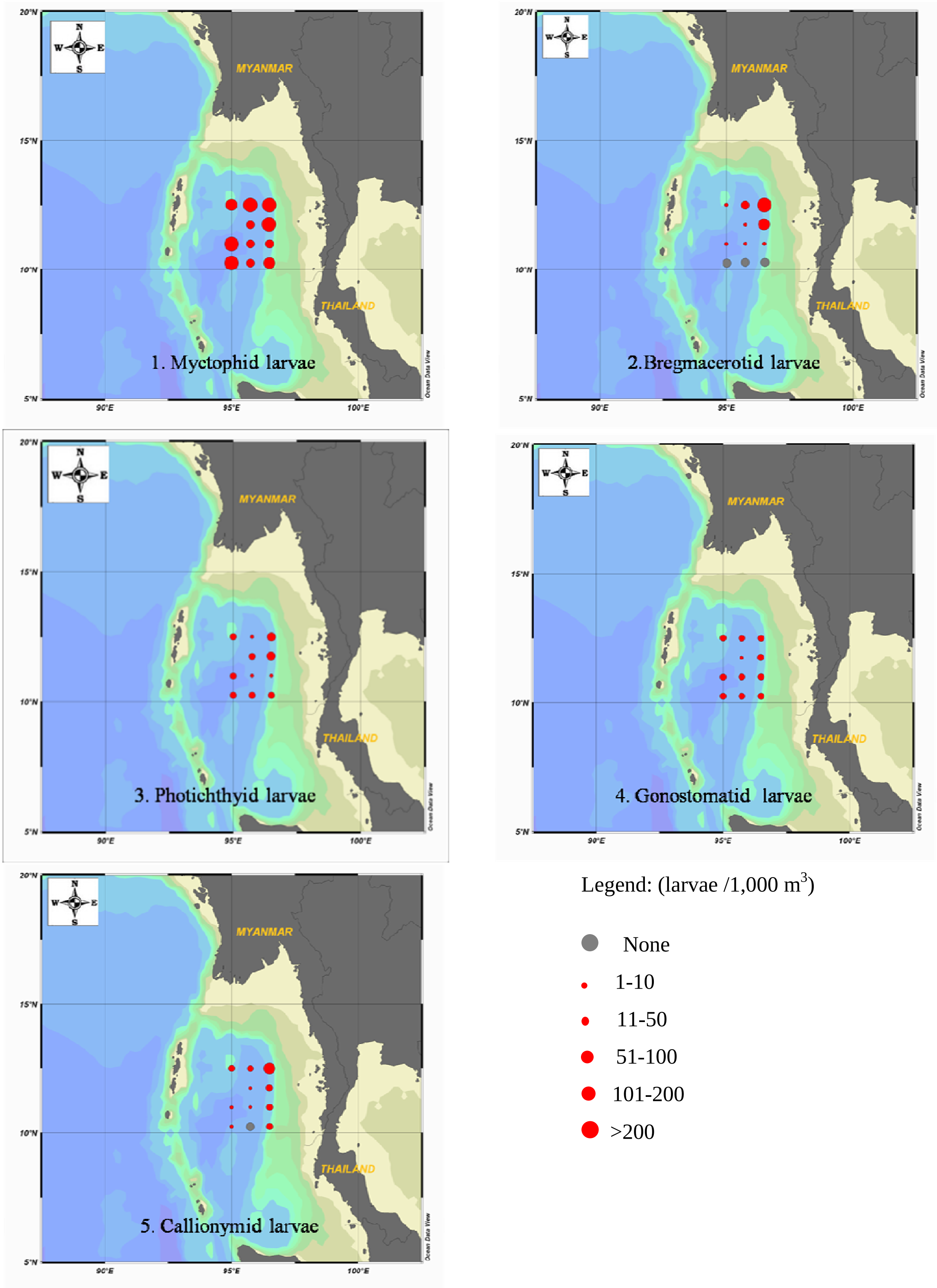

Figure 9 Distribution and abundance of top five most fish larvae in the Andaman Sea (area C).

1.3.2.4 Gonostomatidae

Gonostomatid larvae were found in 11 stations. These larvae distributed throughout the study area. The highest abundance was found at station 9 (48 larvae/1,000 m^3) (Table 6, Figs. 8, 9 and Appendix 4).

1.3.2.5 Callionymidae

Callionymid larvae ranked the fifth in abundance. They contributed 4.54% to the total fish larvae. Callionid larvae were found in 10 of 11 sampling stations.The most abundance 118 larvae/1,000 m^3 occurred at station 10 (Table 6, Figs. 8, 9 and Appendix 4).

2. Abundance and Distribution of Tuna Larvae in the Bay of Bengal.

Tuna larvae are in the family Scombridae and are very important fish in the study areas. In this study, Scombrid larvae in area A, B and C were ranked the 6, 13 and 22 in percentage, respectively. Tuna larvae were rarely found during the survey period and were not distributed throughout the study areas. They were observed in 13 of 33 stations, however, more larvae were presented in area A than Area C and B. Tuna larvae were identified deep to the lowest taxa (species) and were presented as following.(Tables 2,4, 6 and Fig.10).

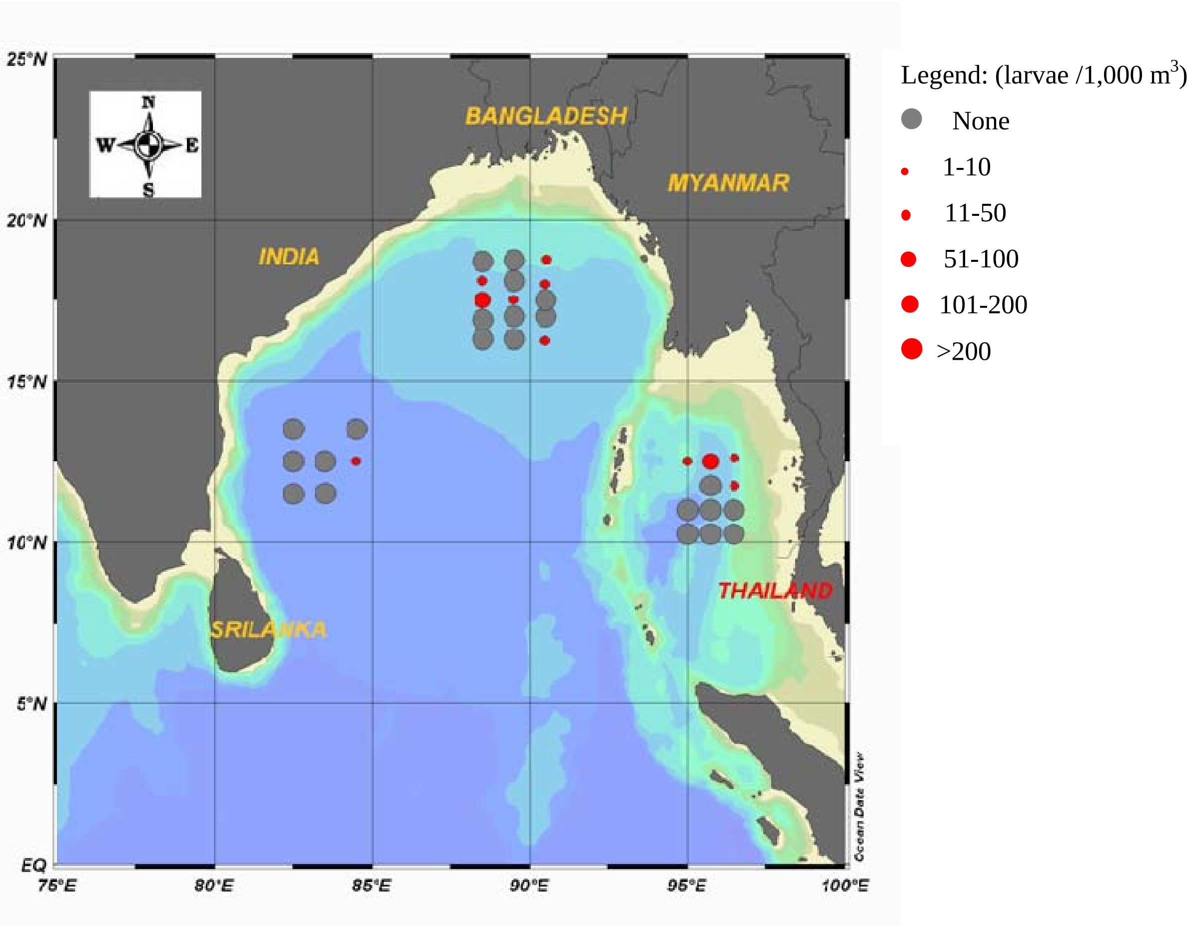

Figure 10 Distribution and abundance of Scombridae in the Bay of Bengal.

2.1 *Euthynnus affinis*

Kawakawa larvae, epipelagic, neritic species were present at station 9 in area C (3 larvae/1,000 m^3).

2.2 *Auxis thazard*

Frigate tuna were found only at station 10 in area C (3 larvae/1,000 m^3). They are epipelagic, neritic and oceanic fish.

2.3 *Katsuwonus pelamis*

Skipjack larvae were observed in 4 of 33 stations. They were found at station 10, 12, 21 and 30 with 3, 2, 2 and 3 larvae/1,000 m^3, respectively.

2.4 *Thunnus obesus*

Bigeye tuna larvae, epipelagic and mesopelagic in oceanic waters, were observed in 3 of 33 stations. They occurred at station 11, 24 and 25 with 6, 4 and 4 larvae/1,000 m^3 respectively.

2.5 *T. alalunga*

Albacore larvae were found at station 11 and 20 with equal number of 3 larvae/1,000 m^3.

2.6 *T. albacares*

Yellowfin tuna larvae occurred in 4 of 33 sampling stations with numbers 2-4 larvae/ 1,000 m^3.

2.7 Unidentified tuna larvae

Unidentified tuna larvae were also found in low number between 2-4 larvae/1,000 m^3.

3. Comparison of Larval Fish Assemblages by Station

3.1 Area A

Classification of fish assemblage by station using dendrogram was shown in Fig. 11. The similarity cluster indicated the presence of two major groups based on larval number in families with roughly similar abundance. The first group was characterized by 2 stations which were stations 13 and 17. They were similar sharing of 5 families namely Photichthyidae, Myctophidae, Bregmacerotidae, Callionymidae, and Gempylidae. Within this group Photichthyidae and Bregmacerotidae were the first and second most abundant.

The second group comprised the rest of stations. Likewise, Photichthyid larvae were the most abundant and Bregmacerotid larvae ranked the second. This group can be devided into 4 subgroups. Stations 14, 15 and 23 formed the first sub-group and comprised 8, 9 and 6 families respectively and were sharing by 5 families namely Photichthyidae, Myctophidae, Bregmacenrotidae, Carangidae and Callionymidae. The second sub-group consisted of stations 20, 24, 26 and 22, these stations comprised 9, 6, 7 and 7 families respectively. This sub-group was shared by 5 families Photichthyidae, Myctophidae, Bregmacerotidae, Carangidae and Calliomymidae. The third sub-group included 4 stations, station 18, 21, 19 and 27, and comprised 3, 6, 6 and 3 families, respectively. They were shared by only 2 families, Bregmacerotidae and Callionymidae. The last sub-group consisted station 16 and 25 where comprised 12 and 9 families respectively and were shared by 7 families namely Photichthyidae, Myctophidae Bregmacerotidae, Carangidae, Callionymidae, Gempylidae and Scombridae (Appendix 2).

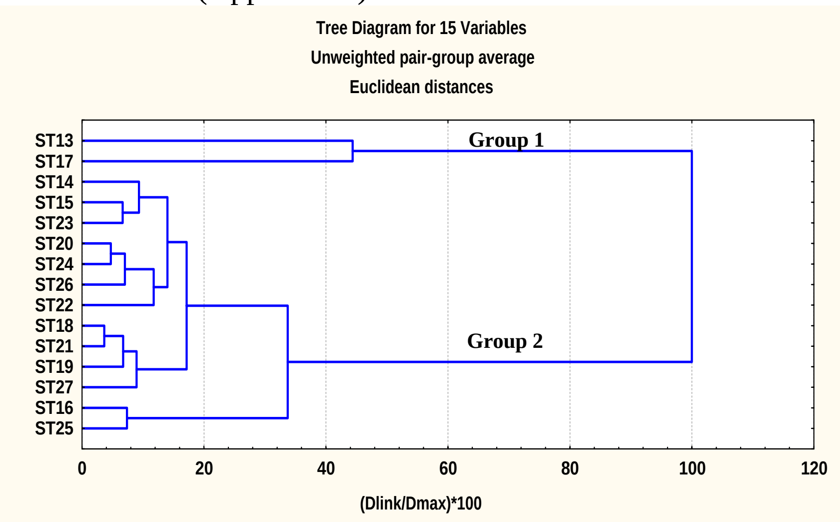

Figure 11 Tree diagram of fish larvae between 15 stations in the upper part of the Bay of Bengal (area A).

3.2 Area B

The similarity cluster analysis indicated the presence of 3 groups in this area (Fig. 12). The first group was characterized by 2 stations, station 28 and 34, and comprised 3 and 5 families, respectively. This group was shared by 3 families namely Gonostomatidae Photichthyidae and Bregmacerotidae. The second group was given to 3 stations (station 30, 33 and 32). The sharing families belonged to this group were Gonostomatidae, Photichthyidae, Myctophidae, Bregmacerotidae, Carangidae, and Bothidae. The third group consisted of station 29 and 31, and were sharing of 6 families namely Photichthyidae, Myctophidae Bregmacerotidae, Apogonidae, Carangidae and Callionymidae (Appendix 3).

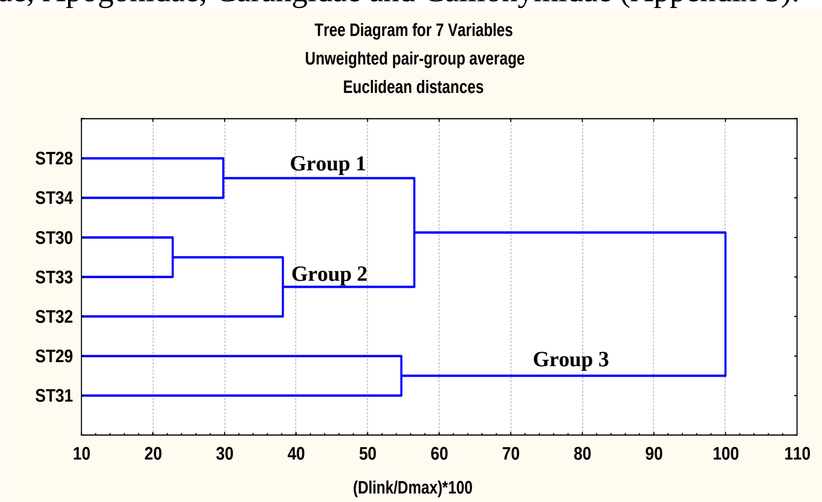

Figure 12 Tree diagram of fish larvae among 7 stations in the western part of the Bay of Bengal (area B).

3.3 Area C

The dendogram classification of fish larvae assemblage was shown in Fig. 13. The first group was 4 which distinguished only 1 station (station 1) comprising 20 families in which Myctophidae was the most abundant and followed by Photichthyidae, the second abundant family. The second group was characterized by 2 stations, 9 and 10, where comprised 29 and 31 families, respectively. This group was a great similarity of 21 families. The third group (stations 2, 8, 3, 4 and 5) was a similarity of 4 families (Gonostomatidae, Photichthyidae Paralepididae and Myctophidae). The fourth group was characterized by 3 station which were 6, 11 and 12 where was shared by 8 families namely Ophichthidae, Gonostomatidae, Photichthyidae, Paralepididae, Myctophidae, Bregmacerotidae, Callionymidae and Gobiidae. (Appendix 4).

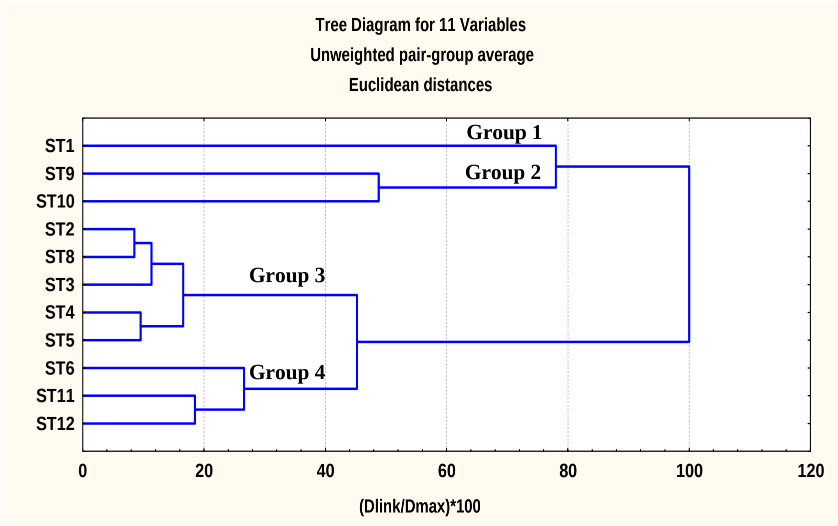

Figure 13 Tree diagram of fish larvae among 11 stations in the Andaman Sea (area C).

4. Temperature and Salinity Observation

4.1 Temperature

The horizontal distribution of temperature in area C (station 1 to 12), area A (station 13 to 27) and area B (station 28 to 34) were shown in fig. 14. The spatial changes in temperature at surface and 150 m depth were not obviously different, but varied between 27.5°C-28.75°C and between 15°C-18°C. On the contrary, the fluctuation of temperature at 75 m depth was clearly observed different. This result suggested that the temperature at 75 m depth might vary upon whether it was in a mixed layer (high temperature) or in a thermocline layer (lower temperature).

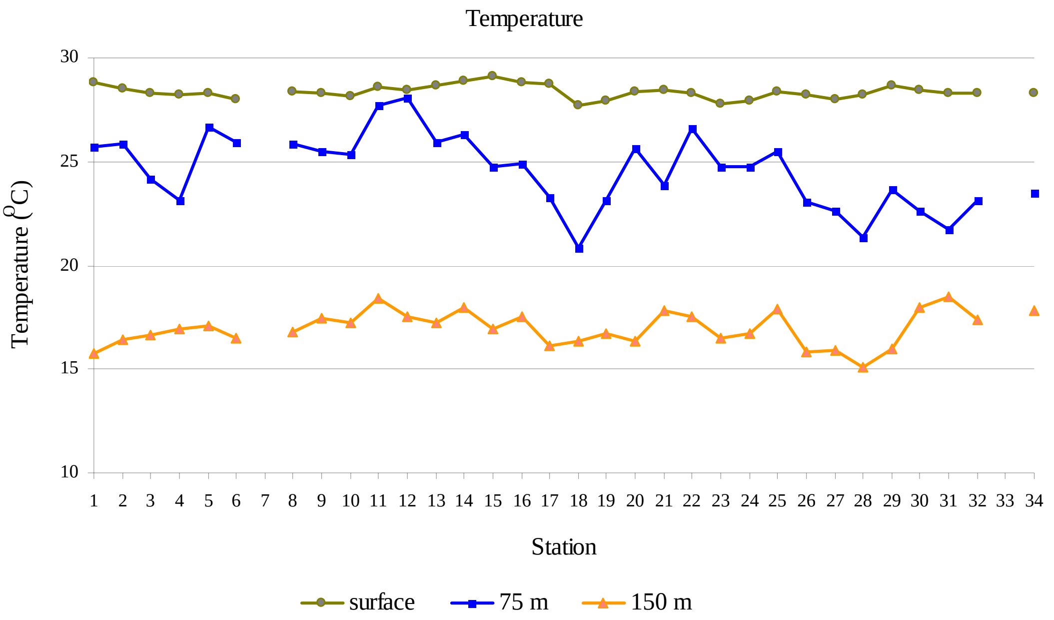

Figure 14 Spatial pattern of variation in temperature for 3 levels at the study area.

4.2 Salinity

The horizontal distribution of salinity in 3 depth levels of area A, B and C were shown in fig. 15. The changes in salinity at the surface water and 75 m depth illustrated an obvious variation pattern, 30.8-33.0 psu at surface and 32.8-34.5 psu at 75 m, whilst at 150 depth kept almost the same level at 34.5 psu. It was remarkable that in station 1-12 (area C) the salinity at 3 layers was quite different. From station 13 to 34, the salinity at 75 m depth increased close to that at 150 m depth, and from station 18 to 34 the surface salinity varied above 32.5 psu. This result possibly reflected the influence of fresh water run off in area C and the east of area A near to Myanmar waters.

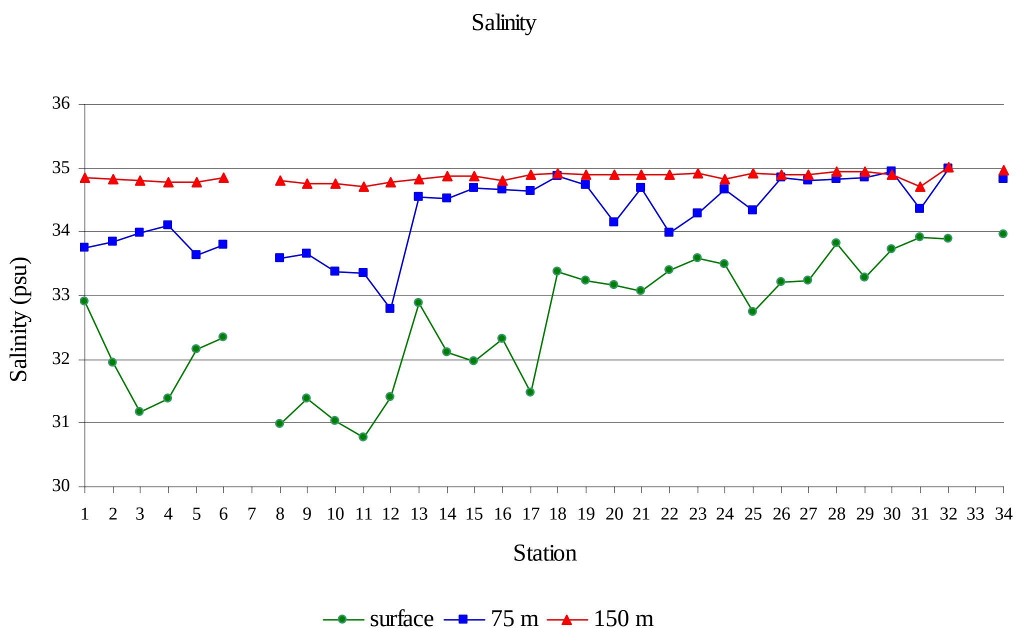

Figure 15 Spatial pattern of salinity variation in 3 depth levels at the study area.

Discussion

The total fish larvae of 52 families found in this present study seem to be lower diversity than the former works that conducted in more productive area of the other part of the Indian Ocean. Nellen (1973) reported the total of 102 fish larval families in the northwest Indian Ocean (Red Sea, Arabian Sea and Persian Gulf). He found 44 families of the oceanic plus deep benthic fish larvae and 58 families of the shelf fish larvae. In southeast Indian Ocean (NW continental shelf, Australia), Young *et al*. (1986) found 103 families of which 36 and 67 families were oceanic and shelf fish larvae.

In this study, during post summer monsoon, area C was found to be the richest fish larvae diversity (51 families) followed by area B (19 families) and area A (18 families). Although, the highest average density of fish larvae was also found in area C (485 larvae/1,000m^3) but it was not so much different comparing to 445 and 411 larvae/1,000m^3 that found in area B and A. Considering area C which is in the upper part of the Andaman Sea both of hydrographic conditions and fisheries resource information are not available except a few information in the lower part along the west coast of Thailand. As for fish larvae composition and abundance, Janekarn (1988) reported the diversity of 55 and 62 families of fish larvae found from the west coast of Thailand in 1982 and 1983. He also estimated the aggregated number of 123 families of fish larvae in the west coast of Thailand based upon his and other studies (Janekarn, 1992). This information indicated that the Andaman Sea was an area of high diversity of fish larvae in the Indian Ocean. However, referring to Mc Gowan and Frauendorf (1966) the diversity value was influenced not only by area but also by depth of haul, time and type of net used.

Based on the constancy of occurrence, among the 18 families in area A, the percentages by families of constant:accessory:accidental families were 28:22:50; in area B (19 families) were 32:21:47 and in area C (51 families) were 27.5:27.5:45, respectively. This study was similar to Chamchang (2006) who reported a relative low number of constant families suggesting the system appeared not to be stable. From this reference, 62 families of fish larvae were found in the Andaman Sea along the west coast of Myanmar and Thailand between 6°44.47'N to 12°40.80'N and 95°51.20'E to 96°45.30'E. Half of the mentioned study site were located almost the same latitude as area C but the sampling stations were located in more shallow waters. Furthermore, in that survey the fish larvae samples were collected in November 2004 which was almost the same month as this survey. Thirty six families of that finding were shared by 15, 13 and 6 families belonging to group 3 (inshore-reef fish), group 5 (oceanic fish) and group 4 (shallow to oceanic fish). This result suggested that fish larvae of group 3 and 5 were widely distributed between inshore and offshore waters, implying that this area was very important for habitat of adult fish and their larvae. Similar to this study, the relative large numbers of inshore-reef families and oceanic families, particularly area C, may also indicate that the Bay of Bengal is the connected boundary of inshore and oceanic currents. In addition, the occurrence of many accidental families possibly reflects that the majority of the adult fish exiting in the Bay of Bengal are commonly inshore residents and their larvae are occasionally carried out offshore by currents.

In this study the most of the abundant families were Photichthyidae, Myctophidae, Bregmacerotidae, Gonostomatidae, Callionymidae, and Carangidae. Family Myctophidae is the largest family of oceanic fish with 500 species found around the world, they are an important constituent in the food chain of many local system being heavily preyed upon by cetaceans including whales and dolphins as well as large pelagic fish such as tuna and sharks (Nellen , 1973; Fish Base, 2004). Chamchang (2007) reported family Myctophidae was the most abundant contributing 30.41% to the total number of larvae followed by Stomiidae. Morliere *et al*. (1994) reported that *Vinciguerria nimbaria* (family Photichthyidae) must sustain the high concentration of small tuna and must be considered a major chain in the local food webs. Small tunas fed mainly on *V. nimbaria* for 40% by weight of tuna stomach content.

Larvae of the commercial important fish were not very high. Carangid larvae were common and abundant in area A and B which in addition appeared in considerable quantities at some stations in the Bay of Bengal. Very important to high sea fisheries, tuna larvae appeared more frequently in area A but their density was not remarkably high at any stations. Frigate tuna and kawakawa larvae were observed only one station in area C. The scantiness of tuna larvae may be attributed to the survey period that did not cover the spawning seasons of tunas. Yoshida (1979) reported frigate tuna's spawning season in the Indian Ocean was occurred from January to April. Stequert and Marsac (1989) reported the greatest abundance of skipjack larvae in the eastern Indian Ocean in February.

Regarding to larval fish assemblage, based on a cluster analysis, it illustrated the patchy distribution of the majority of fish larvae because the stations appearing similarity in fish families and their abundance tended to be located adjacent to each other. This may be, in some extents, underline the influence of currents because larval lives are generally carried to elsewhere by currents.

Although, the relationships between environmental parameters and fish larvae abundance have not been analyzed statistically due to the small sample sizes in this study. Nevertheless, the linkage between oceanographic parameters and fish larvae abundance have been pointed out by a number of authors. Munk *et. al*., 2004 investigated linkages among physics, chemistry and plankton biology across the continental shelf and shelf slope of the Andaman Sea. They found that the abundant peak of both mesozooplankton and fish larvae were at mid-shelf (50 to 65 m bottom depth) coinciding with a hydrographic front generated. Other studies in the tropics have found strong cross- shelf gradients in abundance, but were unable to detect consistent patterns related to hydrography or other factors (Williams *et. al.*, 1988, Leis, 1993). The study of mesopelagic fish larvae in the northern Arabian Sea during the intermonsoon period (March-June 1987) by Röpke (1993) showed that prey abundance and distribution in the water column were related to fish larval distribution. Most of the Myctophid and Photichthyid larvae avoided the upper mixed layer, which contained the highest concentrations of potential prey organisms, and their distribution was also not directly related to pycnocline depth. Below the mixed surface layer the abundance and vertical distribution of potential prey was more important in determining the vertical distribution of the larvae than the gradient of physical stratification. The results also indicted that larvae of mesopelagic moved downward during early development and adapted to their later life in the mesopelagic zone.

Like the tropical Asian Waters, the BOB was influenced by monsoons as well as by the river runoff. Area A in the north and area B in the west of the BOB were influenced by two great rivers (Ganga and Brahmaputra rivers) and some other smaller rivers. Area C was largely influenced by Salween and Irrawaddy rivers. These river systems carried huge quantities of nutrient-rich and freshwater mass into the bay during south-west monsoon. In addition, area C seems to be a basin enclosed by the Andaman and Nicobar Islands. This area is not only topographically different from the other two areas but also hydrological richer and more suitable than those areas. These favorable conditions probably supported the distribution and abundance of fish larvae as shown in Tables 2, 4 and 6. The richest in diversity of fish larvae in this area might due to the influence of nutrient-rich from two great rivers that discharged nutrients into the north of area C and also the reef areas around the enclosing islands. Further more, the investigation of large pelagic fisheries resources by pelagic long line (Nuangsang *et al.,* 2008) conducted during same cruise as this present study showed that percentage of hooking rate was the highest in area C (2.17%) followed by area B (0.91%) and area A (0.78%). Desai and Bhargawa(1998) estimated he potential pelagic production in 4 exclusive economic zone of India which were along west coast, east coast, around the Andaman , Nicobar islands and Lakshadweep. He found that the average potential pelagic productions during monsoon (June-September) and postmonsoon (October-January) period in the Andaman and Nicobar area were higher than those along the east coast of India. These results suggested that Andaman and Nicobar area was the important fishery potential area in BOB. However, further study focused on the relationships of fish larvae and oceanographic parameters in different monsoon systems are needed for more understanding of the whole picture of fish larvae composition and abundance in the BOB.

Conclusion

A total of 52 families of fish larvae were identified and 24 families represented economically important group. Photichthyidae was the most abundant family in the survey area followed by Myctophidae, Bregmacerotidae, Callionymidae and Carangidae which was the most dominant of economic group. It was observed that not many families distributed widely in the Bay of Bengal whilst a large number accidentally occurred. In addition, most of the fish families were categorized inshore reef-fish and oceanic fish. In overall, area C appeared the richest diversity of fish families and also the highest average density of fish larvae compared to area A and B**.**

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Appendix 1 Position and operation of fish larvae sampling in the Bay of Bengal during 6 Nov. - 4 Dec. 2007.

Area	Station no.	Date	position		Time		Flow meter rev. Fish larvae	Bottom Depth. (m)	volume of water filtered(m^3)
			Latitude	Longitude	Start	Finish			
Area C	01	6/11/07	10°15.6'N	95°00.9'E	12.16	12.46	10,950	2,365	257.71
	02	7/11/07	10°16.0'N	95°45.1'E	12.26	12.56	14,840	2,551	384.26
	03	8/11/07	10°16.0'N	96°28.9'E	07.20	07.51	13,681	538	321.98
	*04	10/11/07	11°01.6'N	96°25.0'E	07.01	07.31	15,651	890	368.35
	05	11/11/07	11°00.2'N	95°44.7'E	12.40	13.10	19,330	513	454.93
	06	11/11/07	11°00.2'N	95°01.3'E	13.00	13.30	12,025	3,526	283.01
	08	12/11/07	11°44.9'N	95°44.9'E	13.50	14.22	15,070	2,556	354.67
	09	13/11/07	11°45.1'N	96°30.1'E	09.00	09.35	16,637	883	391.55
	10	13/11/07	12°30.0'N	96°30.0'E	14.30	15.05	14,680	1,128	345.5
	11	14/11/07	12°30.3'N	95°45.5'E	16.30	17.02	15,252	2,551	358.96
	12	15/11/07	12°29.8'N	94°59.0'E	08.35	09.07	15,595	1,418	367.03
Area A	13	17/11/07	16°29.6'N	90°30.5'E	09.50	10.25	21,122	2,430	497.11
	14	17/11/07	16°59.8'N	90°30.1'E	14.33	15.05	16,450	2,353	387.15
	15	18/11/07	17°29.9'N	90°29.9'E	12.19	12.55	18,890	2,231	444.58
	16	18/11/07	18°00.1'N	90°30.3'E	16.35	17.10	16,230	2,136	381.97
	17	19/11/07	18°30.3'N	90°30.8'E	12.00	12.30	12,350	2,005	290.66
	18	20/11/07	18°30.0'N	89°30.4'E	14.54	15.37	13,230	2,012	311.37
	19	21/11/07	17°59.0'N	89°30.3'E	11.37	12.07	19,562	2,146	460.39
	20	21/11/07	17°30.2'N	89°30.0'E	15.25	16.01	16,995	2,249	399.98
	21	22/11/07	17°00.3'N	89°29.9'E	12.46	13.16	19,440	2,402	457.52
	22	22/11/07	16°29.7'N	89°29.9'E	16.46	17.16	11,310	2,511	266.18
	23	23/11/07	16°29.9'N	88°30.2'E	13.03	13.33	13,805	2,633	324.9
	24	27/11/07	17°00.3'N	88°30.0'E	14.27	14.58	10,190	2,530	239.82
	25	27/11/07	17°29.9'N	88°29.9'E	11.25	11.56	12,330	2,396	290.19
	26	26/11/07	18°00.3'N	88°30.1'E	12.30	12.59	9,510	2,114	223.82
	27	25/11/07	18°29.8'N	88°29.9'E	15.24	15.53	9,640	2,082	226.88
Area B	29	28/11/07	13°30.3'N	84°30.2'E	13.49	14.23	13,590	3,412	319.84
	30	29/11/07	12°30.0'N	84°30.0'E	14.00	14.30	12,720	3,329	299.37
	31	30/11/07	12°29.8'N	83°29.9'E	11.57	12.29	14,870	3,381	349.97
	28	1/12/07	13°30.2'N	82°29.9'E	19.18	19.49	13,625	3,368	320.67
	32	1/12/07	13°30.0'N	82°30.0'E	07.40	08.08	11,270		265.24
	33	2/11/07	12°30.2'N	82°29.9'E	12.43	13.11	10,830	3,425	254.89
	34	4/12/07	11°30.0'N	82°29.9'E	15.24	15.49	9,465	3,528	222.76

Appendix 2 Composition and abundance of fish larvae (larvae/1,000 m^3) in the upper part of the Bay of Bengal(Area A).

Family	**Station**														
	13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Ophicthidae		5		5	4										
Photichthyidae	816	134	47	330	967		59	125	15	188	90	104	359	72	4
Stomiidae													7		
Paralepididae	12	10	2	3											
Myctophidae	72	44	32	73	113		20	20	9	11	25	13	38	13	
Bregmacerotidae	460	168	164	79	131	3	15	65	26	83	130	54	107	45	
Exocoetidae	4			3											
Hemirhamphidae *	8												3		
Carangidae *		15	11	16	58		7	3	7	8	9	29	41	27	
Labridae		3								3					
Callionymidae	6	28	11	21	10	16	2	15	13	9	12	29	24	54	75
Gobiidae	2						4	3						9	9
Sphyraenidae *								3							
Gempylidae *	2			3	10			5					14	4	
Scombridae *	2			8				3	4	8	6	4	8		
Bothidae *	8		2			3									
Cynoglossidae *				3	7										
Ostraciidae				3											
Unknown	6							3			9	4	2		
Incomplete	16	3	9	16	3			5					6		
Total	1414	410	278	563	1303	22	107	250	74	310	281	237	609	224	88

*Economic fish

Appendix 3 Composition and abundance of fish larvae (larvae/1,000 m^3) in the western part of the Bay of Bengal (Area B).

Family	**Station**						
	28	29	30	31	32	33	34
Gonostomatidae	9		7	23	4	4	13
Photichthyidae	9	103	144	149	241	94	90
Stomiidae			7				
Scopelarchidae			3				
Synodontidae*		3	3				
Evermannellidae			3				
Myctophidae	10	247	197	255	192	141	67
Bregmacerotidae		241	57	423	68	47	13
Apogonidae		3		9			
Carangidae *		13	7	6	11	12	4
Labridae			3		4	4	
Callionymidae		10		14			
Gobiidae		16					
Sphyraenidae *				6			
Gempylidae *			7				
Trichiuridae*				3			
Scombridae*			3				
Bothidae*		22	3		4	4	
Cynoglossidae*		3					
Unknown					15	8	
Incomplete			3		8	12	9
Total	28	661	447	888	547	326	196

*Economic fish

Appendix 4 Composition and abundance of fish larvae (larvae/1,000 m^3) in the Andaman Sea (area C)

Family	Station										
	1	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**11**	**12**
Ophicthidae		3		3	2	7		13	3	8	3
Engraulidae *										3	
Gonostomatidae	19	20	28	16	11	32	8	48	12	25	36
Photichthyidae	39	34	25	5	7	21	25	74	58	6	22
Stomiidae	8		6	3	2	7		3	6		7
Chlorophthalmidae	16										
Scopelarchidae			6						6		5
Synodontidae (Econ)	8				2	4	3	8	14		5
Paralepididae	27	9	9	5	9	18	17	23	32	6	11
Evermannellidae							6		3		
Myctophidae	490	100	121	52	75	279	96	354	370	212	199
Carapidae									3	3	
Ophidiidae			3					3	3		
Bregmacerotidae				3	4	7	8	153	208	45	3
Ceratiidae								5			
Hemirhamphidae (Econ)		3				4		84		5	
Holocentridae	4										
Scorpaenidae	8		6	3			3	8	14	2	
Liparidae										8	
Acropomatidae*								3			
Serranidae *	4	6				7	3	3	11		
Priacanthidae *							11	5	32	20	
Apogonidae	4			5				26	43	3	8
Coryphaenidae *	8			3							2
Carangidae *							3	10	46		
Menidae *									3		
Bramidae *			3	3				20	3		
Lutjanidae *	4							3	28		
Gerreidae *										3	
Lethrinidae *	4										
Nemipteridae*									3		
Mullidae *								3			
Teraponidae *								3			
Labridae	19					14		3			
Champsodontidae *			3					18	12	2	
Ammodytidae									6		
Blenniidae	4	3							3		
Callionymidae	8		12	22	4	7	3	23	118	25	20
Gobiidae	19					11	6	28	26	3	8
Schindleriidae									3		
Sphyraenidae *		3	3								
Gempylidae *					4	7		5		6	19
Trichiuridae *				3							
Scombridae *								3	6	12	4
Bothidae	23	3					11	43	72	22	4
Pleuronectidae									3		
Cynoglossidae *		9		5				8	11		
Triacanthidae		3	3								
Balistidae *			6								
Ostraciidae	8										
Tetraodontidae						3				3	
Unknown	16		12		15	35		5	20	16	
Incomplete	31	3	9	3	2	32	37	8	81	14	36
Total	771	199	255	134	137	495	240	996	1262	450	391

*Economic fish

Distribution and Abundance of Cephalopod Paralarvae in the Bay of Bengal

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Abstract

The 34 survey stations were conducted to collect the cephalopod paralarvae in the Bay of Bengal aboard M.V. SEAFDEC during 6 November to 7 December 2007 using a pair of bongo nets. A total of 278 paralarvae of 13 families and 19 genera were collected from 29 of 34 stations. The most numerous families were the Ommastrephidae (41% of total catch) followed by families Enoploteuthidae (14%) and Onychoteuthidae (6%). The majority of individuals were *Nototodarus hawaiiensis* (49 individuals) and *Abraliopsis* sp. (24 individuals). The paralarvae catch during the survey are all oceanic species (suborder Oegopsida) except 2 families from suborder Incirrata (order Octopoda). The compositions of the cephalopod paralarvae from the results show that the abundant paralarval squid is the commercial and/or minor-commercial target species to fisheries (Ommastrephidae, Enoploteuthidae, Thysanoteuthidae, Octopodidae).

Key words: cephalopod paralarvae, Bay of Bengal, distribution, abundance

Introduction

The composition and distribution of the cephalopod early life stages or 'paralarvae' (Young and Harman, 1988) has been investigated in the Pacific coast of Japan (Okutani, 1968 and 1969; Yamamoto and Okutani, 1975; Saito and Kubodera, 1993), the Gulf of Guinea (Arkhipkin *et al.*, 1988), the Northwest Pacific (Okutani, 1966; Kubodera and Okutani, 1981; Kubodera and Jefferts, 1984a; Kubodera and Jefferts, 1984b; Kubodera, 1991), the Arabian Sea (Nesis, 1974; Piatkowski and Welsch, 1991; Piatkowski *et al.*, 1993), and California current (Okutani and Mcgowan, 1969). Although, the Bay of Bengal is one of the largest marine ecosystem, the investigation of paralarvae distribution in the area is still sparse. The knowledge of the early life stages cephalopod distribution and abundance patterns is useful to determining the spawning area and period (Bower *et al.*, 1999). It can also help in understanding cephalopod population dynamics and in developing stock-recruitment models for commercial important species (Vecchione, 1987). The joint research survey by the fishery sector of BIMSTEC to observe and collect scientific data concerned with fishery and oceanographic aspects in 2007 provided a valuable opportunity to analyze the data from the bongo net collection. The present study is objective to provide the information on the composition and distribution of young stages of cephalopod in an extensive region of the Bay of Bengal.

Materials and methods

The sampling of cephalopod paralarvae at 34 survey stations were conducted in three areas off Bangladesh waters (area A; between latitude 16°N-19°N, longitude 88°E-91°E), India and Sri Lanka waters (area B; between latitude 09°N-14°N, longitude 82°E-85°E), and Myanmar waters (area C; latitude 10°N-12°N, longitude 95°E-97°E) (Fig. 1).

The standard sampling procedure was conducted aboard M.V. SEAFDEC during 6 November to 7 December 2007. All oblique tows made during the day of about 30 minute duration were taken at each station with a pair of bongo nets 45 cm mouth diameter with 330 micron mesh zooplankton net equipped with a calibrates flowmeter at the mouth to measured volume of water filtered. The tow were made from about 150 m depth (mean depth=142 m, S.D.=18.9 m) to the surface at a speed of approximately 2 to 3 knots.

The samples were fixed in 5% formalin seawater solution and bring back to laboratory for sorting and transfer to 50% isopropyl alcohol for permanent preservation.

Cephalopod paralarvae were identified to the lowest possible taxa with the aid of published figures and descriptions of Okutani and Mcgowan (1969); Sweeney *et al.* (1992); Wakabayashi (1993) and Jivaluk (2001).

Dorsal mantle length (mm ML) of all undamaged paralarvaes was measured to the nearest 0.1 mm with an ocular micrometer connected to a stereomicroscope.

The number of cephalopod paralarvae per tow was standardized to number of paralarvae per 1,000 m^3 (individuals/1,000 m^3).

Small paralarvae of families Ommastrephidae and Onychoteuthidae could be distinctive identified only at family level. The identification was not possible either genus or species level because a growth series connecting paralarvae to known adults were not available.

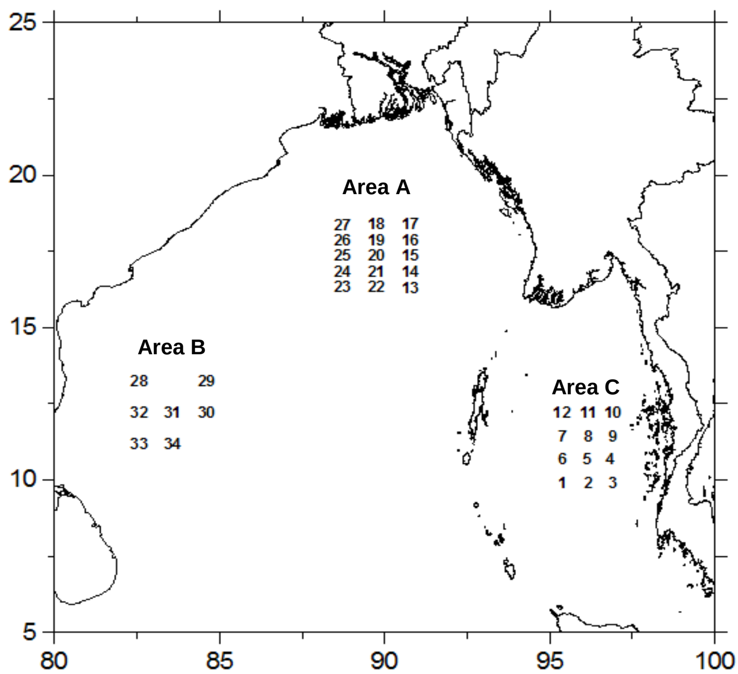

Figure 1 Map of sampling stations of the cephalopod paralarvae in the Bay of Bengal.

Results

Captured Composition

A total of 278 paralarvae of 13 families and 19 genera was collected from 29 of 34 stations (Table 1). The most numerous families were the Ommastrephidae (41% of total catch) followed by families Enoploteuthidae (14%) and Onychoteuthidae (6%). The majority of individuals were *Nototodarus hawaiiensis* (49 individuals) and *Abraliopsis* sp. (24 individuals).

Only a small number of 24 squids from 9 genera of other families (Ancistrocheiridae, Brachioteuthidae, Chiroteuthidae, Chtenopterygidae, Cranchiidae, Histioteuthidae, Octopoteuthidae, and Thysanoteuthidae) and 6 octopods (order Octopoda; suborder Incirrata) of 2 genera from family Bolitaenidae and Octopodidae were captured (Table 1).

Distribution and Abundance

Order Teuthida (Suborder Oegopsida)

Family Ommastrephidae was the most widely distributed, occurring at 26 stations (Fig. 2). *Nototodarus hawaiiensis* was the most numerous species collected, comprising 43% of the ommastrephid catch, occurring at 13 stations of the survey area A and B (Fig. 3). *Sthenoteuthis oualaniensis* was occurred in survey area A, B and C, collected at 9 stations (Fig. 4).

Family Enoploteuthidae was collected at 18 stations and also occurred in every survey areas (Fig. 5) but less abundance than family Ommastrephidae. *Abraliopsis* sp. was the highest number collected at 11 stations, composed 25% of enoploteuthid catch and more abundance in area B (Fig. 6). *Abralia* sp. and *Enoploteuthis* sp. collected at 4 and 3 stations, occurring in the survey area B and C, but *Enoploteuthis* sp. was less abundance than those of *Abralia* sp. (Figs. 7 and 8).

Family Onychoteuthidae was less abundance than family Ommastrephidae and Enoploteuthidae, occurring at 8 stations in survey areas A, B and C (Fig. 9). *Onychoteuthis* sp. was collected at 3 stations of survey area A and B and composed 25% of onychoteuthid catch (Fig. 10). Onychoteuthid species A were collected only in survey area C, composed 75% of onychoteuthid catch (Fig. 11).

Family Chtenopterygidae contained 9 individuals of *Chtenopteryx* sp. (3% of total catch) were collected at 5 stations of area B and C (Fig. 12).

Family Chiroteuthidae was collected at 5 stations from area A, B and C (2% of total catch). *Chiroteuthis* sp. occurred in three areas but *Asperoteuthis* sp. was found a single specimen in area B (Fig. 13).

Family Brachioteuthidae was collected 3 individuals of *Brachioteuthis* sp. at 2 stations of area B and C (Fig. 14).

Family Thysanoteuthidae was collected only 2 individuals of *Thysanoteuthis rhombus* at 2 stations of area A and C (Fig. 15).

Single specimen of 4 genera (*Ancistrocheirus lesueuri*, *Liocranchia* sp., *Histioteuthis* sp., *Octopoteuthis* sp.) from 4 families (Ancistrocheiridae, Cranchiidae, Histioteuthidae, Octopoteuthidae) were found in area B and C (Table 1).

Order Octopoda (Suborder Incirrata)

Octopus sp. (family Octopodidae) was collected at 2 stations (3 individuals) of area C and 1 station (1 individual) of area A. Only 2 individuals of *Japettella* sp. (family Bolitaenidae) was collected at the same station (station 23) in area A (Fig. 16).

Table 1 Number of species and individuals of cephalopod paralarvae collected by zooplankton net during the BIMSTEC survey and mantle length range (mm) of samples.

	Area C												Area A															Area B							Total	ML range (mm)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34		
Order Octopoda																																				
Family Bolitaenidae																																				
Japettella sp.?																							2												**2**	**2.3 - 8.5**
Family Octopodidae																																				
Octopus sp.			2					1																			1								**4**	**1.7 - 3.9**
Order Teuthidae																																				
Family Ancistrocheiridae																																				
Ancistrocheiru s lesueuri									1																										**1**	
Family Brachioteuthidae																																				
Brachioteuthis sp.	2																														1				**3**	**3.5 - 4.2**
Family Chiroteuthidae																																				
Asperoteuthis sp.																															1				**1**	
Chiroteuthis sp.	1													1					1													2			**5**	**3.9 - 6.9**
Family Chtenopterygidae																																				
Chtenopteryx sp.			1																											2	1	4	1		**9**	**0.9 - 4.5**
Family Cranchiidae																																				
Liocranchia sp.	1																																		**1**	
Family Enoploteuthidae																																				
Abralia sp.	3					2			2	3																					1				**11**	**1.8 - 7.2**
Abraliopsis sp.	3	1						1								1			2		1			1					7	1	4			2	**24**	**1.4 - 5.6**
Enoploteuthis sp.										1																				1			1		**3**	**2.2 - 5.1**
Family Histioteuthidae																																				
Histioteuthis sp.									1																										**1**	
Family Octopoteuthidae																																				
Octopoteuthis sp.				1																															**1**	
Family Ommastrephidae																																				
Sthenoteuthis oualaniensis	1	2									1							1	3		2	7											1	2	**20**	**2.0 - 5.1**
Nototodarus hawaiiensis?																2	4		2		9	7	8	3	7					1	1	3	1	1	**49**	**0.8 - 2.6**
Ommastrephid species	1	2	1	3		3		7	2		3	3			2	1	3					3				2			7	2				1	**46**	**0.4 - 2.1**
Family Onychoteuthidae																																				
Onychoteuthis sp.																					1		1											2	**4**	**2.4 - 7.4**
Onychoteuthid species A	3	6		1				1	1																										**12**	**1.7 - 2.9**
Family Thysanoteuthidae																																				
Thysanoteuthis rhombus?			1																				1												**2**	
Unidentified	12	6	1	12		1		6	11	5	5	2		1							1					1			4	3	7	1			**79**	**0.5 - 10.8**
Total cephalopods	**27**	**17**	**6**	**17**	**0**	**6**	**0**	**16**	**18**	**9**	**9**	**5**	**0**	**2**	**2**	**4**	**7**	**1**	**8**	**0**	**14**	**17**	**12**	**4**	**7**	**3**	**1**	**0**	**18**	**10**	**16**	**10**	**4**	**8**		

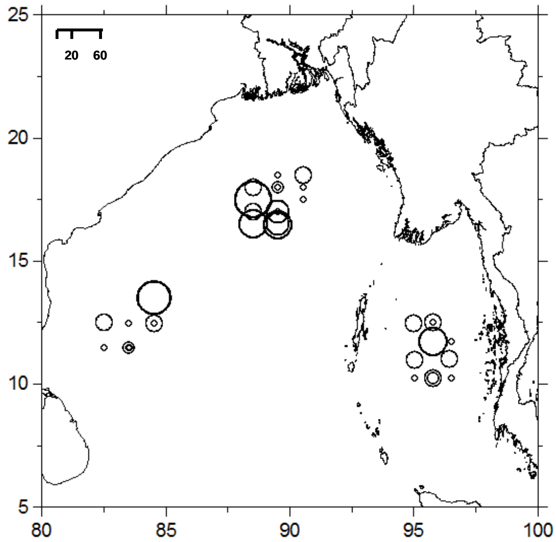

Figure 2 Distribution and abundance (ind./1,000m^3) of family Ommastrephidae.

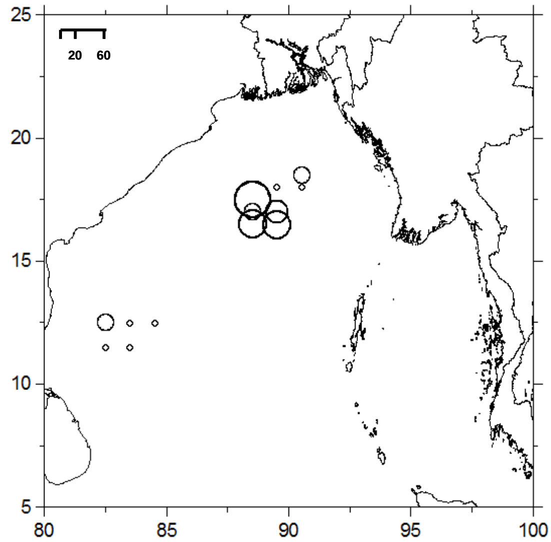

Figure 3 Distribution and abundance (ind./1,000m^3) of *Nototodarus hawaiiensis*.

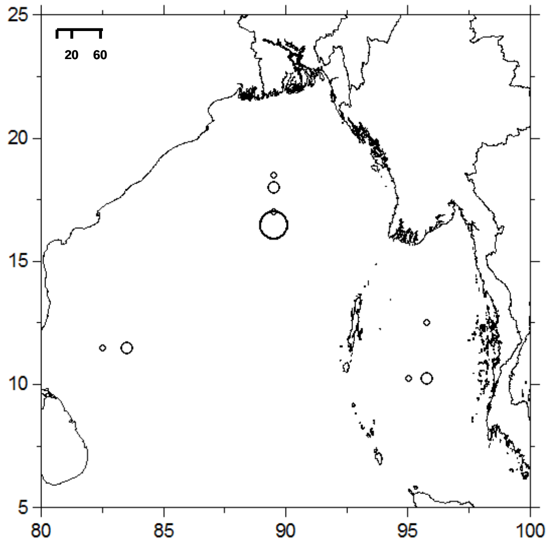

Figure 4 Distribution and abundance (ind./1,000m^3) of family *Sthenoteuthis oualaniensis*.

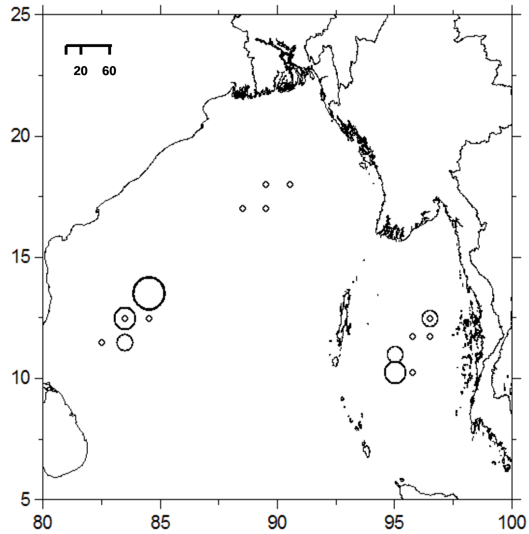

Figure 5 Distribution and abundance(ind./1,000m^3) of family Enoploteuthidae.

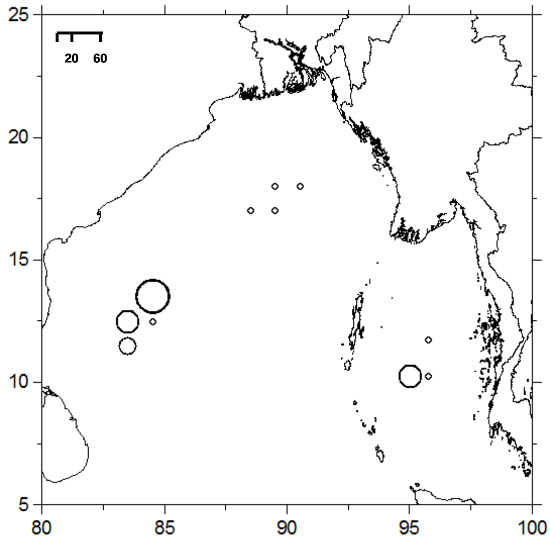

Figure 6 Distribution and abundance (ind./1,000m^3) of *Abraliopsis* sp.

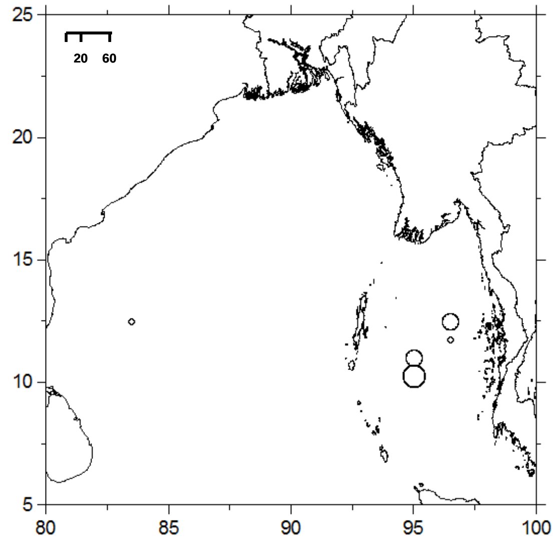

Figure 7 Distribution and abundance (ind./1,000m^3) of *Abralia* sp.

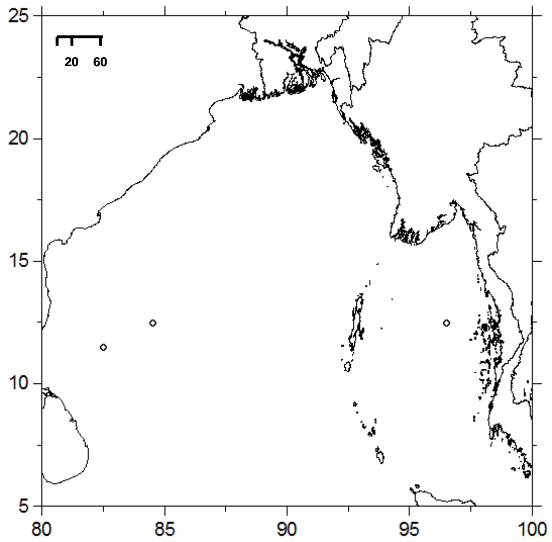

Figure 8 Distribution and abundance (ind./1,000m^3) of *Enoploteuthis* sp.

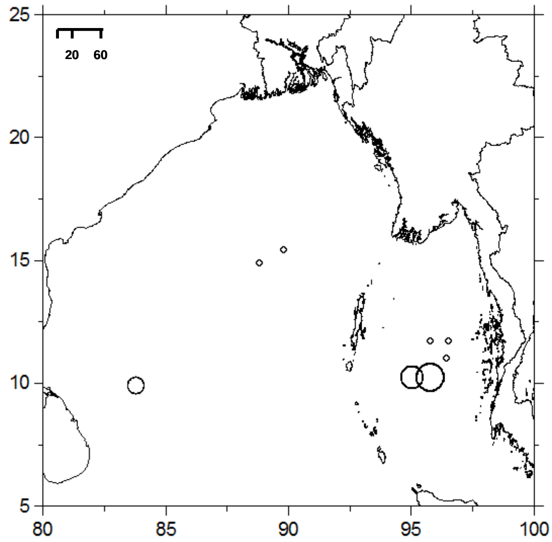

Figure 9 Distribution and abundance (ind./1,000m^3) of family Onychoteuthidae.

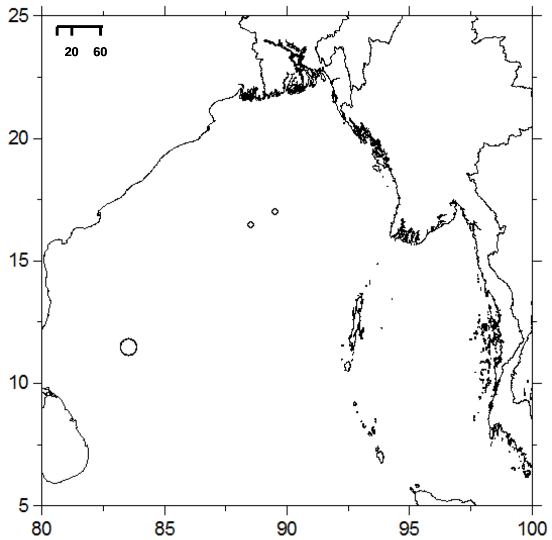

Figure 10 Distribution and abundance (ind./1,000m^3) of *Onychoteuthis* sp.

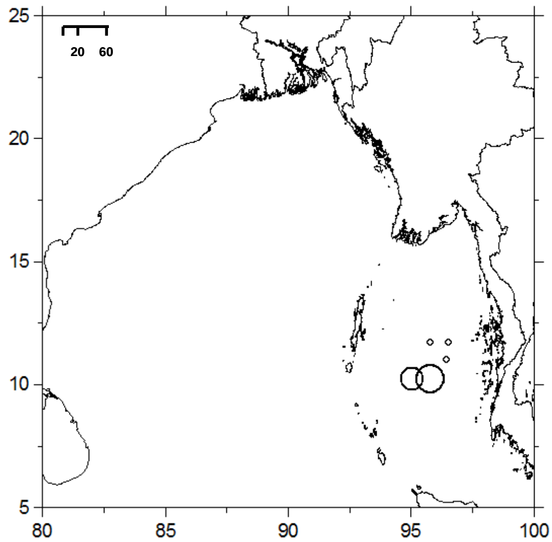

Figure 11 Distribution and abundance (ind./1,000m^3) of Onychoteuthid species A.

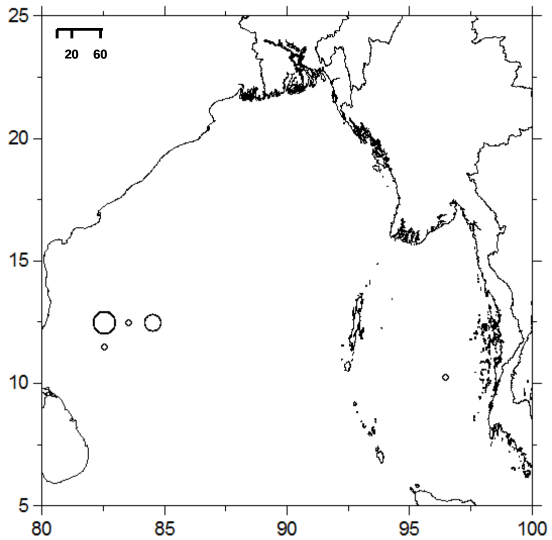

Figure 12 Distribution and abundance (ind./1,000m^3) of *Chtenopteryx* sp.

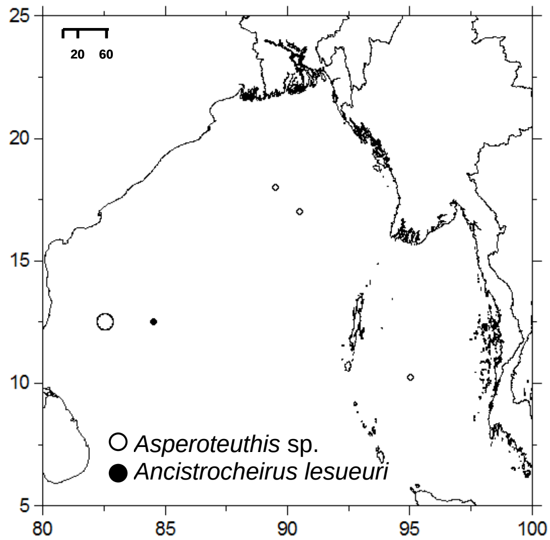

Figure 13 Distribution and abundance (ind./1,000m^3) of *Asperoteuthis* sp. and *Ancistrocheirus lesueuri.*

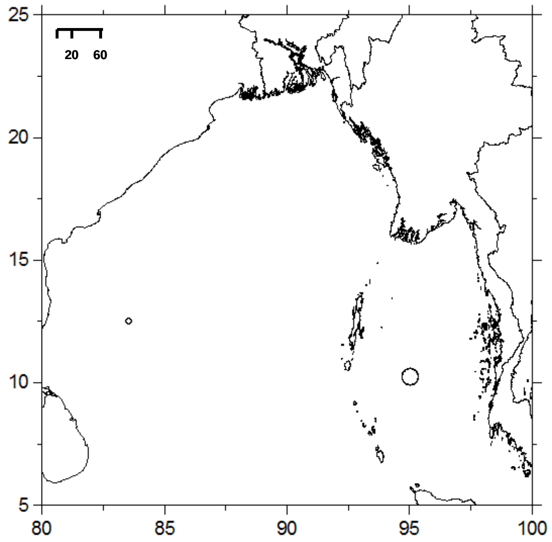

Figure 14 Distribution and abundance (ind./1,000m^3) of *Brachioteuthis* sp.

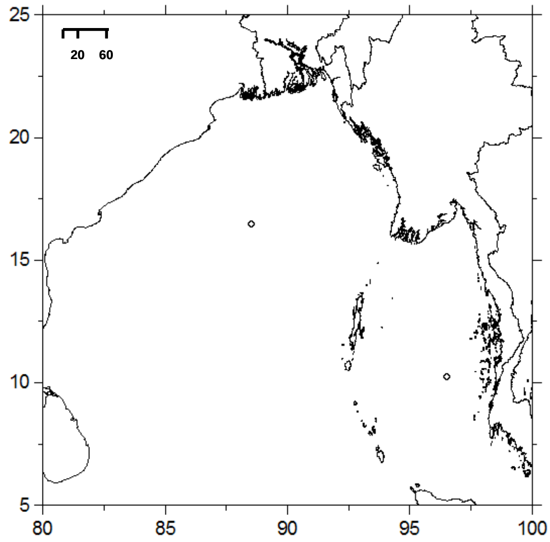

Figure 15 Distribution and abundance (ind./1,000m^3) of *Thysanoteuthis rhombus*.

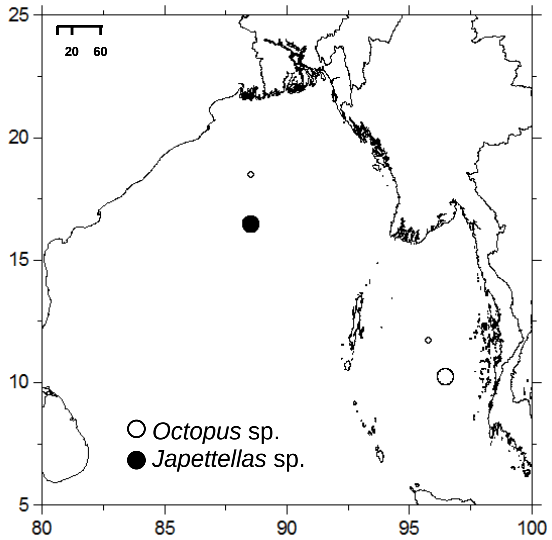

Figure 16 Distribution and abundance (ind./1,000m^3) of *Octopus* sp. and *Japettella* sp.

Discussion

The results of the present study showed that the paralarvae catch by zooplankton net during the survey are all oceanic species of various families of suborder Oegopsida (order Teuthida) except 2 families from suborder Incirrata (order Octopoda). The benthic adult octopods (*Octopus* sp.) were found occurred more than 200 km offshore of the Myanmar and Bangladesh waters. The results of the distribution found the assemblages of the pelagic adults in the continental slope and oceanic waters (*Abralia* sp., *Abraliopsis* sp., *Enoploteuthis* sp.), epi-mesopelagic adults (*Sthenoteuthis oualaniensis*, *Nototodarus hawaiiensis*, *Onychoteuthis* sp. *Thysanoteuthis rhombus*), mesopelagic adults (*Asperoteuthis* sp., *Chiroteuthis* sp., *Histioteuthis* sp.), and meso-bathypelagic adults (Chtenoteryx sp., *Liocranchia* sp., *Octopoteuthis* sp., *Brachioteuthis* sp.). A diverse community and the most numerous numbers of captured occurred in the survey area off Myanmar waters. Especially, the abundance of the small size of Ommastrephid species (<2 mm) suggesting the nearshore spawning in this area. Possibly the good feeding grounds influenced by surface water runoffs transporting nutrient-rich freshwater into the coastal areas (Sundström *et al*., 1987; Janecarn and Chullasorn, 1997; Limpsaichol *et al.*, 1998) and/or upwelling conditions create by warm surface waters mixing the nutrient rich bottom (Dwivedi and Choubey, 1998). As the inshore-offshore spawning migrations is common in many cephalopod species (Nesis, 1993a; Mangold, 1987). Some *Enoploteuthis* species have also been reported to spawn only over the slopes or in nearshore oceanic regions (Nesis, 1993a and 1996). It is possible that spawning of ommastrephid squids may occur throughout the Bengal Bay. The composition from the results also show that the abundant paralarval squid is the commercial and/or minor-commercial target species to fisheries (Carpenter and Niem, 1998).

The results from the present study is useful for determining when and where adults spawn, particularly for species whose adults are difficult to catch (Bower *et al*., 1999). Further sampling survey in different monsoon season will help to provide a better understanding on life history of cephalopod species in these areas.

Acknowledgements

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Large Pelagic Fishery Resource Survey using Pelagic Longline in the Bay of Bengal

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Abstract

The fishery research vessel, M.V. SEAFDEC, of the Southeast Asian Fisheries Development Center (SEAFDEC) collaborated with the BIMSTEC member countries was conducted a survey using pelagic longline with thirteen fishing operations to investigate the potential of large pelagic fishery resources in the Bay of Bengal within 3 areas during 5 November to 4 December 2007.

The mainline of pelagic longline was made from nylon monofilament in the reel system. Number of hook deployed in each station varied from 303-520, the hook operation depth was between 40-300 m. Shooting gear was done at dusk, baits using were round scads, milk fish and Indian mackerel then the gear was retrieved in the next morning. Total catch were weighing 1,754.65 kg and 77 numbers. Identified seventeen species belonged to 16 genera and 12 families were caught during the survey. Main catch, by weight and number, were swordfish (*Xiphias gladius*) 650.0 kg (37.044%), 21 individuals followed by bigeye thresher shark (*Alopias superciliosus*) 641.0 kg (36.531%), 11 individuals and yellowfin tuna (*Thunnus albacares*) 75.0 kg (4.274%), 3 individuals. The overall average catch rate was 1.23% (individuals/100 hooks). The highest catch rate 3.94% was found at station 12 at latitude 12°30′.30 N longitude 094°59′.70 E. The catch rate of swordfish was quite high comparing to commercial longline fleet. This suggests the prominent potential yield of swordfish in this surveyed area whilst the tuna is low.

Keywords : Bay of Bengal, pelagic longline**,** large pelagic fishery

Introduction

The Bay of Bengal is a bay that forms the northeastern part of the Indian Ocean. It occupies an area of 2,172,000 km², 2,090 km long and 1,600 km wide with an average depth of more than 2,600 m. It resembles a triangle in shape, and is bordered by India and Sri Lanka to the West, Bangladesh and the Indian state of west Bengal to the North (where the name comes from), and Myanmar, southern part of Thailand and the Andaman Sea and Nicobar Islands to the East. Its southern boundary extends as an imaginary line from Dondra Head at the southern end of Sri Lanka to the northern tip of Sumatra. The Bay of Bengal is full of biological diversity, diverging amongst coral reefs, estuaries, fish spawning and nursery areas, and mangroves. The Bay of Bengal is one of the world's 64 largest marine ecosystems. Marlin, barracuda, skipjack tuna, (*Katsuwonus pelamis*), yellowfin tuna (Thunnus albacares), Indo-Pacific humpbacked dolphin (*Sousa chinensis)*, and Bryde's whale (*Balaenoptera edeni*) are a few of the marine animals living in the Bay of Bengal ecosystem (http://en.wikipedia.org/ wiki/Bay_of_Bengal).

The FAO 10 years trend showed a steady increased in catch from 1.4 million tons in 1990 to 2.2 million tons in 1999. The average catch was 2 million tons. This tropical region has a relatively great marine biodiversity that was reflected in the catch composition. There was a high catch percentage for miscellaneous coastal fishes and pelagic fishes (tuna, yellowfin tuna, bigeye tuna and skipjack tuna) (FAO, 2003). Catch trends were quite diverse and it was difficult to identify a pattern due to the fact that there is inadequate information on the status of the fishery resources and their exploitations. Despite a steady rise in total landings since the 1950s, there were signs that the harvest levels may not be sustainable, especially with regarded to tuna fishing in the Maldives, Malaysia, Andaman coast of Thailand and Sri Lanka. Ecological changes in the estuaries and coastal areas have not yet affected total production trends (Dwivedi, 1993).

The Ecosystem-Based Fishery Management in the Bay of Bengal is a collaborative survey project of the BIMSTEC member countries (Bangladesh, India, Myanmar, Sri Lanka, Nepal and Thailand) aims to manage the fishery resources in the Bay of Bengal. This project is collaborated among member countries and Thailand takes a lead country in research surveys. In line with the concept of the project, it is incorporated to settle 17 sub-projects. The large pelagic fishery resource survey using pelagic longline is one of the sub-projects to investigate its potential yield and resources in the Bay of Bengal.

Materials and Methods

1. Fishery Research Vessel

The fishery research vessel, M.V. SEAFDEC, of the Southeast Asian Fisheries Development Center (SEAFDEC) was deployed in the proposed survey areas throughout the survey period.

2. Fishing Gear

The pelagic longline gear was used for the exploration of large pelagic species. The gear was composed of nylon monofilament mainline (4.0 mm diameter). The mainline was stored in a 2.0 meter-winch mainline reel which was driven by hydraulic power. The total length of mainline stored in the reel was about 70,000 m. The branch line, which was made of 2.0 mm nylon monofilament, was attached to the mainline by stainless steel snap clip. Total length of each branch line was 12 m. One tuna hook was attached to the branch line by aluminum sleeve at the end. One 40 g lead sinker was attached at 1.5 m above the hook. The distance between each branch line was maintained at 40 m. A PVC float (300 mm diameter) with single eye was attached to a 25 m long nylon rope (5 mm diameter) known as float line which was further attached to the mainline gear after every 15-20 hooks (which is called one basket). Two temperature-depth recorders (TDR) were also attached to the mainline gear (one at the beginning and the other at the middle portion of the basket) so as to ascertain the actual depth of the hook and the sea water temperature at that depth. About 500 hooks were operated in each pelagic longline (PLL) operation. While deploying the gear both ends of the mainline were attached with radio buoy and flag pole with light buoy for easy location of the line. The sketch of the PLL gear accessories are depicted in fig.1.

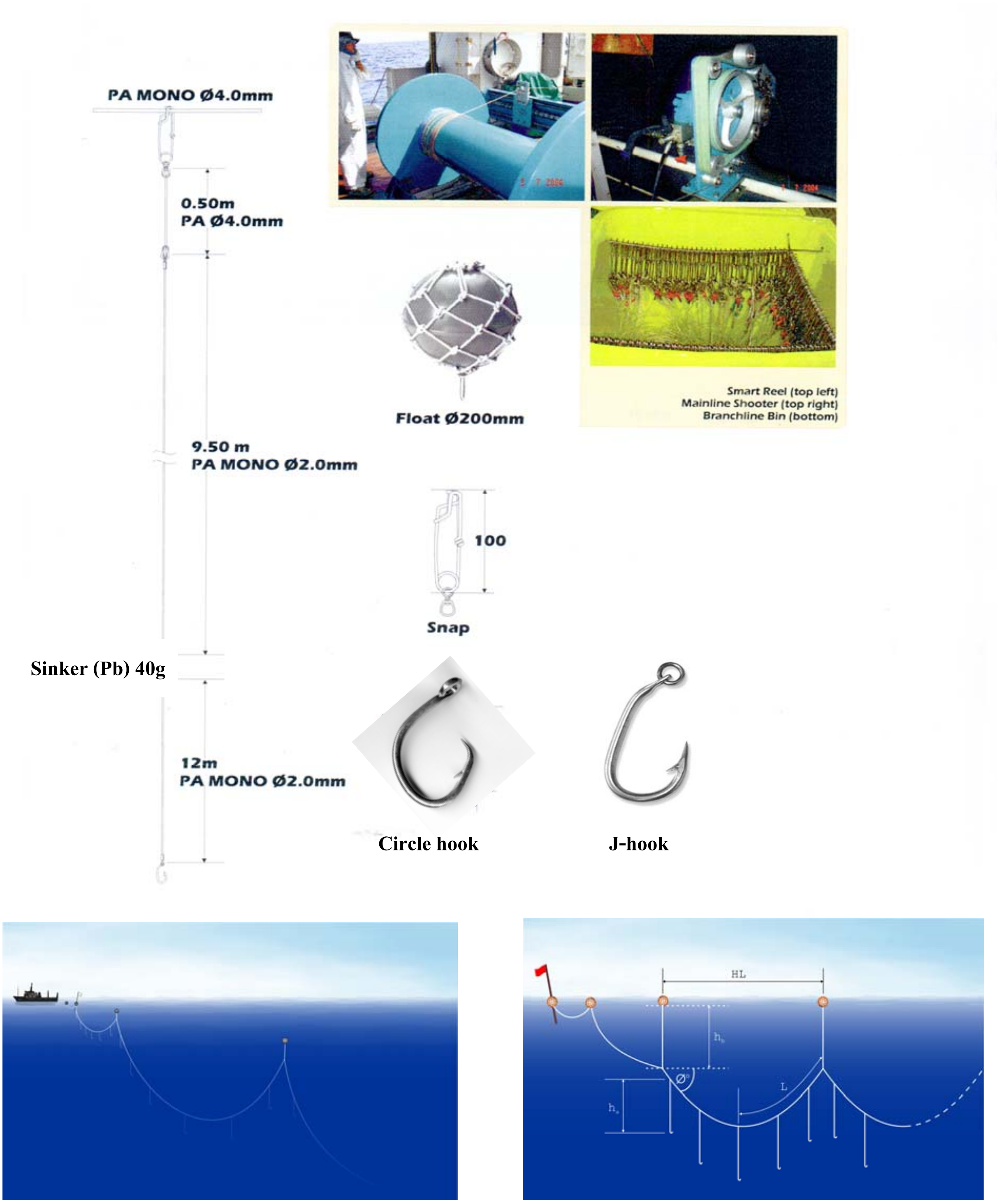

Figure 1 Accessories of pelagic longline gear and construction.

3. Survey Area

The survey areas

Area A: latitude 16°N-19°N, longitude 88°E-91°E
Area B: latitude 09°N-14°N, longitude 82°E-85°E
Area C: latitude 10°N-12°N, longitude 95°E-97°E

4. Survey Period

The pelagic longline survey was conducted within 18 different stations in three designated areas during 5 November to 4 December 2007.

5. Fishing Activity

Shooting operation was at dusk. Three different types of baits i.e., round scad (*Decapterus* sp.) , milk fish (*Chanos chanos*) and Indian mackerel (*Rastrelliger kanagurta)* were used to mask the hook. Bait sizes were approximately 8-10 individuals per kilogram. Baitfish was hooked at the end of its skull to secure it fastened with the hook. Two types of tuna hooks were used during the survey operations i.e., 3.6 Sun tuna hook (known as 'J'hook) and stainless steel circle hook (No.14). Line shooter speed was calculated in relation to the vessel speed in order to maintain the mainline sac at proper fishing depth. From the temperature depth recorder (TDR) operated in every operation, the depth of the hook and temperature were recorded. The shooting of the PLL was done during the evening hours whereas the hauling of the line was carried out in the next day morning. The immersion time for the gear was more than 13 hours. After hauling the gear, the catch was identified up to species level and the morphometric characteristics (length and weight) of each specimen were measured on board. Oceanographic condition of each station was also observed using ICTD and recorded in oceanographic logsheet.

Results

Thirteen fishing operations were carried out during the survey. The survey was mutually defined as area A: latitude 16°N-19°N and longitude 88°E-91°E (5 stations), area B: latitude 9°N-14°N and longitude 82°E-85°E (4 stations), area C: latitude 10°N-12°N and longitude 95°E-97°E (4 stations) as shown in fig.2. The depth of the sea at the survey stations varied between 1,128 m and 3,525 m. About 303 to 520 hooks were used in each PLL operation and hook depth varied between 40-300 m. Total numbers of 6,277 hooks were deployed over the survey areas. The mainline length ranging 13,004 m to 21,897 m was paid out in all PLL operations.

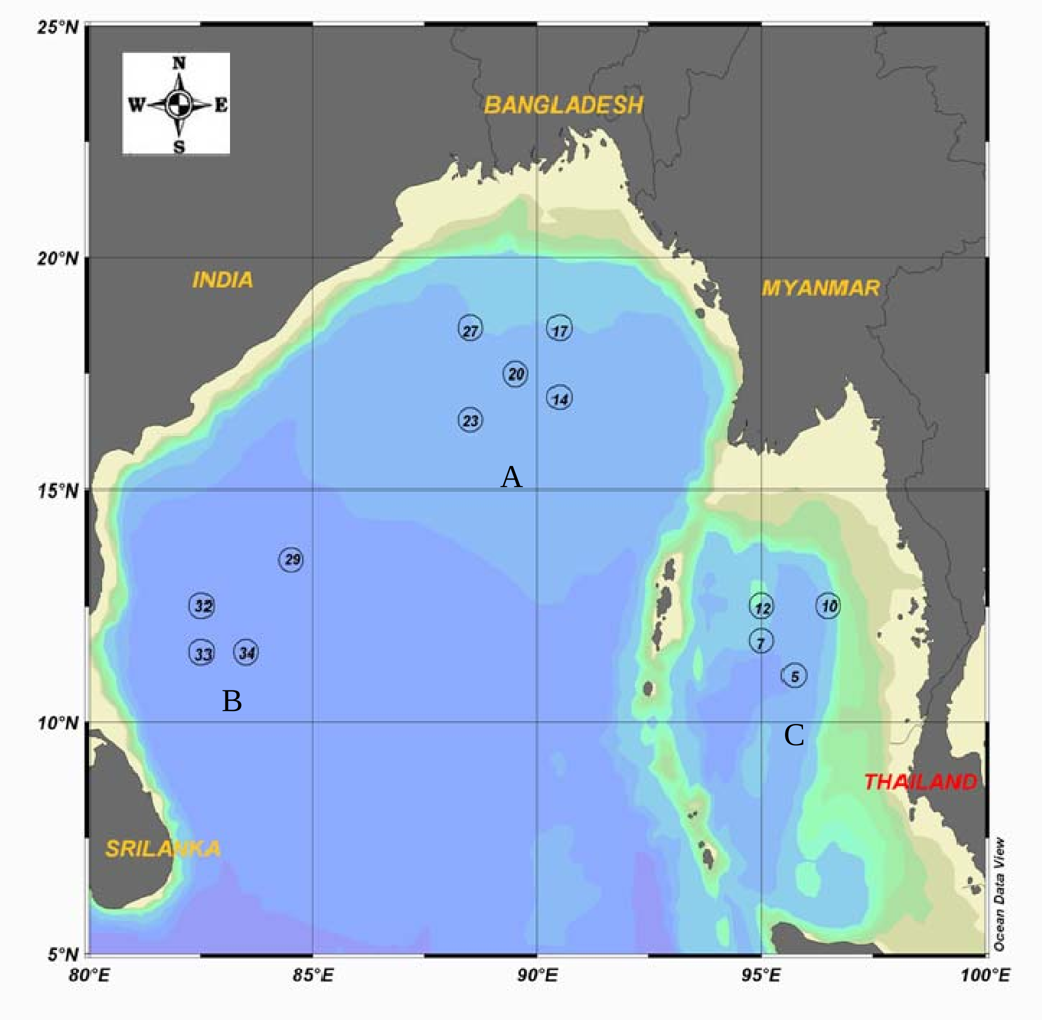

Figure 2 Map depicting the survey stations of pelagic longline.

The details of the results were summarized in table 1 and 2. A total of 77 numbers weighing about 1,754.65 kg were caught during the survey. The catch was identified into 12 families, 16 genera and 17 species. The species caught were yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*), black marlin *(Makaira indica*), pelagic thresher shark *(Alopias pelagicus),* bigeye thresher shark (*Alopias superciliosus),* longnose houndshark (*Iago garricki),* silky shark (*Carcharhinus falciformis),* tiger shark (*Galeocerdo cuveri),* pelagic stingray (*Pteroplatytrygon violacea),* lancet fish (*Alepisaurus ferox),* great barracuda *(Sphyreana barracuda),* giant trevally *(Caranx ignobilis),* dolphinfish *(Coryphaena hippurus),* sailfish (*Istiophorus platypterus),* roudi escolar *(Promethichthys prometheus),* snake mackerel (*Gempylus serpens)* and escolar (*Lepidocybium flavobrunneum).* Regarding to the catch by station, the highest catch of 16 numbers weighing 362.0 kg was obtained at the station 7 in area C.

Table 1 Results of the pelagic longline operation.

Area	Station	Position		Sea depth	Hook depth	Total	Total catch	Tuna	Swordfish	Shark	Others
		Latitude	Longitude	(m)	(m)	hooks	No./kg	No./kg	No./kg	No./kg	No./kg
C	5	11°05'.80 N	095°41'.80E	2513	60-200	495	4/6.85	0	0	0	4/6.85
	7	11°46'.00 N	094°58″.90E	2841	60-130	510	16/362.00	1/2	4/221	3/117	8/22
	10	12°34'.30 N	096°26'.70E	1128	50-220	510	7/285.60	0	2/102	3/173	2/10.6
	12	12°30'.30 N	094°59'.70E	200-1418	60-150	330	13/309.10	0	7/264	2/24	4/21.1
A	14	16°55'.60 N	090°25'.90E	2535	40-80	510	5/107.40	2/73	1/30	1/3.3	1/1.1
	17	18°31'.10 N	090°26'.70E	2005	50-80	510	9/79.10	0	0	6/61.4	3/17.7
	20	17°31'.50 N	089°28'.20E	2249	40-80	519	2/52.50	0	0	1/40	1/12.5
	23	16°30'.70 N	088°24'.50E	2633	80-300	510	4/38.60	0	1/26	0	3/12.6
	27	18°30'.40 N	088°28'.30E	2082	80-230	520	0/0.00	0	0	0	0
B	29	13°30'.00 N	084°30'.1E	3221	60-200	520	4/186.50	0	1/11.5	3/175	0
	32	12°32'.90 N	082°24'.90E	3425	60-190	520	5/167.80	0	2/24	2/139	1/4.8
	33	11°31'.80 N	082°26'.10E	3525	70-250	520	5/121.50	0	2/17.5	2/101	1/3
	34	11°29'.60 N	083°28'.10E	3470	60-240	303	3/37.70	0	2/34	1/3.7	0
						6,277	77/1,754.65	3/75	22/730	24/837.4	28/112.25

Species inventory:

Tuna;	yellowfin tuna (*Thunnus albacares*)
Swordfish;	swordfish (*Xiphias gladius*), black marlin (*Makaira indica*)
Shark;	thresher shark (*Alopias pelagicus*), bigeye thresher shark (*Alopias superciliosus*), longnose houndshark (*Iago garricki*), silky shark (*Carcharhinus falciformis*), tiger shark (*Galeocerdo cuveri*)
Others;	pelagic stingray (*Pteroplatytrygon violacea*), lancet fish (*Alepisaurus ferox*), great barracuda *(Sphyreana barracuda*), giant trevally *(Caranx ignobilis*), dolphinfish (*Coryphaena hippurus*), sailfish (*Istiophorus platypterus*), roudi escolar *(Promethichthys prometheus*), snake mackerel (*Gempylus serpens*), escolar (*Lepidocybium flavobrunneum*)

Table 2 Species list of fishes caught by pelagic longline separated by area.

No.	Family	Scientific	Name	Area A	Area B	Area C	Remark
1	Dasyatidae	*Pteroplatytrygon*	*violacea*	/*		/	
2	Alopiidae	*Alopias*	*pelagicus*			/	
3	Alopiidae	*Alopias*	*Superciliosus*		/	/	
4	Triakidae	*Iago*	*garricki*	/			
5	Carcharhinidae	*Carcharhinus*	*falciformis*	/	/	/	
6	Carcharhinidae	*Galeocerdo*	*cuvieri*			/	Escape
7	Alepisauridae	*Alepisaurus*	*ferox*	/	/		
8	Sphyraenidae	*Sphyraena*	*baracuda*	/	/		
9	Carangidae	*Caranx*	*ignobilis*			/	
10	Coryphaenidae	*Coryphaena*	*hippurus*	/		/	
11	Istiophoridae	*Istiophorus*	*platypterus*	/			
12	Istiophoridae	*Makaira*	*indica*			/	
13	Xiphiidae	*Xiphias*	*gladius*	/	/	/	
14	Scombridae	*Thunnus*	*albacares*	/		/	
15	Gempylidae	*Promethichthys*	*prometheus*			/	
16	Gempylidae	*Gempylus*	*serpens*	/		/	
17	Gempylidae	*Lepidocybium*	*flavobrunneum*			/	

/* occur

The station wise catch composition and the average size were shown in table 3 and 4 respectively. From table 3 it showed that swordfish dominated the catch by weight 650.0 kg (37.044%) followed by bigeye thresher shark 641.0 kg (36.531%), silky shark 130.3 kg (7.426%) and yellowfin tuna 75.0 kg (4.274%). From table 4 it appeared that swordfish also dominated the catch by number and, likewise, followed by bigeye thresher and silky shark. It was rather disappointing that only 3 individuals of yellowfin tuna were obtained throughout the survey period. The fork length of yellowfin tuna ranged from 52-140 cm with an average length 109.7 cm and weighing about 2-38 kg with an average weight 25 kg. The size of swordfish ranged by weight from 5-100 kg with an average weight 30.95 kg, and the total length ranging 129-295 cm with an average length 170.3 cm. Only one black marlin with total length 276 cm and weight about 80 kg was caught during this survey.

Table 3 Station-wise and species-wise average weight (kg) obtained by pelagic longline.

Scientific name	Stations														%	Average	min.	max
	5	7	10	12	14	17	20	23	27	29	32	33	34	Total				
Pteroplatytrygon violacea	2.50	2.20	9.50	3.00				10.60						27.80	1.5844	4.6333	2.20	9.50
Alopias pelagicus		34.00												34.00	1.9377	34.0000	34.00	34.00
Alopias superciliosus		53.00	173.00							175.00	139.00	101.00		641.00	36.5315	58.2727	31.00	100.00
Iago garricki						2.10								2.10	0.1197	2.1000	2.10	2.10
Carcharhinus falciformis				24.00	3.30	59.30	40.00						3.70	130.30	7.4260	13.3000	3.30	40.00
Galeocerdo cuveri		30.00												30.00	1.7097	30.0000	30.00	30.00
Alepisaurus ferox								2.00				3.00		5.00	0.2850	2.5000	2.00	3.00
Sphyreana barracuda						3.90					4.80			8.70	0.4958	43.5000	39.00	48.00
Caranx ignobilis				15.60										15.60	0.8891	7.8000	7.60	8.00
Coryphaena hippurus				2.50		13.00								15.50	0.8834	7.7500	2.50	13.00
Istiophorus platyurus							12.50							12.50	0.7124	12.5000	12.50	12.50
Makaira indica			80.00											80.00	4.5593	80.0000	80.00	80.00
Xiphias gladius		221.00	22.00	264.00	30.00			26.00		11.50	24.00	17.50	34.00	650.00	37.0444	30.9524	5.00	100.00
Thunnus albacares		2.00			73.00									75.00	4.2744	25.0000	2.00	38.00
Promethichthys prometheus		1.60												1.60	0.0912	1.6000	1.60	1.60
Gempylus serpens	2.70	4.20	1.10		1.10	0.80								9.90	0.5642	1.1750	0.80	1.50
Lepidocybium flavobrunneum	1.65	14.00												15.65	0.8919	3.9125	1.50	6.50
Total	6.85	362.00	285.60	309.10	107.40	79.10	52.50	38.60	0.00	186.50	167.80	121.50	37.70	1,754.65	100.0000	22.7877	0.80	100.00

Table 4 Station-wise and species-wise average length (cm) obtained by pelagic longline.

Scientific name	Stations														No.	Average	min.	max
	5	7	10	12	14	17	20	23	27	29	32	33	34	Total				
Pteroplatytrygon violacea	98.0	94.0	133.0	100.0				222.0						647.0	6	107.8	94.0	133.0
Alopias pelagicus		256.0												256.0	1	256.0	256.0	256.0
Alopias superciliosus		276.0	801.0							827.0	573.0	482.0		2,959.0	11	269.0	205.0	329.0
Iago garricki						80.0								80.0	1	80.0	80.0	80.0
Carcharhinus falciformis				252.0	85.0	571.0	178.0				93.6			1,179.6	10	118.0	85.0	178.0
Galeocerdo cuveri		0.0												0.0	1	0.0	0.0	0.0
Alepisaurus ferox								120.0				135.0		255.0	2	127.5	120.0	135.0
Sphyreana baracuda						88.0					88.5			176.5	2	88.3	88.0	88.5
Caranx ignobilis				184.0										184.0	2	92.0	92.0	92.0
Coryphaena hippurus				80.0		135.0								215.0	2	107.5	80.0	135.0
Istiophorus platyurus							194.0							194.0	1	194.0	194.0	194.0
Makaira indica			276.0											276.0	1	276.0	276.0	276.0
Xiphias gladius		1,012.0	212.0	954.0	215.0			210.0		162.0	160.0	297.0	354.0	3,576.0	21	170.3	129.0	295.0
Thunnus albacares		52.0			277.0									329.0	3	109.7	52.0	140.0
Promethichthys prometheus		76.0												76.0	1	76.0	76.0	76.0
Gempylus serpens	214.0	305.0	97.0		102.0	96.0								814.0	8	101.8	96.0	111.0
Lepidocybium flavobrunneum	60.9	239.0												299.9	4	75.0	60.0	92.0

Table 5 Catch and catch rate in each station.

Area	Station	No. of hook	Catch (No./kg)				Catch rate (No./kg/100 hooks)			
			Total	Tuna	Swordfish	Shark	Total	Tuna	Swordfish	Shark
C	5	495	4/6.85	0	0	0	0.81/1.38	0	0	0
	7	510	16/362.00	½	4/221	3/117	3.14/70.98	0.20/0.39	0.78/43.33	0.59/22.94
	10	510	7/285.60	0	2/102	3/173	1.37/56.00	0	0.39/20.00	0.59/33.92
	12	330	13/309.10	0	7/264	2/24	3.94/93.67	0	2.12/80.00	0.61/7.27
Sub-total		1,845	40/963.50	½	13/587	8/314	2.17/52.22	0.05/0.11	0.70/31.82	0.43/17.02
A	14	510	5/107.40	2/73	1/30	1/3.3	0.98/21.06	0.39/14.31	0.20/5.88	0.20/0.65
	17	510	9/79.10	0	0	6/61.4	1.76/15.51	0	0	1.18/12.04
	20	519	2/52.50	0	0	1/40	0.39/10.16	0	0	0.19/7.71
	23	510	4/38.60	0	1/26	0	0.78/7.57	0	0.20/5.10	0
	27	520	0/0.00	0	0	0	0	0	0	0
Sub-total		2,569	20/2,77.60	2/73	2/56	8/104.7	0.78/10.81	0.08/2.84	0.08/2.18	0.31/4.08
B	29	520	4/186.50	0	1/11.5	3/175	0.77/35.87	0	0.19/2.21	0.58/33.65
	32	520	5/167.80	0	2/24	2/139	0.96/32.27	0	0.38/4.62	0.38/26.73
	33	520	5/121.50	0	2/17.5	2/101	0.96/23.37	0	0.38/3.37	0.38/19.42
	34	303	3/37.70	0	2/34	1/3.7	0.99/12.44	0	0.66/11.22	0.33/1.22
Sub-total		1,863	17/513.50	0	7/87	8/418.7	0.91/27.56	0	0.38/4.67	0.43/22.47
Total		6,277	77/1,754.65	3/75	22/730	24/837.4	1.23/27.95	0.05/1.19	0.35/11.63	0.38/13.34

Table 6 Catch result and data of temperature and depth in each station.

St.	Date	Shooting				Hauling				Immersion	Sea depth	Thermocline	TD No.1	TD No.8/10	Number	Total catch	Total catch	Hook rate	CPUE
no.		Start		Finish		Start		Finish		time	(m)	m/°C	m/°C	m/°C	of hook	(number)	weight(kg)	(%)	inds./ 1000 hooks
5	10-11/Nov/07	Time	1820	Time	1936	Time	0720	Time	1010	13 hrs.	2,513	47-250 m	60m/27.5°C		495	4	6.9	0.81	**8.08**
		lat.	11°05'.80 N	lat.	11°07'.10 N	lat.	11°11'.90 N	lat.	11°14'.00 N	50 min		28-10°C		200m/14°C					
		long.	095°41'.80E	long.	095°33'.10 E	long.	095°41'.90 E	long.	095°33'.70 E										
7	11-12/Nov/07	Time	1820	Time	1942	Time	0612	Time	0924	12 hrs.	2,841	40-215 m	60m/27.°C	130m/20°C	510	16	362.5	3.14	**31.37**
		lat.	11°46'.00 N	lat.	11°51'.00 N	lat.	11°57'.20 N	lat.	11°55'.70 N	47 min		28.5-12.6°C							
		long.	094°58'.90E	long.	095°07'.10 E	long.	095°00'.80 E	long.	094°52'.30 E										
10	13-14/Nov/07	Time	1746	Time	1912	Time	0613	Time	1220	14 hrs.	1,128	50-180 m	50m/27.°C	200m/16°C	510	7	285.6	1.37	**13.73**
		lat.	12°34'.30 N	lat.	12°42'.40 N	lat.	12°47'.20 N	lat.	12°43'.90 N	41 min		28.5-15.25°C							
		long.	096°26'.70E	long,	096°20'.00 E	long.	096°18'.80 E	long.	096°19'.50 E										
12	15-16/Nov/07	Time	1731	Time	1823	Time	0612	Time	0906	14 hrs.	200-1,418	70-250 m	60m/28.°C	150m/20°C	330	13	309.1	3.94	**39.39**
		lat.	12°30'.30 N	lat.	12°30'.30 N	lat.	12°32'.70 N	lat.	12°33'.30 N	36 min		28.3-12.8°C							
		long.	094°59'.70E	long.	094°52'.90 E	long.	094°45'.70 E	long.	094°49'.40 E										
															1,845	**40**	**964.1**	**2.17**	**21.68**
14	17-18/Nov/07	Time	1731	Time	1847	Time	0646	Time	1005	14 hrs.	2,353	50-220 m	40m/28.0°C	80m/26°C	510	5	107.4	0.98	**9.80**
		lat.	16°55'.60 N	lat.	16°46'.70 N	lat.	16°53'.60 N	lat.	17°00'.10 N	35 min		28.5-13.3°C							
		long.	090°25'.90E	long.	090°21'.10 E	long.	090°13'.80 E	long.	090°16'.60 E										
17	19-20/Nov/07	Time	1732	Time	1847	Time	0645	Time	1015	14 hrs.	2,005	50-240 m	50m/27.5°C	80m/26°C	510	9	79.1	1.76	**17.65**
		lat.	18°31'.10 N	lat.	18°23'.00 N	lat.	18°22'.10 N	lat.	18°23'.40 N	21 min		28.4-12.4°C							
		long.	090°26'.70E	long.	090°26'.40 E	long.	090°34'.70 E	long.	090°38'.60 E										
20	21-22/Nov/07	Time	1800	Time	1920	Time	0645	Time	1030	13 hrs.	2,249	22-280 m	40m/27.5°C	80m/26°C	519	2	52.5	0.39	**3.85**
		lat.	17°31'.50 N	lat.	17°24'.80 N	lat.	17°25'.50 N	lat.	17°31'.80 N	57 min		28.3-11.7°C							
		long.	089°28'.20E	long.	089°24'.60 E	long.	089°25'.70 E	long.	089°31'.20 E										
23	23-24/Nov/07	Time	1731	Time	1910	Time	0645	Time	1027	14 hrs.	2,633	50-240 m	80m/23.0°C	300m/12°C	510	4	38.6	0.78	**7.84**
		lat.	16°30'.70 N	lat.	16°22'.10 N	lat.	16°21'.10 N	lat.	16°27'.90 N	1 min		28.4-12.4°C							
		long.	088°24'.50E	long.	088°20'.30 E	long.	088°16'.10 E	long.	088°16'.90 E										
27	25-26/Nov/07	Time	1730	Time	1850	Time	0654	Time	0957	14 hrs.	2,082	47-220 m	85m/21.5°C	230m/13°C	520	0	0.0	0.00	**0.00**
		lat.	18°30'.40 N	lat.	18°28'.90 N	lat.	18°31'.70 N	lat.	18°33'.70 N	9 min		27.8-12.5°C							
		long.	088°28'.30E	long.	088°18'.50 E	long.	088°22'.10 E	long.	088°32'.20 E										
															2,569	**20**	**277.6**	**0.78**	**7.79**

Table 6 (Cont.)

St. no.	Date	Shooting Start		Shooting Finish		Hauling Start		Hauling Finish		Immersion time	Sea depth (m)	Thermocline m/°C	TD No.1 m/°C	TD No.8/10 m/°C	Number of hook	Total catch (number)	Total catch weight(kg)	Hook rate (%)	CPUE inds./ 1000 hooks
29	28-29/Nov/07	Time	1803	Time	1921	Time	0702	Time	1000	13 hrs.	3,221	30-200 m	N/R	200m/13°C	520	4	186.5	0.77	**7.69**
		lat.	13°30'.00 N	lat.	13°24'.80 N	lat.	13°24'.40 N	lat.	13°29'.00 N	49 min		28.9-13.8°C							
		long.	084°30'.1E	long.	084°22'.20 E	long.	084°29'.60 E	long.	084°38'.20 E										
32	1-2/Dec/07	Time	1827	Time	1954	Time	0718	Time	1023	13 hrs.	3,425	40-270 m	60m/24.5°C	190m/15°C	520	5	167.8	0.96	**9.62**
		lat.	12°32'.90 N	lat.	12°30'.40 N	lat.	12°34'.40 N	lat.	12°37'.50 N	49 min		28.2-12.4°C							
		long.	082°24'.90 E	long	082°15'.70 E	long.	082°19'.90 E	long.	082°29'.50 E										
33	2-3/Dec/07	Time	1800	Time	1919	Time	0712	Time	1123	14 hrs.	3,528	N / R	70m/22.5°C	250m/12°C	520	5	121.5	0.96	**9.62**
		lat.	11°31'.80 N	lat.	11°32'.50 N	lat.	13°37'.70 N	lat.	11°35'.50 N	39 min									
		long.	082°26'.10 E	long.	082°17'.00 E	long.	082°21'.40 E	long.	082°19'.80 E										
34	3-4/Dec/07	Time	1828	Time	1916	Time	0710	Time	0855	13 hrs.	3,470	45-200 m	60m/23.0°C	240m/13°C	303	3	37.7	0.99	**9.90**
		lat.	11°29'.60 N	lat.	11°26'.250 N	lat.	11°22'.50 N	lat.	11°25'.50 N	22 min		28.2-14.2°C							
		long.	083°28'.10 E	long.	083°24'.40 E	long.	083°13'.70 E	long.	083°15'.20 E										
															1,863	**17**	**513.5**	**0.91**	**9.13**
															6,277	**77**	**1,755**	**1.23**	**12.27**

Discussion and Conclusion

From the catch result, considering the catch rate or hooking rate (individuals/100 hooks) in table 5 and 6, it was found that the highest hooking rate 3.94% (individuals/100 hooks) was at station 12 whilst the highest catch was obtained at station 7 with 16 individuals of fish (362.0 kg). Looking over station 7 and 12 which were in area C and showed the best catch result during the survey, catch composition of these two stations were mostly swordfish aggregated 11 individuals from a total of 29 individuals and contributed 72.28% to the total catch weight. An overall average hooking rate of 1.23% was obtained during the survey, out of which the average hooking rate of yellowfin tuna, swordfish and sharks were 0.05%, 0.35% and 0.38% respectively. The area wise aggregated hooking rate appeared that area C ranked on the top with 2.17% followed by area B 0.91% and area A 0.78%. One yellowfin tuna was caught from area C at latitude 11°N longitude 94°E and two from area A at latitude 16°N longitude 90°E.

Regarding to the catch composition, swordfish dominated the total catch with 650.0 kg by weight (37.044%) followed by bigeye thresher 641.0 kg (36.531%), silky shark 130.3 kg (7.426%) and yellowfin tuna 75.0 kg (4.274%). When consider to the catch in number, it was apparent that swordfish also came out on the top followed by bigeye thresher and silky shark. Takahashi *et al*.(2005) and Brill *et al*.(2005) found that swordfish swim in could water (3-6°C) during daytime at depth of up to 650 m and migrate vertically to stay near the warmer surface water (21-26°C) at night. By integrated consideration the catch results and the physical property of the sea on the temperature and depth, it was found that the temperature at hook depth for swordfish was between 20-28°C which covered the temperature range of their diurnal migration behavior.

Referring to Poison and Taquet (2000) CPUE (catch per unit effort = individuals/1000 hooks) from French's commercial swordfish longline fleet that operated over 4 million hooks in the southwest Indian Ocean each year, CPUE declined continuously from 16 in 1994 to 8 number of fish per 1,000 hooks in 1999. When comparing to the catch result in this survey area, especially at station 7 and 12, the CPUE of swordfish, which were 7.8 and 21.2 respectively, it indicated the high potential yield for swordfish longline fishing. For tunas, it was apparent that there were only 3 individuals (total weight 75 kg) of yellowfin tuna caught during the survey period, at station 7 and 14. Catch rate for tuna was only 0.05% which was similar to result of the last survey by SEAFDEC in the Andaman Sea, in November 2004. That survey deployed a total of 3,871 hooks in 7 fishing operations and two individuals tunas were caught weighing 45 kg and 64 kg. The catch rate was also reported 0.05% (Prajakjitt, 2004). During the year 1987-1990 tuna resource surveys using tuna longline in the eastern Indian Ocean were conducted, the results showed the total catches 12,169.6 kg were obtained from 69,949 hooks and the CPUE of total catch was 8.93 individuals/1,000 hooks. Thus tunas were dominant species which constituted 52.16% of the total catch. The CPUE of tunas was 4.64 of which 3.04 belonging to yellowfin tuna (Tantivala, 1991).

From thirteen fishing operations in this survey it may be too few operations to conclude that tunas are less abundant in this area. RV Chulabhorn of the Department of Fisheries, Thailand, has been surveyed tuna resource in the Andaman Sea within the the EEZ of Thailand in December 1999. The survey using tuna longline deployed totally 3,360 hooks in 7 stations and 27 individuals of yellowfin tuna were caught with total weight 775 kg. The average catch rate was 0.80% to the total (Uttayamakul, 2001). Thus this information confirms the distribution of yellowfin tuna in the Andaman Sea however it may be low season in December.

For further research survey, daytime fishing operation and increasing number of hook line per basket in order to cover wider range of fishing depth are suggested to ascertain about the abundance of tuna resource in the Bay of Bengal.

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Marine Resource Surveys by Drift Gill Net in the Bay of Bengal

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Abstract

This paper presented the first time survey of marine resources in the Bay of Bengal in terms of catch composition; Catch per unit effort (CPUE) and catch per unit area (CPUA) by drift gill net (DGN). The survey was conducted in eight stations of three sub-areas during October–December 2007 under the mission of BIMSTEC collaborative project. The fishery research vessel, M.V. SEAFDEC (cruise No. 75-1/2007) was deployed in the proposed survey. A total catch of 137.60 kg from 108 fishing hours composed of 15 fish species (99.60% by weight) and one piece of diamondback squid (Thysanoteuthidae: *Thysanoteuthis rhombus*) was captured (0.40% by weight). The highest catch species of marine resources was skipjack tuna, *Katsuwonus pelamis*, (42.96% by weight). The CPUE was ranged from 0.15 to 2.08 kg h^{-1} and gave the average of 1.22 kg h^{-1}. The CPUA was ranged from 1.297×10^{-4} to 1.651×10^{-3} kg m^{-2} of net area and gave the average of 8.809×10^{-4} kg m^{-2} of net area. Average catch was not shown significant different among the three survey areas. Skipjack tuna was also the most important economical species (66.72% IRI) and widely distributed in the survey area especially in area A. Silky shark (*Carcharhinus falciformis*), which was the second important (10.55% IRI), was distributed only in area C whereas frigate tuna (*Auxis thazard thazard*), which was the third important (7.47% IRI), was distributed only in area A.

Key words: catch composition, marine resources, drift gill net, Bay of Bengal, BIMSTEC

Introduction

Drift netting is a fishing technique where nets, called drift nets, are allowed to drift free in a sea or lake. Usually a drift net is a gill net with floats attached to a rope along the top of the net, and weights attached to another rope along the foot of the net. Drift net can range in length from 25 m to 2.5 miles. (http://en.wikipedia.org/wiki/Drift_net) The nomenclature of drift net or drift gill net depends on the target species. The common species are mackerel, flying fish, tuna and tuna-like, manta ray and other pelagic species. These fish species require different mesh and twin sizes as well as material to maximize catch. For mackerel, flying fish, sardines and other small pelagic species the nets are made of nylon monofilament of 0.20 mm to 0.40 mm diameter with mesh size from 25 mm to 90 mm. For tuna species, the material is nylon multifilament PA 210/12 to 210/18 in the main webbing whole iron rings and/or thicker multifilament nettings (210/30 to210/36) are used as weights. The mesh size ranges from 50 mm to 90 mm. There are 10 to 20 meshes of thicker netting acting as weights in the lower portion of the webbing. (http://map.seafdec.org/Monograph project/gill_net_2.php)

Drift nets have been commonly used by many countries in the coastal waters. This type of net was heavily used by many Japanese, South Korean and Taiwanese fishing fleets on the high seas in the 1980s to target tunas. Generally, fish which are smaller than the meshes of the gill nets are able to pass through unhindered, while those which are too large to push their heads through the meshes as far as their gills are not retained. This gives a selectivity ogive which is skewed towards medium size fish, unlike active fishing gears such as trawl nets in which the proportion of fish entering the nets which are retained increases with length. Although highly selective with respect to size class of the fish captured, practically gill nets are blamed for the impact on non-target species particularly dolphins, turtles and seabirds. In 1993 gill nets were banned by the United Nations in international waters, although their use is still permitted within 200 nautical miles (400 km) of a coast.
(http://en.wikipedia.org/wiki/Gillnet)

However, in international waters which generally cover deep water areas, there are only a few types of fishing gear suitable for harvesting fishery resources. The important fishing gears suitable for fishing in deep water areas are purse-seine, pelagic longline and drift gill net (DGN). For pelagic fish commonly distribute in the upper layer, drift gill nets are widely deployed to catch these fishes because of the simplicity in operating. Thus, DGN is chosen to be one of the 3 types of fishing gear, besides pelagic longline and automatic squid jigging, for the survey and study of marine fishery resources in the Bay of Bengal and being the rationale of the sub-project on Marine Resource Surveys by Drift Gill Net in the Bay of Bengal. This sub-project aims to assess the potential of marine fishery resources captured by DGN in terms of species and catch composition, catch per unit effort (CPUE) and stock abundance in term of index of relative importance (IRI). The result from this research will support a useful background for effective fishery resource management in the Bay of Bengal. Furthermore, it will improve capabilities in fish stock assessment of the biologists and researchers in the member countries as well as to develop the academic ability in training the staff of the Faculty of Fisheries, Kasetsart University and establish a good collaboration among member countries in research and academic activities.

Materials and Methods

Area of Fishing Operation

The study was carried out in the Bay of Bengal during 25 October to 21 December 2007. Three sub-areas were defined namely area A: latitude 16°N-19°N and longitude 88°E-91°E (5 stations); area B: latitude 9°N-14°N and longitude 82°E-85°E (5 stations); and area C: latitude 10°N-12°N and longitude 95°E -97°E (5 stations) (Fig. 1).

Fishing Gear

The fishery research vessel, M.V. SEAFDEC, of the Southeast Asian Fisheries Development Center (SEAFDEC) was used in this study. Field sampling was conducted using two types of net materials for drift gill net (DGN), monofilament and multifilament nylon twines. Total length of monofilament DGN was 2,200 m with 100 mm of mesh size and 93 meshes at depth. Multifilament DGN was 2,500 m with 160 mm of mesh size and 100 meshes at depth. Net material composition was separated into 2 types: the first 75 meshes from the head rope was polyamide (PA) and 25 meshes left was Saran. On the head rope of both nets, a float line made by polyethylene (4.0 mm diameter) with a plastic float (350 mm length, 95 mm diameter) was attached at every 10 m interval to keep the net floating. The foot rope composed of polypropylene (PP) (10 mm diameter) combination with lead which also acted as a sinker for stretching the net vertically. Radio buoys, flag and light buoys were attached to the end of the head rope at both sides for marking the net location. The sketch diagrams of DGN were described in fig. 2.

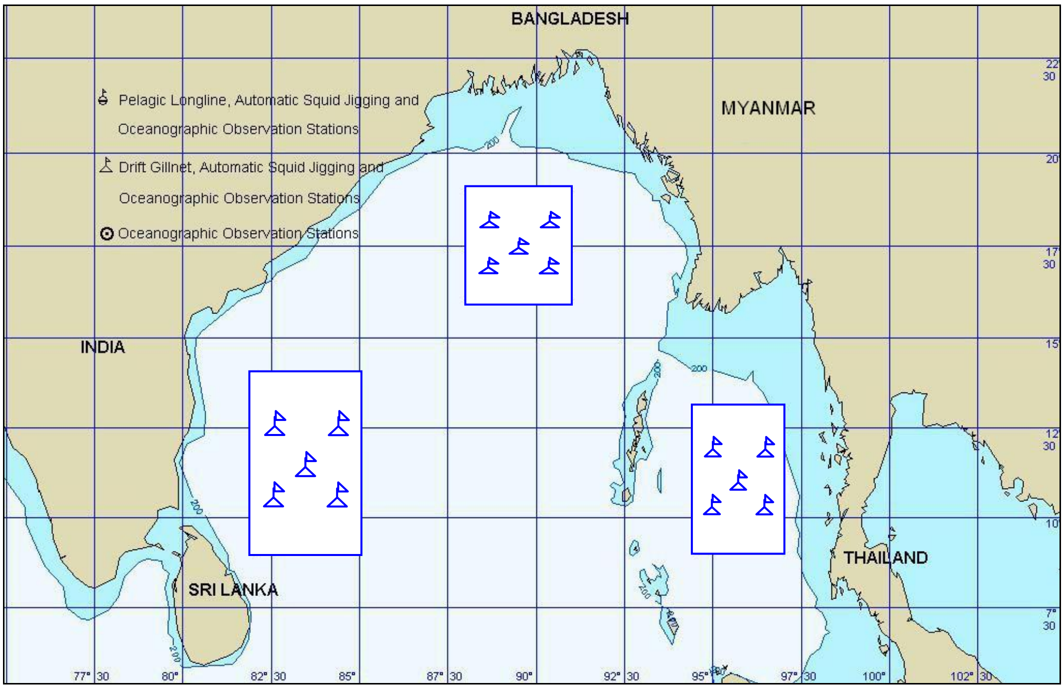


Figure 1 The assigned survey areas.

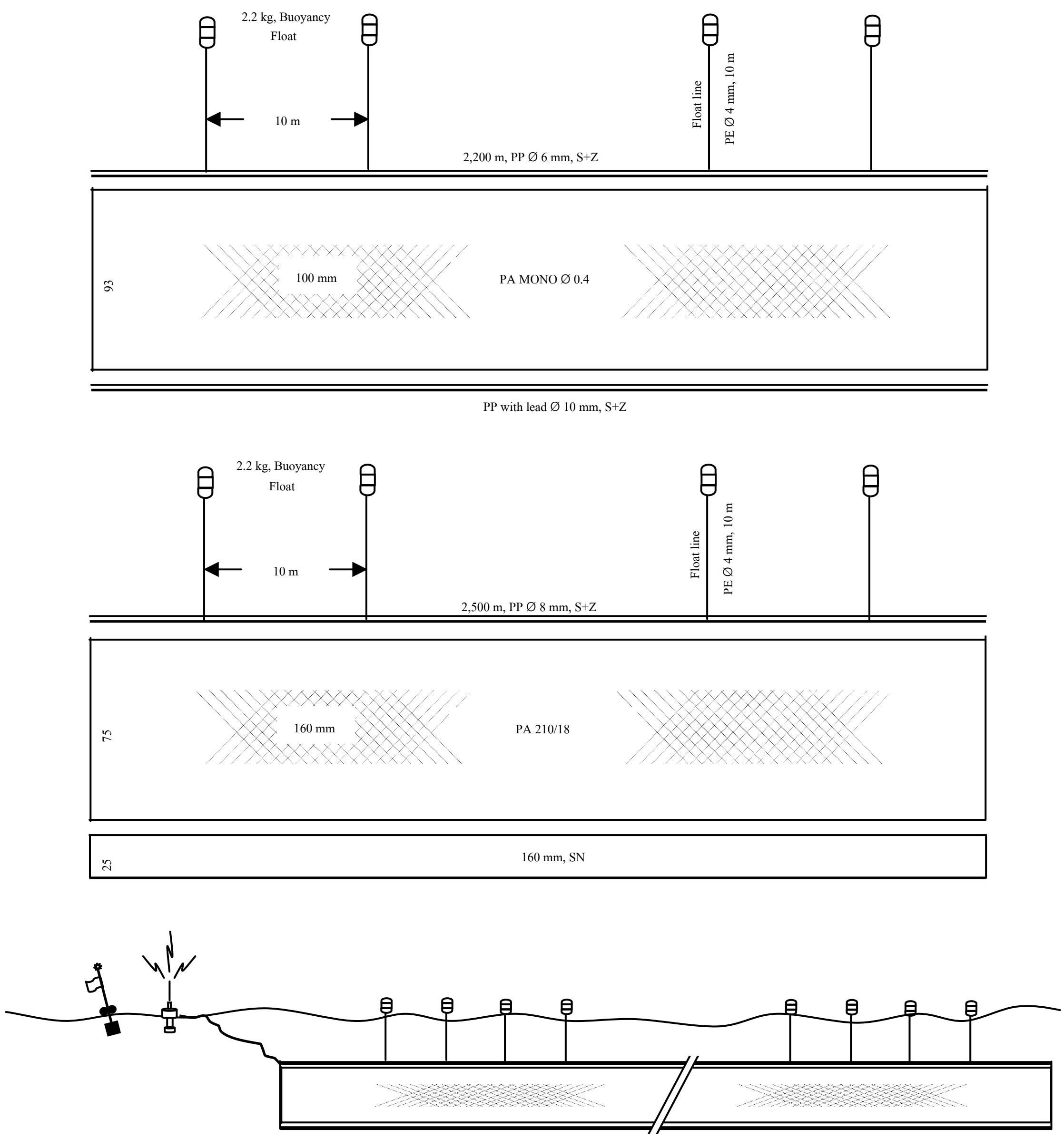


Figure 2 Drift gill net diagrams.

DGN was started shooting at the sun down and leaved overnight. The hauling was started in the next morning around 6.00 A.M. Depth of each sampling station and the immersion period were recorded.

Field Work and Data Collection

After marine resources were on board, identification was made at the species level. Overall fish size: total length (TL), fork length (FL), standard length (SL), head length (HL) and girth length (GL) were measured to the nearest 0.1 cm. and body weight (BW) was also recorded to the nearest 0.1 g. Primary sexual characters of the fishes were determined by dissecting. Testes were classified into two stages whereas ovaries were classified at least four stages of development. Ripening ovaries were collected in zip-log bags and deep frozen for further analyzed at laboratory. The data were recorded separately by sampling stations and areas.

Laboratory Study

Paired ovaries were carefully removed from zip-log bags, washed, cleaned with distilled water. Blotting paper was used to help the ovaries as dried as possible before weighting by electronic weighting machine to the nearest 0.01 g. Ovaries were fixed in 10% of buffered formaldehyde solution, shaken vigorously and stored in the dark at least fortnight. Then eggs were counted gravimetrically (Bagenal and Brown, 1978).

Data Analyses

1. Species and catch compositions:

Species composition was calculated in terms of percentages by weight and number. Catch per unit effort (CPUE) was calculated in term of weight per immersion period (kg h^{-1}). Catch per unit area (CPUA) was estimated in term of weight per net area (kg m^{-2}).

To avoid the zero-values in computing the mean and confidence limit of the mean, CPUE and CPUA were transformed applied from Emerson and Stoto (1983) as:

$$Y_i = \ln(x + \text{CPUE/CPUA})$$

Where x is a constant value that makes Y_i be positive.

One-way ANOVA was used for comparing the catches among three sub-areas.

2. Stock abundance and distribution:

The percentage of index of relative importance (% IRI; Green, 1979; Pinkas *et al.*, 1971) was applied to identify the importance of species in the community as:

$$\%IRI = \frac{(\%W_i + \%N_i)\%F_i}{\sum_{i=1}^{n}\{(\%W_i + \%N_i)\%F_i\}} \times 100$$

Where %W, %N were percentages in weight and percentage in number of the i^{th} species, and %F was percentage in frequencies of occurrence of each species.

3. Fecundity:

Absolute fecundity was estimated on the basis of total weight of ovaries. The fecundity was obtained using the following ratio (Le Cren, 1951).

$$F = \frac{\text{No. of samples eggs} \times \text{Gonad weight}}{\text{Sample weight}};$$

and gonadosomatic index (GSI) was estimated from the formula:

$$GSI = \frac{\text{Weight of ovary}}{\text{Fish body weight}} \times 100$$

Results and Discussion

At the first 15 stations, five stations per sub-areas, were assigned to operate by DGN. During the survey, the cyclone disaster 'Sidr' affected to the sea condition so rough that the survey stations hade been skipped out for safety. Practically DGN could only be operated in eight sampling stations: three in area C, four in area A and one in area B, respectively (Fig. 3).

Multifilament net was operated only both at the first and the second stations. According to the lack of sinkers in multifilament net, it was found that the net could not fully expand. Consequently, the monofilament net was used in the left six stations.

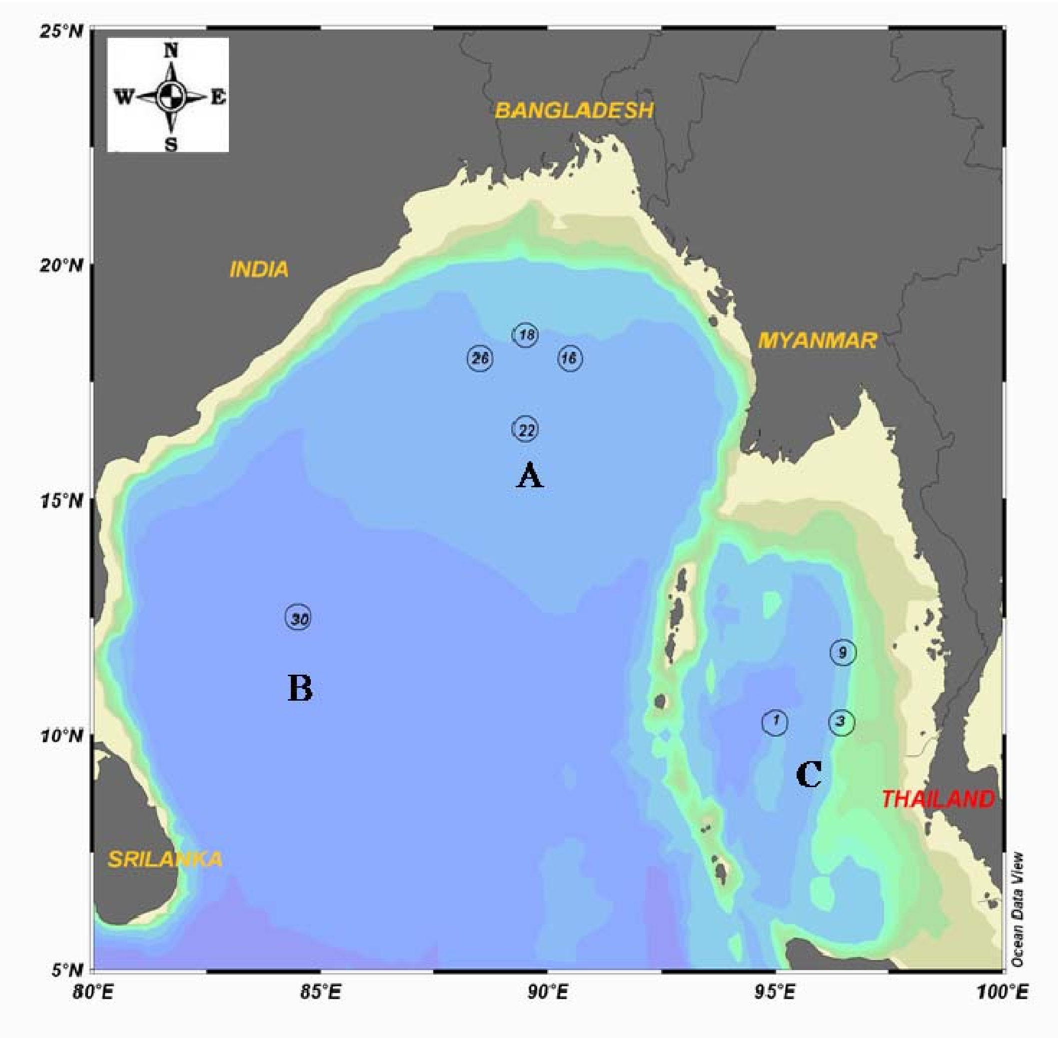


Figure 3 The practical DGN survey stations.

Species Composition

Total catch from this study was separated into two major groups: fishes and invertebrate. For fish composition, 15 species in 9 families were identified. For invertebrate, only one piece of diamondback squid, *Thysanoteuthis rhombus* Troschel, 1857 was identified (Table 1).

Table 1 Species list of marine resources in the Bay of Bengal separated by operations and area.

No.	Family	Species	Operation							
			Area C			Area A				Area B
			1	2	3	4	5	6	7	8
1	Carcharinidae	*Carcharhinus falciformis (*Müller & Henle, 1839)		✓				✓	✓	✓
2	Carangidae	*Caranx tille* Cuvier, 1833		✓						
3	Nomeidae	*Psenes cyanophrys* Valenciennes, 1833		✓						
4	Coryphaenidae	*Coryphaena equiselis* Linnaeus, 1758		✓	✓	✓			✓	
5		*Coryphaena hippurus* Linnaeus, 1758	✓						✓	
6	Echeneidae	*Remora remora* (Linnaeus, 1758)				✓				
7	Scombridae	*Auxis rochei rochei* (Risso, 1810)						✓		
8		*Auxis thazard thazard* (Lacepède, 1800)				✓	✓	✓		
9		*Euthynnus affinis* (Cantor, 1849)	✓			✓				
10		*Katsuwonus pelamis* (Linnaeus, 1758)	✓	✓		✓	✓	✓	✓	✓
11		*Thunnus albacares* (Bonnaterre, 1788)	✓							
12		*Thunnus obesus* (Lowe, 1839)	✓		✓			✓		
13	Gempylidae	*Ruvettus pretiosus* Cocco, 1833								✓
14	Xiphiidae	*Xiphias gladius* Linnaeus, 1758								✓
15	Lobotidae	*Lobotes surinamensis* (Bloch, 1790)								✓
16	Thysanoteuthidae	*Thysanoteuthis rhombus* Troschel, 1857						✓		

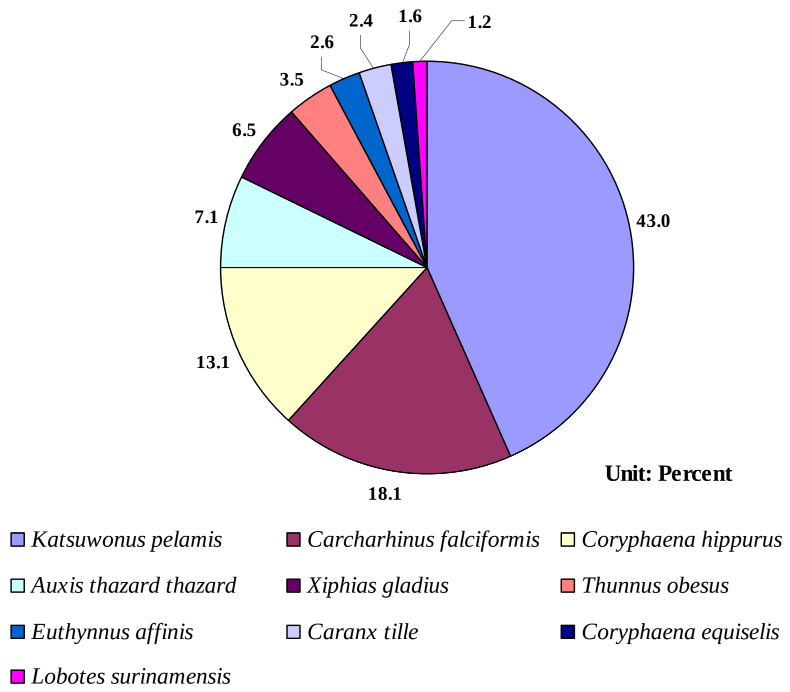
A total number of 93 individuals weighing about 137.6 kg from 108 h 8 min of fishing hours (immersion period) were identified. Among the fish species, *Katsuwonus pelamis* dominated the catch by number followed by *Auxis thazard thazard, Coryphaena hippurus, Thunnus obesus, Euthynnus affinis, Carcharhinus falciformis, Coryphaena equiselis* etc. The catch by weight, on the other hand, *Katsuwonus pelamis* was the dominant species followed by *Carcharhinus falciformis, Coryphaena hippurus, Auxis thazard thazard, Xiphias gladias* etc (Fig. 5, Appendix 1). In addition, the catch of marine resources had a low positive correlation with water depth (r=0.27).

Catch Composition

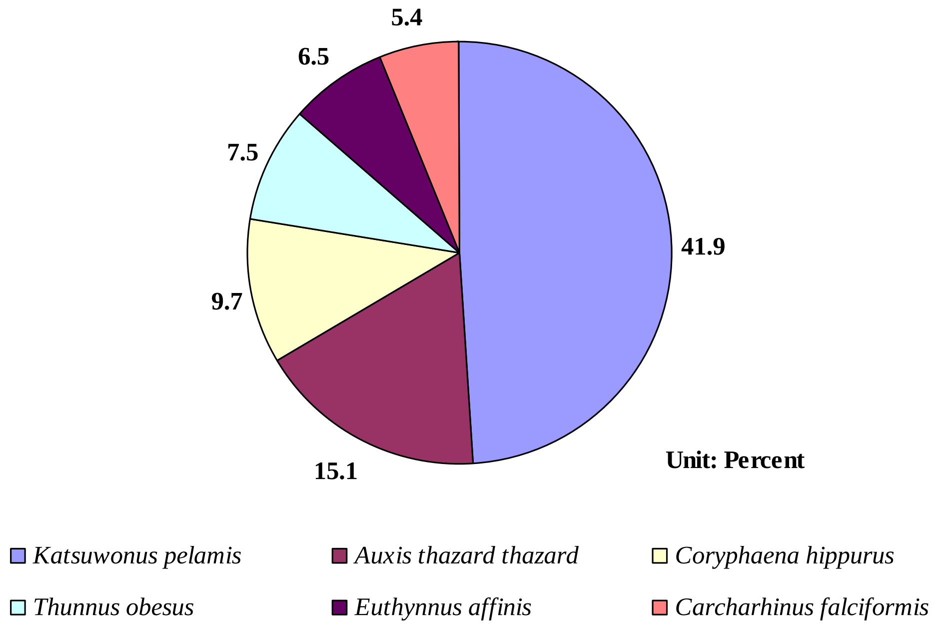
1. Catch per unit effort (CPUE)

The CPUE was varied from 0.15 to 0.28 kg h^{-1}. The seventh operation (station 26, area A) was the highest CPUE with 2.08 kg h^{-1} (20.21%) even though 4 species of fish were caught. The second highest catch was the fourth operation (station 16, area A) with CPUE 2.04 kg h^{-1} (19.83%) and composed of 5 fish species. The detail of catch composition was summarized in Appendix 2.

According to the low value of CPUE, the transformation was used by ln(3+CPUE) to compute the mean and 95% C.I. The average CPUE was 1.22 kg h^{-1} and gave the 95% C.I. of $0.61 \le \overline{U} \le 1.94$ kg h^{-1}.



a.



b.

Figure 4 Species composition of dominant marine resources in the Bay of Bengal.
a. percentage by weight (top-ten) b. percentage by number (top-six)

2. Catch per unit area (CPUA)

The net area of DGN in this study was estimated by rectangular area (length x depth). For the estimation of the net depth (D), hanging ratio (h) and number of meshes (n) was used as the following formula (Prado and Dremiere, 1990).

$$D = \sqrt{(1-h^2)} \times (n \times m)$$

The hanging ratio of PA both in multifilament and monofilament were 0.5 while Saran was 0.47. Hence, the net area of multifilament was 34,807.44 m^2. The net area of monofilament, however, was 14,722.43 m^2 for the net length of 1,700 m and 14,722.43 m^2 for the net length of 2,200 m.

The CPUA was ranged from 1.297×10^{-4} to 1.651×10^{-3} kg m^{-2} of net area. According to the low value of CPUA, the transformation was used by $\ln(7 + \text{CPUA})$ for computing the mean and 95% C.I. of mean. The average CPUA was 8.809×10^{-4} kg m^{-2} and gave the 95% C.I. of $3.923 \times 10^{-4} \le \overline{A} \le 1.369 \times 10^{-3}$ kg m^{-2}.

3. Area-based of catch composition

Overall, area-based of catch composition separated from survey stations were shown in appendix 3.

3.1 Area C:

DGN was operated in three survey stations, two for multifilament and one for monofilament. Nine species belong to five families of fish were caught in this area (Table 2). Total number of 17 fishes weighing about 28.91 kg were caught.

Table 2 Catch composition of marine resources in area C.

No.	Family	Species	Catch No.	%	W (g)	%
1	Carcharinidae	*Carcharhinus falciformis* (Müller & Henle, 1839)	1	5.88	12,200	42.21
2	Carangidae	*Caranx tille* Cuvier, 1833	1	5.88	3,300	11.42
3	Nomeidae	*Psenes cyanophrys* Valenciennes, 1833	1	5.88	260	0.90
4	Coryphaenidae	*Coryphaena equiselis* Linnaeus, 1758	2	11.76	280	0.97
5		*Coryphaena hippurus* Linnaeus, 1758	1	5.88	3,700	12.80
6	Scombridae	*Euthynnus affinis* (Cantor, 1849)	2	11.76	140	0.48
7		*Katsuwonus pelamis* (Linnaeus, 1758)	4	23.53	6,600	22.83
8		*Thunnus albacares* (Bonnaterre, 1788)	1	5.88	220	0.76
9		*Thunnus obesus* (Lowe, 1839)	4	23.53	2,205	7.63
	Total		**17**		**28,905**	

3.2 Area A:

Monofilament net was operated in four survey stations. Nine species belongs to four families of fish and one individual of diamondback squid was caught in this area (Table 3). Total number of 67 fishes weighing about 82.50 kg was caught.

Table 3 Catch composition of marine resources in area A.

No.	Family	Species	Catch			
			No.	%	W (g)	%
1	Carcharinidae	*Carcharhinus falciformis* (Müller & Henle, 1839)	3	4.41	10,570	12.73
2	Coryphaenidae	*Coryphaena equiselis* Linnaeus, 1758	2	2.94	1,880	2.26
3		*Coryphaena hippurus* Linnaeus, 1758	8	11.76	14,260	17.17
4	Echeneidae	*Remora remora* (Linnaeus, 1758)	1	1.47	560	0.67
5	Scombridae	*Auxis rochei rochei* (Risso, 1810)	1	1.47	320	0.39
6		*Auxis thazard thazard* (Lacepède, 1800)	14	20.59	9,770	11.76
7		*Euthynnus affinis* (Cantor, 1849)	4	5.88	3,430	4.13
8		*Katsuwonus pelamis* (Linnaeus, 1758)	33	48.53	40,860	49.20
9		*Thunnus obesus* (Lowe, 1839)	1	1.47	850	1.02
10	Thysanoteuthidae	*Thysanoteuthis rhombus* Troschel, 1857	1	1.47	550	0.66
	Total		**68**		**83,050**	

3.3 Area B:

Monofilament DGN was operated in only one survey station due to stormy sea conditions. In one operation six species belong to six families of fish were caught in this area (Table 4). Total number of 6 fishes weighing about 23.85 kg were caught.

Table 4 Catch composition of marine resources in area B**.**

No.	Family	Species	Catch			
			No.	%	W (g)	%
1	Carcharinidae	*Carcharhinus falciformis* (Müller & Henle, 1839)	1	16.67	2,200	9.22
2	Scombridae	*Katsuwonus pelamis* (Linnaeus, 1758)	2	33.33	11,650	48.85
3	Gempylidae	*Ruvettus pretiosus* Cocco, 1833	1	16.67	300	1.26
4	Xiphiidae	*Xiphias gladius* Linnaeus, 1758	1	16.67	8,900	37.32
5	Lobotidae	*Lobotes surinamensis* (Bloch, 1790)	1	16.67	800	3.35
	Total		**6**		**23,850**	

An ANOVA (single factor) was used to test the different catch among three sub-areas in term of CRD with unequal replication (Steel and Torrie, 1986). The result was not shown significantly different among the three sub-areas ($p>0.05$).

Abundance and Distribution

Index of relative importance (IRI) was the first mentioned in the study on feeding ecology (Green, 1979; Pinkas *et al*., 1971). This index shows how importance of food items in fish stomach followed by trophic level. Nowadays, the IRI was applied to explain how important of fish species in the community by multi-dimensions: percentage of weight, number and frequency of occurrence at the same time. IRI also applies for describing spatial stock abundance and distribution.

In this study, the IRI was used to examine the importance of marine resources captured by DGN both in holistic and station-based conditions. For holistic condition, IRI was estimated by summing the catch of all survey stations as represent to the Bay of Bengal

(Appendix 4). The top-eight important species in the Bay of Bengal was described as follow (Fig. 5):

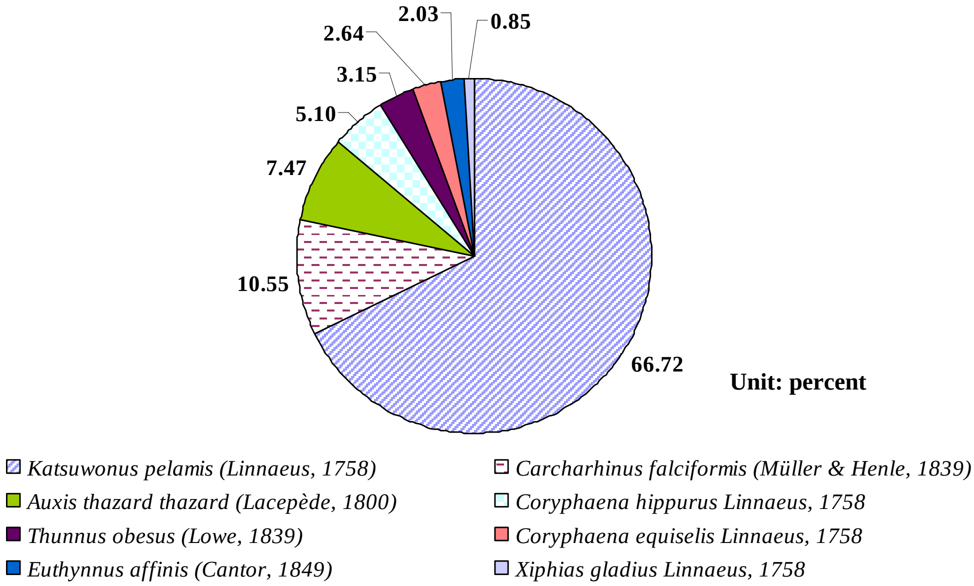


Figure 5 The top-eight important marine resources in the Bay of Bengal.

The result from fig. 5 revealed that, skipjack tuna was the most important species for DGN fishery in the Bay of Bengal. It can be occurred in every part of the survey area except in station 9 (area C). Silky shark was the second important species. It can be found in 4 survey stations from 3 sub-areas; area C in station 3, area A in station 22 and 26, and area B in station 30, respectively. In holistic view point, most of the important species in the Bay of Bengal were economic fishes.

The station-based IRI of the top-eight important species was explained as the following (Fig. 6):

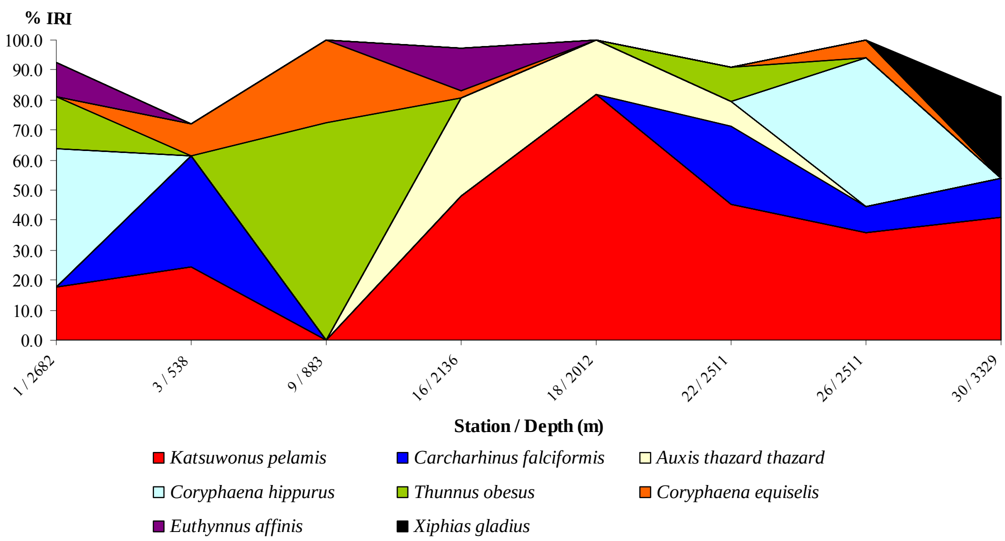


Figure 6 The station-based, top-eight important marine resources in the Bay of Bengal.

Fig. 6 shows the important of top-eight species according to survey stations and depths. It can be said that skipjack tuna (red colour), which was the most important species, distributed in every part of the survey area without any correlation with the depth whereas frigate tuna (yellow colour) was mainly important and distribute only in area A with the sea depth over 2,000 m but not more than 2,600 m. The distribution of silky shark (dark-blue colour) was more important in area A than the left but no correlate with the sea depth. Bigeye tuna (green colour) was more important in area C than area A and prefer to live in rather shallower water (<900 m) than other species as well as pompano dolphinfish (orange colour). In contrast with pompano dolphinfish, common dolphinfish (light-blue colour) seemed to prefer the deeper zone in area A and more important than pompano dolphinfish. Kawakawa (purple colour) distributed both in area A and area C in the same degree of important whereas swordfish (black colour) distributed only in area B which was the deepest sea.The area-based size distribution of skipjack tuna can be shown in table 5.

Table 5 Size distribution of skipjack tuna captured by DGN in the Bay of Bengal.

Area	No. of capture	Size range (FL; cm)	Mean FL (cm)
C	3	17.6 – 68.0	34.6
A	34	35.8 – 51.4	40.8
B	2	66.0 – 70.0	68.0

From the table 5, it was found that small skipjack tuna distributed in area C and the biggest lived in area B. The movement of this species followed by size range seemed to start from area C to area A, then from area A to area B. For further study, it should be concerned on the migratory route supporting from reproductive biology of this species.

Fecundity

There were 12 samples belonging to 2 species which were frigate tuna and common dolphinfish that could be collected to investigate the ripened ovaries (Table 6). For frigate tuna, all specimens were collected from area A. Fecundity ranged from 57,062 to 273,396 eggs, with a 95% C.I. of mean $67{,}226 \leq 184{,}131 \leq 301{,}037$ eggs. The mean relative fecundity, however, was 233.59 eggs g^{-1} body weight. In overall, the size (SL) of frigate tuna in area A (16 pieces) ranged from 23.60 to 36.0 cm with the mean length at 32.11 cm whereas the specimen that gave the ripened ovaries have a size range from 31.5 to 34.5 cm. According to this species, it could be caught only in the area A with some gravid females, area A should be concerned for fishing activities. Nevertheless, the study on reproductive biology and exploring for spawning ground are needed for clarifying the management regime in the Bay of Bengal.

From NOAA (http://www.nmfs.noaa.gov/habitat/habitat_protection/profile/westernpacific/frigate_tunahome.htm, 22 July 2008), it is revealed that frigate tuna has fecundity estimates from 78,000 to 717,900 eggs. It will be noted that, even though the fecundity of frigate tuna in this study was not different to NOAA mentioned, but the specimens to investigate were very low number and it need more specimens to study for better comparison.

Table 6 Fecundity, GSI and relative fecundity of frigate tuna and common dolphinfish.

Auxis thazard thazard

Area	Fecundity	GSI	Relative fecundity (eggs g^{-1})
A	217,556	3.92	255.95
A	57,062	0.88	71.33
A	114,847	2.08	176.69
A	273,396	4.91	341.75
A	257,794	5.21	322.24

Coryphaena hippurus

Area	Fecundity	GSI	Relative fecundity (eggs g^{-1})
A	34,765	0.19	8.82
A	354,928	3.40	236.62
A	338,393	2.71	169.20
A	259,761	2.48	185.54
A	232,184	3.82	145.12
A	124,941	2.47	96.11

For common dolphinfish, on the other hand, all six specimens were collected from Area A. Fecundity ranged from 34,765 to 354,928 eggs, with a 95% C.I. of mean $93{,}765 \leq 224{,}162 \leq 354{,}560$ eggs. The mean relative fecundity, however, was 140.23 eggs g^{-1} body weight. This result conformed to the study of Masssuti and Morales-Nin (1997). They reported that the relative fecundity of common dolphinfish ranged from 71 to 197 eggs g^{-1} body weight, with a mean value of 120±31.3 eggs g^{-1}. The evidence of size distribution of oocytes, with at least two groups of oocytes in the ovaries, suggested that common dolphinfish was a multiple spawner.

In the study on fecundity of fish, it usually has a distinguishable different in the number of eggs at the same length, especially the large fish. Bagenal (1968) pointed out that large fish has a more variable number of eggs since the effect of multiple-spawner in one spawning season has occurred (Bagenal, 1966). Moreover, fecundity also varied with the seasons, climatic conditions, environmental habitat, nutritional status and genetic potential (Bromage *et al.*, 1992).

Conclusions and Recommendations

It can be concluded from all aspects of this study that skipjack tuna was the dominant species not only in number and weight but also be the most important for DGN fishery in the Bay of Bengal. Most of the capturing fishes were economic species. Area A seemed to be the richest area with the highest degree of species diversity, CPUE and high number of female gravidity. The reproductive biology of some economic species should be prioritized before studying. Area B is the deepest zone, even the catch was very low according to the rough sea condition but the catch here seemed to be composed of the biggest sized fish. Moreover, the migratory routes of fishes among the three sub-areas around the Bay of Bengal should be given precedence to study as well.

The magnitude of the importance of marine resources from this study will serve the understanding of pelagic community in the Bay of Bengal. It will also be beneficial to the DGN fishery management in the future.

Acknowledgements

The authors would like to acknowledge the Ministry of Foreign Affairs and Department of Fisheries, Ministry of Agriculture and Cooperatives, Kingdom of Thailand for providing the research expenses under the BIMSTEC collaborative research project. We are also indebted to SEAFDEC/TD for supporting the research vessel, M.V. SEAFDEC and all the ship crews for their kind hospitality and smoothly management during the research survey. Thanks are also due to Mr. Montri Sumontha (Thai DOF.) for collecting ovarian samples and Miss Jeerawat Thammaratsuntorn (Department of Fishery Biology, Faculty of Fisheries, KU.) for fecundity counting. We are also forwarded our thanks to whom that may concern for editing this manuscript.

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Appendix 1: Species composition of marine resources by number and weight.

Family	Local Name	Species	Catch			
			No.	%	W (g)	%
Carcharinidae	Silky shaek	*Carcharhinus falciformis (*Müller & Henle, 1839)	5	5.38	24,970	18.15
Carangidae	Tille trevally	*Caranx tille* Cuvier, 1833	1	1.08	3,300	2.40
Nomeidae	Freckled driftfish	*Psenes cyanophrys* Valenciennes, 1833	1	1.08	260	0.19
Coryphaenidae	Pompano dolphinfish	*Coryphaena equiselis* Linnaeus, 1758	4	4.30	2,160	1.57
Coryphaenidae	Common dolphinfish	*Coryphaena hippurus* Linnaeus, 1758	9	9.68	17,960	13.05
Echenidae	Common remora	*Remora remora* (Linnaeus, 1758)	1	1.08	560	0.41
Scombridae	Bullet tuna	*Auxis rochei rochei* (Risso, 1810)	1	1.08	320	0.23
Scombridae	Frigate tuna	*Auxis thazard thazard* (Lacepède, 1800)	14	15.05	9,770	7.10
Scombridae	Kawakawa	*Euthynnus affinis* (Cantor, 1849)	6	6.45	3,570	2.59
Scombridae	Skipjack tuna	*Katsuwonus pelamis* (Linnaeus, 1758)	39	41.94	59,110	42.96
Scombridae	Yellowfin tuna	*Thunnus albacares* (Bonnaterre, 1788)	1	1.08	220	0.16
Scombridae	Bigeye tuna	*Thunnus obesus* (Lowe, 1839)	7	7.53	4,845	3.52
Gempylidae	Oilfish	*Ruvettus pretiosus* Cocco, 1833	1	1.08	300	0.22
Xiphiidae	Swordfish	*Xiphias gladius* Linnaeus, 1758	1	1.08	8,900	6.47
Lobotidae	Atlantic tripletail	*Lobotes surinamensis* (Bloch, 1790)	1	1.08	800	0.58
Thysanoteuthidae	Diamondback squid	*Thysanoteuthis rhombus* Troschel, 1857	1	1.08	550	0.40
Total			**93**		**137.05**	

Appendix 2: Catch composition of marine resources in the Bay of Bengal.

Operation	Station no.	Depth (m)	Total Catch (kg)	%Catch by Station	Immersion Time (min)	CPUE (kg h^{-1})	Net Area (m^2)	CPUA (kg m^{-2})
1	1	2,682	4.52	3.28	803	0.34	34,807.44	$1.297x10^{-04}$
2	3	538	22.29	16.20	761	1.76	34,807.44	$6.404\ x10^{-04}$
3	9	883	2.10	1.53	846	0.15	14,722.43	$1.426\ x10^{-0}4$
4	16	2,136	25.54	18.56	751	2.04	17,718.80	$1.441\ x10^{-03}$
5	18	2,012	11.29	8.21	840	0.81	17,718.80	$6.372\ x10^{-04}$
6	22	2,511	18.75	13.63	805	1.40	17,718.80	$1.058\ x10^{-03}$
7	26	2,511	29.26	21.27	844	2.08	17,718.80	$1.651\ x10^{-03}$
8	30	3,329	23.85	17.33	838	1.71	17,718.80	$1.346\ x10^{-03}$
Total			**137.60**		**108 h 8 min**			

Appendix 3: Area-based of catch composition separated from survey stations.

Operation no. 1
Station no. 1

No.	Species	Weight (g)	% by wt.	Number	% by no.
1	*Coryphaena hippurus* Linnaeus, 1758	3,700	81.95	1	10.00
2	*Euthynnus affinis* (Cantor, 1849)	140	3.10	2	20.00
3	*Katsuwonus pelamis* (Linnaeus, 1758)	250	5.54	3	30.00
4	*Thunnus albacares* (Bonnaterre, 1788)	220	4.87	1	10.00
5	*Thunnus obesus* (Lowe, 1839)	205	4.54	3	30.00
Total		**4,515**	**100**	**10**	**100**

Operation no. 2
Station no. 3

No.	Species	Weight (g)	% by wt.	Number	% by no.
1	*Carcharhinus falciformis (*Müller & Henle, 1839)	12,200	54.73	1	20.00
2	*Caranx tille* Cuvier, 1833	3,300	14.80	1	20.00
3	*Psenes cyanophrys* Valenciennes, 1833	260	1.17	1	20.00
4	*Coryphaena equiselis* Linnaeus, 1758	180	0.81	1	20.00
5	*Katsuwonus pelamis* (Linnaeus, 1758)	6,350	28.49	1	20.00
Total		**22,290**	**100.00**	**5**	**100.00**

Operation no. 3
Station no. 9

No.	Species	Weight (g)	% by wt.	Number	% by no.
1	*Coryphaena equiselis* Linnaeus, 1758	100	4.76	1	50.00
2	*Thunnus obesus* (Lowe, 1839)	2,000	95.24	1	50.00
Total		**2,100**	**100.00**	**2**	**100.00**

Appendix 3: (cont.).

Operation no. 4
Station no. 16

No.	Species	Weight (g)	% by wt.	Number	% by no.
1	*Coryphaena equiselis* Linnaeus, 1758	180	0.70	1	3.45
2	*Remora remora* (Linnaeus, 1758)	560	2.19	1	3.45
3	*Auxis thazard thazard* (Lacepède, 1800)	7,360	28.82	10	34.48
4	*Euthynnus affinis* (Cantor, 1849)	3,430	13.43	4	13.79
5	*Katsuwonus pelamis* (Linnaeus, 1758)	13,160	51.53	12	41.38
6	*Thunnus obesus* (Lowe, 1839)	850	3.33	1	3.45
Total		**25,540**	**100.00**	**29**	**100.00**

Operation no. 5
Station no. 18

No.	Species	Weight (g)	% by wt.	Number	% by no.
1	*Auxis thazard thazard* (Lacepède, 1800)	1,840	16.30	2	20.00
2	*Katsuwonus pelamis* (Linnaeus, 1758)	9,450	83.70	8	80.00
Total		**11,290**	**100.00**	**10**	**100.00**

Operation no. 6
Station no. 22

No.	Species	Weight (g)	% by wt.	Number	% by no.
1	*Carcharhinus falciformis (*Müller & Henle, 1839)	7,350	39.20	2	13.33
2	*Auxis rochei rochei* (Risso, 1810)	320	1.71	1	6.67
3	*Auxis thazard thazard* (Lacepède, 1800)	570	3.04	2	13.33
4	*Katsuwonus pelamis* (Linnaeus, 1758)	8,170	43.57	7	46.67
5	*Thunnus obesus* (Lowe, 1839)	1,790	9.55	2	13.33
6*	*Thysanoteuthis rhombus* Troschel, 1857	550	2.93	1	6.67
Total		**18,750**	**100.00**	**15**	**100.00**

* Diamondback squid

Operation no. 7
Station no. 26

No.	Species	Weight (g)	% by wt.	Number	% by no.
1	*Carcharhinus falciformis (*Müller & Henle, 1839)	3,220	11.00	1	6.25
2	*Coryphaena equiselis* Linnaeus, 1758	1,700	5.81	1	6.25
3	*Coryphaena hippurus* Linnaeus, 1758	14,260	48.74	8	50.00
4	*Katsuwonus pelamis* (Linnaeus, 1758)	10,080	34.45	6	37.50
Total		**29,260**	**100.00**	**16**	**100.00**

Appendix 3: (cont.).

Operation no. 8

Station no. 2

No.	Species	Weight	% by wt.	Number	% by no.
1	*Carcharhinus falciformis (*Müller & Henle, 1839)	2,200	9.22	1	16.67
2	*Katsuwonus pelamis* (Linnaeus, 1758)	11,650	48.85	2	33.33
3	*Ruvettus pretiosus* Cocco, 1833	300	1.26	1	16.67
4	*Xiphias gladius* Linnaeus, 1758	8,900	37.32	1	16.67
5	*Lobotes surinamensis* (Bloch, 1790)	800	3.35	1	16.67
Total		**23,850**	**100.00**	**6**	**100.00**

Appendix 4: IRI of marine resources captured by DGN in the Bay of Bengal.

No.	Scientific Name	%IRI
1	*Katsuwonus pelamis* (Linnaeus, 1758)	66.72
2	*Carcharhinus falciformis (*Müller & Henle, 1839)	10.55
3	*Auxis thazard thazard* (Lacepède, 1800)	7.47
4	*Coryphaena hippurus* Linnaeus, 1758	5.10
5	*Thunnus obesus* (Lowe, 1839)	3.15
6	*Coryphaena equiselis* Linnaeus, 1758	2.64
7	*Euthynnus affinis* (Cantor, 1849)	2.03
8	*Xiphias gladius* Linnaeus, 1758	0.85
9	*Caranx tille* Cuvier, 1833	0.39
10	*Lobotes surinamensis* (Bloch, 1790)	0.19
11	*Remora remora* (Linnaeus, 1758)	0.17
12	*Thysanoteuthis rhombus* Troschel, 1857	0.17
13	*Auxis rochei rochei* (Risso, 1810)	0.15
14	*Ruvettus pretiosus* Cocco, 1833	0.15
15	*Psenes cyanophrys* Valenciennes, 1833	0.14
16	*Thunnus albacares* (Bonnaterre, 1788)	0.14
Total		**100.00**

Efficiency of the Circle Hook in Comparison with J-Hook in Longline Fishery

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Abstract

The efficiency of circle hook and J-hook in pelagic longline fishery were determined in 13 fishing stations in three designated areas. The research/training vessel, namely M.V. SEAFDEC, was employed for the fishing operations during 5 November to 4 December 2007. The survey area was mutually defined as area A: latitude 16°N-19°N and longitude 88°E-91°E (5 stations), area B: latitude 9°N-14°N and longitude 82°E-85°E (4 stations), area C: latitude 10°N-12°N and longitude 95°E-97°E (4 stations). The main objective of this work is to evaluate the efficiency of 18/0 10° offset circle hook in comparison with the J-hook using three different types of baits i.e., round scad (*Decapterus* sp.), milk fish (*Chanos chanos*) and Indian mackerel (*Rastrelliger kanagurta*). A total of 6,277 hooks was deployed during the survey program. The results appeared that, using circle hook, the percentage compositions of target fish (tuna and billfish) and by-catch fish were not much different, 46.67% and 53.33% respectively. In contrast, J-hook showed a higher difference between these 2 components, target fish 25.53% and by-catch fish 74.47%. Considering catch rates, in overall CPUE (individual/1,000 hooks) of circle hook was lower than that of J-hook (4.77 versus 7.48). When separated by fish group, for target fish the CPUE of circle hook was a little higher than J-hook (2.23 versus 1.91), but for by-catch fish the CPUE of J-hook was obviously higher (5.58 versus 2.55). Regarding to hooking position, the percentage of hooking position in mouth using circle hook was higher than that of J-hook (73.33% versus 53.19%) but the percentage in digestive system was lower (10% versus 38.3%).

Key words: efficiency, circle hook, J-hook, longline fishery

Introduction

Circle hook are not recent phenomena. Excavations of graves from pre-Columbian Indians in Latin America uncovered hooks made from seashells that resembled modern circle hook. Early Japanese fishermen tied pieces of reindeer horn together in the shape of a circle hook, while a similar design has been found from Easter Island (Moore, 2001). Pacific coast native Americans also used hooks that fished similarly to modern circle hook. The configuration of the tackle promoted hooking as fish tried to expel bait that they could not swallow (Stewart, 1977 cited after Trumble *et al*., 2002). Modern commercial longline fishermen have used circle hook for many years (Moore, 2001; Prince *et al*., 2002).

Circle hook are generally circular in shape, with the hook point bent back at the hook shaft. California statute defines a circle hook as, “a hook with a generally circular shape and a point which turns inwards, pointing directly back at the shank at a 90° angle” (Fig. 1)

Prince *et al.* (2002) defined a circle hook as "hook having a point that is perpendicular to the main hook shaft", whereas J-hook is defined as hook having a point parallel to the hook shaft. When looking at the barb from behind the hook shank, the greater the "offset" angle, the more the barb is visible (the barb and the shank are not in the same plane). The amount of "offset" may be important for the evaluation of hooking location. However, Lukacovic (2001) detected no difference in deep hooking rates in striped bass between offset and non-offset hook.

Circle hook is designed to prevent the exposed barb point from puncturing internal organs if the hook is swallowed. Fish swallow the baited hook and begin to move away. This movement pulls the hook from the throat, decreasing the chance of gut hooking. As the hook shaft begins to exit the mouth, the shape of the hook causes the shaft to rotate towards the corner of the mouth and the barb embeds in the corner of the jaw (Florida Sea Grant College Program, 1999; Artmarina Fishing Fleet, 2002).

A comparison of efficiency between the circle hook and the J-hook in longline fishery is the sub-project under the Ecosystem-Based Fishery Management in the Bay of Bengal Project. The pelagic longline (PLL) operation was conducted in 13 different stations in three designated areas, during 5 November to 4 December 2007, in the Bay of Bengal.

Objectives

To determine the efficiency of circle hook and J-hook with respect to:

- catch composition
- catch rate
- hooking position
- length frequency distribution of some dominant fishes

Materials and Method

Survey Area

The survey area was mutually defined as area A: latitude 16°N-19°N and longitude 88°E-91°E (5 stations) area B: latitude 9°N-14°N and longitude 82°E-85°E (4 stations) and area C latitude 10°N-12°N and longitude 95°E-97°E (4 stations). The depth of the sea at the survey stations was varied between 1,128 m and 3,525 m. (Fig. 1).

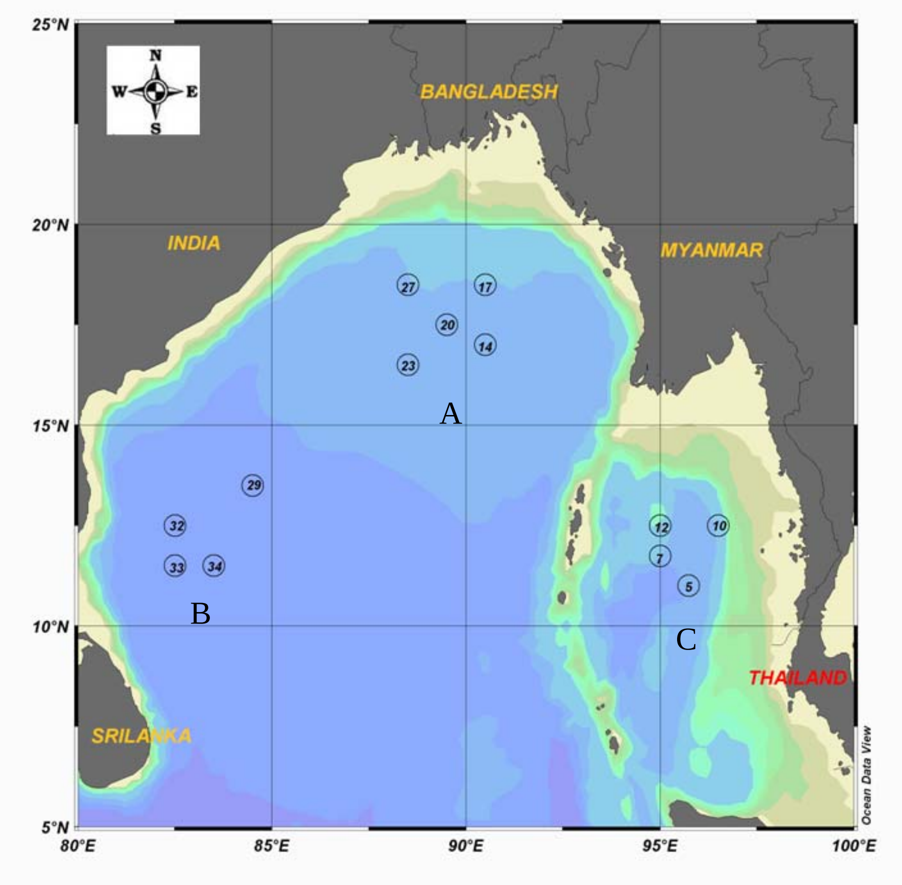


Figure 1 Map showing the survey stations of pelagic longline.

Fishing Gear

M.V. SEAFDEC has installed an automatic longline system. The system is composed of mainline spool, automatic line shooting machine and branch line setting beeper. Mainline spool is made by aluminum alloy with a diameter of 100 cm and a length of 200 cm. The spool is able to contain monofilament mainline with a diameter of 4 mm and the length is more than 30 km. The mainline shooter is made by aluminum alloy. Function of mainline shooter is to release the mainline from spool with very precise shooting rate in order to control the depth of branch line in the sea. While the controller wants to emergency stop the mainline shooter, mainline spool must be instantly stopped as well. Setting speed of mainline shooter needs to compatible control with the speed of vessel. M.V. SEAFDEC is shooting with a speed of approximately 7-8 knots and setting mainline shooter at a speed of approximately 8-10 knots. In order to control speed of mainline shooter, SEAFDEC/TD technician develops the computer software to command the shooting of branch line and float, as well as counting length of mainline and number of branch line.

Complete set of pelagic longline is composed of mainline, branch line and buoy line (Fig. 2). Mainline is made from nylon monofilament with a diameter of 4 mm. Breaking strength of mainline is more than 0.5 metric ton. The standard operation of pelagic longline carried out onboard M.V. SEAFDEC is set for more than 25 km. Branch line is made by nylon monofilament with a diameter of 2.0 mm and a length of 11 m. There are 2 designs of hooks as shown in fig. 3: stainless circle hook size 18/0 10° offset and J-shape, setting with branch line in order to investigate and compare the efficiency of hook designs. Three hundred to five hundred-twenty hooks per one operation were deployed. Fifteen to twenty hooks are set per basket, and in each set, the circle hook were set alternate with the J-hook, basket by basket. In general, the length of the float line was 25 m. However, for area: A, the length of float line was longer, that was 40 m, as the hook could not reach the themocline layer due to the strong current in the area. Two set of temperature and depth sensors (TD sensors) were attached at the branch line no.1 and 10 for 20 hooks per basket and no.1 and 8 for 15 hooks per basket in order to check the actual depth of hook. TD sensors showed that the shallowest branch line was 50-80 m and deepest branch line no.10 and 11 was 90-300 m.

On this cruise, the Indian mackerel, round scads and milk fish were used for baits. Normal size of bait was 8 to 10 individuals per kg but for the milk fish bigger size was used (6-8 individuals per kg).

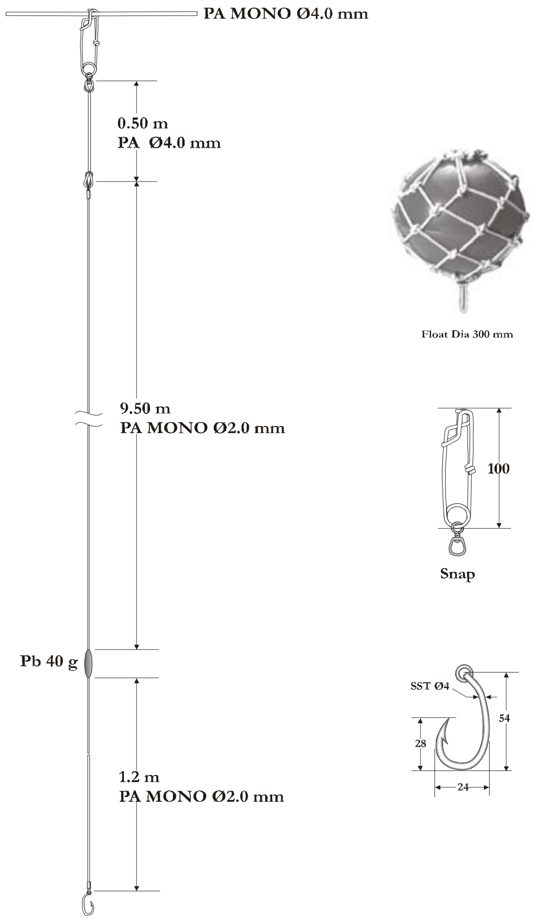


Figure 2 Branch line monofilament.

Figure 3 J-hook and circle hook.

Hook Size, Pattern and Part

The size of a fish hook is determined by its pattern which is given in term of the width of the gap of the hook. The hook sizes of other patterns are bound to differ to some extent; the reference number of a hook should therefore always be quoted together, and regarded as inseparable.

The various parts of a fish hook are shown together with their names as illustrated in fig. 4. The two most important dimensions of the hook are its gap and its throat. The hook shown here is a Mustad saltwater hook. It should be noted that the width of the gap is made for the bigger bite, the distance between point and shank is made for the deeper penetration and the depth of the throat of the hook is made for the better holding power. The weight of the fish is carried high up on the center of the bend (Mustad catalogue, 1995).

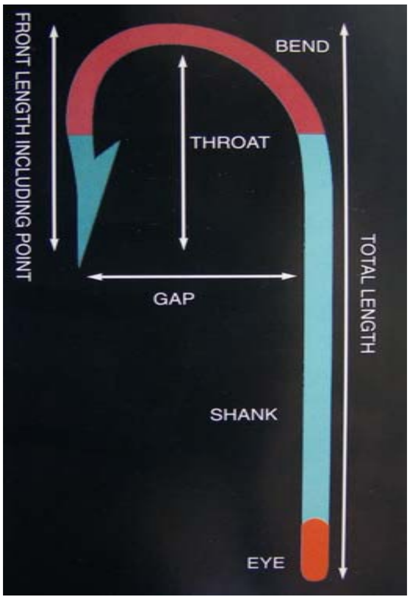


Figure 4 Illustration of hook parts.

Data Collection

Species, length, weight, hook type, and hooking position of all target fishes, as well as by-catch fish were recorded. Length of fish that was damaged during haul back on board was estimated. Some sharks and large fishes were released by cutting the branch line and rays were released after finishing the measurement. Small fishes, such as snake mackerels *Gempylus serpens*, were generally hauled onto the deck and hook recovered.

The hooking positions were categorized as shown in fig. 5. “upper jaw”, “lower jaw” and “jaw angle” were considered as “mount”. The hooking positions inside the mount, such as “esophageal sphincter”, “gill arch” were considered as “digestive system”. All other locations “gill slit”, “entangle”, “body” and all of some loosed fishes were considered as “other”.

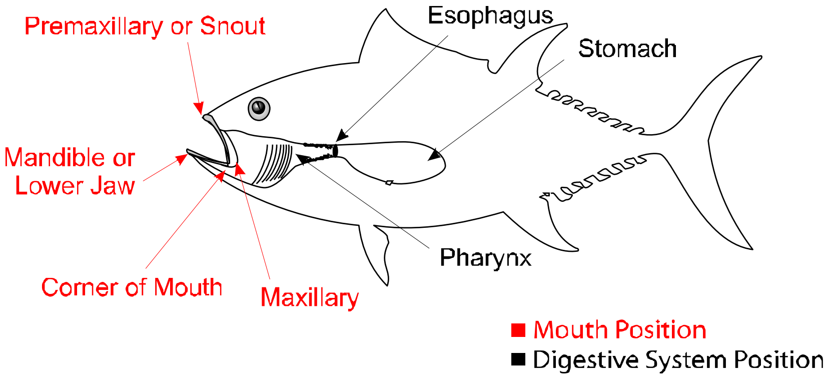


Figure 5 Hooking position of fish.

Result and Discussion

Catch Composition

All catches from C and J types experiment were mixed up and compared in percentage composition (Table 1). Catches were categorized into 2 groups: target fish and by-catch fish. The target fish comprised 4 species namely yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*), black marlin (*Markaira indica*) and sailfish (*Istiophorus platypterus*). All are commercial fish that are most commonly caught by pelagic longline. A total number of 26 of target fish was caught which constituted 33.76 % of the total catches. Among the target group, the highest composition 27.27% was swordfish. When comparing between C and J types, the C-type could catch target fish 18.18% and J-type could catch target fish 16.58 %.

Regarding to by-catch group, there were 51 individuals caught representing 13 species and were 66.23% of the total catch. Within this group, bigeye thresher shark possessed the highest composition of 14.28%. This species was caught in area B and C but none in area A. In contrast, by-catch fish, the catch composition of J-style hook was more than that of circle hook. For J-hook the catch composition was 45.45% whereas for circle hook it was 20.78%.

Based on catch composition of each hook type, for circle hook the percentages of target fish (46.67%) and by-catch fish (53.33%) were not much different, whilst for J-hook the percentage of target fish (25.53%) was much lower than that of by-catch fish (74.47%).

Table 1 Catch composition by fish group, species and hook type.

Scientific name	Percent composition (n)	Hook type	
		Circle hook	**J- hook**
Target fish			
Thunnus albacares (Yellowfin tuna)	3.89 (3)	2	1
Xiphias gladius (Swordfish)	27.27(21)	12	9
Makaira indica (Black marlin)	1.29 (1)	-	1
Istiophorus platypterus (Sailfish)	1.29 (1)	-	1
% composition (n)	**33.76 (26)**	**18.18 (14)**	**16.58 (12)**
By-catch fish			
Sphyreana barracuda (Great baraccuda)	2.59 (2)	1	1
Coryphaena hippurus (Dolphinfish)	2.59 (2)	-	2
Caranx ignobilis (Giant trevally)	2.59 (2)	-	2
Pteroplatytrygon violacea (Pelagic stingray)	7.79 (6)	2	4
Alopias superciliosus (Bigeye thresher shark)	14.28 (11)	2	9
Alopias pelagicus (Thresher shark)	1.29 (1)	-	1
Galeocerdo cuvieri (Tiger shark)	1.29 (1)	-	1
Carcharhinus falciformis (Silky shark)	12.98 (10)	5	5
Iago garricki (Longnose houndshark)	1.29 (1)	-	1
Lepidocybium flavobrunneum (Escolar)	5.19 (4)	4	-
Gempylus serpens (Snake makeral)	10.38 (8)	1	7
Alepisaurus ferox (Lancet fish)	2.59 (2)	1	1
Promethichythys prometheus (Roudi escolar)	1.29 (1)	-	1
% composition (n)	**66.23 (51)**	**20.78(16)**	**45.45 (35)**
Total	**100 (77)**	**30**	**47**
% composition		**38.96**	**61.04**
% Target fish composition		**46.67**	**25.53**
% By-catch fish composition		**53.33**	**74.47**

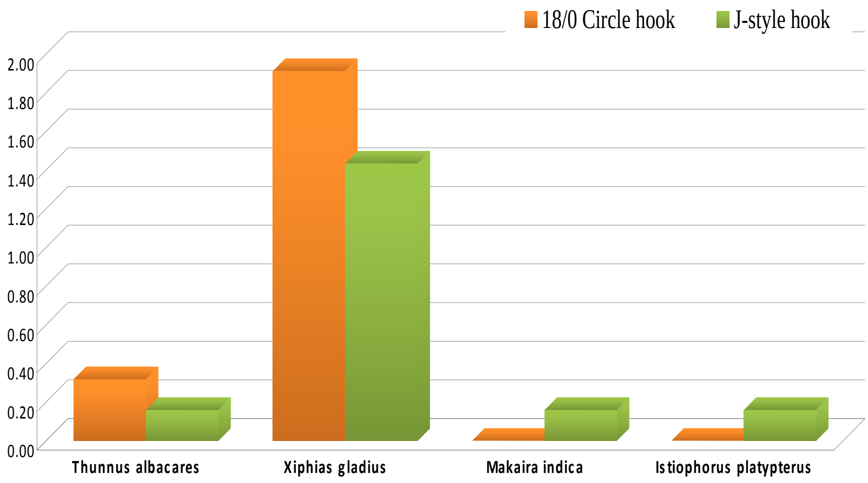
Catch Rate

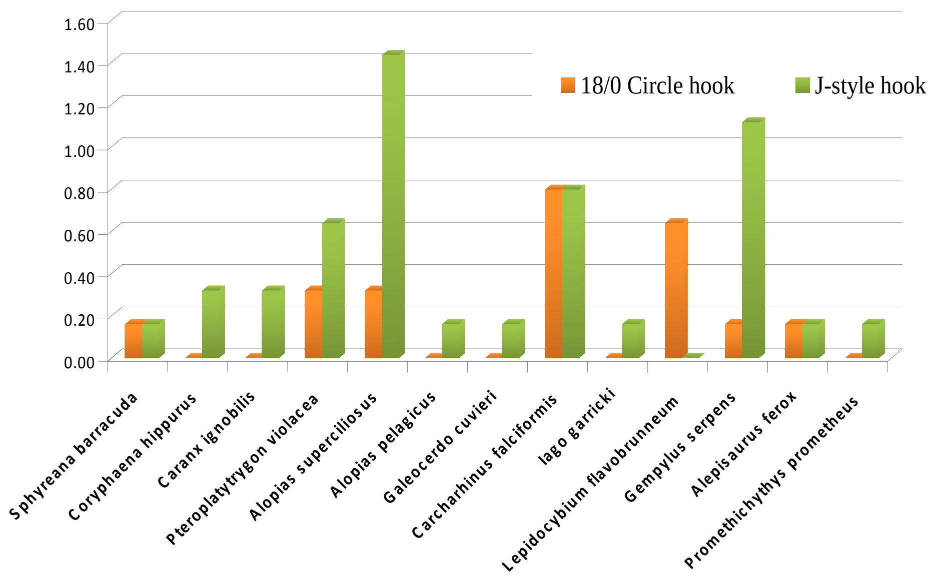
A total of 77 by number weighing approximately 1,754.65 kg was caught during the survey. Total numbers of hook deployed were 6,277 hooks. Catch per unit effort (CPUE) of pelagic longline survey separated by areas were 21.68 individuals/1,000 hooks in area C of Myanmar waters, 9.13 individuals/1,000 hooks in area B, and 7.79 individuals/1,000 hooks in area A. The overall CPUE was 12.27 individuals/1,000 hooks. Considering the CPUE by station, the highest CPUE 39.39 individuals/1,000 hooks was found in station 12 (operation no. 4) followed by station 7 (operation no.2) with CPUE of 31.37 individuals/1,000 hooks and station 17 (operation no. 6) with CPUE of 17.65 individuals/1,000 hooks.

Catch rates varied by fish groups and hook types. In overall, the CPUE of circle hook and J-hook were 4.77 and 7.48 individuals/1,000 hooks respectively (Table 2). When separated by fish group the result appeared that the CPUE of total target fish was 4.14 individuals/1,000 hooks of which 2.23 individuals/1,000 hooks belonging to circle hook and 1.91 individuals/1,000 hooks obtained by J-hook. Within this group, sword fish *Xiphias gladius* showed the highest CPUE of 3.35 individuals/1,000 hooks. For total By-catch fish, the CPUE was 8.12 individuals/1,000 hooks of which the significant higher contribution 5.58 individuals/1,000 hooks was from J-hook whilst 2.55 individuals/1,000 hooks belonging to circle hook. Within this group, bigeye thresher shark was remarkable the highest CPUE of 1.75 individuals/1,000 hooks followed by silky shark *Carcharhinus falsiformis* with CPUE of 1.59 individuals/1,000 hooks. Details of catch rate by species and hook types were shown in table 2 and fig. 6.

Table 2 Catch in number and catch rate (CPUE-individual/1,000 hooks) by species and hook type.

Scientific name	Number of fish	CPUE (individual/1,000 hooks)	
	from 6,277 hooks	Circle hook	J- hook
Thunnus albacares (Yellowfin tuna)	3	0.32	0.16
Tunas group	**3**	**0.32**	**0.16**
Xiphias gladius (Swordfish)	21	1.91	1.43
Makaira indica (Black marlin)	1	-	0.16
Istiophorus platypterus (Sailfish)	1	-	0.16
Billfishes group	**23**	**1.91**	**1.75**
Pteroplatytrygon violacea (Pelagic stingray)	6	0.32	0.64
Alopias superciliosus (Bigeye thresher shark)	11	0.32	1.43
Alopias pelagicus (Thresher shark)	1	-	0.16
Galeocerdo cuvieri (Tiger shark)	1	-	0.16
Carcharhinus falciformis (Silky shark)	10	0.8	0.8
Iago garricki (Longnose houndshark)	1	-	0.16
Sharks and rays group	**30**	**1.43**	**3.34**
Sphyreana barracuda (Great baraccuda)	2	0.16	0.16
Coryphaena hippurus (Dolphinfish)	2	-	0.32
Caranx ignobilis (Giant trevally)	2	-	0.32
Lepidocybium flavobrunneum (Escolar)	4	0.64	-
Gempylus serpens (Snake makeral)	8	0.16	1.12
Alepisaurus ferox (Lancet fish)	2	0.16	0.16
Promethichythys prometheus (Roudi escolar)	1	-	0.16
Other fishes groups	**21**	**1.11**	**2.23**
Total	**77**	**4.77**	**7.48**





Hooking Position

From total catches, it was observed that 61.04% of fishes caught were hooked in mouth, 27.27% were found in digestive system and 11.69% were at other. In comparison, when used circle hook, 73.33 % of fishes caught were hooked in mouth and only 10% were found in the digestive system. Using J-hook, the majority of the captured fish were also hooked in mouth 53.19% followed by digestive system 38.3%. (Fig. 7) Details of the observed hooking position were in Appendix 1, and yellowfin tuna, swordfish, silky shark and snake mackerel were chosen as examples for distinguishing comparison illustrated in Fig 8.

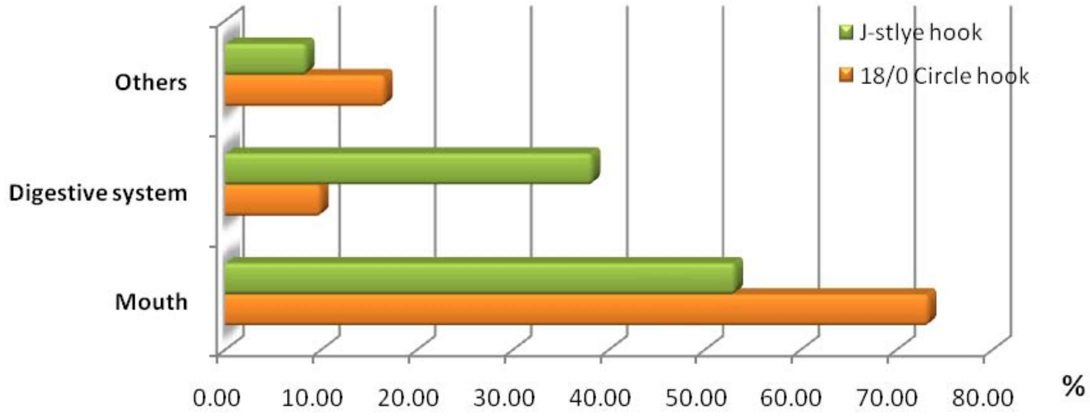


Figure 7 Chosen the hooking positions for circle hook and J- hook.

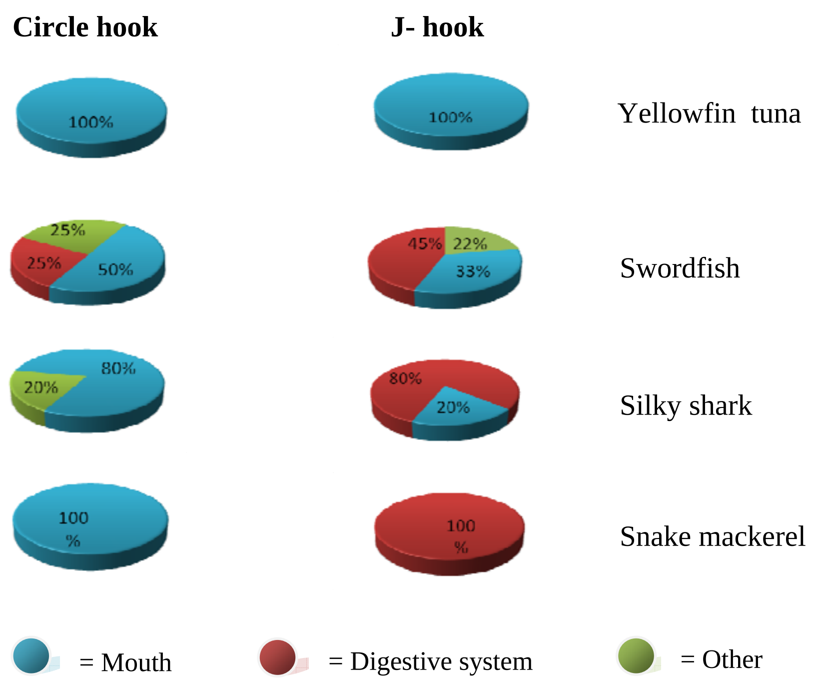


Figure 8 Percentage of hooking position by species and hook type.

Length Frequency Distribution of Some Dominant Fishes

Swordfish *Xiphias gladius* was the most dominant species in the target fish group. The total length of this species, from a total of 21 by number weighing 650 kg, was in the range from 129 to 295 cm. The length of specimens caught by circle hook ranged from 129 to 255 cm with mode of 210-229 cm. Those caught by J-hook were from 139 to 295 cm with mode of 250-269 cm (Fig. 9)

Catch percentage

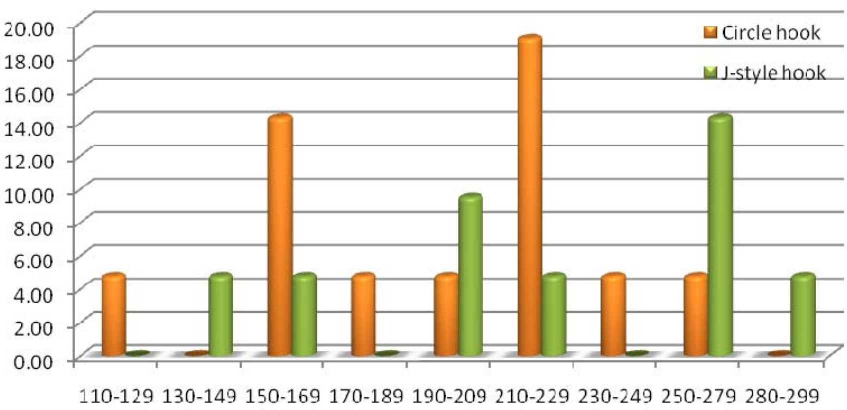


Figure 9 Length frequency distribution of Swordfish.

Bigeye thresher shark *Alopius superciliosus* was the most dominant species in the by-catch fish group. The total length of this species, from a total of 11 by number weighing 641 kg, ranged from 205 to 329 cm. The length of this species caught by circle hook and J-hook were 250-276 cm and 205-309 cm respectively, with mode of 250-259 cm for J-hook but not remarkable for circle hook (Fig. 10).

Catch percentage

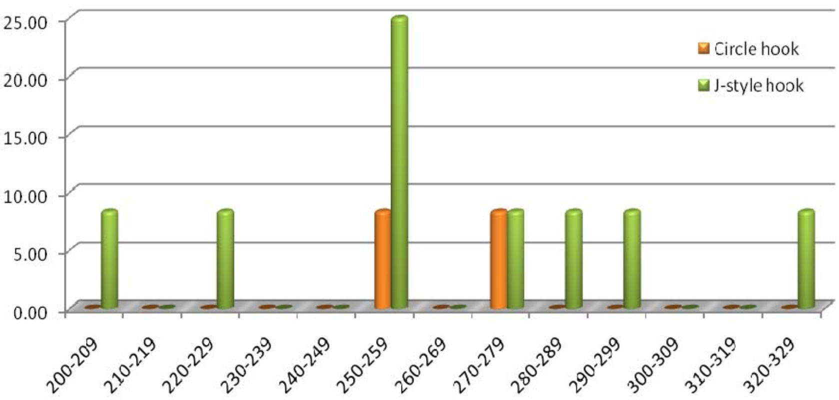


Figure 10 Length frequency distribution of Bigeye thresher shark.

It was found that there was not much difference in the percentage composition between target fish and by-catch fish using circle hook (46.67% versus 53.33%), on the contrary, the J-hook showed a higher difference between these 2 components (25.53% target fish and 74.47% by-catch fish). There was a 3% increasing in total tunas and other target species caught by the 18/0 10° offset circle hook compared to J-hook but there was 22% reduction in total sharks-rays and other non valued by-catch caught by the 18/0 10° offset circle hook compared to J-hook (Siriraksophon *et al.*,2007).

Considering the catch rates (individual/1,000 hooks), the results of this study appeared that the catch rate of target fish, which were tuna and billfish, using the circle hook was a little higher than that of the J-hook (2.23 versus 1.91), on the contrary, the catch rate of by-catch fish obtained by J-hook was approximately twofold of that belonging to circle hook (5.58 versus 2.55).Thus this result indicate that the catch-ability of circle hook and J-hook are almost equal for target fish but J-hook are more effective for by-catch fish. Furthermore, the effects of circle hook and J-hook on pelagic long line catch rate have been investigated with interesting results. One of the important by-catch fish from pelagic longline fishing is shark. In some areas sharks are non-target fish but in the western North Pacific they are the target fish (Simpfendorfer *et al.,* 2005; Watson *et al*., 2005). When compared the blue shark catch rates (individual/1000 hooks) using 0° and 10° offset 18/0 circle hook with a combination of squid and mackerel baits to those using 25° offset 9/0 J-hook with squid bait. They used data collected by onboard observer during pelagic longline fishery in the west North Atlantic. Their results appeared that, compared to J-hook, catch rates significantly increased by 8-9% when circle hook were used with squid bait. However, Watson *et al.*(2005) discussed that circle hook might not actually catch more sharks than J-hook, they hypothesized that the results of J-hook might be erroneous because during haul back, sharks that were gut-hooked were more likely to bite off monofilament leaders and thus could escape from detention. In this study the difference in CPUE of bigeye thresher shark between J-hook and circle hook was obvious. The J-hook showed the higher CPUE than circle hook (1.43 versus 0.32). Only the silky shark *Carcharhinus falciformis* was observed a similar CPUE between J-hook and circle hook (0.8 individual/1,000 hooks).

Regarding to hooking position, the use of circle hook has been known to reduce the rate of deep hooking and increase mouth hooking in some pelagic fishes such as Atlantic bluefin tuna (*Thunnus thynnus*), yellowfin tuna (*Thunnus albacares*) and billfish (Prince *et al*., 2002; Skomal *et al*.,2002; Kerstetter and Graves, in press). Falterman and Graves (2002) reported that gut, foul and roof hooking events were seen with the J-hook but not with the circle hook. In this study hooking positions varied by hook type and fish species. From all species caught the circle hook were hooked in mouths with 61.04%. For yellowfin tuna both types of the hooks were recorded at 100% in mouths. For swordfish, the circle hook were hooked in mouth 50%, while the J-hook were found in digestive system 45%. Stillwell and Konler (1985) noted that many of the squid and mesopelagic fishes in swordfish gut contents showed an evidence of decapitation or slashing. This feeding behavior may explain the relatively high incidence of bill hooking. Silky sharks caught by the circle hook were hooked 80% in mouth but only 20% was observed from J-hook. In contrast, the hook type found most in digestive system was the J-hook (80%). These results are in good agreement with the observation from Kerstetter and Graves (in press). They reported that the circle hook caught fishes in the mouth more frequently than J-hook, whereas the J-hook hooked more often in the throat of gut. Although the differences in hooking position between hook types were not statistically significant, the yellowfin tuna in the fall fishery was over four times more likely to be hooked in the mouth with the circle hook than with the J-hook.

In considering the length frequency distribution of the 2 dominant species, both types of hooks are capable to detain a very large size of fish (over 100 cm). However, it was noticeable that the sizes caught of swordfish (*Xiphias gladius*) by J-hook were larger than those by circle hook. For bigeye thresher shark (*Alopius superciliosus*), the specimens caught by J-hook had length range wider than that obtained by circle hook.

From such results, it was recommended that for longline fishery, fishermen should use the C-type hook instead of J-type for higher catch of tuna target fish and at the same time the hook can reduce by-catch especially for those sharks and rays. Since shark and ray are distinguished as endanger species. Furthermore if the by-catch was caught, they will be released and still alive due to the hooking position that causes the fish less damage.

Acknowledgement

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Appendix

Appendix 1. Hooking positions by species with comparison between circle hook and J- hook.

Operation no. / Station	Circle hook				J-hook			
	Species	Total length (cm)	Weight (kg)	Hooking position	Species	Total length (cm)	Weight (kg)	Hooking position
1	*Lepidocybium flavobrunneum*	60.9	1.65	Lower jaw	*Gempylus serpens*	103.2	1.2	Esophageal sphincter
st. 05					*Gempylus serpens*	111	1.5	Esophageal sphincter
					Pteroplatytrygon violacea	98	2.5	Lower jaw
2	*Lepidocybium flavobrunneum*	61	6.50	Lower jaw	*Xiphias gladius*	253	60.0	Jaw angle
st.07	*Xiphias gladius*	242	40.00	Lower jaw	*Xiphias gladius*	262	60.0	antangle with line
	Lepidocybium flavobrunneum	-	1.50	Jaw angle	*Pteroplatytrygon violacea*	94	2.2	Gill slit
	Alopias superciliosus	276	53.00	Lower jaw	*Gempylus serpens*	111	1.5	Esophageal sphincter
	Xiphias gladius	255	61.00	U.jaw to eye socket	*Gempylus serpens*	97	1.2	Esophageal sphincter
	Lepidocybium flavobrunneum	92	6.00	Upper jaw	*Galeocerdo cuvieri* *	-	~30	-
	Thunnus albacares	52	2.00	Lower jaw	*Promethichythys prometheus*	76	1.6	Esophageal sphincter
					Gempylus serpens	111	1.5	Esophageal sphincter
					Alopias pelagicus	256	34.0	Lower jaw
3	*Pteroplatytrygon violacea*	133	9.50	Lower jaw	*Gempylus serpens*	97	1.1	Esophageal sphincter
st.10					*Alopias superciliosus*	252	42.0	Jaw angle
					Xiphias gladius	212	22.0	Esophageal sphincter
					Makaira indica	276	80.0	Jaw angle
					Alopias superciliosus	220	31.0	Jaw angle
					Alopias superciliosus	329	100.0	Jaw angle
4	*Xiphias gladius* *	170	~15	-	*Caranx ignobilis*	92	7.6	Jaw angle
st.12	*Xiphias gladius* *	205	~20	-	*Caranx ignobilis*	-	~8	Jaw angle
	Xiphias gladius *	212	~30	-	*Coryphaena hippurus*	80	2.5	Esophageal sphincter
	Pteroplatytrygon violacea *	-	~3	-	*Xiphias gladius*	202	21.0	Jaw angle
	Carcharhinus falciformes	128	13.00	Jaw angle	*Xiphias gladius*	207	21.0	Esophageal sphincter
					Carcharhinus falciformes	124	11.0	Esophageal sphincter
					Xiphias gladius	250	51.0	Esophageal sphincter
					Xiphias gladius	295	100.0	-
5	*Xiphias gladius*	215	30.00	Jaw angle	*Thunnus albacares*	137	35.0	Jaw angle
st.14	*Thunnus albacares*	140	38.00	Jaw angle	*Carcharhinus falciformes*	85	3.3	Esophageal sphincter
					Gempylus serpens	102	1.1	Esophageal sphincter
6	*Carcharhinus falciformes*	93	4.30	Jaw angle	*Carcharhinus falciformes*	178	38.0	Jaw angle
st.17	*Carcharhinus falciformes*	88	3.30	Upper jaw	*Coryphaena hippurus*	135	13.0	Esophageal sphincter
	Carcharhinus falciformes	101	6.50	Jaw angle	*Iago garricki*	80	2.1	Lower jaw
	Sphyreana barracuda	88	3.90	Upper jaw	*Carcharhinus falciformes*	111	7.2	Esophageal sphincter
	Gempylus serpens	91	0.80	Lower jaw				

Biological Aspects of Economic Fishes in the Bay of Bengal

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Abstract

Six dominant large sized fish species, *Katsuwonus pelamis*, *Xiphias gladius*, *Auxis thazard*, *Alopias superciliosus*, *Carcharhinus falciformis* and *Coryphaena hippurus* are economic important fishes in the Bay of Bengal which were chosen to study on biological aspect. The fish samples from 21 stations were obtained from drift gill net and pelagic long line operated by M.V. SEAFDEC during 25 October-21 December 2007 in the Bay of Bengal. The results showed that the average size of *K. pelamis* was 41 ± 10.19 cm whereas *X. gladius*, *A. thazard*, *A. superciliosus*, *C. falciformis* and *C. hippurus* were 211.00 ± 46.36, 35.14 ± 4.86, 271.00 ± 40.25, 111.33 ± 8.79 and 72.94 ± 12.58 cm respectively. The relationship between length and body weight showed high significant correlation in all respected species. There was significant difference in sex ratio of *K. pelamis* ($p<0.05$) but none in others species ($p>0.05$). The study of gonad development in this survey could not use to indicate the spawning season due to less specimens and the survey did not cover all year round.

Key words: Bay of Bengal, economic fishes, sex ratio, gonad development

Introduction

The Bay of Bengal, a sea in the north-east arm of the Indian Ocean, is located between 5°N-22°N latitudes and 80°E-100°E longitudes. Fisheries are of major socioeconomic importance to all countries bordering the bay. The main commercial fish species are shrimp, tuna, yellowfin tuna, bigeye tuna and skipjack tuna. There is a high percentage catch for miscellaneous coastal fishes and pelagic fishes, however shrimp is the major export earner in this region. The Food and Agriculture Organization (FAO) 10 years trend showed a steady increased in catch from 1.4 million tons in 1990 to 2.2 million tons in 1999. An average catch was 2 million tons. Catch trends were quite diverse and it was difficult to identify a pattern due to the fact there was inadequate information on the status of the fishery resources and their exploitations. There were signs that the harvest levels may not be sustainable, especially with regard to tuna fishing in the Maldives, Malaysia, Andaman coast of Thailand and Sri Lanka. Furthermore, the most of countries surrounding the bay are weak in developing clear policies, appropriate strategies and the sustainable management of the fishery resources (NOAA. http:// na.nefsc.noaa.gov/lme/text/lme 34 htm; FAO, 2003).

Therefore, the study on biological aspects (e.g. length and weight relationship, sex ration and maturation) is very useful and essential for fishery enhancement and management. It will support future fishery development with scientific data for not only conservation of the fishery resources but also appropriate fishery management for sustainable fishery in the Bay of Bengal.

Materials and Methods

Six dominant species of pelagic fish, *Katsuwonus pelamis*, *Xiphias gladius*, *Auxis thazard*, *Alopias superciliosus*, *Carcharhinus falciformis* and *Coryphaena hippurus* were collected from drift gill net (8 stations) and pelagic longline (13 stations) operated in the Bay of Bengal by M.V. SEAFDEC, a vessel of the Southeast Asian Fisheries Development Center, during 25 October-21 December 2007 (Fig.1). All sampled fishes were examined, measured and weighted on board in a fresh condition. Some biological parameters were recorded and analyzed as follow:

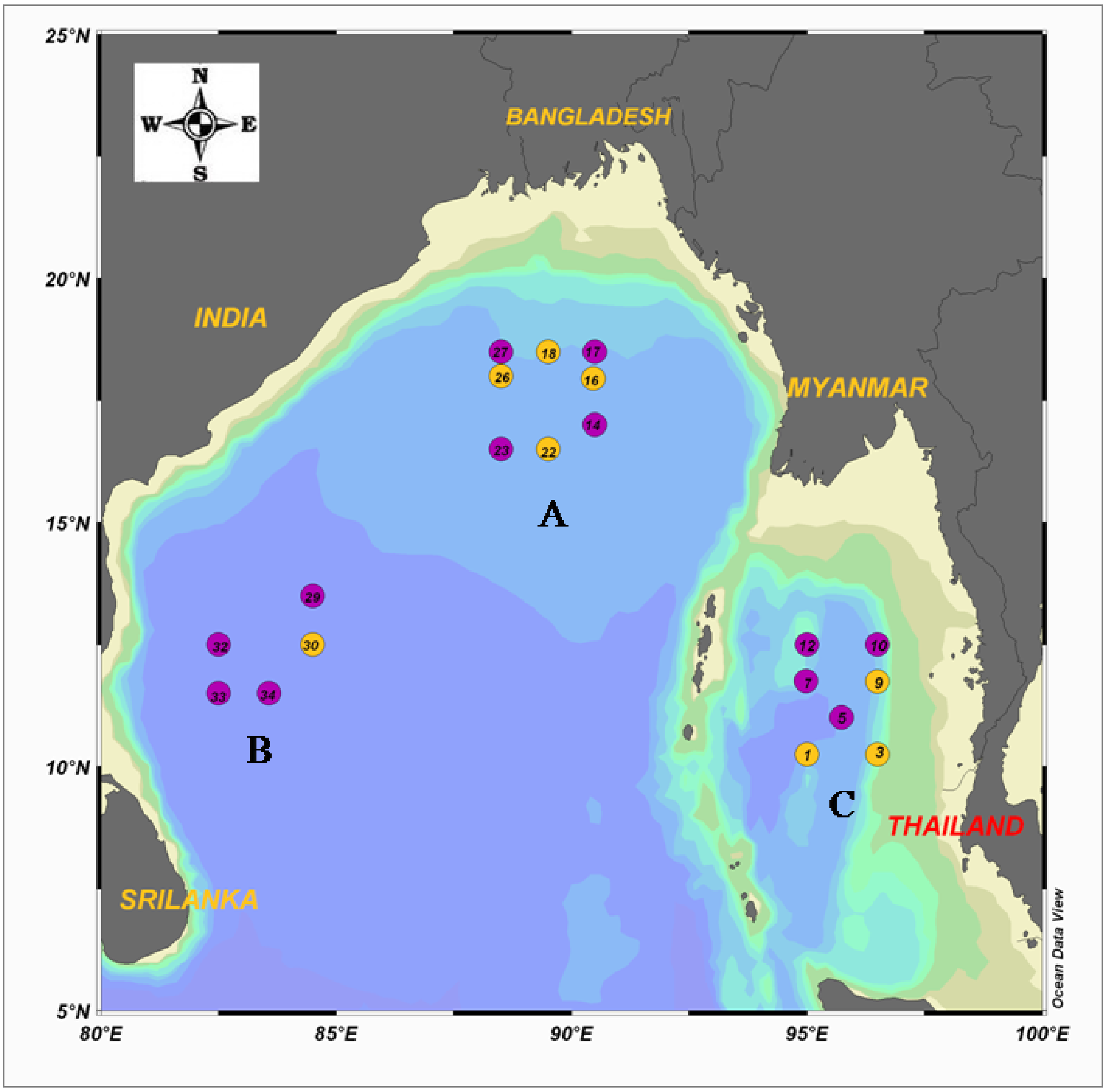

Figure 1 Survey and sampling stations of the six dominant species in the Bay of Bengal.
○ Drift gill net
● Pelagic longline

1. Length Frequency Distribution

Both fork length and total length were measured in centimetre (cm) and illustrated as histogram via length interval and frequency. The average, maximum and minimum size of fishes were also figure out.

2. Length-Weight Relationship

All sampled fishes were measured and weighted in a fresh condition. Fork length and total length were measured in centimetre (cm) and the weights were recorded in kilogram (kg). The relationship equations of length-weight of these six species were estimated using the regression analysis (Ricker, 1975). In the analysis process, length and weight data were transformed into logarithms.

$$W = a L^b$$

$$\log W = \log a + b \log L$$

W = body weight (kg)
L = total length or fork length (cm)
a, b = output from regression line (b is slope)

3. Sex Ratio

Hypothetically, the sex ratio of male to female equals to 1:1 which is significant at 95% of confident level. All data were analysed using Chi-square test.

$$\chi^2 = \frac{\Sigma\left(\left|\text{Observed} - \text{Expected}\right| - 0.5\right)^2}{\text{Expected}} \qquad (n < 50)$$

χ^2 = Chi – square
Observed = number of male (female)
Expected = average between male and female

4. Maturation

Male and female sexual maturities were determined from gonad development which are categorized into 6 stages.

Stage 1 Virgin. Very small sexual organs close to the vertebral column. Testis and ovary transparent, colorless grey. Egg invisible by naked eye.

Stage 2 Maturing virgin and recovering spent. Testis and ovary translucent, grey red. Length half, or slightly more than half the length of ventral cavity.

Stage 3 Developing. Testis reddish-white. No milt drops appear under pressure. Ovary organ reddish, egg clearly discernible of opaque. Testis and ovary occupy about two-thirds of central cavity.

Stage 4 Developed. Testis and ovary opaque, reddish with blood capillaries, occupy about half of ventral cavity. Eggs visible to eye as whitish granular.

Stage 5 Spawning. Roe and milt with slight pressure. Most eggs translucent with a few opaque eggs left in cavity.

Stage 6 Resting. Testis and ovary empty, red. A few eggs in the stage reabsorption.

Stages 1-3 are immature and stages 4-6 are mature stage.

Results and Discussion

Six dominant species of pelagic fish obtained from drift gill net and pelagic long line operation in the Bay of Bengal, were consisted of *K. pelamis*, *X. gladius*, *A. thazard*, *A. superciliosus*, *C. falciformis* and *C. hippurus*. They are economic important fish and abundant in the surveyed area these species were taken for biological analyses. The results were as follow:

1. Size Frequency Distribution

The analyzed data and histogram are shown in table 1 and fig. 2.

Skipjack tuna, *K. pelamis*, was the top most species caught in this study. Fork length ranged from 17.80-70.00 cm, the average size was 41.46±10.19 cm.

Swordfish, *X. gladius*, was the second dominant species. The average, minimum and maximum sizes were 211.00±46.36, 129.00 and 295.00 cm respectively. The rest of the caught fishes were observed as shown in table 1 and fig. 2 either.

Table 1 Size range including mode and mean sizes of the six dominant species.

Species	n	Minimum (cm)	Maximum (cm)	Mode (cm)	Mean±SD (cm)
Katsuwonus pelamis (FL)	38	17.80	70.00	40.00	41.46±10.19
Xiphias gladius (TL)	17	129.00	295.00	162.00, 212.00	211.00±46.36
Auxis thazard (TL)	11	25.60	40.00	38.00	35.14±4.86
Alopias superciliosus (TL)	9	205.00	331.00	250.00	271.00±40.25
Carcharhinus falciformis (TL)	9	85.00	178.00	93.00	111.33±8.79
Coryphaena hippurus (TL)	9	62.00	97.00	66.00	72.94±12.58

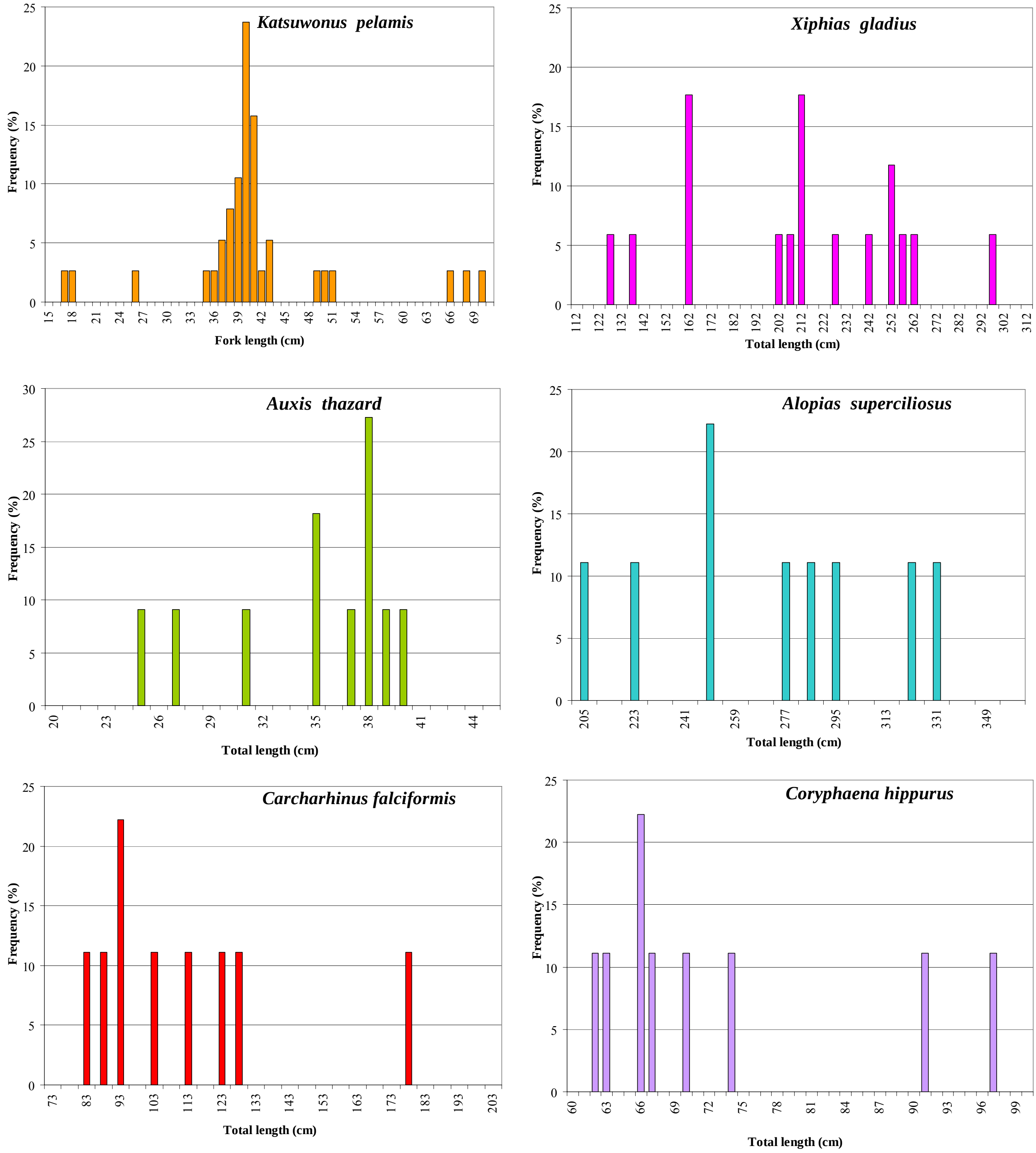

Figure 2 Length frequency distribution of six dominant species in the Bay of Bengal.

2. Length-Weight Relationship

The relationship between length and weight of *K. pelamis*, *X. gladius*, *A. thazard*, *A. superciliosus*, *C. falciformis* and *C. hippurus* showed high coefficient of correlation (r^2) which meant that weight absolutely increased with length. In addition they were allometric growth because the obtained b values were close to or bigger than 3 (Table 2 and Fig.3).

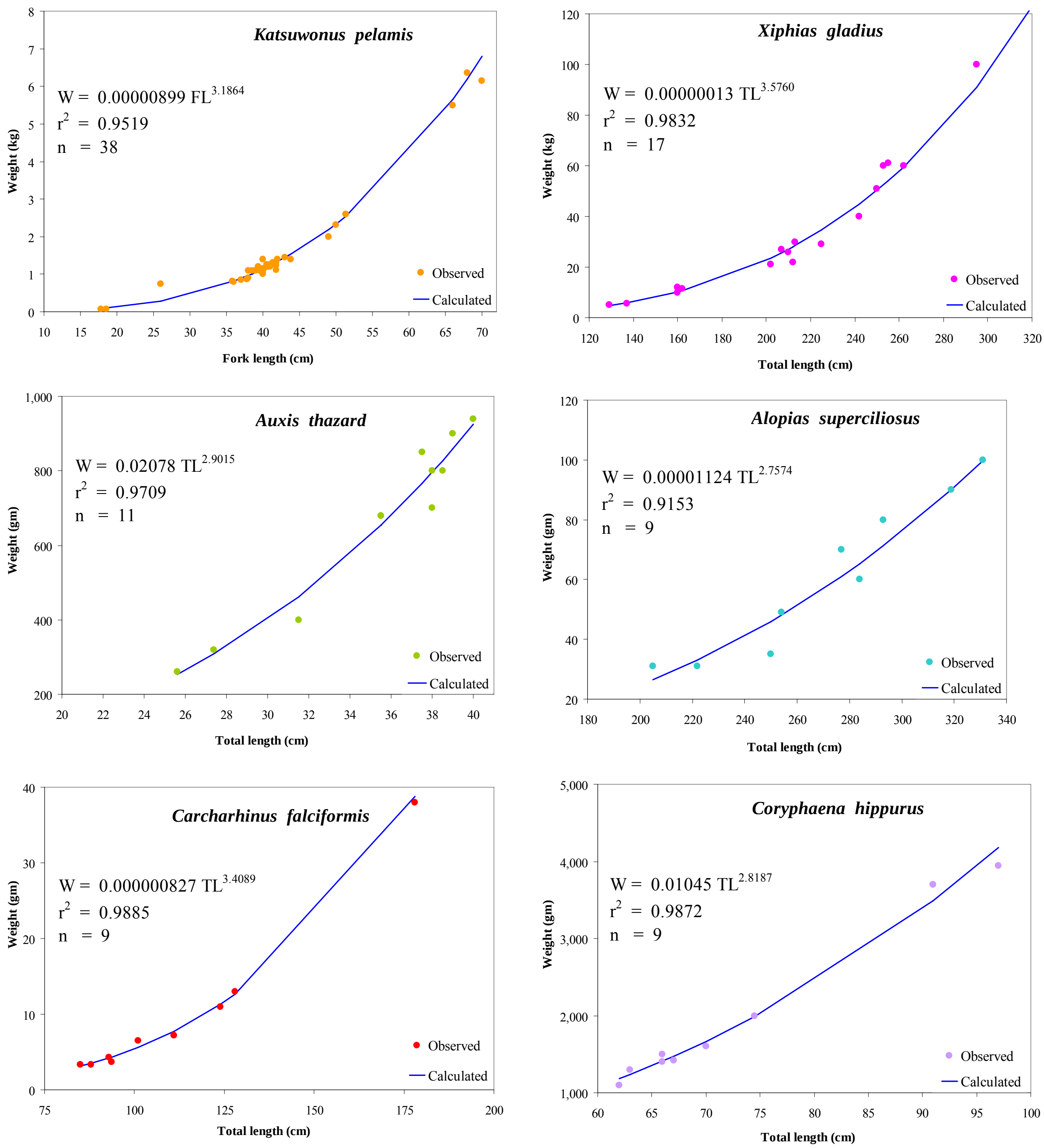

Figure 3 The relationship between length and body weight of six dominant species.

Table 2 The equations of length-weight relationship of six dominant species.

Species	n	Linear equation	Power equation	r^2
Katsuwonus pelamis	38	log W = 3.1864 log FL-5.0462	$W = 0.00000899\ FL^{3.1864}$	0.9519
Xiphias gladius	17	log W = 3.5760 log TL-6.8861	$W = 0.00000013\ TL^{3.5760}$	0.9832
Auxis thazard	11	log W = 2.9015 log TL-1.6824	$W = 0.02078\ TL^{2.9015}$	0.9709
Alopias superciliousus	9	log W = 2.7574 log TL-4.949	$W = 0.00001124\ TL^{2.7574}$	0.9153
Carcharhinus falciformis	9	log W = 3.4089 log TL-6.0825	$W = 0.000000827\ TL^{3.4089}$	0.9885
Coryphaena hippurus	9	log W = 2.8187 log TL-1.9809	$W = 0.01045\ TL^{2.8187}$	0.9872

3. Sex Ratio

The sex ratio of male and female of *K. pelamis*, *X. gladius*, *A. thazard*, *A. superciliousus* were 1:0.48, 1:0.75, 1:0.83 and 1:1.25 respectively whereas both *C. falciformis* and *C. hippurus* were 1:2. The statistic analysis showed that there was significant difference ($p<0.05$) in sex ratio of *K. pelamis* while there were no significant differences ($p>0.05$) in the others species (Table 3). In general, it could be concluded that sex ratio of male to female were mostly 1:1. Nevertheless, sex ratio also varied by environmental habitat, mortality, and nutritional status (Wenner, 1972).

Table 3 Chi-Square test of sex ratio of six dominant species in the Bay of Bengal.

Spicies	n	Male	Female	Unidentified	Sex ratio M:F	Chi-Square χ^2
Katsuwonus pelamis	38	21	10	7	1:0.48	**4.87***
Xiphias gladius	17	8	6	3	1:0.75	1.18
Auxis thazard	11	6	5	-	1:0.83	0.18
Alopias superciliosus	9	4	5	-	1:1.25	0.22
Carcharhinus falciformis	9	3	6	-	1:2.00	1.11
Coryphaena hippurus	9	3	6	-	1:2.00	1.11

Note : Chi-square from Table = 3.84, df = 1 (95% Significant)

* significance at 95% of confident level

4. Maturation

The result showed that the percentage of female maturation of developed, spawning and resting stages were higher than males whereas the percentage of female maturation of virgin, maturing virgin and recovering spent and developing stages were lower. There were over 50% of matured females in samples of *A. thazard* and *C. falciformis* but *C. hippurus* was found 100% of mature females. Both sexes of *A. superciliousus* were found 100% of maturation. Further both *K. pelamis* and *C. falciformis* were found 100% of immature females and males respectively (Fig. 4).

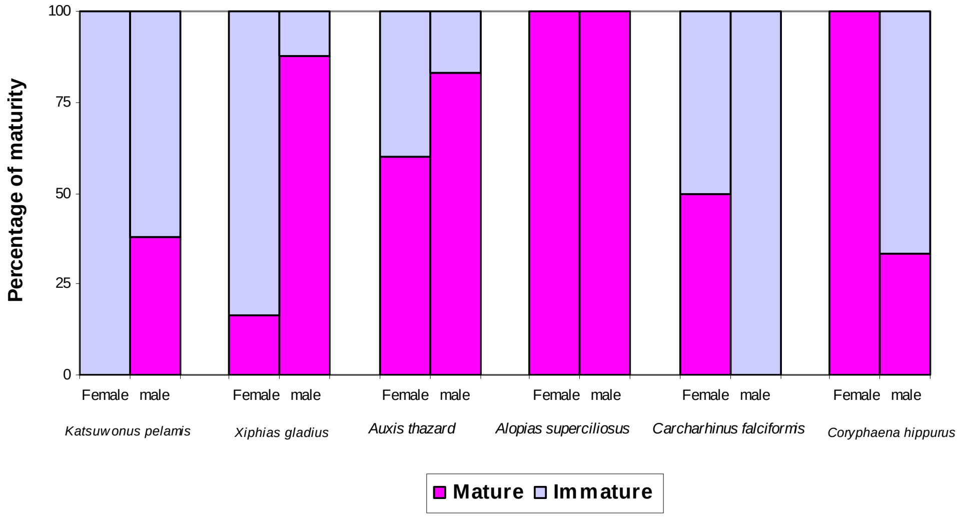

Figure 4 Percentage of mature and immature stages of the six dominant species.

It was difficult to determine spawning season in this survey because of the small number of captured fish as well as a short period to survey and absence of year round gonadosomatic index (GSI) analysis. Gonadosomatic index is one of important parameters to determine breeding cycle of fish. Sub-tropical and tropical fishes usually have an extended breeding season with females spawning many times and show changes in the amplitude of the gonadosomatic index (Wooton, 1992).

Conclusions

Generally, the average size of sampled fishes showed larger size fishes. Sex ratio of males to females were approximately 1:1. This was excluding *K. pelamis*. Although there were high percentage of mature male and female but it was difficult to indicate spawning season in this result.

Acknowledgement

This research is successed by the cooperations of many organisation and people which are highly appreciated. The authors would like to extend their thanks to the captain and crews of the M.V. SEAFDEC, Ms.Chanthip Bunluedaj, Ms.Natinee Sukramongkol, Mr.Opas Chamason and Mr.Ritthirong Prommas for their kind cooperation during this operation survey.

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Elasmobranches Found in the Bay of Bengal from Pelagic Longline and Drift Gill Net Fishing

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Abstract

The elasmobranches caught by pelagic longline and drift gill net in the Bay of Bengal were identified into 6 species, 5 genera and 4 families. Two species belonging to family Alopiidae were *Alopius pelagicus* and *A. superciliosus*. Only one species of family Triakidae was *Iago garricki*. The species representing family Carcharhinidae were *Galeocerdo cuvier* and *Carcharhinus falciformis*. The last species, *Pteroplatytrygon violacea*, belonged to family Dasyatidae. The diagnostic characters of these species were the main content of this report.

Keywords: elasmobranches, Bay of Bengal, pelagic longline, drift gill net, diagnostic character

Introduction

The amount of elasmobranches (sharks and rays) killed in large-scale high sea fisheries is poorly known and has not been systematically assessed and an unknown part of the by catch is discarded at sea. Several large-scale fisheries operating in the high seas around the world are known to take a substantial by-catch of elasmobranches, particularly sharks. Although sharks are retained and utilized in some of these fisheries, they usually are dumped, sometimes alive after their fins have been chopped off. The survival of released sharks varies depending on the type of gear used. Trawls and gill nets and perhaps purse seines, almost certainly cause 100% mortality. While longline permit prolonged survival of sharks by allowing limited movement and thus some respiration, survival rates depend on the metabolism and endurance of individual species. Overall, it is believed that most of by-catch of sharks in large-scale fisheries have high mortality. This might not be true for batoids which generally have different mobility requirements in order to respire. However, their catch are normally small in large-scale high sea fisheries due to their more demersal habits (Bonfil, 1994). Eleven species of shark are commonly caught by tuna longlines in the Indian Ocean such as *Isurus oxyrinchus*, *Lamna ditropis*, *Alopias pelagicus*, *A. superciliosus*, *Prionace glauca*, *Galeocerdo cuvier*, *Carcharhinus longimanus*, *C. falciformis*, *C. albimarginatus*, *C. melanopterus* and *Sphyrna* spp. (adapted from Sivasubramaniam, 1964).

This survey was to study the elasmobranches caught in the Bay of Bengal by pelagic longline (PLL) and drift gill net (DGN).

Method

1. The elasmobranches (sharks and rays) were collected after capturing by PLL and DGN.
2. Fish identification was followed Carpenter and Niem (1998, 1999).
3. Measurement of total length (TL) in each specimen was recorded.

Results

Thirty-five specimens of elasmobranches were identified representing 5 species of shark (29 specimens) and 1 species of ray (6 specimens). They belonged to 4 families and 5 genera as shown in table 1 and fig. 1.

Table 1 The Elasmobranches caught by PLL and DGN in 3 areas (A, B and C).

Family	Species (n=specimen)	Pelagic longline (PLL)			Drift Gill net (DGN)		
		A	B	C	A	B	C
Alopiidae	*Alopias pelagicus* (1)			/			
	A. superciliosus (11)		/	/			
Triakidae	*Iago garricki* (1)	/					
Carcharhinidae	*Galeocerdo cuvier* (1)			/			
	Carcharhinus falciformis (15)	/	/	/	/	/	/
Dasyatidae	*Pteroplatytrygon violacea* (6)	/		/			

/ occurred

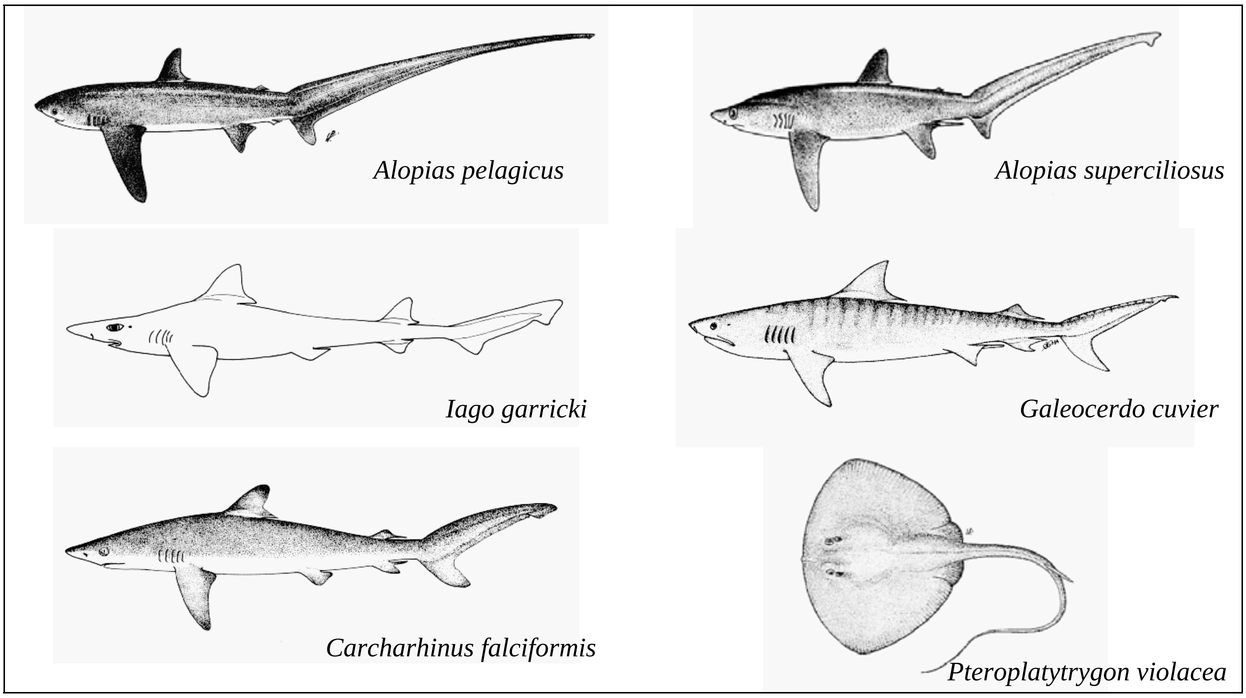

Figure 1 Six species of elasmobranches were found in this survey.

Only twelve specimens of Alopiidae (thresher sharks) were caught by PLL and were identified representing 2 species of *Alopias pelagicus* and *A. superciliosus*. *A. pelagicus* (TL 256 cm) was found only 1 specimen in area C whilst *A. superciliosus* (TL 205-329 cm) was found in area B and C (Fig. 2). The diagnostic characters of these 2 species are as follow:

A. pelagicus is a large shark. Head with 5 medium-sized gill slits; snout moderately long and conical; forehead nearly straight in lateral view, broadly arched between eyes; head narrow; no nictitating eyelids; mouth moderately long and semicircular, placed below eyes, with labial furrows rudimentary; teeth small, sharp-edged, with a single narrow. Two dorsal fins, the first moderately large and located equidistant between the pectoral and pelvic fin bases; second dorsal fin minute and positioned well ahead of the small anal fin; pectoral fins narrow, long and nearly straight, broad-tipped, and not falcate; upper lobe of caudal fin very long and strap-like, about as long as the rest of the shark; lower lobe short but strong; terminal lobe very small. Upper precaudal pit present but no caudal keel. Body with bluish or grey above, white below, with a silvery sheen in gill region; white color from belly not expanded over pectoral-fin bases.

Figure 2 *Alopias superciliosus* was caught by PLL in area C.

A. superciliosus is a large shark and look like *A. pelagicus*. Differentiation from *A. pelagicus*, it has a deep horizontal groove on nape on each side from the level of mouth to pectoral fin; eyes very large, expanding onto dorsal surface of head; mouth moderately long and semicircular, placed below eyes, with labial furrows rudimentary; teeth moderately large, sharp-edged, with a single broad. Two dorsal fins, the first moderately large and located just in front of the pelvic fin origins; pectoral fins very narrow, long and falcate, broad-tipped. Upper lobe of caudal fin very long and strap-like. Body with purplish grey above, cream below, light colour of abdomen not expanded over pectoral-fin bases.

The Triakidae (Hound sharks) was found only *Iago garricki* (TL 80 cm) from PLL in area A. The diagnostic character of this specie is as follow:

I. garricki is a small shark. Head with 5 small gill slits; small spiracles present; snout moderately long and conical; eyes lateral oval with nictitating eyelids, subocular ridges obsolete; mouth small and semicircular, placed below eyes, with labial furrows moderately long; teeth small usually similar in both jaws. Two dorsal fins, the first moderately large and located over pectoral fin bases; second dorsal fin medium and located ahead of the small anal fin; pectoral fins large; upper lobe of caudal fin moderately long; lower lobe short.. No caudal keel and precaudal pits. Body with grey above and white below.

The Carcharhinidae (Ground sharks) was found 2 species from PLL and DGN. *Galeocerdo cuvier* (TL 200 cm) was found only 1 specimen in area C, but it could escape from PLL. *Carcharinus falciformis* (TL 85-178 cm by PLL and 55-131 cm by GN) was caught from both gears in area A, B and C (Fig. 3). The diagnostic characters of these 2 species are as follow:

G. cuvier is a large and fusiform shark. Head with 5 medium-sized gill slits; snout very short and bluntly rounded, eyes lateral with nictitating eyelids; spiracles small, slit-like, but easily visible; mouth large and semicircular, upper labial furrows as long as snout, reaching to front of eyes; teeth coarsely serrated. Two dorsal fins, the first moderately large and located nearly pectoral fin bases; second dorsal fin medium and long base, located over the small anal fin; pectoral fins moderately large and falcate; upper lobe of caudal fin long; lower lobe long and point. A low rounded keel on each side of caudal peduncle. Back dark grey or black, rectangular bars on sides and fins.

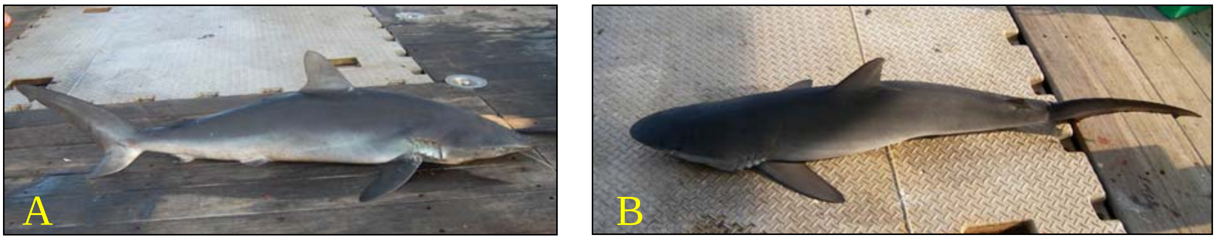

Figure 3 *Carcharinus falciformis* was caught by PLL (A) and DGN (B).

C. falciformis is a large shark, with elongate and slender body. Head with 5 small-sized gill slits; snout narrowly, rounded, moderately long; eyes lateral with nictitating eyelids; no spiracles; mouth moderately large and semicircular, upper teeth serrated and labial furrows very short. Two dorsal fins, the first moderately high and apex rounded, its origin behind the free rear tips of pectoral fin; second dorsal fin very low, its located over the small anal fin; pectoral fins long and falcate; interdorsal ridge present; upper lobe of caudal fin long. Back dark grey, grayish brown or bluish black; belly grayish or white.

Six specimens of the Dasyatidae (Stingrays) were caught from PLL in area A and C and only one species was found ,*Pteroplatytrygon violacea* (TL 94-133 cm, DL. 31-51 cm and DW 42-64 cm) (Fig. 4). The diagnostic character of this species is as follow:

Figure 4 *Pteroplatytrygon violacea* was caught by PLL in area C.

P. violacea is a pelagic stingray with thick trapezoidal disc, anterior margin uniformly convex. Body depressed and flattened with denticles and tubercles on the mid-dorsal surface of disc and tail; 5 small gill opening on underside of front half of pectoral disc; eyes dorsolateral on head and just anteromedial to spiracles; pectoral fin very large, originating at anterior tip of snout and ending posterior to pelvic fin origins; low skin fold present on undersurface of tail; whip-like tail longer than disc with large 2 stinging spine. Dark purple, black on both surfaces (ventral surface almost entirely dark).

Discussion and Conclusion

The result of this survey appeared that only 6 species of elasmobranch were found. Most of them are epipelagic or mesopelagic fish. Catch of elasmobranches were not so many because the types of fishing gear used were selective fishing gear (PLL and GN).

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Age and Reproduction of *Sthenoteuthis oualaniensis* in the Bay of Bengal

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Abstract

The specimens of *Sthenoteuthis oualaniensis* were caught by automatic squid jigging machines in the Bay of Bengal from 6 November to 7 December 2007. Fifteen fishing stations were conducted in three areas off Bangladesh waters, India and Sri Lanka waters, and Myanmar waters. Size distribution of *S. oualaniensis* ranged from 105 mm ML to 221 mm ML (169±30.8 mm ML in average and SD, n=32) for females and from 45 mm ML to 124 mm ML (104±28.2 mm ML in average and SD, n=7) for males, respectively. Statoliths from a total of 34 individuals (6 males, 28 females) of specimens (ML ranged from 45 to 221 mm) were used for the age estimation. Age of *S. oualaniensis* estimated from the counting of the statolith increments ranged from 63 days at 175 mm ML to 120 days at 199 mm ML for females and 40 days at 45 mm ML to 114 days at 124 mm ML for males, respectively. The mean age of females and males were 81.1 and 79.2 days old, respectively. The ML-BW relationships for *S. oualaniensis* was expressed as $BW = 16.183ML^{4.1603}$ ($r^2 = 0.855$, n = 32, 105-221 mm ML) and $BW= 2.932ML^{1.4875}$ ($r^2 = 0.622$, n = 7, 45-124 mm ML) for female and male, respectively. Based on the back calculation on the specimens collected from 6 to 30 November 2007, hatching date of the females *S. oualaniensis* was estimated to be from July to October 2007. There were different growth rates between sexes. Males those hatched in the same period with females grew with slower growth rates and captured in a smaller size than females.

Key words: *Sthenoteuthis oualaniensis*, age, reproduction, Bay of Bengal

Introduction

The purpleback flying squid *Sthenoteuthis oualaniensis* (family Ommastrephidae) is widely distributed in the tropical and subtropical areas of the Indo-Pacific and Indian Ocean (Nesis, 1977; Voss, 1973; Carpenter and Niem, 1998). The biomass of *S. oualaniensis* in the Indian Ocean was estimated to be about two million tons by the counting of the squid at the surface at night light stations (Zuev *et al*., 1985). Pinchukov (1989) and Zuev *et al*.(1985) had been reported the biomass of *S. oualaniensis* in the Indian Ocean was generally ranged from 50 to 75 kg per square km and high concentration from 4 to 42 ton per square km was mainly found in the Arabian Sea. The latest assessment of the total biomass of those squid throughout its range was about 8 to 11 million tons (Nigmatullin, 1990). Recent studies had been suggested that *S. oualaniensis* is probable under exploited resources and could sustain higher exploitation levels in the future (Dunning, 1998; Xinjun *et al*., 2007; Yatsu, 1997).

Since the statolith microstructure is useful for age determination of squids as otoliths in teleost fishes, the age and growth of *S. oualaniensis* are relying on the indirect validation studies, assuming the daily deposition of increments (Arkhipkin and Bizikov, 1991; Takagi *et al*., 2002). The squid was reported a short life span (1-1.5 years), high growth rates and complex population structure at least three main forms are distinguishable with and without a large dorsal photophore, and different by the structure of the gladius (Zuev and Nesis, 1971; Nesis, 1977; Zuev *et al.*, 1985; Nesis, 1993; Yatsu, 1997; Yatsu *et al*., 1998). As a consequence of those important component of *S. oualaniensis* in the marine ecosystem and has been interested from the view point of target of commercial fisheries of the Indian Ocean. More information on the fishery biology of *S. oualaniensis* needs more attention. The present study is objective to provide information on age and reproduction of *S. oualaniensis* collected during the BIMSTEC survey in the Bay of Bengal from 6 November to 7 December 2007.

Materials and Methods

Data Ccollection and Method of Analysis

The specimens of *Sthenoteuthis oualaniensis* were caught by automatic squid jigging machines in the Bay of Bengal from 6 November to 7 December 2007. Fifteen fishing stations were conducted in three areas off Bangladesh waters (area A; latitude 16°N-19°N, longitude 88°E-91°E), India and Sri Lanka waters (area B; latitude 09ºN-14ºN, longitude 82°E-85°E), and Myanmar waters (area C; latitude 10°N-12°N, longitude 95°E-97°E) (Fig. 1 and Table 1).

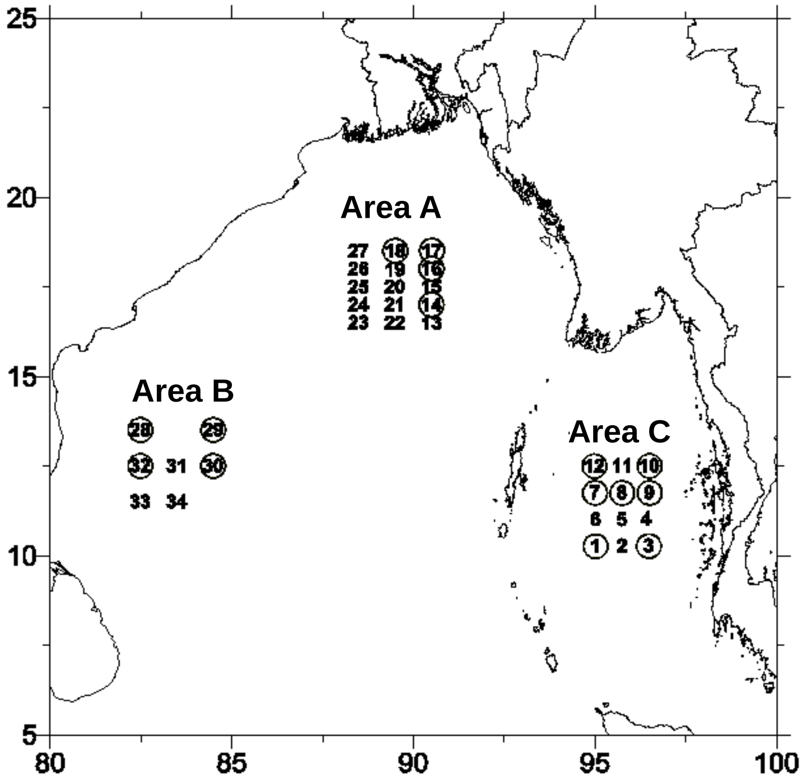

Figure 1 Map of survey stations in the Bay of Bengal. The station numbers in the circle show the fishing stations of the automatic squid jigging.

Squids were sexed using the presence or absence of the male sex organ called hectocotylus. Measurements were made on dorsal mantle length to the nearest 0.1 mm (ML in mm) and wet body weight (BW in g) to the nearest 0.1 g. A total number of individuals of *S. oualaniensis* was examined, and the mantle length ranged from 45 to 124 mm ML (n=7) and from 105 to 221 mm ML (n=32) for male and female, respectively (Table 1).

After dissection of mantle, sexual maturity stages were determined based on the definition of stages I to VI of Lipinski and Underhill (1995), stages I and II were defined as immature stage, stage III as maturing stage, stages IV and V as mature stage, and stage VI as spent in the present study.

Statolith Handling and Ageing Technique

Paired statoliths were collected from specimens and stored in liquid paraffin until preparation following the method of Dawe and Natsukari (1991). The right statolith was used for counting increments. If the increment definition of the right statolith was poor, the left one was also examined. Anterior side of statolith was ground with 3M slim rubbing film sheet No. 4000-15000. Statolith increments were observed under an optical microscope (x400) (with digital camera attached). The image of increments were taken by digital camera and transferred to personal computer for counting on the number of growth increments. Counting of increments was made from the nucleus to the dorsal dome.

Statoliths from a total of 34 individuals (6 males, 28 females) of specimens (ML range from 45 to 221 mm) were readable and used for the age estimation.

Size at Age and Ggrowth

Since the daily deposition of statolith increments had been validated in Ommastrephid squids (*Todarodes pacificus*, *Illex argentinus*, *Ommastrephes bartramii*, *Sthenoteuthis oualaniensis*, *Dosidicus gigas*), age in the present study was estimated relying on the assumption that the increments of *S. oualaniensis* statoliths were estimated as daily increment (Rodhouse and Hatfield, 1990; Arkhipkin and Bizikov, 1991; Jackson, 1994; Yatsu, 1997; Yatsu *et al*., 1998; Takagi *et al*., 2002).

Recently, the non-asymptotic growth models, included linear, exponential and power curves have been applied in many studies (*I. lllecebrosus*, Balch *et al*., 1988; *S. oualaniensis*, Arkhipkin and Bizikov, 1991; *O. bartramii*, Bower, 1996; *D. gigas*, Matsuda *et al*., 1998). In the present study, the linear regression was applied to the relationship between the estimated age (t in day) and mantle length (ML in mm) (Arkhipkin and Bizikov, 1991; Yatsu, 2000) as follows;

$$ML = ML_o + at$$

Where $ML_o = 2.0$ (since the smallest paralarvae of *S. oualaniensis* is 2.0 mm in ML was collected during the survey); ML = Mantle length (in mm); t = estimated age (in day); a = least-squares linear regression coefficient.

The relationship between the mantle length (ML in mm) and total body weight (BW in g), expressed as $BW = aML^b$, were fitted by the least-squares linear regression of log transformed variables.

Table 1 Summary of the survey areas and sample collection of *Sthenoteuthis oualaniensis* between 6 November to 7 December 2007.

Survey station no.	Fishing operation no.	Date	Fishing position		No.of jig	No.of line	Immersion time (hrs.)	Sea depth (m)	Angling depth (m)	Total catch (individual)		ML range (mm)	Weight range (g)	Total weight (g)
			Latitude	Longitude						Female	Male			
Area C														
1	1	6 /11/ 2007	10_18.2 N	095_01.0 E	100	4	4.0	2,365	75-100	5	1	124-180	90-280	1,030
3	2	7 /11/ 2007	10_14.4 N	096_32.8 E	100	4	4.0	538	75-100	-	1	116	75	75
7	3	10 /11/ 2007	11_04.9 N	095_36.3 E	100	4	3.3	513	75-100	4	-	175-210	220-410	1,220
8	4	11 /11/ 2007	11_54.5 N	095_06.7 E	110	4	3.3	2,841	75	5	1	121-202	20-420	980
9	5	12 /11/ 2007	11_45.6 N	096_32.4 E	110	4	3.5	883	75-100	6	1	122-216	90-500	2,020
10	6	13 /11/ 2007	12_04.5 N	096_23.4 E	110	4	4.0	1,128	75-100	2	1	109-175	20-200	260
12	7	15 /11/ 2007	12_29.5 N	094_54.5 E	110	4	4.0	1,418	75	3	-	105-190	50-300	450
Area A														
14	8	17 /11/ 2007	16_49.5 N	090_20.9 E	110	4	4.0	2,353	50	3	1	45-221	18-650	798
16	9	18 /11/ 2007	18_01.4 N	090_35.7 E	110	4	4.0	2,136	75	4	-	163-181	100-180	500
17	10	19 /11/ 2007	18_27.0 N	090_28.3 E	100	4	0.4	2,353	75	operation cancelled due to the damage of jigging lines				
18	11	20 /11/ 2007	18_30.8 N	089_28.9 E	100	4	3.0	2,012	75	-	-	-	-	-
Area B														
29	12	28 /11/ 2007	13_25.0 N	084_27.0 E	100	4	4.0	1,418	75	-	-	-	-	-
30	13	29 /11/ 2007	12_25.0 N	084_25.0 E	100	4	4.0	3,329	75	-	-	-	-	-
28	14	30 /11/ 2007	13_30.6 N	082_29.8 E	100	4	4.0	2,353	75	-	1	93	20	20
32	15	1 /11/ 2007	12_27.6 N	082_18.9 E	100	4	4.0	3,425	75	-	-	-	-	-

Hatching Time and Spawning Period

Date of the hatching was estimated by back-calculation from the data of the capture of the specimen using statolith increment counts.

Results

Variation in Size and Age Distribution

Size distribution of *S. oualaniensis* ranged from 105 mm ML to 221 mm ML (169±30.8 mm ML in average and SD) for females and from 45 mm ML to 124 mm ML (104±28.2 mm ML in average and SD) for males, respectively.

Age of *S. oualaniensis* estimated from the counting of the statolith increments ranged from 63 days at 175 mm ML to 120 days at 199 mm ML for females and 40 days at 45 mm ML to 114 days at 124 mm ML for males, respectively. The mean age of females and males were 81.1 and 79.2 days old, respectively.

ML-BW Relationships

The ML-BW relationships for *S. oualaniensis* was expressed as $BW = 16.183ML^{4.1603}$ ($r^2 = 0.855$, n = 32, 105-221 mm in ML) and $BW= 2.932ML^{1.4875}$ ($r^2 = 0.622$, n = 7, 45-124 mm in ML) for female and male, respectively (Fig. 2).

Size and Age at Sexual Maturation

Length distribution of each maturity stage of female squid ranged in size from 105 mm ML to 134 mm ML for immature stages (stage I and II combined), ranged size of 118-181 mm ML for maturing stage (stage III), and a range size of 168-221 mm ML for mature stage (stage IV). There were differences in male maturities as immature and maturing individuals were smaller than female and ranged in size of 45-109 mm ML and 116-124 mm ML, respectively. A single specimen of mature male at mantle length of 121 mm was found in this study.

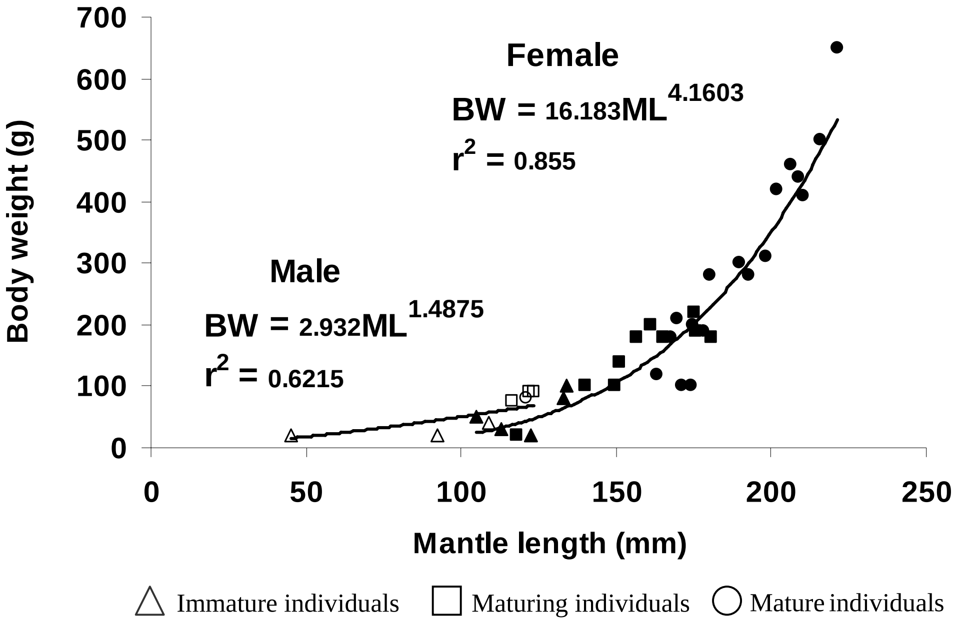

Figure 2 The relationship between mantle length (mm) and body weight (g) for male (open symbol) and female (closed symbol) *S. oualaniensis*.

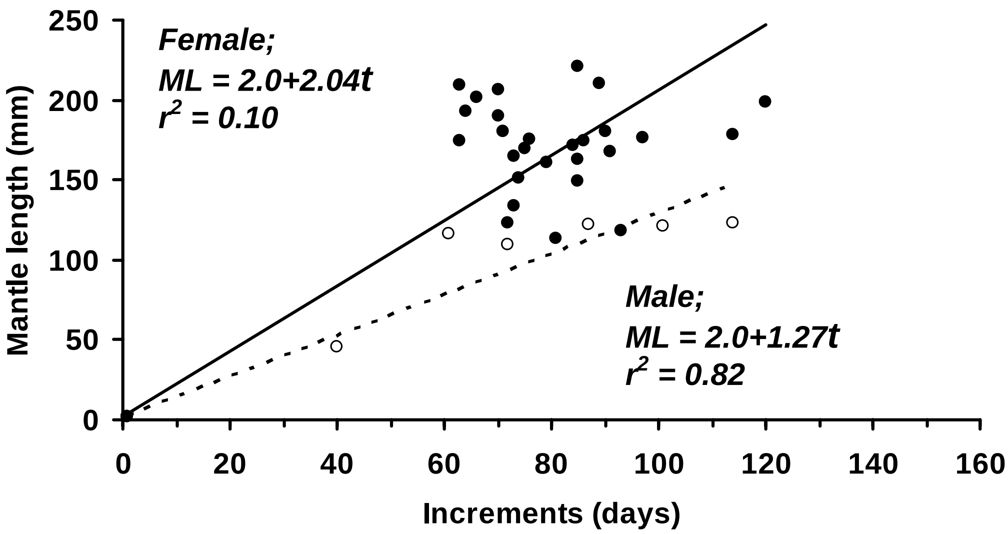

Figure 3 The relationship between statolith increments (days) and mantle length (mm) for male (open circle) and female (closed circle) *S. oualaniensis*.

The age of immature females varied between 72 and 81 days, and that of the males varied between 40 and 70 days old. The age of maturing females were younger than males with a range of 73-97 days old, and that of the males ranged between 61 and 114 days old. Wide range of age at matured females was found between 63 and 120 days old. The biggest squid analyzed was a mature female of 221 mm ML (85 days) whereas the mature male of 121 mm ML was age 101 days old.

Size at Age and Hatching Date

The relationship between the number of increments (days) and ML was plotted in fig. 3. The linear regression lines show that females had progressively faster growth than males (Fig. 3).

Based on the back calculation on the specimens collected from 6 to 30 November 2007, hatching date of the females *S. oualaniensis* was estimated to be from July to October 2007. Fig. 4 indicated the relationships between estimated hatching date and ML at the date of capture. An individual growth lines for each male and female squid hatched in July and early of August had the shallower individual growth slopes indicating a slower rate of growth (Fig. 4). There were differences growth rate between sexes. Likewise those males hatching in the same period of females had lower growth rates and be captured in a smaller size than females.

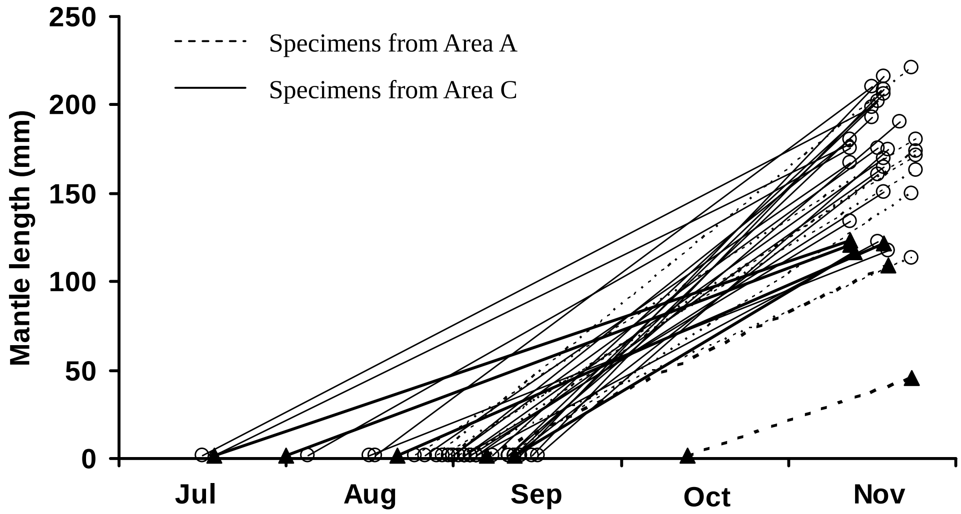

Figure 4 The relationships between estimated hatching date and ML at the date of captured for male (closed triangle) and female (open circle) *S. oualaniensis*.

Discussion

The size distribution of the *S. oualaniensis* specimens in the present study was recognized two forms according to Nesis (1993). First form is the dwarf immature and early maturing males of 45-124 mm ML and females of 105-176 mm ML, without dorsal photophore. Second form is the middle-sized maturing and early mature female of 163-221 mm ML with dorsal photophore. All the squids caught in the eastern Bay of Bengal (area A and C) tended to be smaller than those caught in the Red Sea, Arabian Sea and around the area of the northwestern

Indian Ocean (Nesis, 1977b, 1985, 1993; Yatsu, 1997; Xinjun *et al*., 2007). The *S. oualaniensis* specimens contain form 1 (Nesis, 1993) was also reported in the Andaman Sea of Thailand by Nateewathana (1997). These specimens were lack of dorsal photophores, but the females were much longer than 120 mm ML (the biggest specimen, PMBC no.11795, 323 mm ML; Nateewathana, 1997). The size distribution of *S. oualaniensis* in the present study is consistent with the previous results from the former USSR research in summer of the West Indian Ocean. The ML was mainly in the range of 90-180 mm ML, and 80-270 mm ML, and in the winter mainly ranged from 90 mm to 180 mm ML (Trotsenko and Pinchukov, 1994). The size ranged from 74 mm to 321 mm ML with the dominant group in the range of 110-250 mm ML was also reported as by-catch in the Chinese trawling boats (Yang, 2002).

The complex population of *S. oualaniensis* had been described three major and two minor forms by Nesis (1993). Those characters were important and attempt was made many times to describe as a separated species (Clarke, 1965 and Wormuth, 1976). The dwarf form was also suggested to be a separate species that could only be identified as an adult (Xinjun *et al*., 2007). Snyder (1998) suggested that the giant form resulted from a plastic phenotype in the species. A new study based on RADP DNA (Random Amplified Polymorphic DNA) analysis is being done in Marine Science and Technology of Shanghai Fisheries University, and preliminary findings suggest a large variation in biology among the groups (Xinjun *et al*., 2007).

The development of dorsal photophore and the structure of the hectocotylus were suggested to be affected by the combination of growth and maturation (Nesis, 1977b). The photophore is being to develop when squid reaches a ML of approximately 10 cm, but if maturation does not begin, the photophore development will be blocked. However, this hypothesis was cited but not verified (Nesis, 1993).

Many studies indicate that *S. oualaniensis* had its life span less than 1 year (Nesis, 1993; Dong, 1991; Trotsenko and Pinchukov, 1994). However, the result from age determination based on daily increments of statoliths which samplings were different both in locations and time. Yatsu (2000) determined growth curves for both sexes and reported a female of 120 mm ML at 51 days old which contrast to the data of Zaidi bin Zakaria (2000), which places a 115 mm ML female at an age of 95 days. This may suggests that environmental conditions such as temperature and food availability are the main factors influencing to growth rates, lifespan and fluctuations of relative gonad investment. Lastly the process to count the daily increment might suggest a bit different output since there has no verification from several counters in the same specimens.

S. oualaniensis has been subjected to commercial exploitation in the northwestern Indian Ocean by the Chinese squid jigging boats (Xinjun *et al*., 2007). The species also commercially fished off Okinawa, Taiwan and Hawaii as a tuna bait and human consumption (Okutani and Tung, 1978). Although this species is abundant in the South China Sea region but the fishery has never succeeded. It is low value for human consumption relatively to other squids and due to its toughness. A wide ecological amplitude character, complex intraspecific structure, high fecundity, short life cycle, high growth rate and significant production (Zuev and Nesis, 1971; Nesis, 1977; Zuev *et al*., 1985; Xinjun *et al*., 2007) make this species an interesting for further study on life history. However, the prior needs to the development of a commercial fishery for this species in the survey area especially in the eastern Bay of Bengal, are more data collection and information on distribution and fishery biology. At present this species has not been yet exploited in the Andaman Sea of Thailand.

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Stomach Content of the Large Pelagic Fishes in the Bay of Bengal

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Abstract

Investigation of stomach contents of apex predator; frigate tuna (*Auxis thazard*), skipjack tuna (*Kasuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), bigeye (*Thunnus obesus*) and swordfish (*Xiphias gladius*) were undertaken during November to December 2007. These fishes were caught in the Bay of Bengal with pelagic longline and drift gillnet from the survey cruise by MV. SEAFDEC.

Thirty five percent of 68 stomach samples of tuna and tuna-like species were found diet. The diet content were reported cephalopod (60.70% by weight and 44.83% by number), fish (38.85% by weight, 5.75% by number), and parasite (0.45% by weight, 49.42% by number). Prey fish composed of 3 families; Ostraciidae, Bramidae and Diretmidae, and 1 unidentified fish. Cephalopod was represented by Teuthoidea and *Histioteuthis celetaria pacifica*, Octopoda. Parasite was reported Nematode (black and white) and Digenea. Diet data were compared between surface and deep swimmer predators, the result showed higher the number of prey fish and parasite from deep swimmers (4.79 prey fish and 5.07 parasite per stomach) than that from surface swimmers (1.62 prey fish and 1.15 parasite per stomach).

Community of predator, prey and parasite was categorized into 3 assemblages upon species of such components and habitat (depth of water) of those species. It was found significant differences between groups. Groups B and C had the highest total number of taxon whilst the highest average number of parasite was found in group B, followed by groups C and A.

The preliminary structure of tuna trophic ecology in the Bay of Bengal was explained from the result of the present study. Future development on commercial deep-water fisheries and the taxonomy and field guide of deep-sea fishes and cephalopod beak have been suggested for the study in the Bay of Bengal.

Introduction

The predator-prey interactions play an important part in the structure and the dynamics of multispecies communities. Facing the dramatic increase of the catches of tuna and related species in the Indian Ocean, especially the eastern Indian Ocean, it becomes necessary to assess the impact of the fisheries on the pelagic ecosystems. The implement of research activities leading to a better knowledge of trophic ecology of apex predators will provide such an ecosystem point of view that has to be considered nowadays in the high seas fisheries management.

Feeding studies of tunas and sharks have already been conducted in the western Indian Ocean during the THETIS program (Potier *et al.*, 2004) whereas the tunas feeding habit in the eastern Indian Ocean is still rarely studied, only the reports on stomach content of tropical tunas in the Andaman Sea (Nootmorn *et al.*, 2007 and Panjarat, 2006) are available.

. The purpose of this study considers on the stomach content of large pelagic fish, apex predator, in the Bay of Bengal.

Materials and Methods

On Board

During M.V. SEAFDEC cruise two fishing gears, namely pelagic longline and drift gillnet, were operated for large pelagic fish catching in 3 areas of the Bay of Bengal (Fig. 1); area A (Bangladesh, latitude 16°N-19°N, longitude 88°E-91°E), area B (Indian, latitude 9°N-14°N, longitude 82°E-85°E) and area C (Myanmar, latitude 9°N-13°N, longitude 95°E-97°E). Large pelagic fish sample from pelagic longline and drift gillnet fishing were collected where the sampling sites are presented in table 1. Sixty eight fish samples comprised mainly 28 skipjack tuna (*Kasuwonus pelamis*), followed by 15 swordfish (*Xiphias gladius*), 10 frigate tuna (*Auxis thazard*), 7 kawakawa (*Euthynnus affinis*), 5 yellowfin tuna (*Thunnus albacares*) and 3 bigeye tuna (*Thunnus obesus*). The entire stomach was removed from the freshly caught fish when hauled on board. Sizes of the predator in fork length (FL,cm) and weight (kg) were recorded for each fish. The collected stomach was put in a sealed plastic bag and stored in M.V.SEAFDEC's freezer at -20°C. A label with the main characteristics was enclosed with the bag.

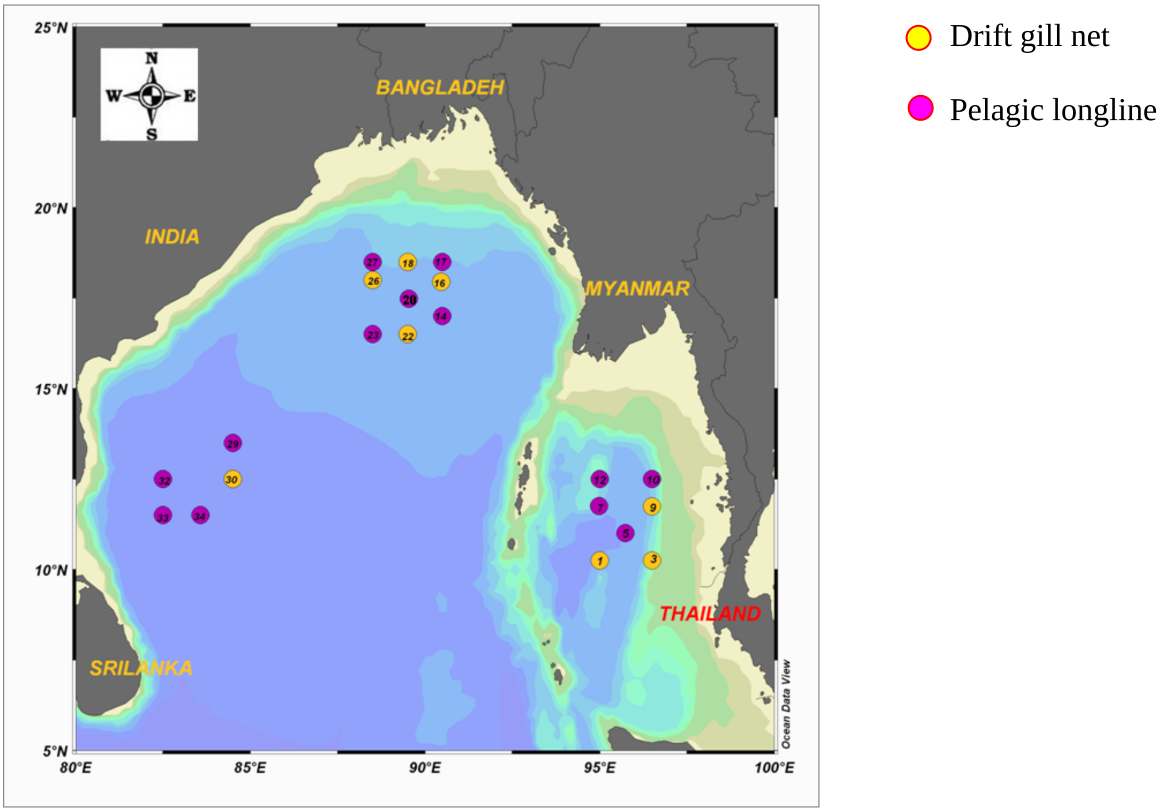

Figure 1 Map of pelagic longline (PLL) and drift gill net (DGN) operated in the Bay of Bengal.

Table 1 The sampling site in the Bay of Bengal.

Station	Operation	Date	Time	Lat	Long
5	PLL1	10-11/Nov/07	18.20	11°05'.80 N	095°41'.80E
7	PLL2	11-12/Nov/07	18.20	11°46'.00 N	094°58'.90E
10	PLL3	13-14/Nov/07	17.46	12°34'.30 N	096°26'.70E
12	PLL4	15-16/Nov/07	17.31	12°30'.30 N	094°59'.70E
14	PLL5	17-18/Nov/07	17.31	16°55'.60 N	090°25'.90E
17	PLL6	19-20/Nov/07	17.32	18°31'.10 N	090°26'.70E
20	PLL7	21-22/Nov/07	18.00	17°31'.50 N	089°28'.20E
23	PLL8	23-24/Nov/07	17.31	16°30'.70 N	088°24'.50E
27	PLL9	25-26/Nov/07	17.30	18°30'.40 N	088°28'.30E
29	PLL10	28-29/Nov/07	18.03	13°30'.00 N	084°30'.10E
32	PLL11	1-2/Dec/07	18.27	12°32'.90 N	082°24'.90 E
33	PLL12	2-3/Dec/07	18.00	11°31'.80 N	082°26'.10 E
34	PLL13	3-4/Dec/07	18.28	11°29'.60 N	083°28'.10 E
1	DGN1	6-7/Nov/07	17.55	10°18'.60 N	095°00'.30 E
3	DGN2	7-8/Nov/07	18.21	10°14'.80 N	096°29'.40 E
9	DGN3	12-13/Nov/07	18.54	11°45'.20 N	096°30'.00 E
16	DGN4	18-19/Nov/07	18.49	17°59'.30 N	090°32'.00 E
18	DGN5	20-21/Nov/07	17.45	18°28'.00 N	089°29'.00 E
22	DGN6	22-23/Nov/07	18.38	16°30'.00 N	089°30'.90 E
26	DGN7	26-27/Nov/07	17.30	18°03'.10 N	088°27'.40 E
30	DGN8	29-30/Nov/07	17.57	12°27'.40 N	084°23'.70 E

Remark: PLL= Pelagic longline, DGN= drift gill net

At the Laboratory

The stomachs were defrosted before analysis in three steps.

1. The stomach content was sorted into large categories as fishes, cephalopods or parasite.

2. The different items constituting the categories were sorted and counted for each, remarkable organ are used to determine the number of item in the stomach such as upper or lower beaks of cephalopods. Specimens of fish were preserved in a 10% buffer formalin solution for 24 hour then change to 70% alcohol. However the beaks of the cephalopods were kept in 70% alcohol at the initial step to prevent decalcification.

3. Prey and other item were identified to group, family and, whenever possible, to species level. The identification of fishes was based on descriptions given in a variety of FAO Volume 2, 4, 5 and 6 (2001a, 2001b, 2001c and 2001d), cephalopods and beak of cephalopod was base on Clarke (1962 and 1986) and Kubodera (2003). The parasite was identified to group based on Smith *et al.* (2007).

Analysis of full and empty stomachs was calculated in percentage of each taxon/group of tunas. Cluster analysis (Kruskal and Wish, 1978) was carried out based on a Bray-Curtis similarity matrix of appropriately transformed species abundance data (only number of prey taxon/group). Analysis of similarities (ANOSIM) and Similarity percentages (SIMPER) were used for analysis of tunas and prey species similarity and species ranking of average dissimilarity between assemblages, respectively (Carr, 1997).

Results and Discussion

Size Distribution

The sizes distribution (length and weight) of frigate tuna from area A and kawakawa from areas A and C, caught with drift gillnet, ranged in length 30.5 to 39.8 cm and 17.3 to 41.0 cm, respectively and in weight 0.56 to 1.15 kg and 0.07 to 1.05 kg, respectively (Figs. 1A-1D). Kawakawa in area C is smaller than fish caught from area A. Skipjack tuna caught with drift gillnet in areas A, B and C was between 17.6 to 70.0 cm in length and 0.07 to 6.35 kg in weight (Figs. 1E-1F). Skipjack tuna caught from area B is bigger sizes than areas A. Yellowfin tuna was caught with pelagic longline in area A and drift gillnet in area C, range of sizes was reported 17.30 to 129.0 cm and 0.06 to 38 kg (Figs. 1G-1H). Fish caught with longline is bigger sizes than fish from drift gillnet fishing, the stomach content was found only fish from drift gillnet fishing in area C. Bigeye tuna was caught with drift gillnet in areas A and C, range of sizes was reported 24.4 to 46.0 cm and 0.22 to 2.0 kg (Figs. 1I-1J). This species was found only juvenile fish. Size range of swordfish was 120 to 280 cm and 5 to 100 kg (Figs. 1K-1L), this species was caught with both gears in areas A, B and C. Size of fish from area C was the biggest, followed by fish from area A and B.

Stomach Content

From 68 stomach samples of tunas and tuna-like species, it was found 44 empty stomachs (Table 2). All of kawakawa (7 specimens) was found empty stomachs, the rest fish samples which constituted 35% of the total fish samples were found prey and parasite in their stomachs. The stomach content was identified to be 3 groups, namely cephalopod (60.70% by weight and 44.83% by number), fish (38.85% by weight and 5.75% by number), and parasite (0.45% by weight and 49.42% by number) (Fig. 3). This study found the percentage of prey and parasite in the stomach (35 %) less than the previous study from Nootmorn *et al.* (2007) in the Andaman Sea. They reported 94% of non-empty stomach of tunas and tuna-like species from tuna longline fishing in the Andaman Sea, the main forage of tuna were reported cephalopods, followed by fishes and deep-sea shrimps.

Usually it is difficult to collect tuna's stomach content from commercial fisheries, especially in the eastern Indian Ocean. As tunas from longline fishing were eviscerated, and from the purse seine fishing most of tunas's stomach samples were empty this might be due to that the fishing times were in very early morning when tunas had not yet feeding (Panjarat, 2006; Nootmorn *et al.*, 2001).

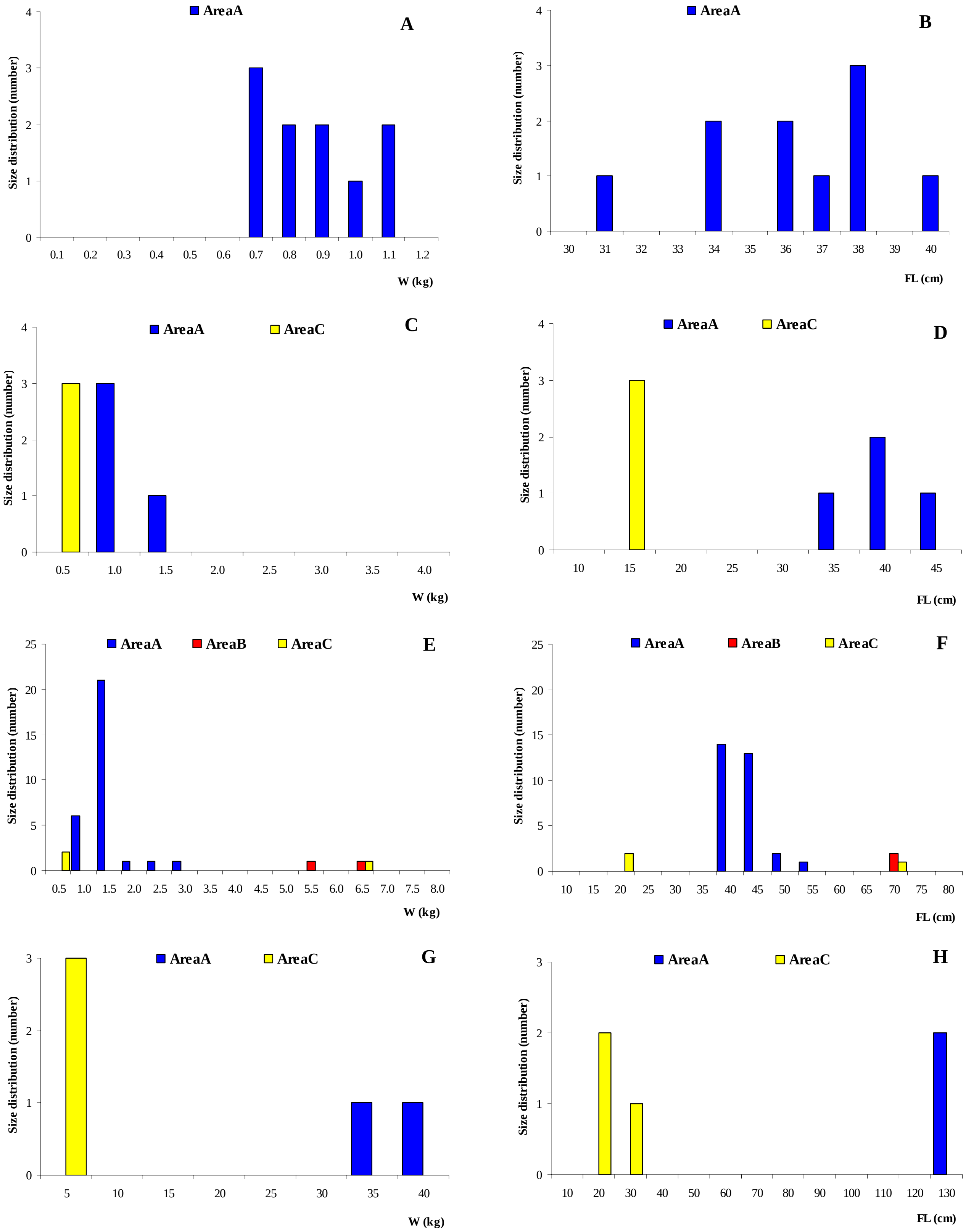

Figure 2 Size distribution of frigate tuna (A and B), kawakawa (C and D), skipjack tuna (E and F), yellowfin tuna (G and H), bigeye tuna (I and J) and swordfish (K and L).

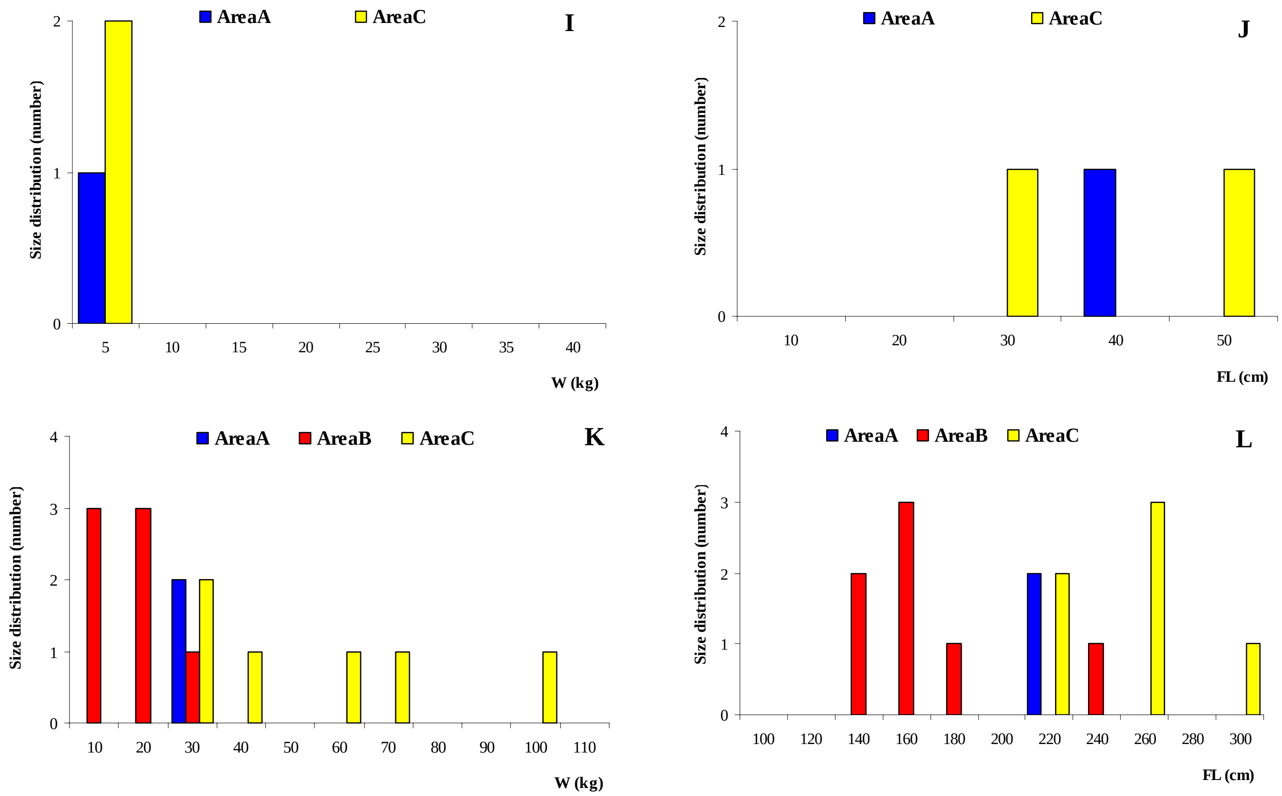

Figure 2 cont.

Stomach Content

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Table 2 Tunas and tuna like species samples with stomach content observation.

Tunas and tuna like species	Stomach		Total
	Non-empty	Empty	
Auxis thazard	5	5	10
Euthynnus affinis	0	7	7
Kasuwonus pelamis	3	25	28
Yellowfin Tuna	4	1	5
Bigeye Tuna	1	2	3
Swordfish	11	4	15
Total	**24**	**44**	**68**

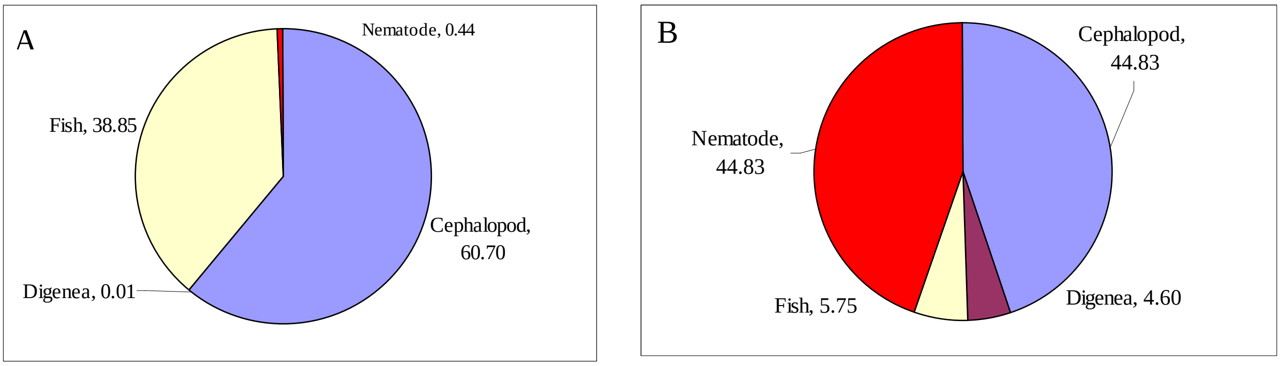


Figure 3 Percentage of prey and parasite composition of tunas and tuna-like species in the Bay of Bengal (A = in weight and B = in number).

Prey fishes were identified 3 families, Bramidae, Ostraciidae, Diretmidae and 1 unidentified fish (Figs. 4A-4D). They contributed, respectively, 13.49, 0.37, 0.11 and 24.88% by weight to the total content.(Remarkable, this study found Indo Pacific mackerel and round scad in stomach of tunas; we checked from the fishing operations, these fishes were used as bait for catching pelagic fishes and so they were excluded from calculation of diet composition.) Cephalopod was identified 2 families and 1 species, namely Teuthoidea and Octopodidae. Their compositions were Teuthoidea (include beak, pen and eye) 60.69% and beak of *Histioteuthis celetaria pacifica*, Octopoda 0.01% of the total sample weight (Figs. 4E and 4F).

Parasite was identified to be 2 groups, namely Nematode (black and white Nematodes) and Digenea which constituted 0.44% and 0.01% of the total sample weight. Figs. 5A, 5B and 5C are illustration of parasites.

The diet composition in number was found cephalopod as the main composition, followed by fishes and Nematode (Fig. 3B). Cephalopod was observed beak of Tuethoidae as the main composition, followed by beak of *Histioteuthis celetaria pacifica*, Octopoda (count all upper and lower beaks). Whilst, the fish component was represented by Ostraciidae, Bramidae, Diretmidae and 1 unidentified fish (1.72, 0.57, 0.57 and 2.87 % of total number of samples, respectively).

The result from this study showed that cephalopod (in number and weight) and fish (in number and weight) were the main prey of tunas in the Bay of Bengal, the same as the previous study in the Andaman Sea (Nootmorn *et al.*, 2007).

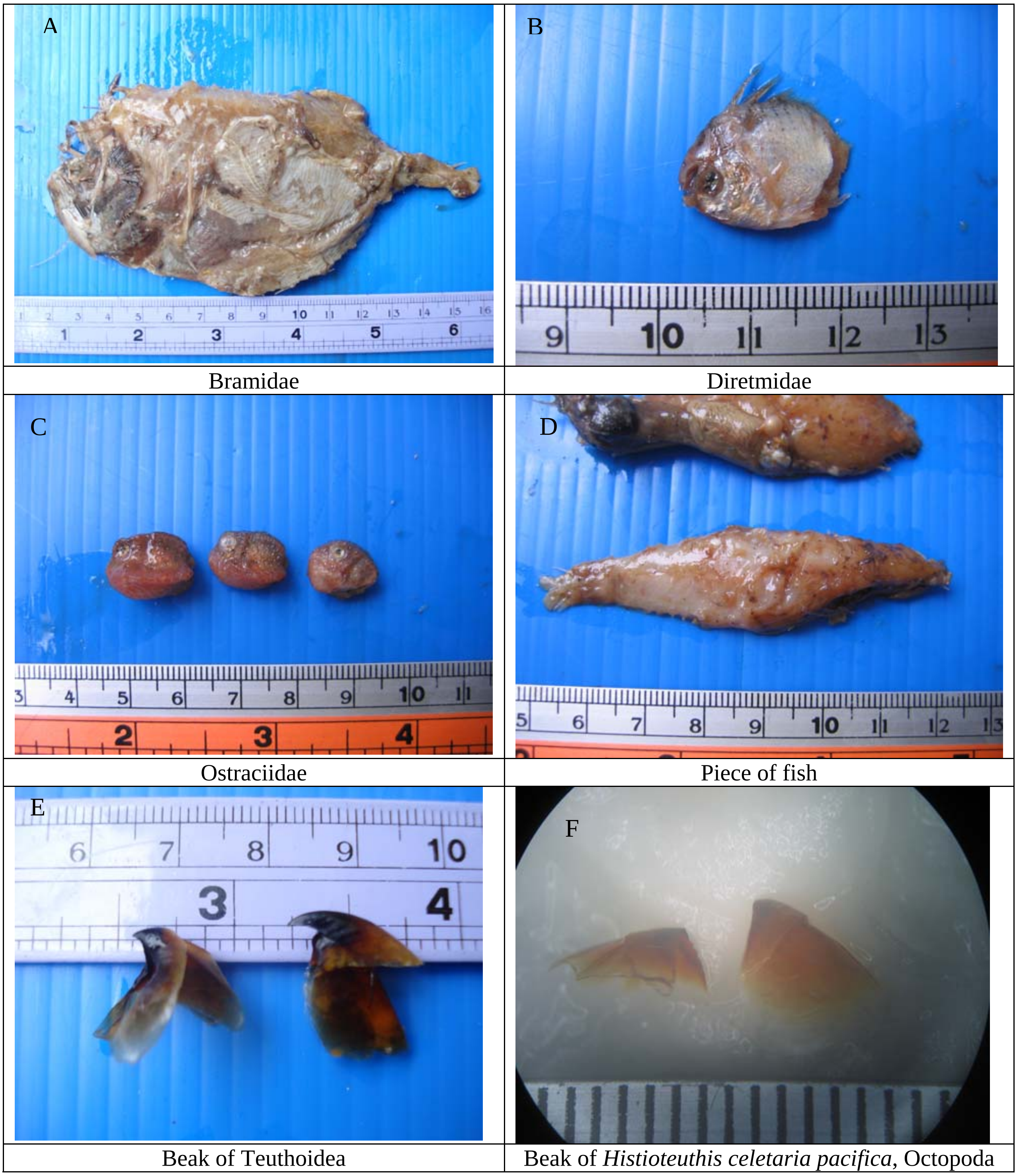
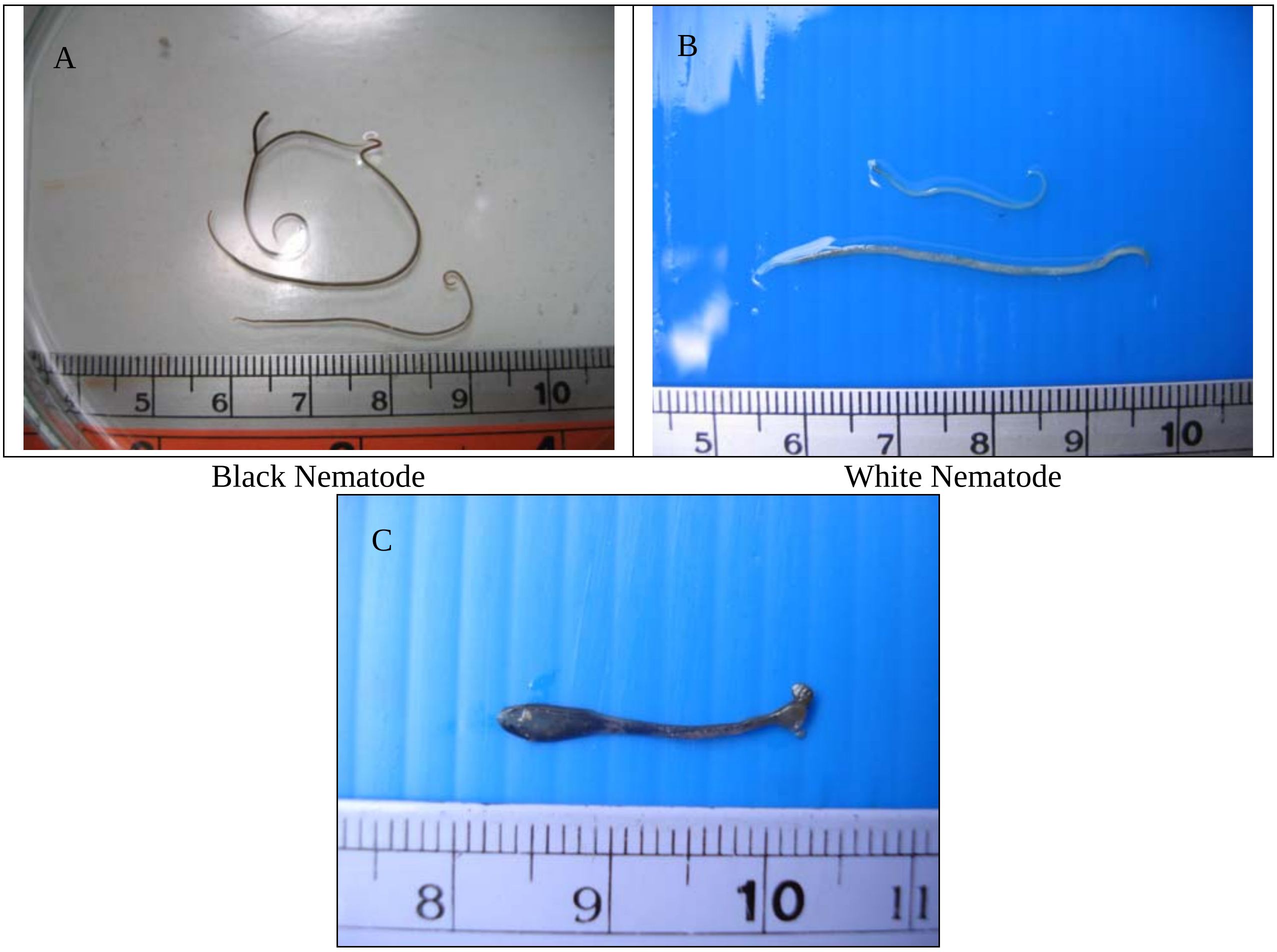


Figure 4 Fish and cephalopod found in stomach content of tunas and tuna-like species in the Bay of Bengal.



Black Nematode White Nematode

Digenea

Figure 5 Parasite of tunas and tuna-like species in the Bay of Bengal.

Table 3 show the stomach content of frigate tuna, skipjack, yellowfin tuna, bigeye tuna and swordfish.

Frigate tuna caught in area A, stomach content was found 2 groups, namely Teuthoidea and fish. This species is epipelagic in neritic and oceanic waters. Feeds on small fish, squids, planktonic crustaceans (megalops), and stomatopod larvae. Because of their abundance, they are considered an important element of the food web, particularly as forage for other species of commercial interest. Preyed upon by larger fishes, including other tunas (Fishbase, 2008).

Skipjack tuna was found Teuthoidea as the main forage, followed by fish (unidentified species) and 2 groups of parasites, Digenea and Nematode (black). Skipjack tuna caught from area A was found only Digenea in the stomach, whereas in area B the diet composition composed of Teuthoidea and unidentified fish, in area C it was found Teuthoidea as forage and Nematode (black) as parasite. Fishbase (2008) reported that skipjack tuna was found in offshore waters; larvae restricted to waters with surface temperatures between 15°C to 30°C. Exhibit a strong tendency to school in surface waters with birds, drifting objects, sharks, whales and may show a characteristic behavior like jumping, feeding, foaming, etc. Feed on fishes, crustaceans, cephalopods and mollusks; cannibalism is common. Spawn throughout the year in the tropics, eggs released in several portions. Preyed upon by large pelagic fishes. Also taken by trolling on light tackle using plugs, spoons, feathers, or strip bait.

Juvenile of yellowfin tuna caught in area A, stomach content was found 2 groups, namely Teuthoidea and unidentified fish. FAO (2001c) reported yellowfin tuna in the western central Pacific, as oceanic species; large fish found below the thermocline. They feed on many kinds of organisms, particularly fishes, squids and crustaceans. Nootmorn *et al.* (2007) reported this species were caught in the Andaman Sea at depth of water ranging from 41-80 m. Size of fish in length and weight was 120-138 cm and 20-31 kg. Stomach content was found fish (unidentified fish (1), Ostraciidae), cephalopod (Octopoda) and deep-sea shrimp (Aritridae). Panjarat (2006) reported the diet of this species, in the same area, composed of fishes (Tetraodontidae, Priacantidae, Balistidae and Syngnathidae) and cephalopod (Loliginidae and Teuthoidea). The previous studies reported high diversities of prey than this study because those fish samples were from pelagic longline fishing.

Juvenile of bigeye tuna caught in area C, the forage comprised of Teuthoidea, Ostracidae, Diretmidae and unidentified fish. Fishbase (2008) reported that this species occur in areas where water temperatures range from 13°-29°C, but the optimum is between 17° and 22°C. Variation in occurrence is closely related to seasonal and climatic changes in surface temperature and thermocline. Juveniles and small adults school at the surface in mono-species groups or mixed with other tunas, may be associated with floating objects. Adults stay in deeper waters. Feed on a wide variety of fishes, cephalopods and crustaceans during the day and at night.

Swordfish was found 6 groups in the stomach content; the main composition was Teuthoidea, followed by Bramidae, unidentified fish, Octopoda *(Histioteuthis celetaria pacifica*), Nematode (black) and Nematode (white) in all areas. In area A the stomach content was found 4 groups; Teuthoidea, Bramidae, unidentified fish and Nematode (black), area B found 4 groups; Teuthoidea, Octopoda, Nematode (black) and Nematode (white), whilst area C found 3 groups; Teuthoidea, Nematode (black) and Nematode (white). Swordfish are widely distribution throughout the study area at water depth range 10-132 m. Nootmorn *et al.* (2007) reported the diet of this species composed of cephalopod (Teuthoidea, Argonautidae and Octopoda), deep-sea shrimp (Aritridae) and fish (*Thyrsiles atun, Cubiceps caeruleus,* Gempylidae). Their study found higher diversity of prey however the groups of prey were the same as this study. FAO (2001c) reported that swordfish in the western central Pacific are an epi- and mesopelagic, oceanic species, usually found in surface waters until 550 m. Adults are opportunistic feeders, known to forage for their food from the surface to the bottom over a wide depth range. They feed on pelagic squids wherever abundant, that is same as this study.

Table 3 Stomach content of tuna and tuna-like species by Area in the Bay of Bengal.

Tunas	Area	Group	Family	Weight (gram)	Number
Frigate tuna	**A**	Cephalopod	Teuthoidae	10	1
		Fish	Pieces of fish	40.05	-
Skipjack tuna	**A**	Digenea	Digenea	0.08	8
	B	Cephalopod	Teuthoidea	15.1	2
		Fish	unidentified	53	2
	C	Cephalopod	Teuthoidea	2.83	7
		Nematode	Nematode(black)	0.07	5
Yellowfin tuna	**A**	Cephalopod	Teuthoidea	6.67	1
		Fish	unidentified	10.3	1
Bigeye tuna	**C**	Cephalopod	Teuthoidea	25.8	2
		Fish	Diretmidae	0.68	1
		Fish	unidentified	1.07	1
		Fish	Ostraciidae	2.23	3
Swordfish	**A**	Cephalopod	Teuthoidea	57.49	26
		Fish	Bramidae	81	1
		Fish	unidentified	45	1
		Nematode	Nematode(black)	0.96	18
	B	Cephalopod	Teuthoidea	32.09	25
		Cephalopod	Octopoda	0.07	1
		Nematode	Nematode(black)	0.3	3
		Nematode	Nematode(white)	0.21	3
	C	Cephalopod	Teuthoidea	214.48	13
		Nematode	Nematode(black)	1.03	41
		Nematode	Nematode(white)	0.06	8
Total				**600.57**	**174**

Table 4 show the stomach content of tunas by type of fishing gears. Stomach content from drift gillnet fishing was found 3 families of prey and 2 groups of parasite were identified. Most of these prey items were Teuthoidea (14 individuals), followed by Ostraciidae (3 individuals), Diretmidae (1 individuals) and unidentified fish (3 individuals), whilst the parasite was found Digenea (8 individuals) and Nematode (black) (7 individuals). On average, 1.62 prey and 1.15 parasite were found per stomach. Cephalopod dominated the diet by occurrence and number. Stomach content from longline fishing was found 3 families of prey and 2 groups of parasite were identified. Most of these prey items were Teuthoidea (63 individuals), followed by Bramidae (1 individuals) and unidentified fish (2 individuals), whilst the parasite was found Nematode (black) (60 individuals) and Nematode (black) (11 individuals). On average, 4.79 prey and 5.07 parasite were found per stomach. Cephalopod dominated the diet by occurrence and number, the same as that of stomach from drift gillnet fishing.

Table 4 Stomach content of tuna and tuna-like species by fishing gears in the Bay of Bengal.

Fishing Gears	Tunas	Prey						Parasite		
		Cephalopod		Fish						
		Octopodidae	Teuthodide	Bramidae	Diretmida	Ostraciida	non-identified	Nematode (white)	Nematode (black)	Digenea
Drift gillnet	Bigeye tuna		2		1	3	1			
	Skipjack		9				2		5	8
	Swordfish		2						2	
	Frigate tuna		1							
Longline	Swordfish	1	62	1			1	11	60	
	Yellowfin tuna		1				1			

Community Structure of Tunas, Prey and Parasite

Ordination analysis categorized tunas, prey and parasite taxon/group into 3 assemblages (Fig. 6 and Table 5). Group A composed of Digenea in stomach of skipjack caught with drift gillnet in water depth range 10-26 m in area A, group B found Nematode (black) in stomach of skipjack tuna and swordfish from drift gillnet fishing in water depth range 10-26 m in areas B and C, and swordfishes from pelagic longline fishing in water depth range 80-132 m in all areas. Group C found Teuthoidea from bigeye tuna caught with drift gillnet in area C (water depth range 10-20 m), frigate tuna caught with drift gillnet in area A (water depth range 10-20 m), yellowfin tuna caught with pelagic longline in area A at water depth 69 m, swordfishes from pelagic longline fishing in all areas in water depth range 60-110 m. Among these 3 groups, group C was the highest in number and diversity of predator. ANOSIM showed significant differences between groups (R =1; groups A and B, A and C ; R = 0.908 group B and C). Table 5 showed the species list and average number of prey and parasite based on a breakdown of average similarity for each assemblage. Groups B and C had the higher total number of prey and parasite group more than group A. The result present abundance in number of parasites and cephalopod, it will be one indicator for grouping the community of large pelagic fish in the Bay of Bengal. Nootmorn *et al.* (2007) reported that the community of tunas and prey taxon in the Andaman Sea was categorized into 5 assemblages, group 1 composed of unidentified fish (1), Teuthoidea, Octopoda, Gempylidae and *Cubicepe caeruleus* in stomach of swordfish and sail fish in Thai waters, group 2 found Teuthoidea, Argonautidae, Octopoda, Aristridae and Carangidae in stomach of blue marlin, sailfish, yellowfin tuna in Thai waters and swordfish in Myanmar waters. Group 3 found Aristridae, Teuthoidea, *Cubicepe caeruleus*, other cephalopod, Octopoda from swordfish in Myanmar waters and swordfish and yellowfin tuna in Thai waters. Group 4 found only unidentified fish from sailfish caught in Myanmar waters. Group 5 found *Thyrsiles atun* and *Gympylus serpens* in stomach of sail fish and sword fish in Thai waters. Their study showed higher assemblages and diversity of prey than this study. Type of prey in the previous study is key to divide the groups of fish community because the previous study didn't identify the group of parasite and so it was not included in the analysis.

Table 5 Breakdown of average similarity between group 1, 2, 3 into contributions from taxon list and average number of prey and parasite in the Bay of Bengal.

Prey Taxon	Group A	Group B	Group C
Teuthoidea		1.5	4
Nematode (black)		8.25	0.09
Digenea	1.6		
Number of predator	5	8	11

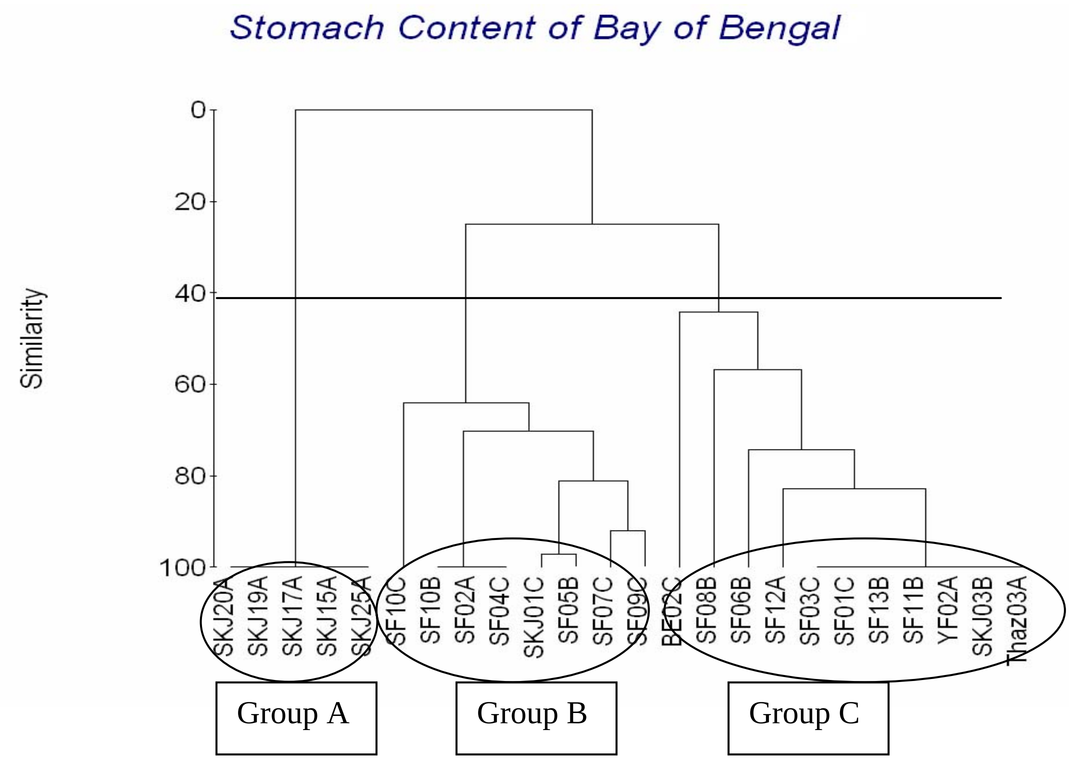


Figure 6. Dendrogram using group-average linking on Bray-Curtis taxon similarities. The 3 groups defined at arbitrary similarity level of 40 % are indicated. A, B and C fill in the behind of label samples, as Bangladesh, Indian and Myanmar waters.

Conclusion and Future Direction

The vertical distribution of large pelagic fish, tunas and tuna-like is known to differ. The depth of hook level in present study suggests that the distribution patterns of all tunas overlap considerably. Frigate tuna and kawakawa are neritic tuna, they distributed in the depth of water range 10-30 m. Skipjack tuna distributed in all areas at the depth of water range 10-30 m. Yellowfin tuna distributed off Bangladesh and Myanmar waters at depth of water range 10-69 m. Whereas, juvenile of bigeye tuna was found in the same areas of yellowfin tuna in the depth of water range 10-26 m. Swordfish exhibit horizontal and vertical distribution widely over the Bay of Bengal (10-132 m). In fact, all these species were caught with drift gillnet and pelagic longline in the Bay of Bengal, diet of these fishes occurred in 35 % of total stomach samples. The prey composition was identified to be 2 groups, namely fish and cephalopods. Parasite was identified to be 2 groups, Nematode and Digenea. The forage of tuna in the entire study area was mainly cephalopods, followed by fish. Prey fish composed of 3 families; Ostraciidae, Bramidae, Diretmidae, and 1 unidentified fish. Cephalopod was identified 1 family and 1 species, namely Teuthoidea and *Histioteuthis celetaria pacifica,* Octopoda. Diet data were compared between surface and deep swimmer predators caught with drift gillnet and pelagic longline, respectively. The result showed higher the number of prey and parasite from deep swimmers (4.79 prey and 5.07 parasite per stomach) than surface swimmers (1.62 prey and 1.15 parasite per stomach). Cephalopod dominated the diet by occurrence and number in predator stomach from both gears.

Community of predator, prey and parasite was categorized into 3 assemblages and significant differences between groups, group A composed of Digenea in stomach of skipjack caught with drift gillnet in Bangladesh waters, group B found Nematode (black) in stomach of skipjack tuna and swordfish from drift gillnet fishing in Indian and Myanmar waters, swordfishes from pelagic longline fishing in all areas. Group C found Teuthoidea from bigeye tuna caught with drift gillnet in Myanmar waters, frigate tuna caught with drift gillnet and yellowfin tuna caught with pelagic longline in Bangladesh waters, swordfishes from pelagic longline fishing in all areas. Groups B and C showed higher in total number and diversity of predator, prey and parasite groups than group A. The result from this study present abundance in number of parasites and cephalopod, it will be indicator to grouping the community of large pelagic fish in the Bay of Bengal.

The results of present study provide an example of interesting questions concerning tuna trophic ecology that may be answered. These data will provide a more complete picture of complex trophic dynamics of mixed-species tuna aggregation, as well as seasonal trends in feeding and aggregation behavior. The preliminary picture of pelagic fish ecology in the Bay of Bengal during November and December 2007 was investigated. **Predator**: frigate tuna is neritic species. The stomach content was found Teuthoidea and fish. Skipjack tuna was widely distributed throughout the study area at water depth range 10-30 m. This species was found Teuthoidea as the main forage, followed by fish (unidentified species), whereas 2 groups of parasites were recorded; Digenea and Nematode (black). Skipjack tuna caught from Bangladesh waters was found only Digenea in the stomach, in Indian waters found Teuthoidea and unidentified fish, in Myanmar waters found Teuthoidae as forage and Nematode (black) as parasite. Yellowfin tuna (juvenile fish) caught from Myanmar waters, prey was found Teuthoidea and unidentified. Juvenile of bigeye tuna caught in Myanmar waters at depth of water range 10-26 m, the forage comprised of Teuthoidea, Ostracidae, Diretmidae and unidentified fish. Swordfishes are widely distributed throughout the study area at water depth range 10-132 m. The diet was reported cephalopod (Teuthoidea and Octopoda) and fish (Bramidae and unidentified fish). **Prey:** pelagic squid, Teuthoidea was the main composition of cephalopod, it was high abundant and widely distributed in the water depth 10-120 m. *Histioteuthis celetaria pacifica*, Octopoda was distributed in water depth 60 m. Deep-sea fish: Ostraciidae showed the highest abundance in water depth range from 10-20 m in Myanmar waters, whilst Diretmidae was also found in same area as Ostraciidae. Bramidae was at water depth range 40 m in Bangladesh waters. **Parasite:** nematode (black) was the main composition, mostly found in stomach of swordfish caught with both gears at water depth range 10-132 m. Nematode (white) was found in stomach of swordfish caught from pelagic longline fishing at water depth range 60-120 m in Indian and Myanmar waters. Digenea was parasite of skipjack caught with drift gillnet at water depth range 10-20 m in Bangladesh waters.

The Bay of Bengal is recognized as one of the area where fisheries resources are under-exploited status. Lack of the field guide and taxonomy of deep-sea species, such as fishes, cephalopods (whole body and beak) is recognized in present study. The taxonomy key will be useful and support for study on the tropic dynamics of large pelagic fish in the Bay of Bengal. Up to date the knowledge of ecosystem to be based on for fisheries management is insufficient. The tropic dynamics of pelagic fish and prey will provide the information on quality of ecology. None/under-exploited tunas and pelagic squid in the Bay of Bengal are very interesting for commercial fishery because there is virtually no deep-sea fishery in the area. Nevertheless, the fact that some species reach a large size and are commonly taken on the basis of exploratory deep-water trawling, jigging and longline fishing suggests that they may have future commercial potential whenever the suitable deep-sea fishing gears are used in the area.

Acknowledgment

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An Assessment of Mercury Concentration in Fish Tissues Caught from Three Compartments of the Bay of Bengal

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Abstract

To assess mercury (Hg) contamination in fishery resources of the Bengal Bay, a total of 78 specimens of 11 pelagic fish species were obtained during the joint survey of BIMSTEC member countries on Assessment and Management of Marine Resources, in November to December 2007. Individual specimen was coded, measured and weighed. The white flesh samples for Hg analyses were taken from the abdominal area of most fishes, and from the caudal area for sharks. Total Hg concentrations (expressed in ng/g wet weight) in the samples were as follow; 514±187 for bigeye thresher shark (*Alopias superciliosus*), 251±128 for copper shark (*Carcharhinus brachyurus*), 122±35 for silky shark (*Carcharhinus falciformis*), 48 for unidentified shark, 886±104 for tille travalley (*Caranx tille*), 64±62 for frigate tuna (*Auxis thazard*), 63±16 for kawakawa (*Euthynnus affinis*), 110±153 for skipjack tuna (*Katsuwonus pelamis*), 92±32 for yellowfin tuna (*Thunnus albacares*), 201 for bigeye tuna (*Thunnus obesus*), and 478 ± 416 for swordfish (*Xiphias gladius*). In general, the relationship between Hg levels in muscles and fish size was observed. Five of 8 bigeye thresher shark, only one tille travalley, 2 of 29 skipjack tuna and 5 of 16 swordfish had Hg concentrations in their fleshes exceeded the EU's upper limit of 0.5 μg/g. Moreover, the swordfish that weighed over 40 kg contained Hg in their tissues higher than 1 μg/g.

Key words: mercury, fish tissues, Bay of Bengal.

Introduction

Effect of mercury (Hg) and its compounds are currently well documented. Hg from either natural or anthropogenic sources enters the environment mainly as Hg vapor, is converted to organic form in aquatic environments by bacteria and phytoplankton (WHO, 1990 and 1991). It was found that total Hg found in fish tissue is chiefly present as methylmercury (MeHg) (Riisgard and Hansen 1990; Spry and Wiener, 1991; Bloom, 1992; Windom and Cranmer, 1998; Kehrig *et al*., 2002; Branco *et al*., 2007). MeHg is soluble, mobile, and quickly enters the aquatic food chain. It absorbed by fish when they eat smaller aquatic organisms and its binds to proteins in the fish tissue. MeHg then becomes biomagnified in the food chain through passage from bacteria, plankton, macroinvertebrates, herbivorous fish, piscivorous fish and finally, to humans (WHO, 1990 and 1991). The biomagnification of MeHg has been demonstrated by the elevated levels found in piscivorous fish compared with fish at lower levels of the food chain (Jackson 1991; Watras and Bloom

1992; Porcella 1994). Hg levels in animals may end up being 10,000–100,000 times higher than the initial concentration in the water (WHO 1990 and 1991; ATSDR, 1999).

Fish appear to accumulate MeHg from both food sources and the water column as it passes over the gills during respiration. MeHg can also be produced within the fish's gastrointestinal tract and on the external slime layer but the amount of MeHg contributed to tissue concentrations by these processes has not been quantified and is assumed to be insignificant. However, food was found to be the predominant source of Hg uptake in fish (Hall *et al*., 1997).

The consumption of fish is recommended because it is a good source of omega-3 fatty acids, which have been associated with health benefits due to its cardio-protective effects. However, the content of heavy metals, especially Hg, discovered in some fish makes it difficult to establish clearly the role of fish consumption on a healthy diet. Currently, dietary intake of fish and fish products is recognized as the most important route of non-occupational exposure to Hg, with fish and other seafood products being the dominant source of Hg in the diet (WHO, 1990 and 1991). Tissues of long-lived, slow-growing and highly migratory oceanic fishes, such as tunas, billfishes and pelagic sharks accumulate high concentrations of Hg, often exceeding the limit recommended for human consumption (Barber and Whaling, 1983; Adams, 2004; Branco *et al.*, 2004).

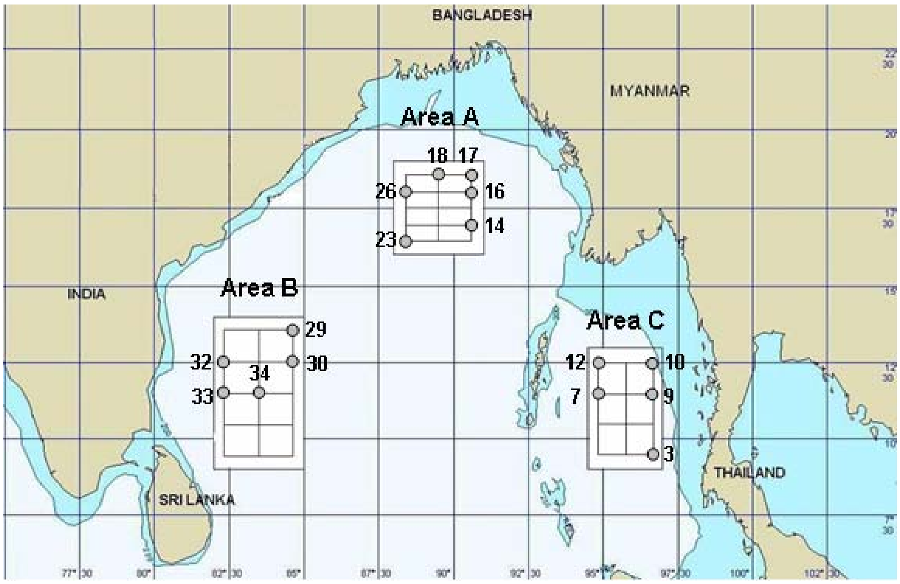
Therefore, contamination of Hg in top predators of pelagic food webs and large fish are of widespread interest and concern. The accumulation of Hg in swordfish (*Xiphias gladius*), a piscovorous fish, is widely recognized (Monteiro and Lopes, 1990; Mendez *et al*., 2001; Storelli *et al*., 2005; Kojadinovic *et al.*, 2006; Chien *et al*., 2007). The presence of Hg in swordfish seems to be a fact independent of human pollution, since values in the range 0.45 and 0.9 μg/g were found in museum specimens caught between 1878 and 1909, that is before industrial activities began to pollute the ambient sea (Miller *et al*., 1972).

To date, there have been very few published studies on Hg in fish from the Bay of Bengal. The objectives of this study were hence to analyze and interpret the total Hg content in the pelagic fish species collected from the Bay of Bengal during November to December 2007. This study will provide baseline data of Hg levels in the fleshy tissues of swordfish, tille trevally, 5 species of tunas (skipjack tuna, kawakawa, yellowfin tuna, frigate tuna and bigeye tuna) and 4 species of shark originating from 3 geographically area of the Bay of Bengal. Because Hg levels almost consistently increase with the size of the fish (Bloom, 1992; Windom and Cranmer, 1998; Gilmour and Riedel, 2000; Stafford and Haines, 2001), relationship between Hg levels and fish sizes (length and weight) was investigated. Hg burden in the same species caught in different area was also compared.

Material and Methods

Sample Collection

Seventy eight specimens of 11 predatory fish species, caught by pelagic longline and drift gill net, were obtained from the joint survey of BIMSTEC member countries on Assessment and Management of Marine Resources during November to December 2007 in 3 compartments of the Bay of Bengal (Fig. 1). Species identification and measuring of fish sizes (length and weight) were carried out on board of M.V. SEAFDEC.



AREA

A: the deep sea area of the EEZ of Bangladesh, India and in the Bay of Bengal at sea depth from 2,000 to 2,600 m

B: western part of the Bay of Bengal included the international waters and the EEZ of India and Sri Lanka waters

C: within the Andaman Sea at sea depth from 1,128 to 2,841 m

Figure 1 Sampling stations in 3 geographically distant sites in the Bay of Bengal.

For practical reasons, white flesh in the abdominal area of the fish was sampled for Hg analysis, except caudal flesh and fin were sampled for all sharks. We considered that Hg is uniformly distributed in fish edible muscle as it has been shown for swordfish (Freeman and Home, 1973). The sampled muscle was conserved frozen and was shipped to the laboratory for Hg analysis.

Sample Digestion and Mercury Determination

All laboratory material was previously decontaminated overnight with 10% (v/v) HNO_3 and washed with deionized water nanopure level (resistivity >18 MΩ cm). Nanopure water was used throughout this work. Thawed samples were dissected under clean atmosphere in Laminar Flow Cabinet Class-100, only flesh were taken off and homogenized with stainless steel knife and laboratory spatula, then immediately kept frozen until analysis. Samples were digested based on wet weight with method modified from AOAC (1990) and US-EPA (2001). Briefly, homogenized subsample (approx. 300 mg) was accurately weighed in a 50-ml plastic lined screw-capped Pyrex tube, 1.5 ml of a 1 : 2 (v/v) mixture of concentrated H_2SO_4–HNO_3 was added and the tubes were placed in a heating box at 90–95°C for 30 minutes. After cooling, 38.5 ml of 0.02 N BrCl was added and was mixed thoroughly. The solution was then left to stand overnight. Immediately prior to the determination of Hg concentration, 1 ml of $NH_2OH.HCl$ solution (prepared by dissolving 12 g NaCl and 12 g $NH_2OH.HCl$ in 100 ml nanopure water) was added and vortex mixed until disappearance of the yellow-brown color. The determination was carried out by a Flow Injection Mercury Analyzer (Perkin-Elmer model FIMS^{TML}400). This instrument based on cold vapor atomic absorption spectrometric technique using 0.2% (w/v) $NaBH_4$ in 0.05% NaOH (prepared by dissolving 2 g $NaBH_4$ in 1 l of 0.05% NaOH) as reducing agent, 3% (v/v) HCl as carrier solution, and argon stream as an inert carrier to transport Hg vapor into the cell. Detection limit of the instrument is <0.01 µg/l. The relative accuracy for the measuring of Hg was evaluated comparing to the certified values for the National Research Council of Canada Certified Reference Materials (NRCC-CRM) DORM-2 (dogfish muscle) and DOLT-2 (dogfish liver). All blanks and the CRM were prepared in the same manure as the samples. Total Hg concentrations in fish flesh are reported as ng/g wet weight. Linear regression was used to describe relationship between fish size and total Hg concentration.

The method validation results are reported in table 1. Analytical precision of the analysis was determined by analyzing every tenth sample in duplicate. The coefficient of variation (SD/mean) for the duplicate samples was less than 10%.

Results and Discussion

A total of 78 specimens of 11 pelagic predatory fish species including 8 bigeye thresher shark (*Alopias superciliosus*), 1 copper shark (*Carcharhinus brachyurus*), 3 silky shark (*Carcharhinus falciformis*), 1 unidentified shark, 12 frigate tuna (*Auxis thazard*), 1 tille travalley (*Caranx tille*), 4 kawakawa (tuna) (*Euthynnus affinis*), 29 skipjack tuna (*Katsuwonus pelamis*), 2 yellowfin tuna (*Thunnus albacares*), 1 bigeye tuna (*Thunnus obesus*) and 16 swordfish (*Xiphias gladius*) were analyzed. The concentrations of Hg range from 48-862 ng/g wet weight for 4 species of shark flesh, 5-625 ng/g wet weight for 5 species of tuna and 23-1245 for swordfish. The mean concentrations of Hg in ng/g wet weight of the fresh tissue were 514±187 for bigeye thresher shark, 251±128 for copper shark, 125±35 for silky shark, 48 for unidentified shark, 886±104 for tille travalley, 64±42 for frigate tuna, 63±16 for kawakawa, 110±153 for skipjack tuna, 92±32 for yellowfin tuna, 201 for bigeye tuna and 478±416 for swordfish. Summary statistics for Hg levels in the fish flesh of each species are presented in table 2.

In skipjack tuna and swordfish, Hg levels were found to be positively correlated with the length and weight of the fish (Fig. 2). This indicates that these fishes can accumulate relatively high levels of Hg with increasing size. This relationship can not be seen in bigeye tresher shark and frigate tuna. Because of too small number of individuals for each species, the rest species are not interpreted.

Box-and-Whisker diagram (Fig. 3) is used to compare Hg concentration in different species and to compare with the CODEX and EU guideline level for total Hg concentration of 0.5 μg/g (or 500 ng/g) for all fish except some predatory fish which a higher level of 1 μg/g is permitted (EU, 2001). According to the median of Hg level in fish tissue, most fish species had Hg contents less than 500 ng/g wet weight, except bigeye thresher shark and tille travalley. Some swordfishes, weighed over 40 kg, contained Hg higher than the EU and CODEX upper limit of 1 μg/g.

To answer the question "would there still be differences in Hg burden among species if there all had the same average size?," mean Hg content against mean sizes (weight and length) has been plotted as shown in fig. 4. Tille trevally (CT) had high Hg levels with respect to their sizes when compared to the other species. In contrast, yellowfin tuna (TA) had low Hg levels with respect to their sizes. The inter-specific differences in Hg levels were probably linked to differences in each species physiology, feeding rate, growth rate, lifespan, migratory patterns, foraging habits and diet. According to fig. 4, the fillets from fish smaller than approx. 15 kg (or 150 cm in length) are not expected to have Hg exceed the EU and CODEX limit of 0.5 μg/g. However, both tille trevally and yellowfin tuna contain excessively small sample size, as well as some other species. A more extensive sampling would be necessary to better estimate Hg levels in these species.

In comparison among 3 different geographically sites of the Bay of Bengal, samples from area C (the Andaman Sea) showed the highest Hg level in all 3 species (bigeye thresher shark, skipjack tuna and swordfish) (Fig. 5). As compare with weight and length, the probably reason for the high Hg level might due to the fish caught in this area was generally larger than those of other areas.

Table 1 Validation of digestion methods for determination of Hg (mean±standard deviation) in µg/g dry weight against NRCC-CRM DORM-2 and DOLT-2.

NRCC-CRM	n	Certified values (µg/g dry weight)	Obtained values (µg/g dry weight)	% Recovery
DORM-2	20	4.64±0.26	4.314±0.324	92.9
DOLT-2	20	2.14±0.28	2.136±0.123	99.8

Table 2 Mean±standard deviation and range of total length (cm), body weight (kg) and Hg levels (ng/g wet weight) in predatory fish flesh collected from the Bay of Bengal during November to December 2006.

Scientific name (Common name)	Code	n	Tissue	Total length (cm) (min-max)	Weight (kg) (min-max)	Hg (ng/g) (min-max)
Alopias superciliosus (Bigeye thresher shark)	AS	8	Caudal and fin	265.8±31.8 205-319	56.3±20.1 31- 90	514±187 198-862
*Carcharhinus brachyurus** (Copper shark)	CB	1	Caudal and fins	131.1	12.2	251±128 108-419
Carcharhinus falciformis (Silky shark)	CF	3	Caudal and fin	101.9±7.1 93.6-111.0	5.8±1.5 3.7-7.2	122±35 74-158
Shrk (Unidentified shark)	Shk	1	Caudal and fin	87.6	3.2	48
*Caranx tille*** (Tille trevally)	CT	1	Caudal/Abdominal	66.8	3.3	886±104 (782-990)
Auxis thazard (Frigate tuna)	AT	12	Abdominal	37.5±2.3 (31.5-40.0)	0.8±0.1 (0.4-1.0)	64±42 (39-202)
Euthynnus affinis (Kawakawa)	EA	4	Abdominal	39.1±2.2 (37-42)	0.9±0.1 (0.75-1.05)	63±16 (46-88)
Katsuwonus pelamis (Skipjack tuna)	KP	29	Abdominal	46.2±10.1 (37.4-77.5)	1.7±1.5 (0.75-6.35)	110±153 (5-625)
Thunnus albacares (Yellowfin tuna)	TA	2	Abdominal	138.5±1.5 (137-140)	36.5±1.5 (35-38)	92±32 (61-124)
Thunnus obesus (Bigeye tuna)	TO	1	Abdominal	52.0	2.0	201
Xiphias gladius (Swordfish)	XG	16	Abdominal	198.3±43.3 (129-262)	25.7±17.9 (5-60)	478±416 (23-1245)

* analysis of 3 parts in one fish
** analysis of 2 part in one fish

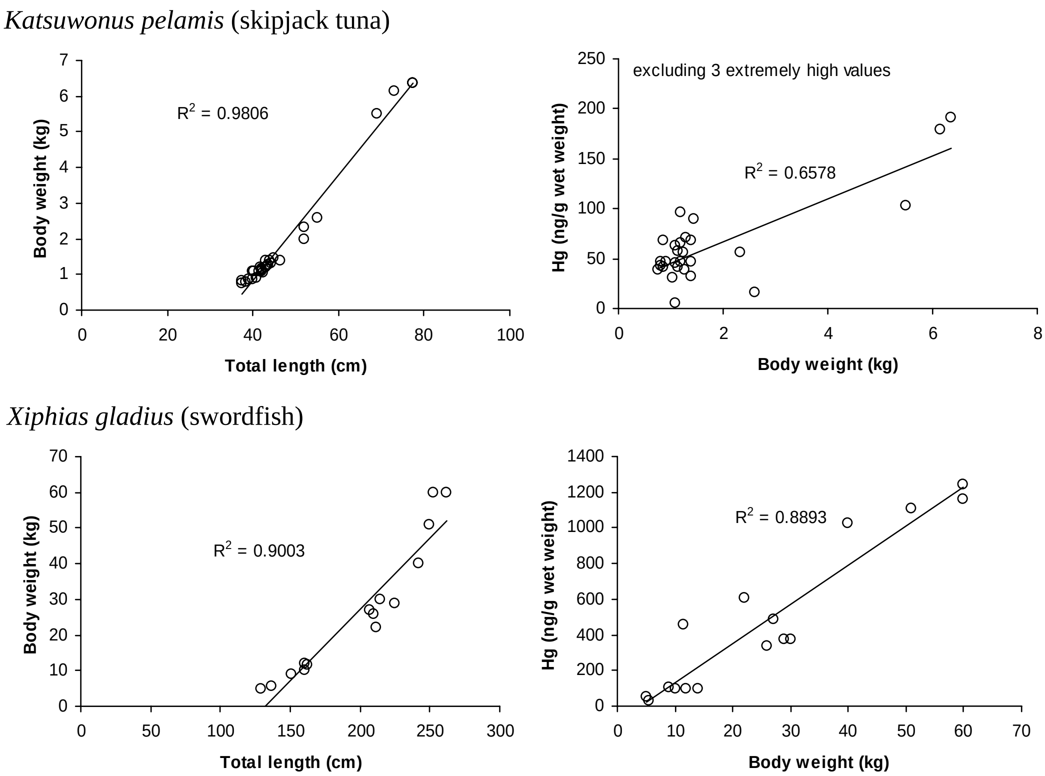


Figure 2 Relationships of body weight against total length (left), and Hg levels against body weight (right) of *Katsuwonus pelamis* (skipjack tuna) and *Xiphias gladius* (sword fish).

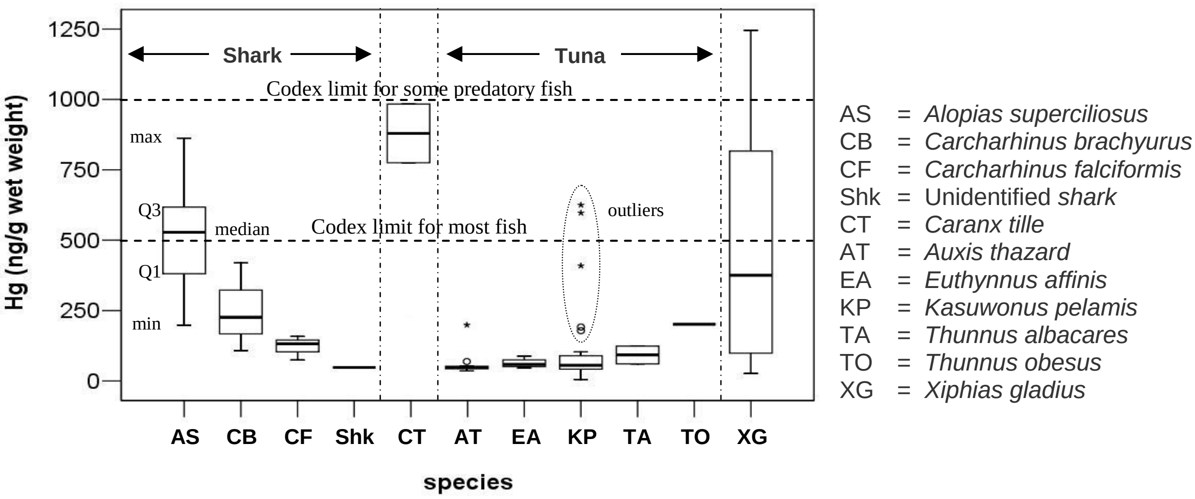


Figure 3 Box-and-Whisker diagram showing a comparison of total Hg concentration in fish flesh of different 11 pelagic fish species in the Bay of Bengal.
(The spacing between the different parts of the box indicates the degree of dispersion and skewness in the data, and identifies outliers.)

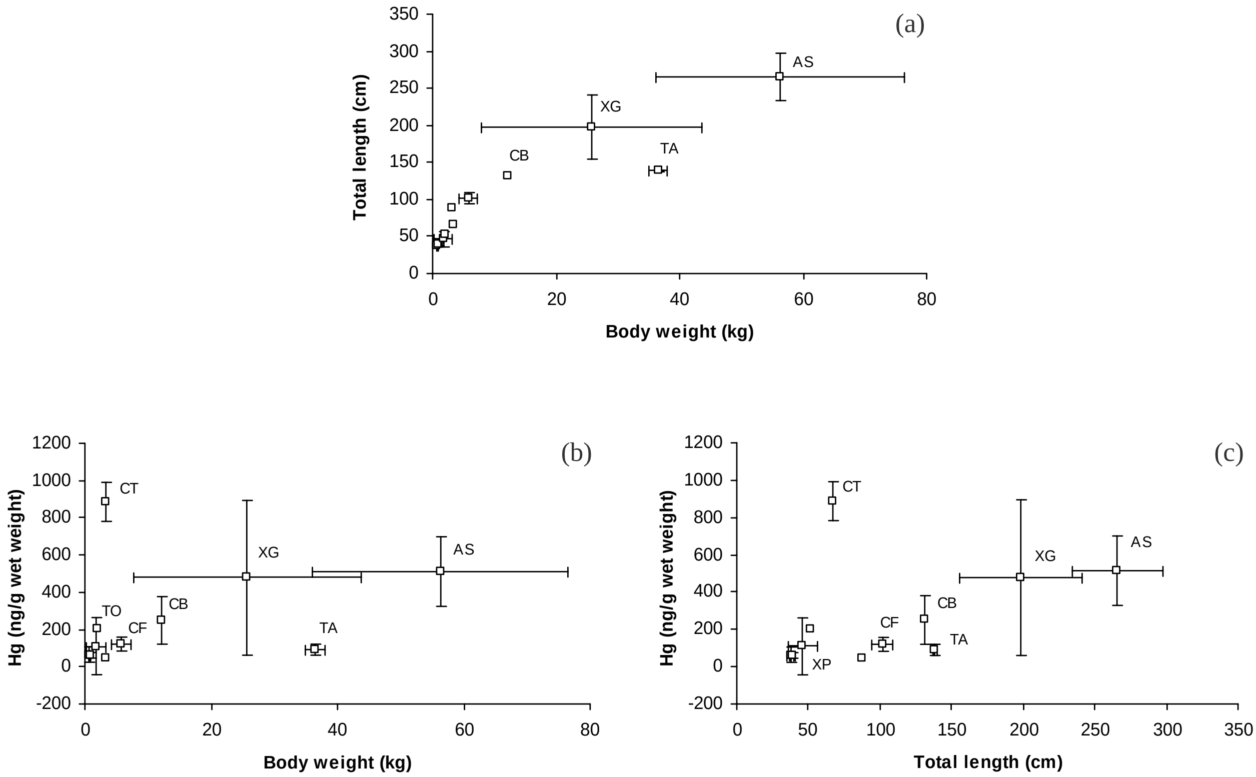


Figure 4 Position of species in relation to their mean value: (a) mean length against mean body weight; (b) mean Hg levels against mean body weight; and (c) mean Hg levels against mean length.
(Error bars represent the standard deviation.)

The highest Hg concentration was found in swordfish caught in area C, particularly in the fish that larger than 40 kg, which contained Hg in their tissues over 1000 ng/g wet weight. Swordfish are quite different to tuna and to other billfish, such as blue marlin. They have a wider geographical distribution than those other species and regularly move between surface waters down to great depths where they tolerate extreme cold. They move with prevailing currents and use their superior eyesight to locate prey. They can grow to enormous sizes. Male and female swordfish grow at different rates and have different distributions. In some areas they regularly descend from the sea surface down to depths of 1000 m or more (Carey and Robinson 1981). Juvenile swordfish are most abundant in tropical and subtropical waters. They migrate to lower latitudes as they mature (Yabe *et al*., 1959). Adult swordfish are opportunistic feeders, taking a wide variety of prey. Their diet varies with location and the species available. A major portion of swordfish diets is comprised of squid, fish and occasionally crustaceans and octopus (Palko *et al*., 1981). The daily ration of food required by adult swordfish has been estimated at 0.9% to 1.6% of body weight, with their yearly consumption ranging from 3-6 times their average body weight per year (Stillwell and Kohler, 1985). Because swordfish is long-lived fish and being top predator with a relatively high metabolic rate, high concentrations of heavy metals, especially Hg, may accumulate in the flesh (Monteiro and Lopes, 1990).

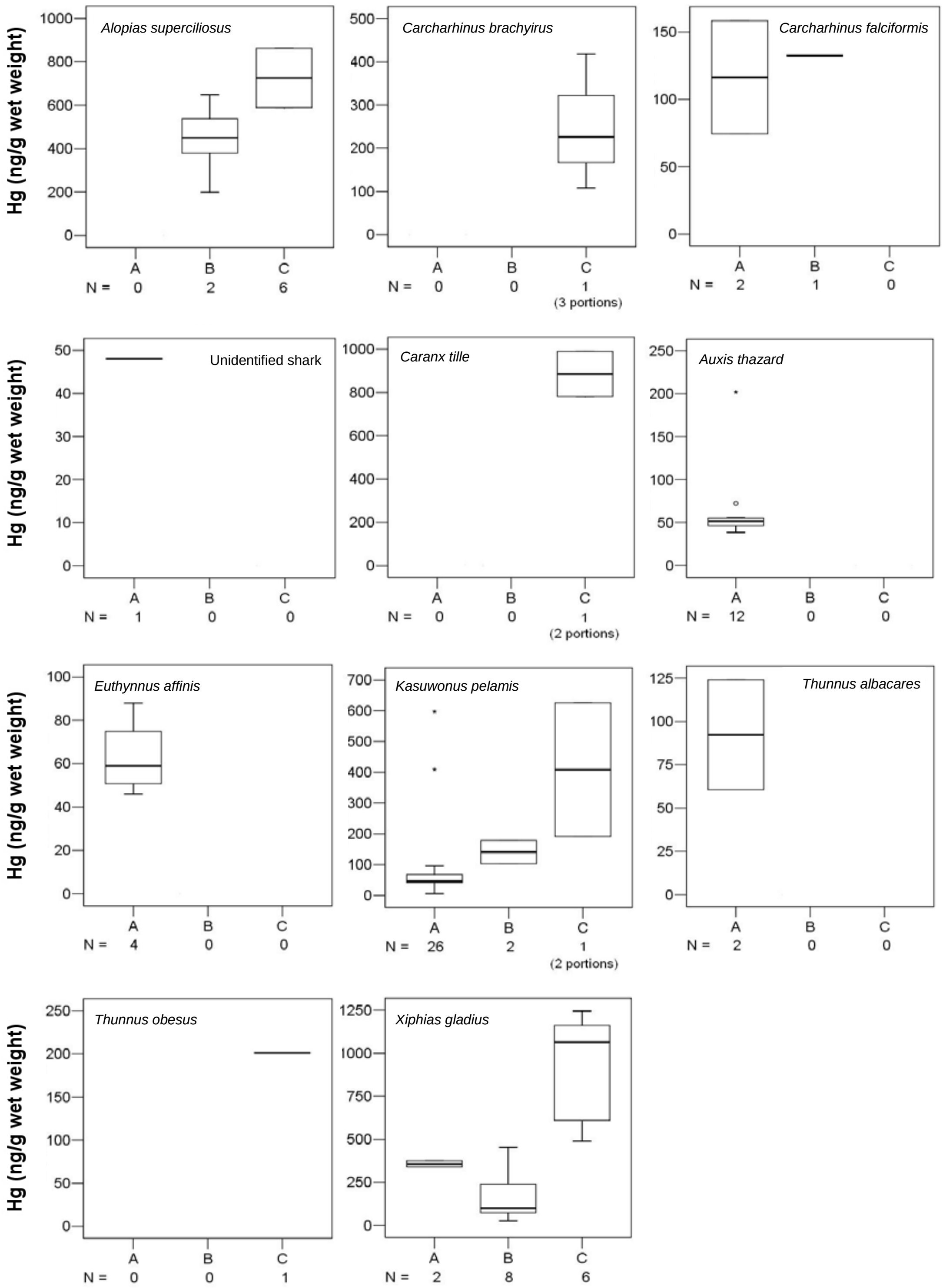


Figure 5 Box-and-Whisker diagrams showing a comparison of total Hg concentration in 11 predatory fish species in 3 different geographically sites of the Bay of Bengal**.**
The spacing between the different parts of the box indicates the degree of dispersion and skewness in the data, and identifies outliers.

In comparison with published data, the Hg levels detected in pelagic fishes during this study were quite similar to phylogenetically related species from oceans around the world as shown in table 3.

Table 3 Mercury levels (mean±standard deviation or minimum-maximum in μg/g wet weight) in muscle of marine fish from various geographical areas.

Species	Origin	n	Hg (μg/g wet weight)	References
Alopias superciliosus (Bigeye tresher shark)	Bay of Bengal (area B)	6	0.444±0.144	This study
	Andaman Sea (area C)	2	0.726±0.137	This study
Carcharhinus brachyurus (Copper shark)	Andaman Sea (area C)	1	0.251±0.128	This study
Carcharhinus falciformis (Silky shark)	Bay of Bengal (area A)	2	0.116±0.040	This study
	Bay of Bengal (area B)	1	0.133	This study
Prionace glauca (Blue shark)	Atlantic Ocean, near Azores	37	0.22-1.3	Branco *et al*. (2007)
	Atlantic Ocean, equator	27	0.68-2.5	Branco *et al*. (2007)
Unidentified shark	Bay of Bengal (area A)	1	0.048	This study
4 species of shark	Andaman Sea		0.057-0.478	Menasveta and Siriyong (1977)
Shark	Sea around Taiwan	41	0.73±0.54	Chien *et al*. (2007)
Auxis thazard (Frigate tuna)	Bay of Bengal (area A)	12	0.064±0.042	This study
Caranx tille (Tille trevally)	Andaman Sea (area C)	1	0.886±0.104	This study
Euthynnus affinis (Kawakawa)	Bay of Bengal (area A)	4	0.063±0.016	This study
	Sea around Malaysia	5	0.01±0.01	Hajeb *et al.* (2009)
Katsuwonus pelamis (Skipjack tuna)	Bay of Bengal (area A)	26	0.085±0.125	This study
	Bay of Bengal (area B)	2	0.141±0.038	This study
	Andaman Sea (area C)	1	0.408±0.217	This study
	Reunion Island*	39	0.19±0.66	Kojadinovic *et al.* (2006)
	Indian Ocean	1	0.53	Kureishy *et al*. (1979)
	Seuchells	5	0.34±0.11	Matthews (1983)
Thunnus albacares (Yellowfin tuna)	Bay of Bengal (area A)	2	0.092±0.032	This study
	Andaman Sea		0.026-0.234	Menasveta and Siriyong (1977)
	Seychells	5	0.23±0.10	Matthews (1983)
	Pacific Ocean	105	0.21±0.11	Kraepiel *et al.* (2003)
	Atlantic Ocean	56	0.25±0.12	Adams (2004)
	Mozambique Channel*	20	0.13±0.09	Kojadinovic *et al.* (2006)
	Reunion Island*	19	0.21±0.15	Kojadinovic *et al.* (2006)
Thunnus obesus (Bigeye tuna)	Andaman Sea (area C)	1	0.201	This study
Parathunnus sibi (Bigeye tuna)	Andaman Sea		0.027-0.233	Menasveta and Siriyong (1977)
Thunnus thynnus (Bluefin tuna)	Mediterranean Sea	73	0.20±0.07	Storelli *et al*. (2005)
Xiphias gladius (Swordfish)	Bay of Bengal (area A)	2	0.357±0.018	This study
	Bay of Bengal (area B)	8	0.163±0.149	This study
	Andaman Sea (area C)	6	0.939±0.286	This study
	Atlantic Ocean, near Azores	88	0.93±0.07	Monteiro and Lopes (1990)
	Atlantic Ocean, near Azores	48	1.30±0.17	Monteiro and Lopes (1990)
	Southwest Atlantic Ocean	192	0.62±0.35	Mendez *et al.* (2001)
	Mediterranean Sea	58	0.07±0.04	Storelli *et al*. (2005)
	Mozambique Channel*	37	0.38±0.26	Kojadinovic *et al.* (2006)
	Reunion Island*	7	1.24±0.83	Kojadinovic *et al.* (2006)
	Atlantic Ocean, near Azores	29	0.031-2.4	Branco *ei al.* (2007)
	Atlantic Ocean, equator	23	0.90-2.3	Branco *ei al.* (2007)
	Sea around Taiwan	58	0.77±0.83	Chien *et al*. (2007)

* the western Indian Ocean

Conclusion

The study provided baseline data for Hg accumulated in fishery resources of the Bay of Bengal. Most fish analyzed in this study still had Hg concentration in the tissue within the EU and CODEX limit of 0.5 μg/g, particularly when fish size not exceeding approx. 15 kg in weight or 150 cm in length. As a predator fish of such longivity, bigeye thresher shark and swordfish are expected to bioaccumulate Hg. The Hg burden in the tissue of both fishes reported in this study was the highest. In addition, swordfish which weighed more than 40 kg accumulated very high Hg contents in their flesh exceeding 1 μg/g wet weight which over the upper limit of the CODEX and EU guideline levels. From the data of 3 species (bigeye thresher shark, skipjack tuna and swordfish) that distributed in all 3 different geographically areas of the Bay of Bengal, fishes caught in the Andaman Sea seems to have higher Hg concentration than those of other areas. The most likely reason might due to the age of fish caught in the Andaman Sea which may be older than those of other areas as compared with length and weight.

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Heavy Metal Contents in Purpleback Squid (*Sthenoteuthis oualaniensis*) from the Bay of Bengal

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Abstract

Oceanic purpleback squid (*Sthenoteuthis oualaniensis*) were sampled at nine locations in the Bay of Bengal by the fishery research vessel M.V. SEAFDEC, of the Southeast Asian Fisheries Development Center (SEAFDEC). The squid were captured by jigging machines, and samples were kept frozen until analysis of heavy metal. Three individual squid were randomly chosen from each location and the edible parts of the squid (mantle, arm and tentacle) were separated from the visceral mass. The samples were homogenized and a portion from each individual was digested in a microwave digester. Hg concentration in the digested solution was determined by cold vapor atomic fluorescence spectrophotometer. Cd, Cu, Zn and Pb concentrations in the digested solution was determined by atomic absorption spectrophotometer. Results from this study show that purpleback squid from the Bay of Bengal accumulate high concentrations of Cd, Cu and Zn. Levels of heavy metals were similar across all sampling stations. These metals accumulate mainly in the visceral mass, which includes the ink sac, digestive gland, gills, and gonads, whereas accumulation in the edible part (mantle, arm and tentacle) is significantly lower. Cd was the only heavy metal in mantle tissue found to exceed safety standards. The concentrations of Cd and Cu in visceral mass were also higher than safety standards. The concentrations of Hg, Pb and Zn in both mantle and visceral mass were lower than safety standards. Our sampling indicates that purpleback squid is not safe for human consumption based on the degree of Cd contamination. Close monitoring is necessary in order to follow changes in Cd contamination. Further study to investigate sources of the heavy metals, especially Cd, may provide a better view on contaminant sources.

Key words: heavy metal, purpleback squid, *Sthenoteuthis oualaniensis*, Bay of Bengal

Introduction

The Ecosystem-Based Fishery Management in the Bay of Bengal, a collaborative survey project of the BIMSTEC member countries (Bangladesh, India, Myanmar, Sri Lanka, Nepal and Thailand) carried out a 58-day survey trip in the Bay of Bengal from 25 October to 21 December 2007. The objectives were to assess the potential of fishery resources, collect biological data (species composition, distribution and catchability) of fishes and oceanic squids as well as study the physico-chemical and hydrological aspects of the survey area.

Purpleback squid (*Sthenoteuthis oualaniensis*) is an oceanic squid widely distributed in the equatorial and tropical waters of the Indo-Pacific Ocean. The squid is characterized by a wide ecological amplitude, complex intraspecific structure, high fecundity, short life cycle, high natural mortality, high growth rate and significant production (Nesis, 1977). It is very abundant and recognized as one of the main squid resources in the South China Sea and especially the northwestern Indian Ocean (Chesalin, 1997; Chesalin and Zuyev, 2002). Similar to all other squid, purpleback squid is carnivorous, feeding mainly on crustaceans, small fish, and other cephalopods (Collins *et al*., 1994; Collins and Pierce, 1996; Quetglas *et al*., 1999). Xinjun *et al*. (2007) found that stomach contents of purpleback squid from the northwestern Indian Ocean contained three major diet groups: fish, cephalopods and crustaceans, mainly *Cypselurus* spp. and *S. oualaniensis*. More than 60% of the stomachs of squid larger than 400 mm ML had evidence of cannibalism.

Squid are themselves important prey items for large fish, sea birds, and marine mammals (Pierce and Santos, 1996; Santos *et al*., 2001). Squid (and other cephalopods) are very efficient accumulators of various trace elements (Martin and Flegal, 1975; Miramand and Bentley, 1992; Bustamante *et al*., 2002). Toxic metals such as cadmium and mercury are bioaccumulated and retained in squid (Bustamante *et al*., 1998, 2006) and consequently passed on to predators, thus potentially increasing the contaminant load in higher trophic levels, including humans (Bustamante *et al*., 1998; Lahaye *et al*., 2005; Storelli *et al*., 2005, 2006).

The purpleback squid population in the Bay of Bengal has been recognized as a potential fishery resource for human consumption. Hence, information on heavy metal concentrations in this squid is important for future policy regarding exploitation of this species. The aims of this study were to determine and compare heavy metal concentrations in the edible portion (mantle, arm and tentacle) and visceral mass of purpleback squid (*Sthenoteuthis oualaniensis*) from nine sampling stations in the Bay of Bengal.

Materials and Methods

Samples of purpleback squid were caught by two Japanese automatic squid jigging machines which were fixed and operated at the starboard side of the fishery research vessel M.V. SEAFDEC, of the Southeast Asian Fisheries Development Center (SEAFDEC). The squid were attracted by 500 kilowatt light from 15 halogen lamps fixed along the starboard side of the ship at a height of 10 m from the surface of water. The lights were switched on 60 minutes before the start of sampling. Collection occurred from 20.00-24.00 PM. for every sampling event. Seven of the sampling stations (1, 3, 7, 8, 9, 10 and 12) were located within area C, or the eastern part of the Bay of Bengal (Fig. 1). Two other sampling stations (14 and 16) were located at the northern part of the Bay (area A; Fig. 1). A list of sampling stations and their positions can be found in Table 1.

Mantle length and body weight of each individual caught were measured and recorded. Sex of the squids was determined by the presence or absence of a hectocotylus (modified ventral arm of the male). Each squid was placed in a plastic zip-log bag and kept frozen until analysis.

Prior to heavy metal analysis the samples of purpleback squid were thawed at room temperature. Three individuals from each sampling station were randomly chosen for the analysis, except for station 3, in which only one squid was available. The edible body parts (mantle, arm and tentacle) and visceral mass of each squid were separated. The samples were cut and homogenized in a blender. A 1.0-1.5 g portion of each homogenized sample was carefully weighed in a Teflon vessel. Hydrogen peroxide and sub-boiled distilled nitric acid was added to the vessels. The vessels were then closed tightly and placed in a microwave digester (CEM; Mar5x). Afterwards, the samples were cooled down and diluted with deionized water. Mercury (Hg) concentration in the digested sample was determined by Cold Vapor Atomic Fluorescence Spectrometer (PSAnalytical; Merlin) whereas Cd, Pb, and Cu were determined by Graphite Furnace Atomic Absorption Spectrophotometer (Unicam;

Solars). Zinc concentration was determined by Flame Atomic Absorption Spectrophotometer (Varian; SpectrAA-50).

To validate the analytical technique, a certified reference material for trace metals, DORM-3 (National Research Council, Canada), was digested and heavy metal levels were determined in the same manner as for our samples. Limit of detection of each heavy metal was calculated from three standard deviations of eight method blanks.

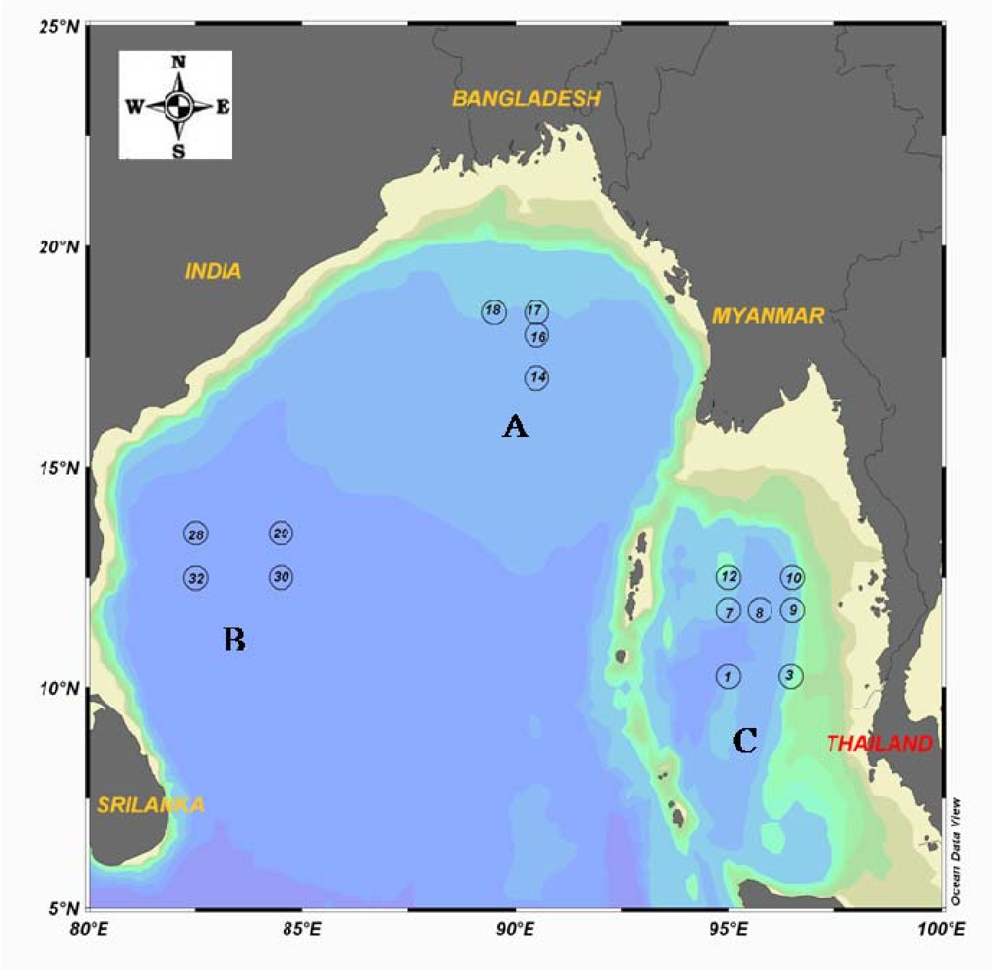

Figure 1 Map depicting the stations of automatic squid jigging in each area.

Table 1 Dates of jigging operation, positions of sampling stations and depth of sampling stations.

Area	Jigggin operation no.	Survey st. no.	Date	Position		Sea depth
				latitude (N)	longitude (E)	
C	1	01	06/11/2007	10°18.20′	95°01.00′	2,628
	2	03	07/11/2007	10°14.40′	96°32.80′	538
	3	07	10/11/2007	11°04.90′	95°36.30′	513
	4	08	11/11/2007	11°54.50′	95°06.70′	2,884
	5	09	12/11/2007	11°45.60′	96°32.40′	883
	6	10	13/11/2007	12°04.50′	96°23.40′	1,128
	7	12	15/11/2007	12°29.50′	94°54.50′	1,418
A	8	14	17/11/2007	16°49.50′	90°20.90′	2,353
	9	16	18/11/2007	18°01.40′	90°35.70′	2,136

Results and Discussion

Validity of Methods

Table 2 shows determined values, certified value and % recovery of Hg, Cd, Cu, Pb, and Zn of certified reference material (DORM-3; National Research Council, Canada) and limit of detection of each heavy metal. The recovery levels of all heavy metals from this study were within an acceptable range (96-103%).

Table 2 Determined value, certified value and percent (%) recovery of heavy metal contents of the DORM-3 (n=4) as validation for analytical technique.

Metals/description	Hg (ug/g)	Cd (ug/g)	Cu (ug/g)	Pb(ug/g)	Zn (ug/g)
Determined value	0.415±0.011	0.292±0.024	16.03±0.34	0.405±0.025	49.51±0.39
Certified value	0.409	0.290	15.5	0.395	51.3
% recovery	101.58±2.78	100.59±8.16	103.43±2.19	102.74±6.56	96.50±0.768
Detection limit[b]	0.001	0.003	0.030	0.012	0.090

Heavy Metal Contents in Squid

Heavy metal concentrations in the edible portion (mantle, arm and tentacle) and visceral mass of purpleback squid (*Sthenoteuthis oualaniensis*) from each station in the Bay of Bengal are shown in table 3. Mean concentrations±standard deviation of Hg, Cd, Pb, Zn and Cu in the edible parts of purpleback squid from all sampling stations were 39.92±34.10 (ng/g), 3.759±4.856, 0.035±0.029, 16.54±2.32 and 10.99±8.60 (µg/g), respectively. Mean concentrations ± standard deviation of Hg, Cd, Pb, Zn and Cu in the visceral mass of purpleback squid from all sampling stations were 34.26±25.32 (ng/g), 17.47±5.70, 0.062±0.020, 43.82±9.86 and 73.68±47.07 (µg/g), respectively.

Panutrakul (unpublished data) determined heavy metal concentrations in mantle tissue of marbled octopus (*Octopus aegina*) and pharaoh cuttlefish (*Sepia pharaonis*) collected from the upper Gulf of Thailand. For octopus, concentrations of Hg, Cd, Pb, Zn and Cu were 12.12±5.59 (ng/g), 0.020±0.037, 0.126±0.169, 19.88±4.42 and 11.48±5.10 (µg/g), respectively. For cuttlefish, concentrations of the same group of metals were 15.39±8.03 (ng/g), 0.055±0.072, 0.061±0.029, 13.5±2.47, 5.76±1.69 (µg/g), respectively. Mean concentrations of Hg, Pb, Zn and Cu in edible tissue of purpleback squid from the Bay of Bengal were similar to concentrations found in octopus and cuttlefish in Thailand. However, Cd concentrations in purpleback squid were much higher than in the other two species.

Pierce *et al*. (2008) measured Hg and Cd concentrations in tissues of two loliginid (*Alloteuthis* sp. and *Loligo forbesi*) and two ommastrephid (*Todarodes sagittatus* and *Todaropsis eblanae*) squid species collected in UK waters during 2004-2005. They found concentrations of Hg and Cd in muscle tissue of the squid to be in the range of 17-80 ng/g and 0.021-0.256 µg/g, respectively. However, the authors also reported that the digestive gland is the main storage organ of Cd in these squid species. Hg and Cd concentrations in the digestive gland of these squid varied from 17-110 (ng/g) and 0.16-3.31 (µg/g), respectively. In comparing results from this study with those of Pierce *et al.* (2008) we found that squid from UK waters show slightly higher Hg concentration in both muscle and digestive gland than our samples from the Bay of Bengal. Meanwhile, Cd concentrations in both muscle and digestive gland of squid from UK waters were lower than our samples.

Bioconcentration and bioaccumulation experiments of Cd by oval squid (*Sepioteuthis lessoniana*) run by Koyama *et al*. (2000) showed that oval squid can take Cd up via diffusion of Cd ions from the water and from their diet. After 14 days of exposure to 0.2 mg Cd/l seawater, the mean Cd concentrations in the liver, gill, digestive tract, mantle, ink sac and the remaining parts of the squid were 49.3, 19.2, 7.08, 0.79, 1.35 and 1.62 µg/g wet weight, respectively. In another experiment, squid were reared in 0.12 mg Cd/l seawater, and also fed a diet of fish raised in the same seawater. The mean Cd concentrations in the liver, gill, digestive tract, mantle, ink sac and remaining parts of the squid were 58.8, 19.4, 13.0, 1.10, 3.30 and 1.13 µg/g wet weight, respectively. Their results showed that oval squid can bioconcentrate and bioaccumulate waterborne and dietary Cd in a short period of time. Cd tends to accumulate primarily in liver whereas Cd concentration in the mantle is lower than in the other tissues.

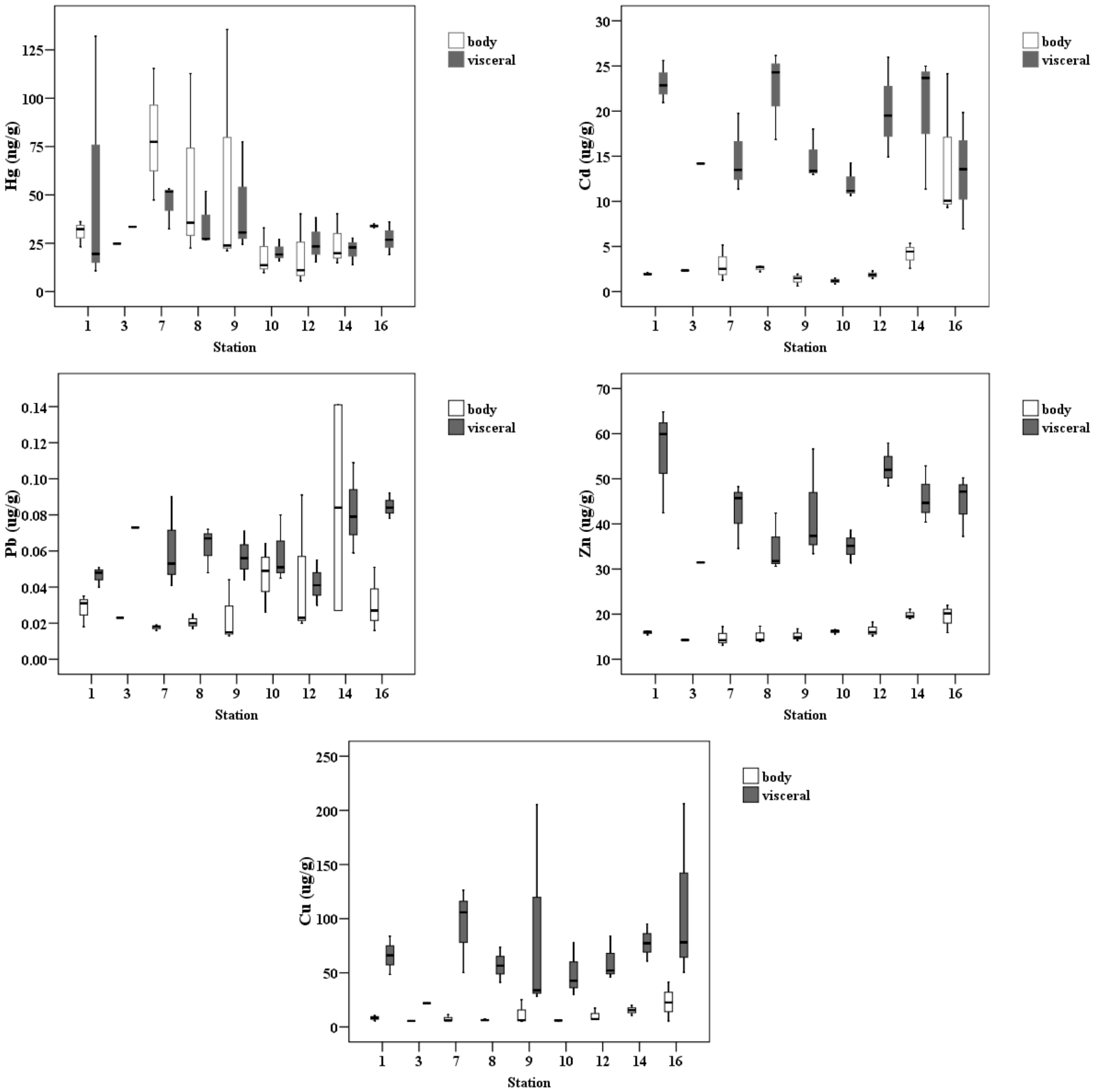

Figure 2 Box plot of heavy metal concentrations in edible parts (mantle, arm and tentacle) and visceral mass of purpleback squid (*Sthenoteuthis oualaniensis*) collected from the Bay of Bengal.

Table 3 Heavy metal concentrations in edible body parts (mantle, arm and tentacle) and visceral mass of purpleback squid (*Sthenoteuthis oualaniensis*) collected from the Bay of Bengal.

Station	Hg (ng/g)		Cd (μg/g)		Pb (μg/g)		Zn (μg/g)		Cu (μg/g)	
	Body	Visceral	Body	Visceral	Body	Visceral	Body	Visceral	Body	Visceral
1	30.58±6.66	54.09±67.66	1.975±0.095	23.136±2.345	0.028±0.009	0.046±0.005	15.92±0.43	55.74±11.76	8.28±5.54	66.12±17.63
3	24.77	33.50	2.336	14.186	0.023	0.073	14.27	31.46	5.54	21.97
7	80.07±34.06	45.74±11.59	2.980±1.999	14.87±4.36	0.018±0.002	0.061±0.026	14.85±2.13	42.84±7.29	7.76±3.12	94.15±39.42
8	56.9±48.75	35.31±14.32	2.570±0.326	22.44±4.92	0.021±0.004	0.062±0.013	15.19±1.87	34.93±6.50	6.65±0.70	57.21±16.24
9	60.17±65.31	44.19±29.00	1.348±0.686	14.78±2.81	0.024±0.017	0.057±0.014	15.27±1.336	42.46±12.41	12.17±11.26	89.21±100.76
10	18.82±12.36	20.69±5.70	1.180±0.332	12.02±1.95	0.046±0.019	0.058±0.019	16.15±0.049	35.04±3.61	5.77±0.37	49.99±24.76
12	18.90±18.58	25.59±11.62	1.865±0.413	20.13±5.57	0.045±0.040	0.042±0.013	16.48±1.57	52.78±4.80	10.54±5.97	60.63±20.32
14	24.99±13.42	21.44±7.01	4.117±1.410	20.01±7.52	0.084±0.080	0.082±0.025	19.86±1.10	45.98±6.33	15.35±4.50	77.80±17.12
16	33.96±0.90	27.32±8.53	14.511±8.347	13.45±6.46	0.031±0.018	0.085±0.007	19.35±3.12	44.87±6.78	23.23±17.95	111.60±83.01

Table 3 Heavy metal concentrations in edible body parts (mantle, arm and tentacle) and visceral mass of purpleback squid (*Sthenoteuthis oualaniensis*) collected from the Bay of Bengal.

Station	Hg (ng/g)		Cd (μg/g)		Pb (μg/g)		Zn (μg/g)		Cu (μg/g)	
	Body	Visceral	Body	Visceral	Body	Visceral	Body	Visceral	Body	Visceral
1	30.58±6.66	54.09±67.66	1.975±0.095	23.136±2.345	0.028±0.009	0.046±0.005	15.92±0.43	55.74±11.76	8.28±5.54	66.12±17.63
3	24.77	33.50	2.336	14.186	0.023	0.073	14.27	31.46	5.54	21.97
7	80.07±34.06	45.74±11.59	2.980±1.999	14.87±4.36	0.018±0.002	0.061±0.026	14.85±2.13	42.84±7.29	7.76±3.12	94.15±39.42
8	56.9±48.75	35.31±14.32	2.570±0.326	22.44±4.92	0.021±0.004	0.062±0.013	15.19±1.87	34.93±6.50	6.65±0.70	57.21±16.24
9	60.17±65.31	44.19±29.00	1.348±0.686	14.78±2.81	0.024±0.017	0.057±0.014	15.27±1.336	42.46±12.41	12.17±11.26	89.21±100.76
10	18.82±12.36	20.69±5.70	1.180±0.332	12.02±1.95	0.046±0.019	0.058±0.019	16.15±0.049	35.04±3.61	5.77±0.37	49.99±24.76
12	18.90±18.58	25.59±11.62	1.865±0.413	20.13±5.57	0.045±0.040	0.042±0.013	16.48±1.57	52.78±4.80	10.54±5.97	60.63±20.32
14	24.99±13.42	21.44±7.01	4.117±1.410	20.01±7.52	0.084±0.080	0.082±0.025	19.86±1.10	45.98±6.33	15.35±4.50	77.80±17.12
16	33.96±0.90	27.32±8.53	14.511±8.347	13.45±6.46	0.031±0.018	0.085±0.007	19.35±3.12	44.87±6.78	23.23±17.95	111.60±83.01

The Ecosystem-Based Fishery Management in the Bay of Bengal

Differences in Heavy Metal Concentrations between Body Parts and among Sampling Location

Two-way analysis of variance was used to test the effects of body part and sampling station on Hg, Cd, Pb, Zn and Cu concentrations of purpleback squid (Table 4). Body part and sampling location were significant factors for Cd, and Zn concentrations. Cd concentration in visceral mass of squid in every station, except station 16, was significantly higher ($p<.01$) than the edible portion (mantle, arm and tentacle) (Fig. 2). Zn concentrations in visceral mass of squid in every station was significantly higher ($p<.01$) than the edible portion. However, the difference found for station 1 was larger than in the other stations (Fig. 2). Body part was the only significant factor for Pb and Cu concentrations. Mean concentrations of these two metals in visceral mass of squid were significantly higher ($p<.01$) than the edible portion for every station. Hg concentrations were similar for both body parts and similar among stations (Table 4). Generally speaking, there were no significant differences of heavy metals among sampling stations. Cd, Pb, Zn and Cu show higher accumulation levels in visceral mass compared to the edible portion. No significant correlations between heavy metal concentration in edible tissues and either mantle length or total body weight were found.

Table 4 Comparisons of Hg, Cd, Pb, Zn and Cu concentrations in purpleback squid (*Sthenoteuthis oualaniensis*) collected from the Bay of Bengal by sampling station and by body part (edible vs. visceral mass).

Metals	Source	df	F	P
	Station	8	1.465	ns
Hg	Part	1	0.256	ns
	Station * Part	8	0.477	ns
	Station	8	36.144	ns
Cd	Part	1	2034.466	**
	Station * Part	8	65.623	**
	Station	8	2.017	ns
Pb	Part	1	15.568	**
	Station * Part	8	1.148	ns
	Station	8	2.958	*
Zn	Part	1	233.191	**
	Station * Part	8	2.276	*
	Station	8	0.830	ns
Cu	Part	1	29.543	**
	Station * Part	8	0.401	ns

Ns = $p>0.05$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Pierce *et al.* (2008) showed that Cd concentration in digestive gland of two loliginid (*Alloteuthis* sp. and *Loligo forbesi*) and two ommastrephid (*Todarodes sagittatus* and *Todaropsis eblanae*) squid species collected from research cruise and fishery (market) samples in UK waters during 2004-2005 is higher than in muscle. Seixas *et al.* (2005) also found that concentration of Hg in digestive gland of common octopus (*Octopus vulgaris*) is higher than in the other tissue. Experimental work of Koyama *et al*. (2000) shows that oval squid (*Sepioteuthis lessoniana*) can bioconcentrate and bioaccumulate Cd from water and dietary. They also show that liver is the main storage organ for Cd in the oval squid (Koyama *et al.*, 2000). Concentrations of Cd, Zn and Cu in digestive gland of cephalopods from the various works has been summarized and reported in table 5 (notice: concentrations of the heavy metals are reported based on dry weight whereas results from this work is based on wet weight).

Hence, results from this study and those previously reported suggest that internal organs, especially digestive gland and liver, are the main storage organs for most heavy metals. Cd, Cu and Zn are the three metals that have been found highly accumulated in digestive gland and liver of cephalopods. The high contamination levels of Cd, Cu and Zn found in Japanese common squid waste (Omid and Hiroyuki, 2005) resulted from highly contaminated visceral mass which is the major component of squid waste.

Sources of Cd and Other Metals Residue in Squid

It has long been recognized that squid and other cephalopods can accumulate high levels of cadmium and other metals. Squid also play a major role in transferring these metals through the food chain (Martin & Flegal, 1975; Smith *et al.* 1984; Miramand & Guary 1980; Finger & Smith 1987; Miramand & Bentley 1992; Bustamante 1998; and Bustamante *et al.*, 1998a). However, the sources of Cd and other metal residues in squid and other cephalopods has never been clear. Squid and most other cephalopods are characterized by high growth rate, high mortality rate, high fecundity and short life. Xinjun *et al.* (2007) reported that most purpleback squid from the northwestern Indian Ocean have a life span of 0.5-1.0 year. Thus, high levels of heavy metals in these organisms are not a result of long term accumulation.

Koyama *et al*. (2000) concluded from their experimental work that accumulation of Cd in oval squid (*Sepioteuthis lessoniana*) can occur via diffusion from seawater into the body and by ingestion. Xinjun *et al*. (2007) found that stomach contents of purpleback squid from the northwestern Indian Ocean contained three major diet groups: fish, cephalopods and crustaceans, mainly *Cypselurus spp.* and *S. oualaniensis*. More than 60% of the stomachs had evidence of cannibalism for the squid larger than 400 mm ML.

Data on dissolved heavy metals in the Bay of Bengal are rare. Therefore, it is difficult to make any conclusion on the sources of the heavy metals in purpleback squid. Since purpleback squid is carnivorous and even cannibalistic (Xinjun *et al*. 2007), it appears that residues of these heavy metals come at least in part via ingestion.

Table 5 Cd, Cu and Zn concentrations (µg/g dry wt) determined in the digestive gland of cephalopods from the literature.

Species	Cd	Cu	Zn	Authors
Sepia officinalis	12.67±0.35	315±3	571±47	Miramand & Bentley (1992)
Loligo opalescens	85.0±51.6	5350±3210	247±131	Martin & Flegal (1975)
L. opalescens	121.5±57.9	8370±3130	449±201	"
N. gouldi	50±25	246±298	696±295	Smith *et al.* (1984)
Ommastrephes bartrami	287±202	195±212	163±55	Martin & Flegal (1975)
Stenoteuthis oualaniensis	782±255	1720±151	513±288	"
Eledone cirrhosa	24.00±1.75	456 ±11	646±86	Miramand & Bentley (1992)
Benthoctopus thielei	215	42	416	Bustamante *et al.* (1998a)
Graneledone sp.	369	1092	102	Bustamante *et al.* (1998a)
Octopus vulgaris		2550		Ghiretti-Magaldi *et al.* (1958)
O. vulgaris	50±10	2500±700	1450±400	Miramand & Guary (1980)

Safety Issues for Human Consumption

Table 6 compares the mean concentration of heavy metals of squid with the safety limits from several countries. The Hg, Pb and Zn concentrations in both edible tissue and visceral mass were within the safety limits at every sampling station. Mean Cu concentration in visceral mass of squid were higher than the safety limits, whereas concentrations in the edible portion were below the safety limit. Mean Cd concentration in both edible tissue and visceral mass of the squid exceeded all of the proposed safety limits at every sampling station. Cadmium concentrations in visceral mass were in fact many times higher than the safety standards. Therefore, due to Cd contamination, purpleback squid from the Bay of Bengal may not be a proper food source for humans.

Conclusion

Results from this study show that purpleback squid (*Sthenoteuthis oualaniensis*), an oceanic squid widely distributed in the Indian Ocean and the Bay of Bengal, accumulate high concentrations of Cd, Cu and Zn. The levels of heavy metals in the squid from all sampling stations were within the same range. Accumulation of these metals takes part mainly in visceral mass which contains the digestive gland, gill, and gonad, whereas accumulation in the edible portion (mantle, arm and tentacle) is lower. The concentration of Hg, Pb and Zn in both edible tissue and visceral mass were lower than safety standards. The concentration of Cd and Cu in visceral mass were higher than the safety standard. Cd was the only heavy metal found in mantle tissue to exceed safety standards, and is thus the most immediate concern for human consumption of purpleback squid. Close monitoring is necessary to follow changes of contamination levels. Further investigation may also provide a better view of contaminant sources, particularly for cadmium.

Table 6 Mean concentrations ($\mu g\ g^{-1}$) of heavy metals found in the edible portion (mantle, arm and tentacle) and visceral mass of purpleback squid (*Sthenoteuthis oualaniensis*) from all sampling stations in the Bay of Bengal and recommended safety limits.[1-5]

Heavy metals	Edible part	Visceral mass	Safety limit (µg/g)	References
Hg	0.040±0.034	0.034±0.025	0.5	1, 2
Cd	3.759±4.856*	17.47±5.70*	2, 3, 0.5	1, 3, 4
Pb	0.035±0.029	0.062±0.020	0.5, 1.5, 0.5	2, 3, 5
Zn	16.54±2.32	43.82±9.86	≤100	2
Cu	10.99±8.60	73.68±47.07*	≤20	2

[1]Australia and New Zealand Food Authority Amendment No. 53. (2000).

[2]Minsitry of Public Health, Thailand (1986).

[3]US Food and Drug Administration (2001).

[4]FAO. Report of the Codex Committee on Food Additives and Contaminants. Draft Guideline level for Cadmium in Food (http://www.fao.org/docrep/meeting/005/x7137e/x7137e20.htm)

[5]FAO. Report of the Codex Committee on Food Additives and Contaminants. Draft Maximum level for Lead (http://www.fao.org/docrep/meeting/005/x7137e/x7137e1z.htm#TopOfPage)

*indicates maximum concentration was higher than safety limit for at least one of the agencies listed.

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Appendix 1

I. Personnel of BIMSTEC Member Countries

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24	Third Engineer / THAILAND	Mr. Roengrit Jirasathit	tunaf3@hotmail.com
25	Second Officer / THAILAND	Lt. JG. Sathaporn Sawangpak	-
26	Male nurse / THAILAND	PO_1 Somchai Koknote	-
27	Assistant Cook / THAILAND	Mr. Visut Tonghong	-
28	Oiler / THAILAND	Mr. Surasak Krainate	k.surasak@hotmail.com
29	Steersman / THAILAND	Mr. Wanchai Pae-thong	-

II. Ship's Personnel of M.V. SEAFDEC and SEAFDEC/TD.

No.	Position	Name	E-mail:
1	Captain	Mr. Sonchai Bumrasarinpai	sonchai@seafdec.org
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9	Boatswain	Mr. Vanich Chaopaknam	
10	Boatswain	Mr. Somkiat Phetrasatien	
11	Able Seaman	Mr. Yuttachai How-harn	
12	Able Seaman	Mr. Jaroon Po-U	
13	Fitter	Mr. Kittinai Sukdit	
14	Oiler	Mr. Dum Tanyacharoen	
15	Oiler	Mr. Nuttapong Chaitanavisut	
16	Oiler	Mr. Teeradat Jantana	
17	Cook	Mr. Veeraphon Vorakun	
18	Able Seaman	Mr. Somsak Phangkumkuk	
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Appendix 2

Opening ceremony of the Ecosystem-Based Fishery Management in the Bay of Bengal on 30 October 2007 in Phuket Province.

Appendix 3

Oceanographic and drift gillnet operation on M.V. SEAFDEC

Appendix 4

Pelagic longline operation

Appendix 5

Closing ceremony of the Ecosystem-Based Fishery Management in the Bay of Bengal on 14 December 2007 in Phuket Province.