Highlights

SEAFDEC INTERDEPARTMENTAL COLLABORATIVE RESEARCH PROGRAM

ON FISHERY RESOURCES IN THE SOUTH CHINA SEA

AREA I

GULF OF THAILAND AND EAST COAST OF PENINSULAR MALAYSIA

SOUTHEAST ASIAN FISHERIES DEVELOPMENT CENTER

BANGKOK

TD/SP/24

HIGHLIGHTS OF THE SEAFDEC INTERDEPARTMENTAL COLLABORATIVE RESEARCH PROGRAM ON FISHERY RESOURCES IN THE SOUTH CHINA SEA

AREA I

GULF OF THAILAND AND EAST COAST OF PENINSULAR MALAYSIA

A Collaborative Research Program
between

MARINE FISHERY RESOURCES DEVELOPMENT AND MANAGEMENT DEPARTMENT,
KUALA TERENGGANU, MALAYSIA

and

TRAINING DEPARTMENT
SAMUT PRAKAN, THAILAND

THE SECRETARIAT
SOUTHEAST ASIAN FISHERIES DEVELOPMENT CENTER
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SEAFDEC 1999

MESSAGE FROM THE CHAIRMAN OF THE SEAFDEC COUNCIL OF DIRECTORS

(1999-2000)

Fisheries of the world oceans are fast entering a global crisis at the end of the 20^{th} Century, as a result of the increasing exploitation of marine resources to meet the growing demand for human food. The problems are particularly acute in the Southeast Asian Region and the SEAFDEC member countries, because of (i) the specific nature of their tropical fisheries based on multi-species exploitation; (ii) conflicts over the possession of fisheries resources and the use of fishing grounds; and (iii) the need to find a delicate balance between the supply-demand situation and the national exigencies to satisfy the aspirations of the traditional subsistence fishermen in a way to ensure both food security and job security. Overfishing, modern fishing technologies and activities of distance-fishing fleets alone cannot explain the root causes of these problems. The most balanced and viable approach to alleviate the situation may lie in realistic planning and innovative management approaches for maintaining the catches at a sustainable level that would ensure the supply on an ecologically-sound basis over the long term by rehabilitating the resource base, and at the same time satisfy the social expectations of the local communities. Lack of background information on the biological and environmental basis that support the sustenance of fish populations, their seasonal aggregations, life-cycles and movements is the fundamental deficiency in all such approaches to planning in the SEAFDEC region. The Collaborative Research Program on the Fishery Resources in the South China Sea, the main results of which are discussed in this report, was launched by SEAFDEC with financial support from the Government of Japan mainly to address this situation. I wish to congratulate SEAFDEC on taking up such a crucially important survey topic, and sincerely hope that the information generated will provide a valuable motivating tool to fisheries planners in coming up with tangible fisheries development programs in the region. Such activities will promote SEAFDEC as a regional center of excellence in the field of fisheries that will bring it enhanced visibility, respect, and authority in the global arena to represent the fisheries interests of the region.

Minoru Morimoto

(Minoru Morimoto)
Deputy Director-General
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PREFACE

Due to gross over-exploitation and paucity of adequate information on fishery oceanographic, marine environmental and biological conditions, fisheries of the South China Sea region have become greatly impoverished in recent times. The deficiency in scientific intelligence has also circumscribed all attempts at substantive and tangible planning and management of fisheries throughout the region. Perceiving the vital importance of fundamental information for sustainable fisheries planning and management, the Training Department [TD] and the Marine Fishery Resources Development and Management Department [MFRDMD] of SEAFDEC jointly launched an Interdepartmental Collaborative Research Program on Fishery Resources in the South China Sea in 1995.

The first of the four defined survey areas, covering the Gulf of Thailand and the East Coast of Peninsular Malaysia was surveyed during two cruises of the Training and Research Vessel, MV SEAFDEC [Two fishery research vessels also joined in exploratory fishing surveys], in September-October 1995 and April-May 1996, by scientists from TD and MFRDMD, and invited institutions, departments and universities. The scientific findings were presented at a Technical Seminar held in Bangkok, Thailand, on 24-26 November 1997 and the proceedings published. This report focuses attention on the major findings of the survey, highlighting its implications to the fishery oceanographic phenomena, fish production mechanisms and marine food chain characteristics in the region. It is fervently hoped that the findings of this survey and information generated will provide a valuable motivating tool to fisheries administrators, managers and development planners to give shape and substance to feasible fisheries programs in the future, and will furnish the scientific data to realize them.

SEAFDEC wishes to record its appreciation to the Government of Japan for the generous financial assistance provided to facilitate the Collaborative Research Program, as part of its long-standing support for the operation of the Center, since its inception. SEAFDEC also wishes to thank all the scientists, the staff of TD and MFRDMD, and the captain and crew of the ship, for their contributions, selfless efforts and dedication in making this scientific expedition a success. Special thanks are due to Dr. Maitree Duangsawasdi and Mr. Udom Bhatiyasevi for their foresight in promoting and stimulating the Collaborative Research Program during their tenures as Secretary General of SEAFDEC.

(Panu Tavarutmaneegul)
Secretary General
SEAFDEC

CONTENTS

1. INTRODUCTION

Fisheries in the South China Sea is extremely complex mainly because of the large variety of species involved and their diverse mechanisms of biological production, sustenance and habits, which bring about a very composite tropical marine ecosystem to operate in the region. Studies have suggested that, unlike in many other tropical ecosystems, benthic organisms may form the dynamic basis of the marine food chain in the area, which explains the well-known abundance of demersal fishery resources in such areas as the Gulf of Thailand, which was one of the richest fishing grounds in the region in recent times. The mechanisms of the system are, however, still far from clear as shown by the recent changes in the nature and pattern of fisheries, whereby the ecological void brought about by the decrease in grazing pressure caused by overfishing of mainly bottom-feeding carnivores was quickly filled by short-lived species and small demersal prey such as squids and *Scolopsis* sp., which precipitated a new fishery on its own. Moreover, all the information that has come to light so far, emerged from an analysis of the situations after they had occurred or came about, rather than through preplanned systematic research and analysis.

Fisheries in the South China Sea region are seriously affected in recent times for lack of adequate background information on fishery oceanographic and environmental conditions that support the fish population, and sufficient knowledge on how they affect the seasonal distribution and fluctuations of fish abundance. An in-depth planning of sustainable fisheries development, both at the national and regional level, could also not be attempted because of this limitation. The fundamental objective of SEAFDEC's Interdepartmental Collaborative Research Program on Fishery Resources in the South China Sea is to provide a database on fishery oceanographic and marine environmental conditions, and information on fisheries production mechanisms, protection of fisheries environment and fish breeding habitats, which is needed to plan sustainable fisheries resources management in the long term. The geographical area of the South China Sea within the Exclusive Economic Zones [EEZ] of SEAFDEC's member countries was divided into four areas for the purposes of the survey, and the Gulf of Thailand and the Malaysian EEZ waters along the East Coast of Peninsular Malaysia, were designated as Area I under this scheme.

Of the two monsoons prevailing in the area, the southwest [SW] monsoon that blows from May to September is weak in the Gulf area, but more persistent in Malaysian waters. The northeast [NE] monsoon from November to January [which sometimes extends to February or even March] is influential in the region, and the conditions that it brings about most affect the fishery oceanography, fish production mechanisms and fish distribution patterns. For a better understanding of these mechanisms and the fishery oceanographic effects of the NE monsoon, Survey Area I was studied during two cruises so timed to straddle the NE monsoon season, in order to bring out the influences and effects of the monsoon [the first cruise no. 26-8/1995 from 4 September to 4 October 1995, and the second cruise no. 32-4/1996 from 23 April to 23 May 1996], and 81 sampling stations were repeated at the same coordinates, as shown in the station grid map [Fig. 1]. The style applied in planning the survey work was to analyze the situation through static studies on various parameters and structure of communities at different trophic levels of the food chain and, whenever possible, to supplement the same through dynamic studies on functional aspects of these communities. However, information on the structure of communities was so lacking in many instances to support any studies on their functions. Under the circumstances, interpretations had necessarily to be restricted to quantitative correlations with the different trophic levels whenever possible, in terms of their significance to fishery production potential. In particular, such an approach ignored the external environmental influences upon the marine ecosystem and their implications, particularly if direct proof or evidence is sought as a basis for scientific analysis and conclusions. The picture so obtained was also rather two-dimensional. However, it is hoped that the data and information on community structure at the different trophic levels, brought to light through these studies, will provide the foundation for more detailed analysis of their functions and operational dynamics in the future.

The scientific results of the Collaborative Research Program in Area I, the salient findings of which are highlighted in this report, were discussed at a technical seminar held in Bangkok, Thailand, on 24-26 November 1997, and the research papers were compiled in a volume of proceedings, which are listed under the bibliography at the end of this report.

Studies in Area II [Waters of Sabah and Sarawak in Malaysia and Brunei Darussalam] and Area III [West Coast of Luzon Island in the Philippines] have already been completed, and studies in Area IV [the Vietnamese waters] are presently underway. When all the studies are completed, it is planned to eventually put together the salient findings from all the areas to produce a composite picture of fishery oceanographic conditions of the entire SEAFDEC region of the South China Sea, as a database for the SEAFDEC Geographic Information System [GIS] that is being developed.

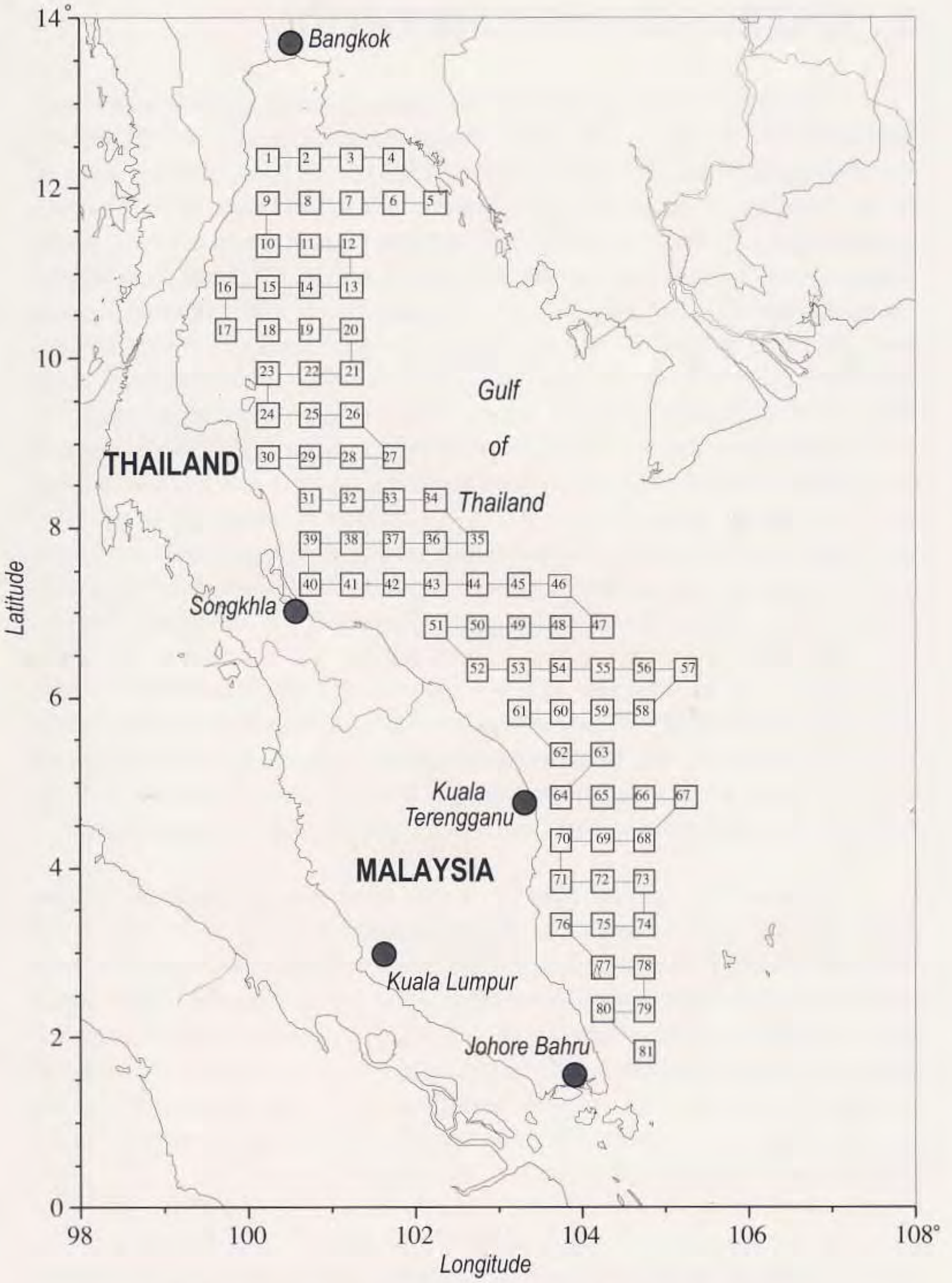


Fig. 1. Map of survey area with cruise track and station grid.

2. MATERIALS AND METHODS

Two cruises were conducted on board the Training and Research Vessel, MV SEAFDEC [Plate 1]. The Thai Fisheries Research Vessel, RV PRAMONG 4 and Malaysian Fisheries Research Vessel, KK MANCHONG also participated in the studies, mainly for exploratory fishing surveys. The physical oceanographic parameters were measured by the Falmouth Scientific Integrated Conductivity, Temperature and Depth Sensor Unit [ICTD][Plate 2], using the sampling rate of 25 Hz. Temperature was corrected to ITS 90 standards. Salinity was calculated by the PSS 78 scale. Dynamic depth relative to the surface was calculated by the EG & G CTD Post-acquisitive Analysis Software at every dbar pressure interval. Density figures were derived from temperature and salinity data using sigma-t computation tables. The dissolved carbonate system in seawater was calculated from total alkalinity and pH was measured using the *in situ* sensor attached to the ICTD [It was later measured on board using the Fisher Scientific Model 1002 pH Meter, when the pH sensor malfunctioned]. Total alkalinity was measured as the capacity of seawater to neutralize hydrochloric acid and the saturation level of seawater was calculated from the ratio between actual carbonate concentration and its concentration at equilibrium. Light intensity in the water column was measured by Alec Electronics Model SPI-9W Underwater Lux Meter. Continuous oxygen profiles were obtained using the Beckman polarographic electrode connected to the ICTD unit and the raw data was averaged at every dbar pressure level [The readings were calibrated at some stations by the Winkler titration method].

Large-scale water samples for various chemical and planktonic studies were collected using a van Dorn Water Sampler [Plate 3] or Rosette Water Sampler [Plate 2]. Seawater samples for dissolved trace metal analysis were collected with a Teflon-coated General Electric GoFlo Sampler. Trace metals from filtered seawater were co-precipitated with cobalt-APDC and the precipitate solutions in nitric acid were measured using a Perkins-Elmer Zeeman Graphite Furnace 4100ZL Atomic Absorption Spectrophotometer. Petroleum hydrocarbons were extracted with nanograde Hexane and measured with a spectrofluorometer using Chrysene as the standard.

Bottom sediments were collected by Smith-McIntyre Bottom-grab and Gravity Corer [Plate 4]. The sedimentological characteristics were analyzed using a Laser Diffractometer with a Malvern-E Particle-size Analyzer, or a sieve for determining skewness and kurtosis. Total organic matter was determined either by measuring weight loss after ignition or by potassium chromate wet oxidation method. Acid volatile sulfide levels were measured by using the Gastec Model 2011 H_2S-absorbent column after acidifying with sulphuric acid. For trace metal analysis, they were dried, ground, sieved and digested in a mixture of nitric, perchloric and hydrofluoric acids. Trace metal concentrations were measured with a Flame Atomic Absorption Spectrophotometer. Cadmium and lead were measured with a Hitachi Z-8270 Graphite Furnace. For hydrocarbon estimates, the Total Aliphatic Hydrocarbons [TAH] and Polynuclear Aromatic Hydrocarbons [PAH] were separated and extracted with a Silica gel and Alumina column, dried and analyzed using a gas chromatograph.

Primary production was measured at selected stations during the second cruise, using the carbon-14 *in situ* dark and light bottle method. Water samples from selected depths were inoculated with radioactive bicarbonate and exposed to sunlight for three hours at their original depths of collection. The absorbed radioactivity by the exposed phytoplankton in the bottles was determined by GC-9A Model Schimadzu Beta-scintillation Counter. Primary production values were calculated from percentage radioactivity absorbed during the exposure period, as photosynthetic rates by the chlorophyll units at the prevailing light intensities at different depths. *In situ* fluorescence was recorded at every meter by the Sea Tech Submersible Fluorometer, which was converted to chlorophyll values using the standard linear correlation curves from actual chlorophyll values measured by spectrophotometer. This was extrapolated over the water column to obtain the production rate/m^2 and integrated over the daylight time using *in situ* biomass, hourly light intensity profiles and time-integrated unit production rates. Using available light intensity at each depth as the basic factor, the values could be further checked through positive correlations between light - depth curves, light - time curves and light - photosynthetic rate curves.

Water samples for phytoplankton were filtered through a phytoplankton net of 20 microns mesh size, preserved and examined both with a compound microscope with phase contrast devise and an electron microscope. Blue-green algae were counted by filaments only. The standard plankton net, with an opening of 45 cm and a mesh size of 56 microns was used for microplankton sampling, and was vertically hauled at a speed of one knot from twice the depth of 1% surface illumination to the surface. The bongo net [Plate 5] was used for oblique hauls, with an opening of 60 cm, and a mesh size of 500 microns at the mouth and 330 microns near the tapering end. Zooplankton samples were collected by hauling the net for about 30 minutes at a speed of 2 knots. Fish larvae were collected by surface sampling using the standard larvae net [also in Plate 5] with an opening of 1.3 m, and 5 mm mesh size at the mouth and 330 microns towards the tapering end, and also by oblique hauls with the bongo net. The amount of water filtered was measured with a flow meter. Benthos was collected by washing the Smith-McIntyre Bottom-grab samples through a set of metallic sieves.

Fish sampling and exploratory fishing were conducted using a high-opening otter-board bottom trawl net, with a mesh size of 25 mm at the cod-end, towed at a speed of 3 knots. Fish samples for species diversity studies were also collected from the local landing piers and fish markets during port calls of the vessel.

Multi-species abundance [density] and biomass of pelagic and demersal fish stocks were estimated from volume back-scattering strength recordings [SV values] at 50 kHz and 200 kHz of the Furuno Scientific Echo Sounder FQ-70, equipped with an echo-integrator and two quasi-ideal beam transducers, which were corrected to eliminate the interference from macroplankton species, noise from other electrical devices and echoes of rough sea conditions, and correlated with the fishery statistics data of recent local fish landings of commercially important species.

Plate 1. Training and Research Vessel MV SEAFDEC.

Plate 2. ICTD Unit with Rosette Water Sampler.

Plate 3. van Dorn Water Sampler.

Plate 4. Smith-McIntyre Bottom-Grab and Gravity Sediment Corer [in front].

Plate 5. Fish larvae net (left) and Bongo net (right).

3. OCEANOGRAPHY AND MARINE ENVIRONMENT

a. FISHERY OCEANOGRAPHY

Oceanography of the survey area is governed by the combined effects of topographical features, tidal regimes, monsoonal water circulation, freshwater runoff, coastal upwelling and downwelling, and offshore water intrusions. Annual surface water temperature in the Gulf varies very little, ranging from 28.40°C - 29.51°C [average, 28.97°C] during the pre-NE monsoon, and 27.78°C - 30.76°C [average, 29.91°C] during the post-NE monsoon season. Before the NE monsoon, surface waters were cooler by about 1°C with corresponding higher densities and bottom temperatures were warmer by about 0.5°C, except in the southern parts of Eastern Peninsular Malaysia. Waters of the Gulf of Thailand were well-mixed before the NE monsoon and the thermocline layers became more distinct after the monsoon. Although the thermocline was recorded both before and after the NE monsoon along the East Coast of Peninsular Malaysia, it moved upwards towards the surface after the monsoon, indicating a decrease in vertical mixing, and surface temperatures became more uniform from north to south. Generally, overcast skies during the NE monsoon season cools the sea surface, which increases the density. Simulated temperature distribution contours at different depths in the Gulf of Thailand during the pre- and post-NE monsoon seasons are shown in Figs. 2 and 3 respectively.

Mean salinity of surface water is highest from July – September and lowest during October – November, mainly due to river discharges. Surface water had higher salinity before the NE monsoon in the Gulf of Thailand, [ranging from $31.2^0/_{00}$ - $33.31^0/_{00}$, for an average of $32.83^0/_{00}$ during the pre-NE monsoon, and $31.63^0/_{00}$ - $33.70^0/_{00}$,, for an average of $32.41^0/_{00}$ during the post-NE monsoon]. Although halocline and pycnocline were recorded throughout the study area before and after the monsoon, both migrated upwards after the monsoon, clearly indicating a decrease in vertical mixing just as in the case of the thermocline. Density fluctuations are influenced mainly by salinity changes, ranging from 19.41 - 20.82, for an average of 20.45 during the pre-NE monsoon, and from 19.18 - 21.35, for an average of 19.82 during the post-NE monsoon. Densities were higher in the upper parts of the Gulf before the NE monsoon. Surface waters are separated from cooler and more saline deeper waters by a sharp discontinuity layer in the offshore areas. Thickness of the discontinuity layer gradually decreases towards the shore until it dissipates in shallow waters because of the effects of vertical mixing. Heavy freshwater runoff from land

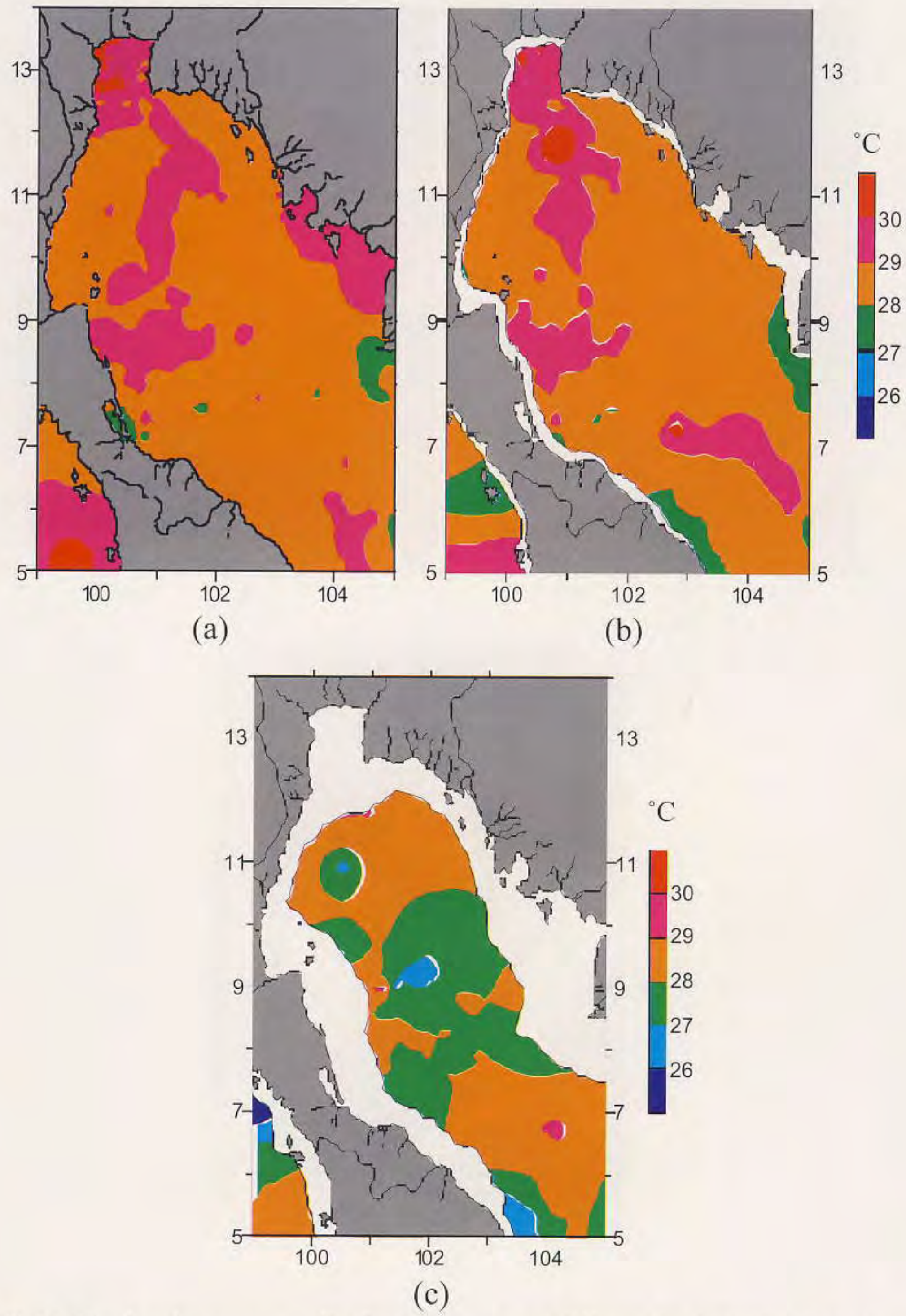


Fig. 2. Simulated temperature distribution contours at different depths during the pre-NE monsoon period (September-November): (a) Surface layers, 0-10m; (b) Mid-depth layers, 10-40m; and (c) Sub-pycnocline deeper layers, >40m.

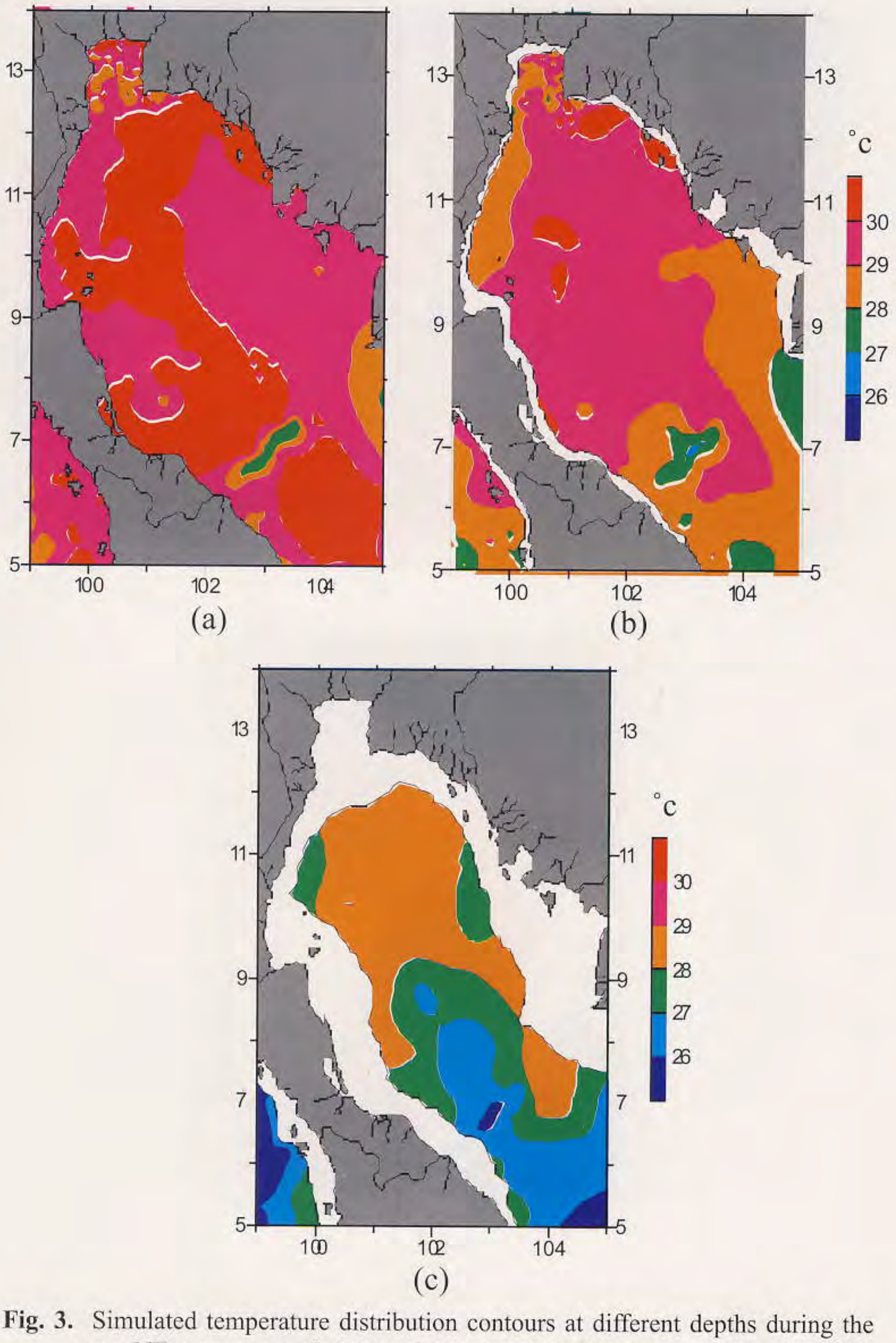


Fig. 3. Simulated temperature distribution contours at different depths during the post-NE monsoon period (March-May): (a) Surface layers, 0-10m; (b) Mid-depth layers, 10-40m; and (c) Sub-pycnocline deeper layers, >40m.

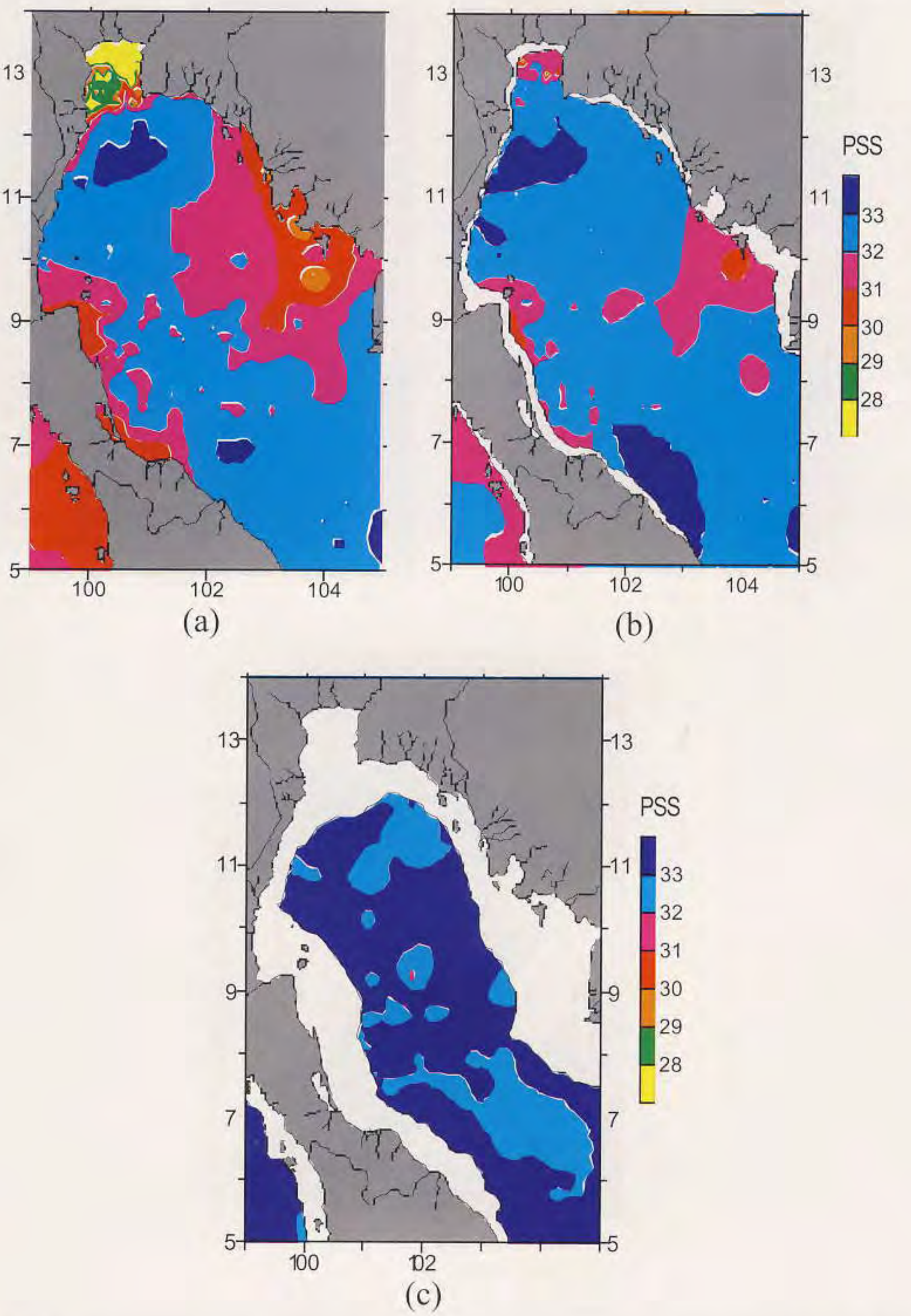


Fig. 4. Simulated salinity distribution contours at different depths during the pre-NE monsoon period (September-November): (a) Surface layers, 0-10m; (b) Mid-depth layers, 10-40m; and (c) Sub-pycnocline deeper layers, >40m.

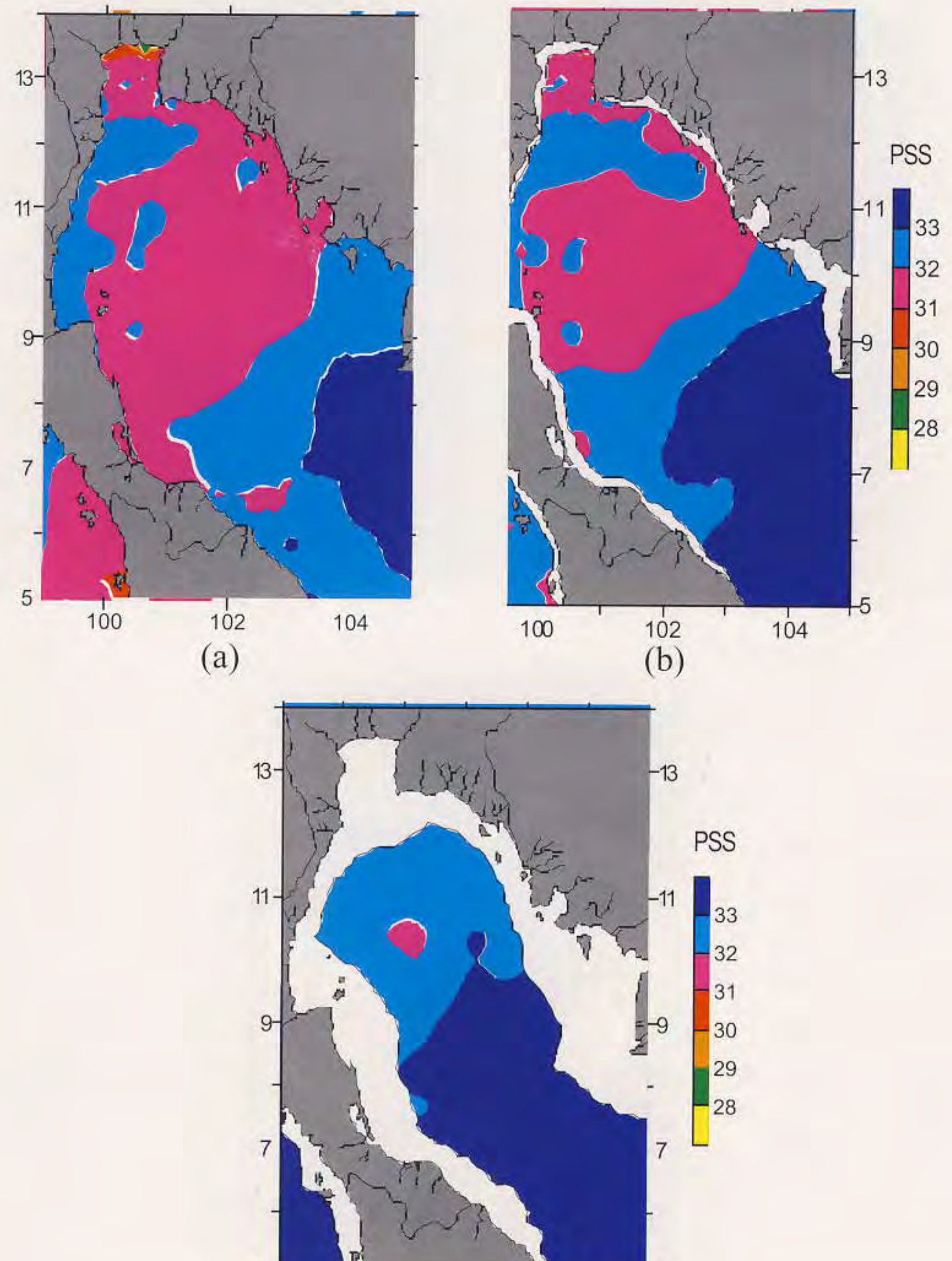


Fig. 5. Simulated salinity distribution contours at different depths during the post-NE monsoon period (March-May), showing the intrusion of high-saline, low-oxygen, mid-depth water from South China Sea into the Gulf: (a) Surface layers, 0-10m; (b) Mid-depth layers, 10-40m; and (c) Sub-pycnocline deeper layers, >40m.

brought about by NE monsoon rains reduces surface salinity and density, resulting in the consolidation of the discontinuity layer, which stands out particularly in deeper waters. Simulated salinity distribution contours at different depths in the Gulf during the pre- and post-NE monsoon seasons are shown in Figs. 4 and 5 respectively.

Net circulation is an important parameter that governs the distribution, dispersion and residence of both dissolved and suspended materials of both biotic and abiotic nature, that determines the distribution patterns of the properties of seawater and the oceanographic situation prevailing in any given area. Prevailing monsoon winds determined the current patterns and water movements above the pycnocline [0-40 m layer] in the Gulf of Thailand. Surface water movements [0-10 m] were generally anti-cyclonic during the SW monsoon and cyclonic during the NE monsoon. Study of physical characteristics of the water masses in the area, and pattern of movements of the thermocline, halocline and pycnocline layers from the deeper to the shallower areas in the transitional [inter-monsoon] periods of the NE monsoon season, indicates possible occurrence of upwelling and downwelling processes in the region, brought about by the effects of the monsoon.

Concentrations of oxygen and carbon dioxide in seawater is the net result of all biological processes, air-sea exchanges at the surface, lateral transport to and from the area and reactions with solid phases such as calcium carbonate. Surface waters were well in equilibrium with the atmosphere as regards dissolved oxygen and carbonate-carbon system is concerned, and supersaturated with mineral calcite, but sub-pycnocline waters [>40 m] of the Gulf of Thailand had a distinctly different chemistry from other areas outside the Gulf. Oxygen concentrations in the sub-pycnocline deep waters of the Gulf were clearly lower than surface waters and deep waters in other areas [Fig. 6 and 7], indicating that net respiration of organic matter in these layers exceeded primary production. Chemistry of deep waters along the East Coast of Peninsular Malaysia also varied considerably during the two seasons. Partial pressure of dissolved carbon dioxide in the sub-pycnocline deeper waters showed a very similar pattern to that of dissolved oxygen. As indicated by the distribution pattern of low oxygen deeper waters in the region and other indicators, intermediate waters from the South China Sea intrude into the Gulf along the coasts of Vietnam and Cambodia [Fig. 5]. This water circulates anti-clockwise near the bottom and flows south along the Gulf coastline of Thailand and Peninsular Malaysia. The water balance indicated a net gain of water in the Gulf during the NE monsoon. In recent years, there has been a noticeable increase in the annual rise of the mean sea-level during this season.

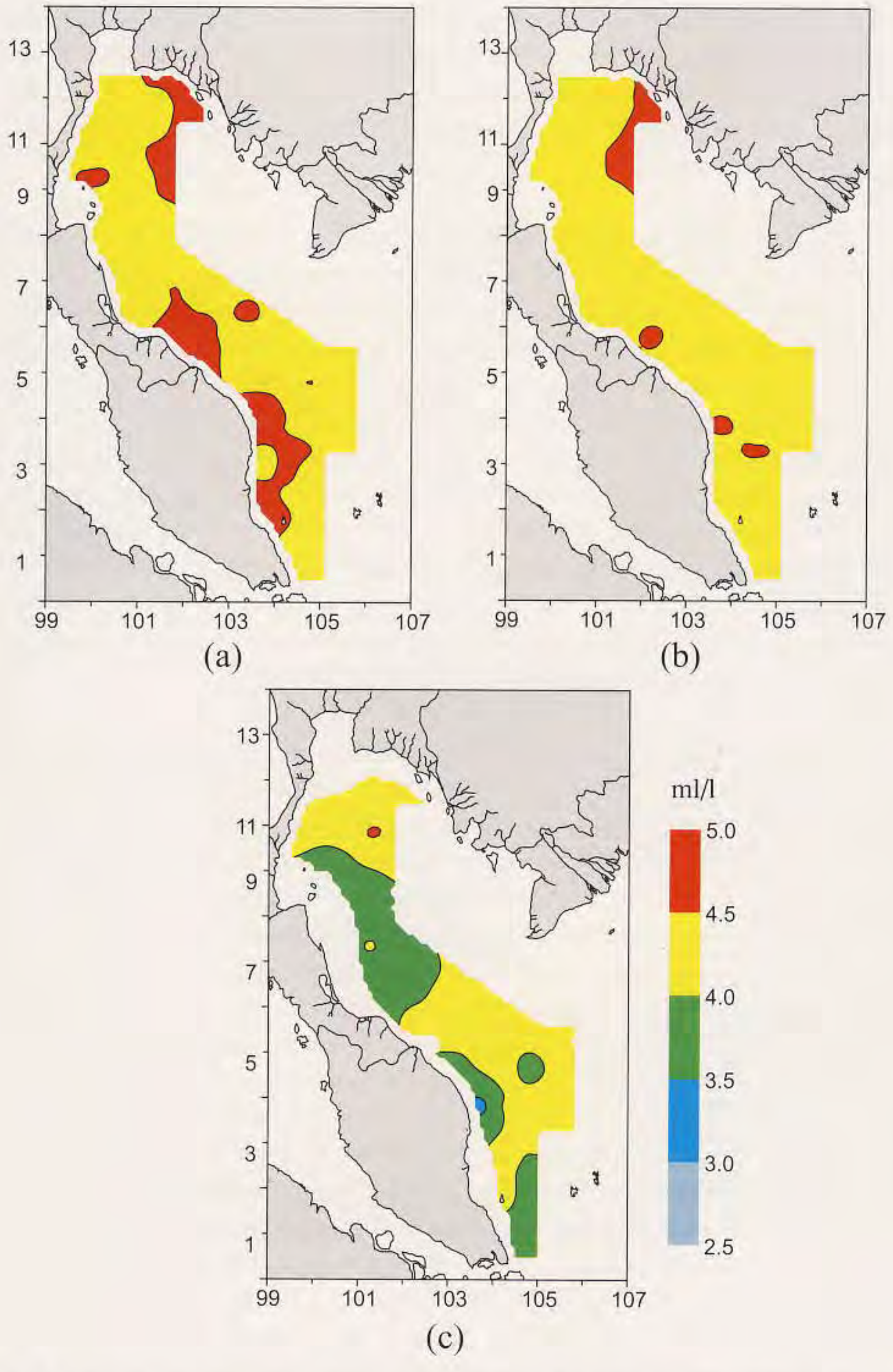


Fig. 6. Dissolved oxygen distribution at different depths during pre-NE monsoon: (a) Surface layers, 0-10m; (b) Mid-depth layers, 10-40m; and (c) Sub-pycnocline deeper layers, >40m.

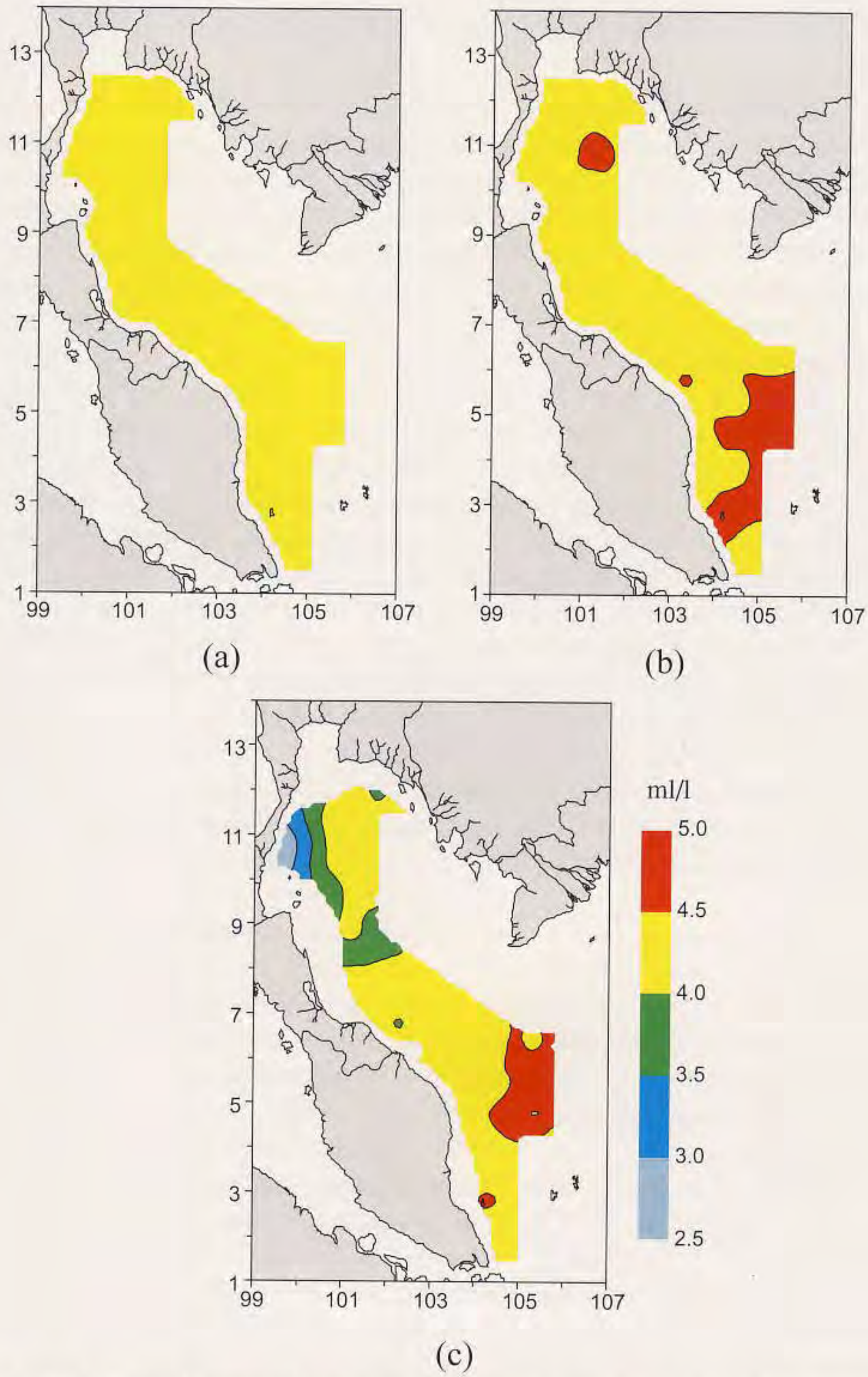


Fig. 7. Dissolved oxygen distribution at different depths during post-NE monsoon: (a) Surface layers, 0-10m; (b) Mid-depth layers, 10-40m; and (c) Sub-pycnocline deeper layers, >40m.

b. SEDIMENTOLOGY AND GEOCHEMISTRY

Sediments tell the sequence of changes that have taken place over time in a given area, and during their formation and diagenesis, take an active part in the biochemical cycles of the elements that affect the overlying water column through many processes. Bottom characteristics showed mainly muddy deposits in the upper Gulf and sandy deposits further south, with abundant calcareous biogenic remains in the Central Gulf, ranging from sandy clay to clayey sand [Fig. 8]. Sandy clay covered virtually half of the survey area, and clay and clayey sand covered 28.75% and 15% of the area respectively. Coarse sediment, such as dull yellow to orange-brown sand and gravel, settled almost exclusively in the near-shore areas, and fine-grained particles, such as greenish-gray to dull gray silt and clay, usually deposited in more stagnant waters further offshore in the Gulf. Monsoonal turbulence kept the finer particles in suspension, while the more protected Inner Gulf provided stable conditions for sedimentation, which also indicates a high degree of organic decomposition. After the NE monsoon, sediments were generally finer but with a wider range in grain size, more positively skewed and more peaked with larger average kurtosis values, especially in the Upper Gulf, where the dominant texture changed from silty clayey loam to silty loam [Fig. 8]. Near-shore sediments turned more sandy after the NE monsoon, reflecting the high degree of erosion in coastal areas and freshwater runoff from land. Earlier studies had suggested that suspended brownish silty clay brought by the discharges of Chao Phraya and other rivers dispersed widely in the Inner Gulf, but does not spread out beyond that area.

Bottom sediments in the area had relatively low amounts of total organic matter and acid volatile sulfides, which were more or less constant vertically. Hard-clayey sediments had higher levels of organic matter. Low levels of total organic matter clearly indicate a relatively oxidized condition of the seabed and low productivity of the water column. Low sedimentation rates of organic matter, coupled with high decomposition rates could play an important role in fast diagenesis of organic substances, and distribution patterns of total organic matter clearly reflect what is left over after their decomposition by biochemical processes. However, pockets of high sedimentation rates with rich benthic communities were identified in some areas, in addition to heavy deposits at river-mouths in the Upper Gulf. This could result in enhanced phytoplankton production in the upper layers due to biogeochemical interactions at the sediment-water interface, causing an aggregation of grazing organisms, particularly including fish. Organic accumulation and abnormal levels of several other parameters near Samui Island indicate the effects of the confluence brought about by the intrusion of high-salinity mid-depth water mass from the South

China Sea into the area. Because of the high productivity resulting from these conditions, plankton-feeding pelagic fish aggregate here, making it a rich fishing ground.

Water content of deposits, which usually reflect their physical properties and mineralogical composition, showed an accumulation of finer particles in the Inner Gulf, accentuated by low water movements in the area. It also affects particle movement patterns of bottom sediments brought about by critical current velocities, especially during monsoon-generated turbulence. The water content also indicated a trend of gradual decrease from mud to sand content, which also correlated with the fluctuation patterns in levels of total organic matter. This property also showed a gradual vertical decrease from surface downwards, mainly because of the effects of compaction. Fine-grained sediments with high water content usually accumulated in two major depositional zones to form deposits rich in organic matter, that reflected the high surface area for organic adsorption offered by such deposits. Water content in the surface sediments along the coastline also decreased to some extent after the monsoon, which areas of fluctuation incidentally coincided with the exit path taken by the mid-depth water from the South China Sea, as discussed earlier.

Low levels of organic productivity is also indicated by the lack of anoxic conditions that occur where the degree of organic loading of detritus particles and their decomposition levels are high. Levels of acid volatile sulfides in the surface sediments were extremely low in the study area, except in isolated pockets especially near the shoreline, which correlated with low levels of organic decomposition. Sulfide levels gradually decreased from the surface sediment [2-4 cm layer] downwards. Abrupt fluctuations in sulfide levels near the surface in some areas, particularly along the shoreline, might reflect the effects of frequent disturbances of bottom deposits caused by trawling activities, together with high organic loading from the overlying water column.

c. MARINE POLLUTION

Petroleum residues in the marine environment originate from urban runoff, industrial wastes, domestic effluents, shipping, as well as offshore oil exploration, exploitation and transportation, and possibly natural seepage. Because of their relative insolubility in seawater and high adsorption on particulate matter, they eventually end up in bottom sediments. Higher, but variable concentrations of Total Aliphatic Hydrocarbons [TAH] were found in the Gulf sediments [Fig. 9], which were mostly of the long-chain type. Polycyclic

Aromatic Hydrocarbons [PAH] followed a similar pattern of distribution as TAH, and were composed of seven benzene compounds. Both petroleum hydrocarbon groups, mostly composed of degraded crude oils, combusted hydrocarbons and alkanes, should be considered predominantly of land origin and anthropogenic in nature. For some reason, the hydrocarbon levels in seawater in the Upper Gulf have not shown any increase during the last fifteen years, although this may most probably be because of the different methodologies applied and varieties of standards used. Only stations close to metropolitan areas showed an increase of >0.5 micrograms/l of hydrocarbons, which is fully understandable. Some offshore sediments also yielded high concentrations of hydrocarbons [Fig. 9], which might probably be related to the effects of shipping activities and possibly oil exploration and exploitation, but this remains to be verified.

Trace elements in seawater are derived from continental rocks by weathering and leaching, and also increasingly from human activities, of the influences of which, some of them could often be taken as an indicator, especially in semi-enclosed areas, such as the Inner Gulf. Low concentrations of dissolved cadmium, iron, lead and nickel in the water column were within the range normally found in near-shore areas. Levels of copper and iron were determined by external input rate, particularly from freshwater runoff and horizontal dispersion, while distribution patterns of cadmium, lead and nickel indicated their removal by biological processes and regeneration by organic decay and internal recycling, often called 'nutrient-type' behavior. These trace metals are anthropogenic in character and are a good indicator of human impact and imprint on environmental quality.

Surface sediments yielded higher concentrations of aluminum, chromium, copper, manganese and lead within the Gulf during the pre-monsoon cruise, although cadmium, iron and zinc levels did not show significant differences between the Gulf and the more southerly areas. After the NE monsoon, aluminum, copper and manganese still maintained higher values in the Gulf, while chromium, iron and zinc levels were more similar in both the areas. Lead content was higher after the NE monsoon, while zinc and copper concentrations varied in the two areas. Low copper : aluminum ratios in the surface sediments further south may indicate a state of depletion of copper. In the Gulf area, chromium, iron, manganese and zinc yielded higher values before the NE monsoon, while only copper and lead were significantly higher after the monsoon. Further south, chromium, iron and manganese showed higher levels during the pre-NE monsoon cruise. Lead levels showed an increase after the NE monsoon, while copper and zinc concentrations remained at the same

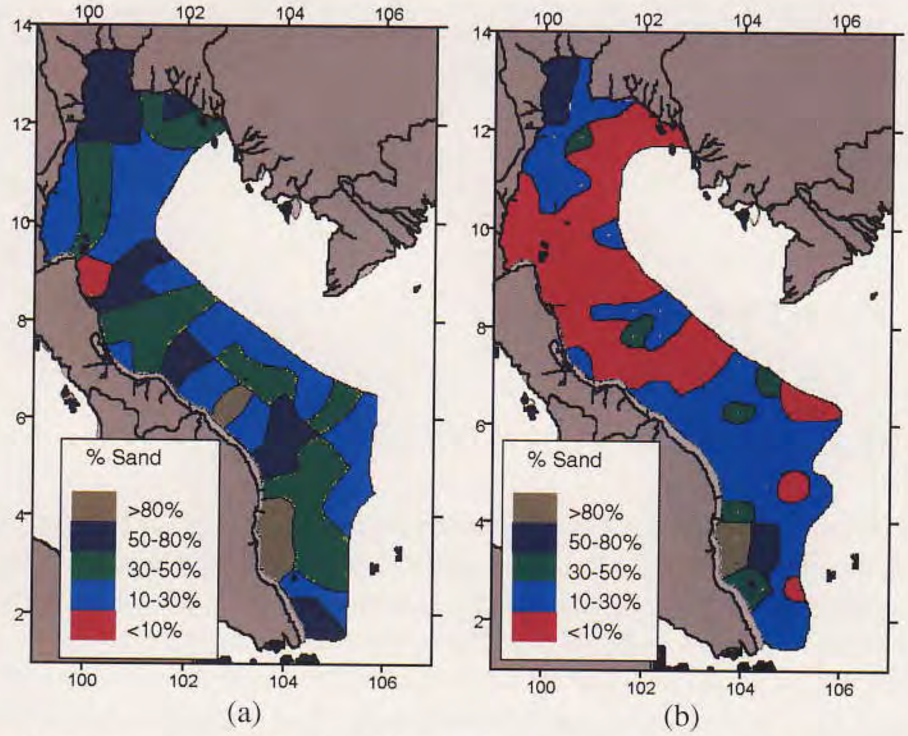


Fig. 8. Sand content distribution [%] in surface sediment: (a) Pre-NE Monsoon; and (b) Post-NE Monsoon.

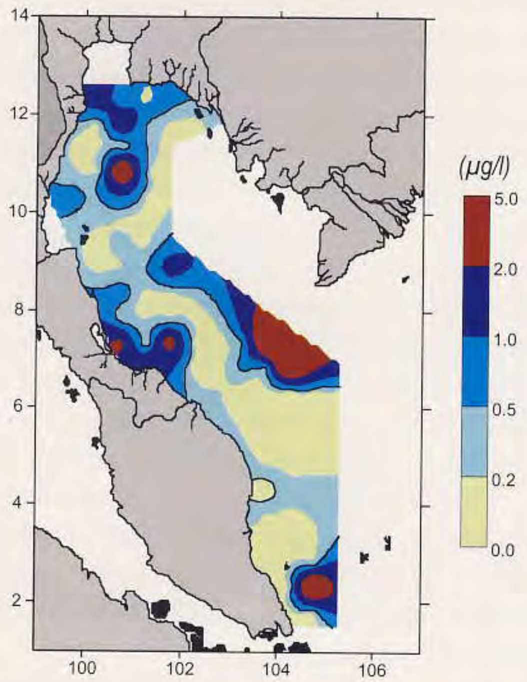


Fig. 9. Distribution of petroleum hydrocarbons in seawater during post-NE monsoon (contour lines of chrysene equivalent).

level. Broad seasonal variations in trace element peaks indicate the effects of monsoonal turbulence that cause significant movements in surface sediments. Silt and clay also bind higher amounts of metals both through absorption and adsorption.

4. MARINE BIOLOGY

a. PRIMARY PRODUCTION

Primary production is the fundamental biological process that sustains life in the sea and indicates its trophic potential at the basic level of the marine food chain. Primary production values, determined by the carbon-14 uptake method and calculated from *in situ* fluorescence [chlorophyll-a against light intensity curve] and light penetration measurements [linearly correlated light-depth (L-D) relationship], ranged between 0.20 - 0.61 and 0.29 - 0.47 $gC/m^2/$ day in the Gulf of Thailand and along the East Coast of Peninsular Malaysia respectively. As expected, the production rates were higher at the near-shore stations and decreased vertically with depth, controlled by turbidity levels, decreasing light penetration and variations in concentrations of phytoplankton [active chlorophyll]. Surprisingly, the primary production rates seem to correlate more with the vertical chlorophyll-a profiles than with the light penetration curves, especially where production rates show an increase at the depths of chlorophyll maxima that are prevalent at the sub-pycnocline layer at some offshore stations [Fig. 10]. This may be caused by low concentrations of phytoplankton standing crop sometimes recorded in the upper subsurface mixed layers at some stations, which relate well with the light-depth curves, that goes to show that light penetrates down to the pycnocline layer because of low phytoplankton concentration, but attenuates fast below that layer because of phytoplankton accumulations at that depth. Production rates decrease below this layer despite the plankton accumulation, because lack of light acts as a limiting factor. The inverse correlation between dissolved oxygen and *in situ* fluorescence resulting from this situation is very characteristic at majority of the stations studied. The productivity in the survey area provides an excellent basis for sustaining a rich food chain, as shown by abundant pelagic fisheries in the Gulf in the past.

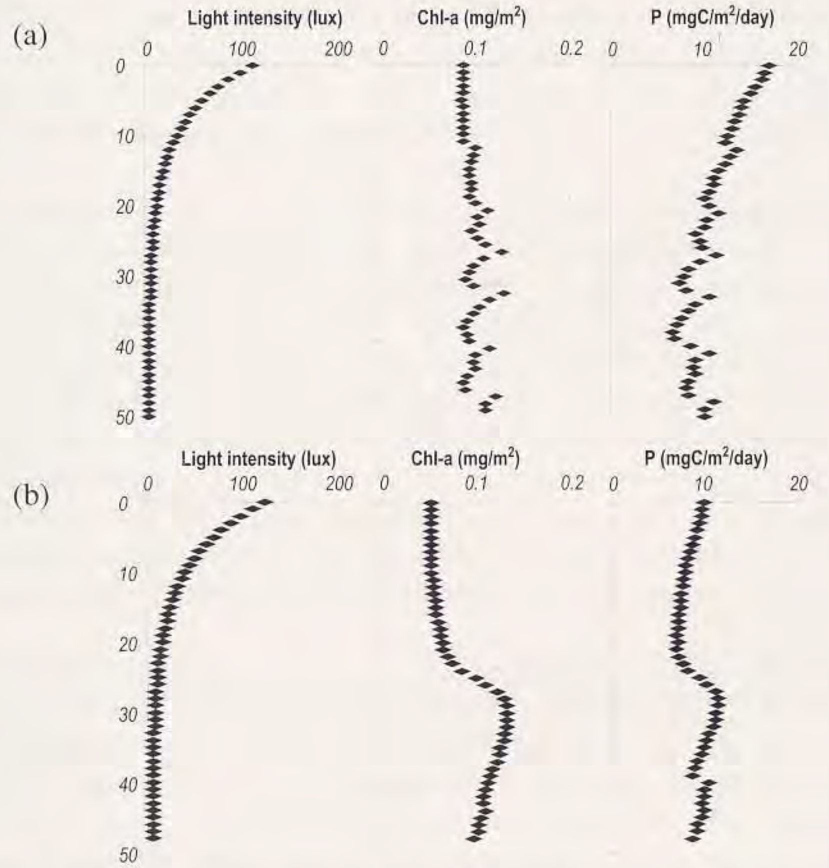


Fig. 10 Correlation between vertical distribution of light penetration curves, Chlorophyll-a values and primary production rates at (a) station 6 and (b) station 43 on September 6 and 17, 1997 respectively, showing the production peaks at the depths of chlorophyll maxima.

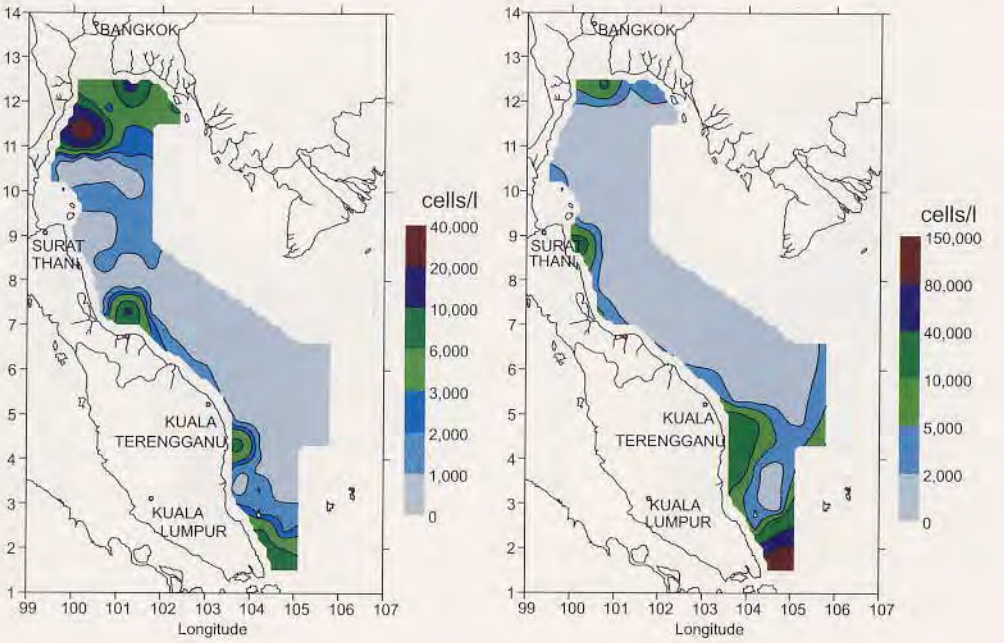
b. PHYTOPLANKTON

Phytoplankton is the primary producer of organic food supply in the marine food chain and therefore an important basic link in the production and sustenance of life at sea, including fish. Studies on species composition, abundance and distribution of phytoplankton identified 133 species of diatoms [55 genera], 107 species of dinoflagellates [31 genera] and two species of blue-green algae [2 genera], of which 17 diatoms and one blue-green alga were predominant. The genera *Chaetoceros, Rhizosolenia, Coscinodiscus, Bacteriastrum* and *Ceratium* had the widest range of species. The most dominant diatom species were *Chaetoceros lorenzianus, C. costatum, Thalassionema frauenfeldii, Skeletonema costatum, Pleurosigma elongatum, Bacteriastrum* *comosum, Bacillaria paxillifera, Coscinodiscus jonesianus* and *Rhizosolenia calcar-avis*. Dinoflagellates were usually more common in the offshore waters and were predominated by *Ceratium fusus, C. pentagonum, C. arietinum, Protoperidinium* sp., *Protoceratium* sp., *Ceratocorys* sp. and *Alexandrium* sp.

Diversity index ranged from 1.95 to 3.4 in the of fshore areas, with increasingly high values towards the coast, and followed a very similar trend during both the seasons. The evenness index was directly proportional to the diversity index. Percentage abundance of diatoms during both the cruises was high in the Upper Gulf, ranging from 63 - 91%, which decreased drastically to 6 - 22% in the offshore areas. Studies on distribution patterns through station cluster analysis clearly show patchiness of the standing crop, where phytoplankton aggregates at localized foci of abundance in usually near-shore semi-enclosed areas with more stable conditions, except for *Trichodesmium*, accumulation patterns of which, as a predominantly surface species, are solely determined by prevailing wind patterns, mainly wind direction and speed.

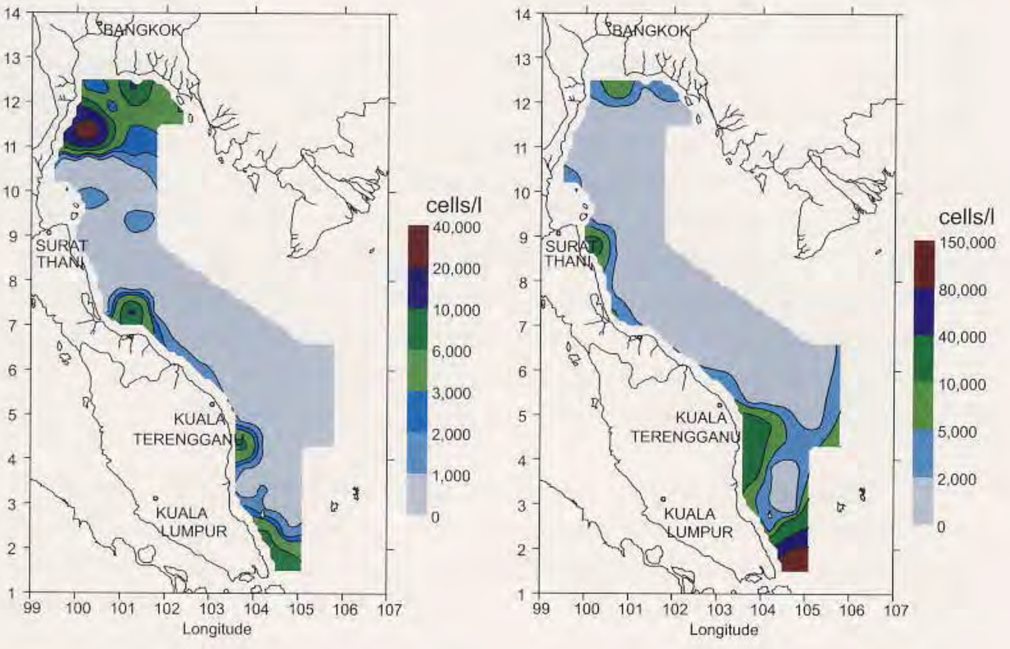
Phytoplankton standing crop was particularly abundant in the Upper Gulf during the pre-NE monsoon cruise, with the highest cell counts near the west coast [214 to 33,520 cells/l] [Fig. 11a]. Diatoms were the predominant group, closely following the distribution pattern of total phytoplankton [Fig. 12a]. *Thalassionema frauenfeldii*, was the most dominant diatom near the coastal areas, while *Chaetoceros lorenzianus* attained maximum cell counts in the central areas of the Upper Gulf and the southern tip of Peninsular Malaysia. Species of *Bacteriastrum, Rhizosolenia, Coscinodiscus, Hemiaulus, Ceratium* and *Protoperidinium* were also common. Dinoflagellate counts were generally low except in the Upper Gulf and offshore regions of the Gulf, where localized blooms with a total abundance ranging from 51% to 76% were recorded. Blue-green algae attained peaks along the eastern parts of the Upper Gulf, in the Central Gulf and along the East Coast of Peninsular Malaysia. *Trichodesmium erythraeum* was dominant covering large offshore areas, attaining peak density values of 2.24×10^6 filaments/m^3 [93.4% of total density] [Fig. 13].

Phytoplankton densities were generally higher after the NE monsoon, with the richest standing crop along the East Coast of Peninsular Malaysia [178 – 14,223 cells/l] [Fig. 11b]. Once again, diatoms, as the predominant group, closely followed the distribution pattern of total phytoplankton [Fig. 12b]. *Chaetoceros compressus, C. affinis, C. didymus* and *Pleurosigma sp.* were more common in the coastal areas of the Gulf, while *Proboscia alata, Pseudosolenia calcar-avis, Bacteriastrum comosum, Chaetoceros peruvianus* and *Cylindrotheca closterium* were abundant in the offshore areas. Species of



(a) (b)

Fig. 11. Abundance and distribution of total phytoplankton: (a) Pre-NE Monsoon; and (b) Post-NE Monsoon.



(a) (b)

Fig. 12. Abundance and distribution of diatoms : (a) Pre-NE Monsoon; and (b) Post-NE Monsoon.

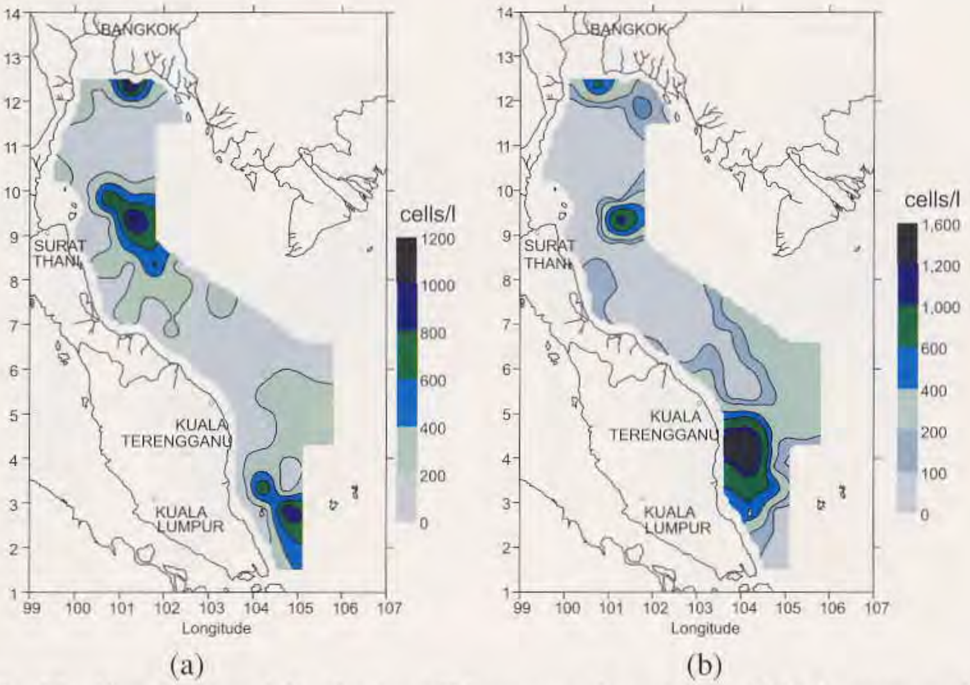


Fig. 13. Abundance and distribution of blue-green algae: (a) Pre-NE Monsoon; and (b) Post-NE Monsoon.

Coscinodiscus, Rhizosolenia, Thalassionema, Hemiaulus, Ceratium and *Protoperidinium* were also common. Species diversity indices were particularly high in the coastal areas, except within the blooms, such as that of the neritic diatom, *Skeletonema costatum*, which reached a density of 113,336 cells/l and a relative abundance of 90.9% towards the southern tip of Peninsular Malaysia. Concentrations of the diatom, *Pleurosigma* sp. had the highest relative abundance of up to 91.4% [14,223 cells/l] at some stations in the Upper Gulf. Dinoflagellate densities were higher along the Malaysian coast as compared to that in the Gulf. Blue-green algae distribution, especially *Trichodesmium erythraeum*, was more patchy, with peaks along coastal areas of Peninsular Malaysia, that sometimes reached bloom conditions, and the lowest concentrations in the Central Gulf [Fig. 13].

Although the species composition was rather similar throughout, phytoplankton standing crop displayed a clear pattern of patchiness, but was generally concentrated in the uppermost and lower regions of the survey area, with a wide area of low concentrations in the Central Gulf [Fig. 11], that could be related to nutrient enrichment and current flow patterns respectively. Increase in the abundance of phytoplankton standing crop after the NE monsoon indicates the effects of the monsoon and the conditions it brings about in stimulating phytoplankton growth in the area. Diatoms contribute to the bulk of the standing crop, the distribution patterns of which clearly follow that of the total phytoplankton standing crop [Fig. 12]. This, together with low concentrations of dinoflagellates, show the strong neritic influence existing in the area. Large species diversity, especially in the coastal areas, clearly follow the pattern expected in normal tropical marine coastal ecosystems. Richness index passed the 2.5 level at some offshore stations during the pre-NE monsoon season, which moved near-shore after the monsoon. Species diversity index ranged wider during pre-NE monsoon especially in the Gulf, which narrowed after the monsoon, mainly because of the tendency of some species to proliferate to bloom conditions, as a result of which the evenness indices were also generally higher during this season. Blooms of only one diatom, *Skeletonema costatum* were recorded after the NE monsoon towards the southern tip of the survey area. *Bacteriastrum comosum* and *Chaetoceros lorenzianus* were associated with this bloom. Species associations of *Ceratium, Coscinodiscus* and *Hemiaulus* were also noticed. *Ceratium fusus* and *Nitzschia closterium* also showed a tendency towards eco-specific associations with blooms of the blue-green alga, *Trichodesmium erythraeum*. On the whole, diatoms contribute to the bulk of primary production recorded in the area, except at those offshore stations where blue-green algae or in rare cases some dinoflagellates were predominant. Toxic dinoflagellate species were quite negligible throughout, which goes to explain the lack of 'red tides' in the study area. There are some indications that planktonic community organization in the water column might have undergone subtle changes in the recent past, especially in the dominance pattern of some species, probably in response to some recent environmental changes such as increase in pollution levels. However, in-depth analyses are needed to verify this assumption. Studies have shown that distribution and abundance of pelagic fish species such as the little tuna [*Euthynnus affinis*], chub mackerel [*Rastrelliger* sp.] and anchovies [*Stolephorus* spp.] are related to the density of phytoplankton.

Life cycles of dinoflagellates generally alternate between a vegetative stage [motile cell in the phytoplankton] and a resting stage [non-motile cell or cyst mostly in the sediments] produced during the sexual phase. They also act as the seed population to trigger potentially toxic red tides. Cysts of 20 dinoflagellate species, belonging to Goniolacoid, Tuberculodinioid and Peridinioid groups were collected from surface sediments in the survey area. Cysts were mostly found at depths of more than 30 m and in low densities, which may be caused by the constant disturbance of the surface sediments by frequent trawling activities in the nearshore areas. *Spiniferites* spp. [cyst phase of *Gonyaulax* spp.] was the most dominant cyst throughout, but was more common and widely distributed in Malaysian waters. [However, red tides of

Gonyaulax have never been reported from the survey area so far.] *Protoperidinium* spp. and *Scrippsiella* sp. were found only in the Gulf and *Operculodinium centrocarpum* and *Tuberculodinium vancampoae* were restricted almost entirely to the Malaysian waters. Cysts of toxic 'red tide' species were recorded only in very negligible numbers. Protoperidiniacean dinoflagellate abundance is closely associated with high diatom productivity and availability of nutrients.

Although many tropical species of coral fish and some pelagic fish are known to be primarily herbivorous [mainly feeding on seaweeds], previous studies have shown that such predominantly herbivorous [phytoplankton-feeding] species are negligible in the Gulf, except perhaps in the vicinity of coral reefs. Only *Leiognathus bindus*, an omnivorous feeder, was seen to ingest diatoms in some quantities. Therefore, phytoplankton seems to be of significance to the food chain in the area mainly as food for zooplankton, fish larvae and possibly juveniles of fish.

c. ZOOPLANKTON

Zooplankton plays a key role in marine food chain as it transfers energy from phytoplankton to higher trophic levels. Especially, the transfer of trophic energy to the fish stocks [both juveniles and adults] through their food supply is of particular interest to the fisheries in the region. A total of 238 zooplankton species have so far been identified from the survey area during previous studies. Studies on species composition, abundance and distribution of zooplankton in the survey area identified 34 systematic groups, predominated by Copepoda throughout [average 208 and 229 individuals/m^3 with a total abundance of 55.99% and 43.9% during the two cruises respectively], followed by Chaetognatha [30 individuals/m^3, 8.02%] during the pre-NE monsoon cruise and Ostracoda [93 individuals/m^3, 17.8%] after the monsoon. Species of Chaetognatha, Polychaeta, Amphipoda, Mysidacea, Heteropoda, Pteropoda, Thaliacea and *Lucifer* were very common during both the cruises, but were particularly abundant nearer to the shore [except for Amphipoda and Mysidacea], and mostly showed an increase after the NE monsoon [except for Amphipoda]. Larvae of Penaeidae, Anomura, Brachyura, Stomatopoda, Mollusca, Echinodermata, and Crustacea, as well as fish eggs, were also common throughout, with a more or less similar pattern of distribution. Medusae and Cyphonautes larvae were very common only during the pre-NE monsoon and Nemertinea only during the post-monsoon. Abundance of Siphonophora and shrimp larvae shifted from the southern parts of the survey area to the Upper Gulf after the monsoon. Pteropoda and Gastropod larvae were abundant near the shore along the East Coast of Peninsular Malaysia before the NE monsoon, but abundant throughout after the monsoon, although in a patchy pattern. Larvae of Brachipoda are outstanding in their very localized foci of patchy distribution. In general, many zooplankton taxa tended towards a patchy and scattered distribution pattern after the NE monsoon.

The biomass and abundance of zooplankton varied from 0.07 - 20.17 ml/m^3 and 36 - 3,413 $individuals/m^3$ during pre-NE monsoon and 0.18 - 2.59 ml/m^3 and 91 - 1,514 $individuals/m^3$ after the monsoon respectively [Fig. 14], which values were generally higher than those recorded during previous investigations in this area, although the pattern of distribution was very similar. Zooplankton biomass as well as abundance was remarkably poor during pre-NE monsoon, which showed a very measurable increase after the monsoon. During post-NE monsoon, zooplankton, although very patchy in distribution, showed maximum abundance in the Upper Gulf and nearer to the shore both in the Gulf and along the East Coast of Peninsular Malaysia. On the whole, 61.25% of the survey area registered an increase in zooplankton biomass, while abundance increased in 75% of the stations sampled. T-test showed a significant variation in abundance of up to 95% between the two seasons.

Results show that NE monsoon season affects the distribution pattern of zooplankton in the survey area, and its species composition and increase in abundance are influenced by the prevailing hydrographic conditions brought about by the monsoon. Salinity plays a crucial role in determining the variability of its abundance. Abundance and distribution pattern of zooplankton show a significant pattern of correlation and covariance with that of nutrients and phytoplankton. Abundance of many nauplii and larvae in the post-monsoon samples also indicates that several zooplankton, as well as many pelagic and sessile species, spawn during the NE monsoon season.

Earlier studies have shown that fish larvae, juveniles and small fish, mostly belonging to Leiognathidae and Engraulidae, as well as smaller shrimps, constitute the major diet of most of the lower level carnivores. Surprisingly, copepods played an insignificant role as fish food, unlike in many other similar areas.

d. BENTHOS

Benthic fauna is a biological parameter that indicates the overall aquatic fertility of the bottom sediments, and the study of benthos may be used as a baseline information to evaluate the demersal fish stocks, as they form a major food item of bottom-feeders. Certain macrobenthic species themselves are also of commercial value. Studies on the distribution of macrobenthos showed a greater density along the East Coast of Peninsular Malaysia during the pre-NE monsoon period at an average of 67.6 individuals/m^{-2}, as compared to 19.5 individuals/m^{-2} in the Gulf of Thailand. The situation was reversed after the NE monsoon, when an average of 60.9 individuals/m^{-2} were collected from the Gulf and 16.8 individuals/m^{-2} from Malaysian waters [Fig. 15]. Polychaeta predominated the samples, abundance of which decreased from 67.4% before the NE monsoon to 53% after the monsoon in the Gulf, while it remained constant at around 71% in Malaysian waters. Crustacea was the next dominant group, ranging from 20.9 – 35% in the Gulf and 13.6 – 16.1% along the East Coast of Peninsular Malaysia, while Echinodermata, Mollusca, Nemertinea and Sipunculidea were also represented. Species diversity increased in the Gulf of Thailand after the NE monsoon [from 20 to 35 families], while the reverse trend holds true along the East Coast of Peninsular Malaysia, where the species diversity decreased from 33 families before the monsoon to 26 families during post-monsoon. Dominant taxa were the Polychaete families, Cirratulidae, Eunicidae and Maldanidae, as well as Ophiuridae and Caridean shrimps. Diversity index ranged between 4.04 – 4.62. Lack of significant dominance in the evenness index shows that the benthic habitat in the area is very stable, despite considerable freshwater discharges. On the other hand, abundance of macrobenthos in the Gulf actually increased during the NE monsoon, while species diversity decreased.

Studies on the abundance of microbenthos showed that the fauna are richer and more abundant in the coastal areas, and increasingly so towards the southern parts of the survey area during both the cruises, while it decreased in deeper waters beyond 22 m depth. A total of 64 species were identified and their overall average abundance fluctuated between 88 individuals/m^{-2} during pre-NE monsoon and 97 individuals/m^{-2} after the monsoon, while the maximum abundance never exceeded 920 individuals/m^{-2}. Polychaeta, Crustacea and Echinodermata, which were the most numerically predominant taxa, displayed a marked change in density and diversity index pattern after the NE monsoon, and their abundance index fluctuated from 54.6%, 27.3% and 10.2% during pre-monsoon to 60.8%, 23.7% and 7.2% after the monsoon respectively. However, this fluctuation is very ambiguous, as the abundance of polychaetes

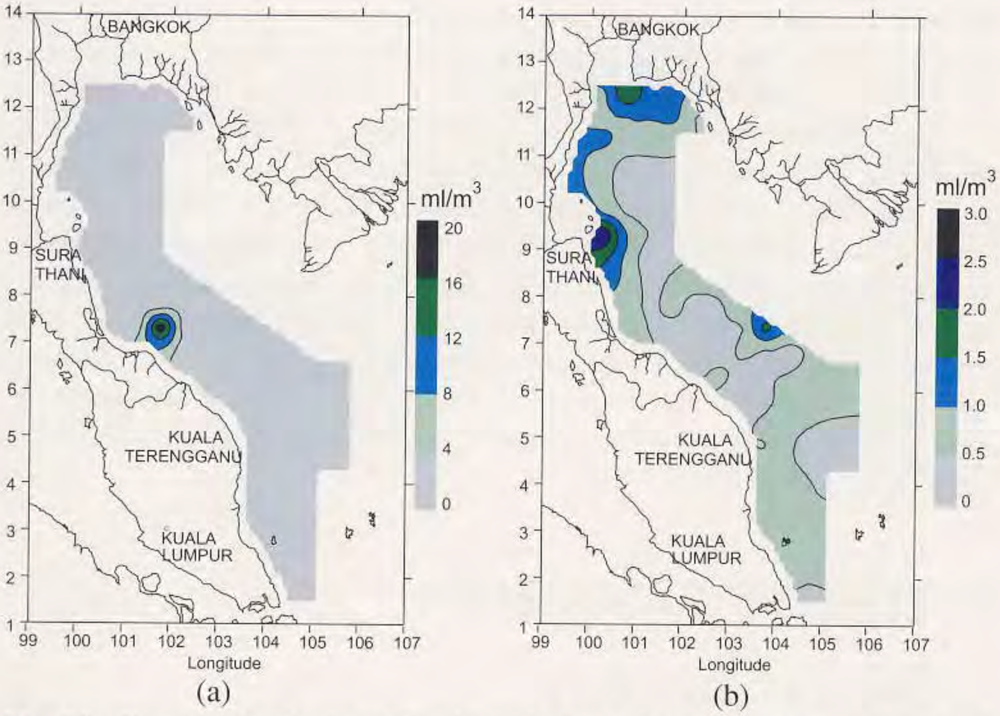


Fig. 14. Biomass distribution of total zooplankton: (a) Pre-NE Monsoon; and (b) Post-NE Monsoon.

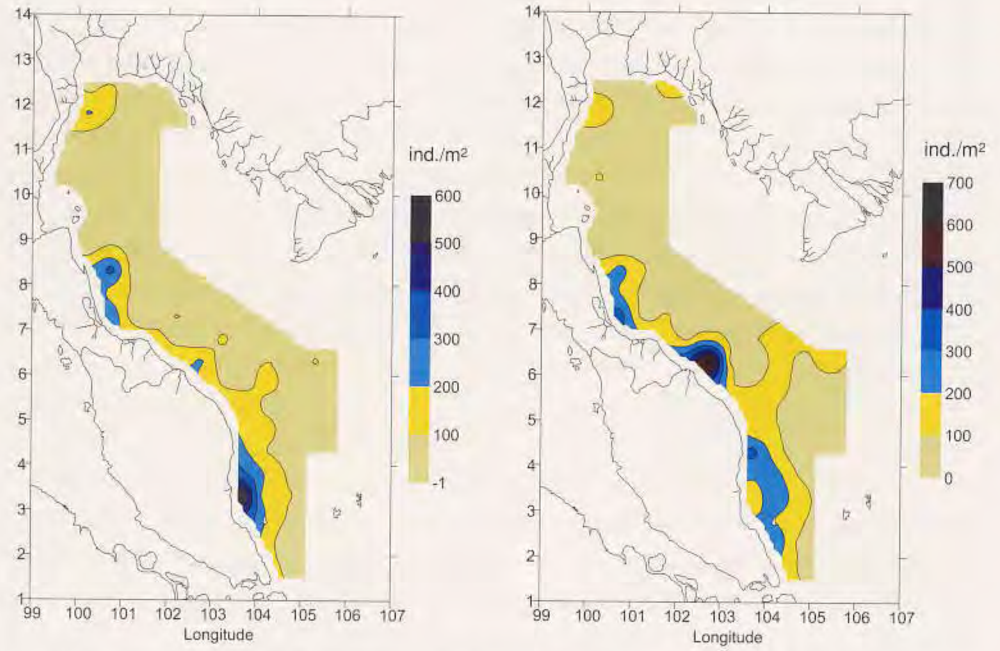


Fig. 15. Abundance and distribution of macrobenthic fauna: (a) Pre-NE Monsoon; and (b) Post-NE Monsoon.

decreased and that of the Crustaceans increased in over 31% of the survey area after the NE monsoon, while Echinoderms remained at more or less the same level in 50% of the samples studied. The diversity index, which never exceeded 3.3, showed an increase from sandy areas [2.87%] to clayey sand [3.2%] during pre-NE monsoon, but was more or less the same after the monsoon. Polychaetes were particularly well-represented and predominant in all but four stations in the study area. Only the smaller Crustaceans, such as Amphipoda, Isopoda and Ostracoda were collected, as the larger and more mobile species lived at the surface, and could easily evade the grab. Brittle stars and heart urchins predominated among the Echinoderms. Burrowing fishes and molluscs were virtually negligible in the samples. Relative scarcity of macrobenthos in the Gulf might probably be an indicator of overfishing and heavy disturbance of the sea-bottom by trawl fisheries.

5. FISHERY RESOURCES

a. FISHERY BIOLOGY

Fish larvae of 97 species, belonging to 73 families were collected during the two cruises. Out of these, 91 species were collected from the surface horizontal hauls during pre-NE monsoon, which decreased to 74 species after the monsoon, indicating that more species probably spawn in the area during the SW monsoon season. The most abundant fish larvae were those of Gobiidae [24.1%, species were identified only up to family level], *Stolephorus* sp. [20.7%], *Sardinella* sp. [15%] and *Upeneus* sp. [9.7%]. In the post-monsoon samples, the most abundant fish larvae were those of *Stolephorus* sp. [33.15%], *Sardinella* sp. [27.2%] and Gobiidae [10.2%], indicating that all species spawn during both the monsoons, but with spawning peaks after the NE monsoon for the first two species and to a lesser extent for Gobiidae. Previous studies had shown that Engraulidae and Clupeidae are the most abundant larvae of economically important fish families in the South China Sea, Engraulidae alone accounting for nearly half of the total catches, indicating its critical importance. *Sardinella* was most abundant in the surface layers with concentrations of 244 and 490 larvae/1,000 m^3 during the two cruises respectively, while *Stolephorus* sp. varied between an average of 125 and 206 larvae/1000 m^3, with a maximum of 2,080 larvae at one station after the NE monsoon. Only a few larvae of *Rastrelliger* spp. were collected from some stations.

Species composition and distribution patterns of fish larvae were rather similar both in the Gulf and along the East Coast of Peninsular Malaysia, but their abundance showed an increase near the coastal areas, around offshore islands and probably in the vicinity of coral reefs. Light intensity affected the vertical distribution of some species because of phototaxis, which caused their diurnal migration, and such larvae were sometimes more abundant in the sub-surface layers on bright days and collected mostly in the oblique hauls. From the two cruises, it is not clear if, where and when the rest of the 300 fish species identified from the area, spawn and breed, as their larvae were not sampled.

Studies on species composition, diversity and distribution of fish species, identified a total of 300 species belonging to 89 families, that showed a decline in diversity from 380 and 400 species collected during previous surveys. Demersal species predominated and contributed to most of the diversity, and 122 of the species recorded were economically important. Four areas showed the richest species diversity, with up to 73 species per haul. Previous studies have shown that differences in species composition in various locations might be related to varying environmental conditions. The survey area has one of the richest and most diverse fish fauna in the world, and the species composition is characteristic of the Indo-West Pacific fish fauna. It is not clear from the present studies whether the reduction in the number of species collected during this survey in any way indicates that these species are becoming endangered or vulnerable.

b. FISHERY SITUATION

Marine fisheries in the Gulf of Thailand grew rapidly from early 1960s with the introduction of bottom trawl fisheries [200,000 mt in 1961 to 1.5 million mt in 1971], but the demersal fishery catches in the coastal and nearshore waters declined equally rapidly by the 1980s [297.6 kg/hr in 1961 to 96.6 kg/hr in 1972, 49.8 kg/hr in 1981 and 20 kg/hr in 1996]. Simultaneously, demersal fish species composition and their rankings also underwent drastic changes, with large and intermediate predators and large zoobenthos being replaced by short-lived species and small demersal prey such as squids and *Scolopsis* sp. But pelagic fisheries for species, such as the round scad [*Decapterus* spp.] and small tuna [*Euthynnus affinis*] developed in the deeper waters of the Gulf in the 1970s, which sustained the total landings at high levels for a longer time. The total marine fish landings from the Gulf in 1994 was approximately 2 million mt [71% of the total]. Out of the total marine fisheries production, pelagic fish comprised of 953,900 mt [30.3%] and demersal food fish, 288,000 mt [9.1%], in addition to 930,500 mt [29.5%] of 'trash fish' of little economic value. Estimates in the past of potential yields of fish stocks in the Gulf have shown that demersal fishery resources in the coastal areas are overfished and severely depleted since 1973 [maximum sustainable yield (MSY) of 750,000 mt]. The five dominant demersal species in the area, viz., *Priacanthus tayenus, Nemipterus hexodon, Saurida undosquamis* and *S. elongata,* all indicated signs of overexploitation. Of the pelagic species, the short mackerel [*Rastrelliger brachysoma*], sardines [*Sardinella* spp.], anchovy [*Stolephorus* spp.], little tuna [*Euthynnus affinis*] and scad [*Decapterus* spp.] stocks have all been fully exploited since late 1970s and early 1980s. The Spanish mackerel [*Scomberomorus commerson*], carangids and hardtail scads are the only species that have not yet been overfished according to these indications. Although already being fully exploited, catches of the Indian mackerel, *Rastrelliger kanagurta,* could still be possibly increased, if timely conservation measures are put in place. The physical target of the current [eighth] Thai National Economic and Social Development Plan is to maintain the annual marine fishery production in Thai EEZ at not less than 1.7 million mt.

Exploratory otter trawl fishing during the survey showed that average catch in the Gulf of Thailand ranged from 12.04 kg per hour of trawling during the pre-NE monsoon cruise to 34.79 kg after the monsoon. The total catches ranged from 4.33 to 69 kg per hour in the Gulf of Thailand, while the economically important species ranged from 26.1% - 89.9% of the catches. Lizard-fish [*Saurida undosquamis* and *S. micropectoralis*], bigeye [*Priacanthus tayenus* and *P. macracanthus*], rabbit-fish [*Siganus canaliculatus*] and hairtail [*Trichiurus lepturus*] were the most economically important species in the catches.

Of a total fish production of 1,181,763 mt landed in Malaysia in 1994, pelagic fish comprised of 373,979 mt [35.9%], out of which 128,445 mt came from the East Coast of Peninsular Malaysia. Out of a total of 182,884 mt of demersal fish landed, 28.8% came from the East Coast. Mostly, demersal fish were caught along the East Coast during the survey, as compared to very negligible pelagic catches [65.87% of total catch as compared to 3.89% during the pre-NE monsoon survey, and 53.29% as compared to 2.53% after the monsoon respectively]. Yields decreased with increasing depth, although species diversity increased, while ranking by abundance also changed with seasons, which correlated well with the low chlorophyll values and zooplankton standing crop in the offshore areas. 21-40 m zone was found to be the most productive, beyond which area the catches were generally poor. The demersal species mostly belonged to Nemipteridae, Priacanthidae, Mullidae and Synodontidae, and *Nemipterus* spp., *Lutjanus* spp., and marine catfish [*Tachysurus* spp., *Arius* spp. and *Osteogenius* spp.] were some of the major fish species landed. The pelagic catches did not show significant change with the seasons and were mainly dominated by the family Carangidae, and *Decapterus* spp., *Selaroides* sp. and *Rastrelliger* spp. On an average, 55.45 – 81.92% of the catches were economically important species.

Exploratory fishing off the East Coast of Peninsular Malaysia showed that the catches increased towards the coastal areas, and that the species rankings varied with depth and season. Juvenile fish from more than one spawning group were preponderant after the NE monsoon, which indicates possible breeding in the area during the monsoon and/or migration of juveniles into the study area for feeding.

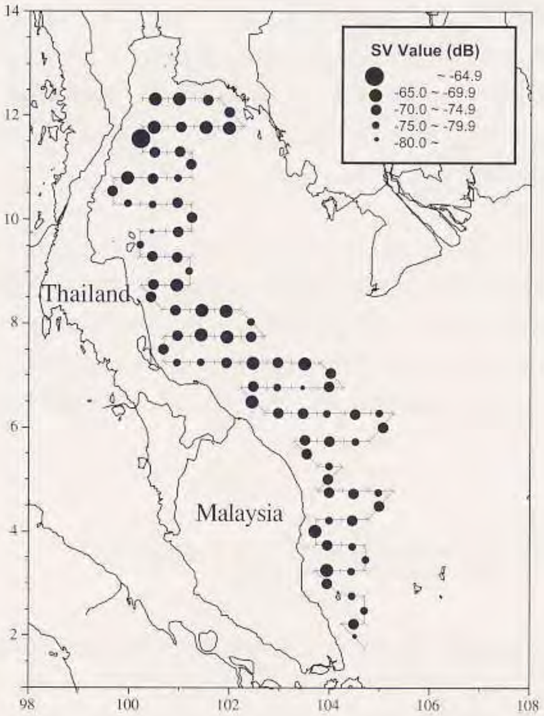
c. FISHERY ACOUSTIC STUDIES

Biomass estimates from volume back-scattering strength recordings [SV values] at 50 kHz and 200 kHz of the Furuno FQ-70 Scientific Echo Sounder, for the water column from 10 m down to the bottom, show concentrations of fish in the upper and central parts of the Gulf of Thailand, as well as the southernmost parts of the survey area [between the coasts of Kuala Terengganu and Johore] during the pre-NE monsoon period, but is restricted only to the central parts after the NE monsoon [Figs. 16 and 17]. SV values at 200 kHz during both the seasons were highest along the coastline and in the shallow nearshore areas up to 40 m depth in the Upper Gulf. Recordings at 50 kHz yielded constantly higher levels, but were relatively stable during both the cruises [The higher recordings may probably be caused by localized concentrations of some macroplankton species, especially as the plankton deep scattering layer was frequently recorded in the survey area]. The highest concentrations were recorded in the Upper Gulf and along the East Coast of Peninsular Malaysia.

Using sardines, which constitute the major catch in the Gulf of Thailand, as the reference species for target strength [TS], the biomass estimates were 2,754,770 mt and 13,136,860 mt for the high and low frequencies respectively, during the pre-NE monsoon period. During the post-monsoon season, the estimates varied between 1,323,150 mt and 20,942,590 mt respectively.

The total multi-species biomass in the Malaysian EEZ of the East Coast of Peninsular Malaysia [as indicated by the recordings at 200 kHz only] was estimated to be of the order of 4.4×10^5 mt and 3.1×10^5 mt during the pre- and post-NE monsoon seasons respectively, out of which 52.27% and 61.61% were

(a)



(b)

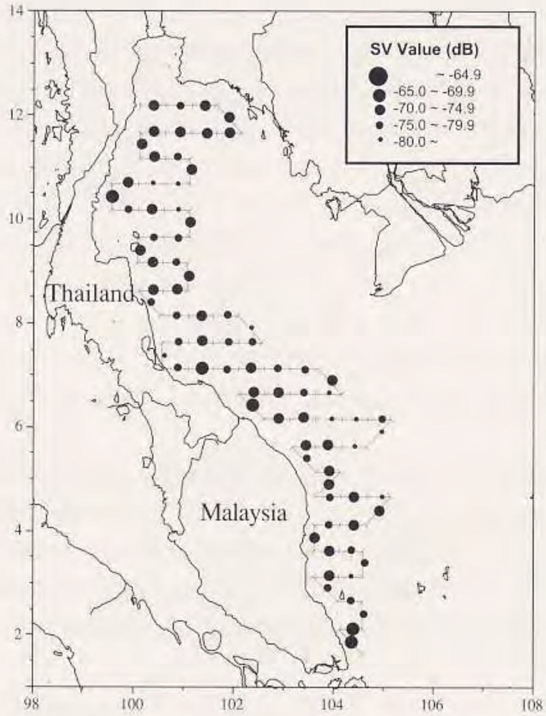
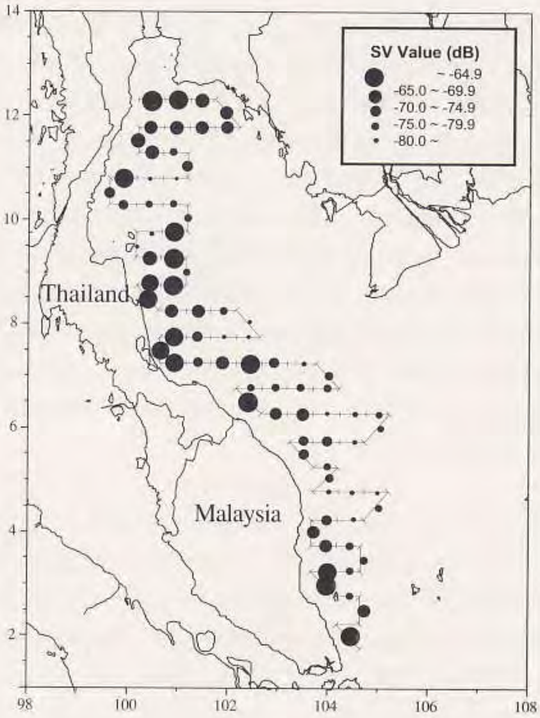


Fig. 16. Back-scattering strength recording (SV values) at 200 kHz for pelagic fish: (a) Pre-NE Monsoon; and (b) Post-NE Monsoon.

(a)



(b)

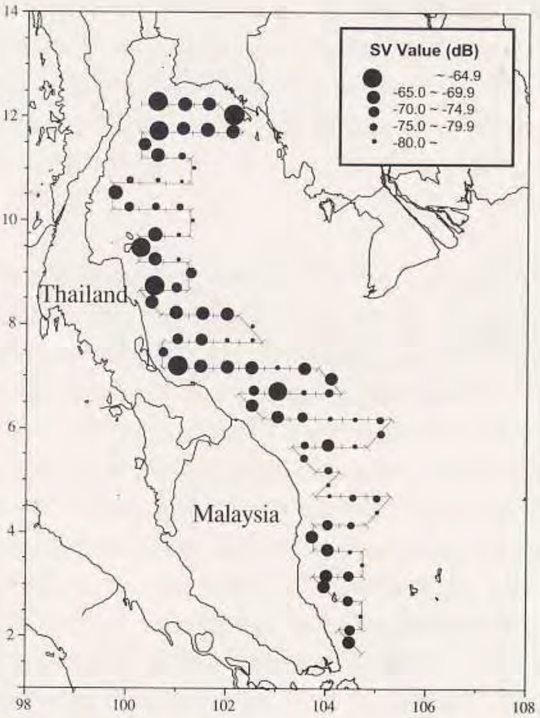


Fig. 17. Back-scattering strength recording (SV values) at 200 kHz for demersal fish: (a) Pre-NE Monsoon; and (b) Post-NE Monsoon.

pelagic fish and the rest, demersal fish. Total biomass estimates showed a tendency towards higher values in the offshore areas during the pre-NE monsoon, although such a difference was not very clear for demersal fish stocks. The situation reversed after the monsoon with more or less increasing values towards the shore, although the estimates were comparatively lower as compared to those before the NE monsoon. The seasonal differences in biomass estimates correlated well with the trends in fish landings at the fishing ports in the area. Fish landings normally decline from November until May, before showing an increase from June onwards. It has been suggested that pelagic fish migrate to the Gulf and the East Coast of Peninsular Malaysia during the NE monsoon season and move to the offshore waters after the monsoon, which agrees well with the trends in landing patterns.

Using *Decapterus russelli,* a commercially important species in the area as the reference for calculations, density of pelagic fish during the two seasons were estimated to be of the order of 2.07 mt/sq. km and 1.74 mt/sq. km, and the biomass, 230,000 mt and 190,000 mt respectively, for an estimated EEZ area of 111,129 sq. km. Similar estimates of density of demersal fish ranged from 1.88 mt/sq. km and 1.1 mt/sq. km, and of biomass, 210,000 mt and 120,000 mt for the two seasons respectively, using *Nemipterus peronii* as the reference species. The total biomass of fish stocks for the whole area was 430,000 mt and 310,000 mt for the two seasons respectively. Two previous acoustic surveys in the area during the SW monsoon season [between June and August] estimated the density of pelagic fish in the area to be of the order of 2.68 mt/sq. km and 1.02 mt/sq. km.

Acoustic surveys of fish abundance are mostly based on the assumption that total echo intensity from a fish school is equal to the arithmetic sum of echo contributions from individual fish. Empirical approximations of the target strength of individual fish, estimated as a function of size and length frequency are then applied to fish school models in order to predict volume back-scattering strength. Although fishery acoustic methods are quite handy in estimating the order of magnitude of fish stocks over large areas, the need for too many assumptions and generalizations raises questions on their reliability and accuracy, especially when applied to multi-species evaluations, such as those occurring in the present survey area. Interference from plankton deep scattering layer is another important factor that also needs to be taken into consideration. The method should, therefore, be considered as a promising approach at the most, which is in need of further refinements and adjustments before it can be sufficiently reliable.

6. CONCLUSIONS

Large amount of oceanographic and marine environmental data have been collected during the two cruises, of importance to a better understanding of the marine fish production mechanisms in the survey area and their inter-relationships. But, being the first comprehensive study of this type for the whole area covered, and considering the geographical extent of the study area with a variety of marine habitats, the significance of interactions and inter-relationships of the various parameters to the marine communities and the various trophic levels of the food chain, as well as its implications to the distribution patterns of fish population in the region, should be expected to be understood only gradually. The profile of events, features and processes occurring during any complete season could also not be wholly characterized through the findings of a single cruise.

The survey has revealed much information on the changes in oceanographic processes brought about during and by the NE monsoon season and the influences of the monsoon on biological productivity and components of the marine food chain in the region, that affect fish production mechanisms and fish distribution patterns. Despite possible occurrence of upwelling and downwelling in some coastal areas during the NE monsoon, the data indicate a decrease in vertical mixing as compared to the SW monsoon, that brings about more stable conditions in the water column, which are more suitable for increased primary production. However, the situation is complicated by the intrusion of low-oxygen deeper water from the South China Sea into the coastal area. The surface sediment distribution patterns were also affected by monsoonal turbulence, whereby heavier particles brought by freshwater discharges from land settle down first, while muddy and clayey portions sedimented only in more stable and stagnant areas further offshore, less affected by monsoonal turbulence. Low organic levels indicate relatively oxidized condition of the seabed and low productivity of the water column, except in such areas of confluence as in the vicinity of Samui Island. This is corroborated by the low primary production values measured, except in the Upper Gulf. Many seasonal variations in the distribution and concentration of trace elements both in the water column and the sediments are also brought about by monsoonal turbulence and the shifts in bottom deposits that it causes.

Phytoplankton densities were higher after the NE monsoon indicating the influence of the monsoonal conditions in stimulating its growth. Predominance of diatoms indicated the neritic influence in the area, except in the offshore areas, where mostly blue-green algae and sometimes some dinoflagellates were abundant. Phytoplankton distribution was characteristically patchy. There were also indications that phytoplankton community organization might have undergone some changes in recent times probably as a result of the effects of pollution. Studies have shown that the abundance of some pelagic species such as small tuna, chub mackerel and anchovies are related to the abundance of nutrients and phytoplankton. Increase in abundance and variability of zooplankton were also related to the effects of the NE monsoon, particularly salinity fluctuations, and their distribution patterns showed a significant covariance with that of nutrients and phytoplankton. Species of market value in the area were predominantly bottom-feeders in nature, and phytoplankton, and surprisingly, even such important zooplankton taxa as the copepods did not play any significant role in their diet. Abundance of benthic organisms also showed an increase after the NE monsoon, but the lack of significant dominance in the evenness index shows that the benthic habitat is very stable despite considerable freshwater intrusion. Seasonal distribution of fish larvae indicates that more fish species spawn during the SW monsoon season than the NE monsoon, except for some economically important species. However, larvae of only 91 out of a total of 300 recorded fish species were collected. Exploratory fishing during the survey showed that CPUE increased three-fold after the NE monsoon and was generally higher towards the nearshore areas. There are also some indications that disturbances caused by constant trawling activities bring about changes in the nature and distribution patterns of bottom deposits and its benthic fauna.

Situations occurring in the vicinity of Samui Island in the Gulf of Thailand have shown the existence of an oceanic front between the well-mixed Inner Gulf water and stratified, high-salinity, low-oxygen offshore South China Sea water mass. Frontal zones are boundary regions of convergence associated with strong vertical mixing that causes better distribution of nutrients and suspension of particulate matter, as shown by the particularly rich mud content of the bottom deposits in the vicinity. This area also shows high rates of production, plankton concentrations and fish larval accumulations. Because of their high biological productivity, the zones of convergence provide ideal conditions for rich fishing grounds for herbivores and plankton feeders, which in their turn attract higher order carnivores, as shown by the frequent catches of black marlin [*Makaira indica*] in the area. This area needs more in-depth studies in the future.

Demersal fish landings from the Gulf of Thailand have drastically decreased in recent times caused by overfishing with the introduction of bottom otter trawl fishing. Simultaneously, demersal fish species composition and their rankings also underwent changes, with intermediate predators and large zoobenthos being replaced by short-lived species and small demersal prey such as squids and *Scolopsis* sp, thereby filling the ecological void created by the decrease in grazing pressure from bottom-feeding carnivorous species. The amount of trash fish of little economic value in the catches has also increased considerably in recent times. Most of the pelagic species of commercial value have also been overfished to various extents beyond their MSY levels. Exploratory trawling survey showed that average CPUE values increased after the NE monsoon period by a factor of almost three. Along the East Coast of Peninsular Malaysia, yields decreased with increasing depth, although species diversity increased, and the species rankings varied with depth and season. 21 – 40 m zone was the most productive, beyond which area catches decreased gradually. Pelagic catches were virtually negligible [2.53 – 3.89% on an average during the two cruises] as compared to demersal landings. Decrease in catches in the deeper waters off the East Coast of Peninsular Malaysia correlated well with lower chlorophyll values and zooplankton standing crop in the offshore regions. Indications are that many species breed in the area during the NE monsoon, and/or juveniles aggregate in the area for feeding and survival.

Preliminary conclusions that have emerged so far highlight the need for continuation of these investigations in the future, with particular emphasis on high sea areas [as defined by the Law of the Sea (UNCLOS)], special areas of interest to fisheries resources, and their seasonal fisheries production mechanisms, life-cycles and food-chain dynamics. Over and above everything else, the survey has provided a database on the structure of communities at different trophic levels as a basis for future studies on mechanisms of their dynamic functions and biological processes in the marine ecosystems, of implication to fisheries in the region. In addition, the studies have pinpointed the fields in need of additional data and information for an in-depth understanding of fisheries abundance, and their production and distribution patterns.

BIBLIOGRAPHY

The scientific papers discussing the research findings of the Collaborative Research Program in Area I were compiled and published in a volume of proceedings and are alphabetically listed below.

MAIN REFERENCE

Southeast Asian Fisheries Development Center [SEAFDEC]

PROCEEDINGS OF THE FIRST TECHNICAL SEMINAR ON MARINE FISHERY RESOURCES SURVEY IN THE SOUTH CHINA SEA, AREA I: GULF OF THAILAND AND EAST COAST OF PENINSULAR MALAYSIA. 24-26 NOVEMBER 1997, BANGKOK, THAILAND. SEAFDEC, Samut Prakan, March 1999, 366 pages.

RESEARCH PAPERS

Abdul Hamid Yasin, & Solahuddin A. Razak.

Distribution of Macrobenthos in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 285-293.

Albert Chuan Gambang, Hadil bin Rajali, Raja Bidin bin Raja Hassan, Rosidi bin Ali, Kunimune Shiomi, Shunji Fujiwara & Shamusudin bin Basir.

Multi-Species Fish Stock Assessment by Acoustic Method in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 336-346.

Boonyapiwat, Sopana.

Distribution, Abundance and Species Composition of Phytoplankton in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 111-134.

Chareonpanich, Charumas & Siriporn Seurungreong.

Some Physical and Chemical Characteristics of Bottom Sediments in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 12-33.

Jivaluk, Jutamas.

Distribution, Abundance and Composition of Zooplankton in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 256-284.

Lirdwitayaprasit, Thaithaworn.

Distribution of Dinoflagellate Cysts in the Surface Sediment of the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 294-309.

Lokman Shamsudin, Abdul Hamid Yasin, Solahudin Abdul Razak & Mohd Shukri Yusoff.

Microplankton [Including Dinoflagellate and Foraminifera] in the South China Sea, Area I: Gulf of Thailand and Peninsular Malaysia. p. 310-335.

Mansor Mat Isa, Abd Haris Hilmi Ahmad Arshad & Samsudin Basir.

Distribution, Abundance and Biological Studies of Economically Important Fishes in the South China Sea, Area I: East Coast of Peninsular Malaysia. p. 147-155.

Mohamed Kamil Abdul Rashid.

Polynuclear Aromatic Hydrocarbon [PAH] and Total Aliphatic Hydrocarbon [TAH] in the Bottom Sediment of the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 100-104.

Mohd-Lokman Husain, M.R. Harith, J. Maurice, Y. Rosnan & K.K.Y. Kassim.

Sedimentological Characteristics of the Sediments of the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 34-53.

Mohd. Nasir Saadon, Penjan Rojana-anawat & Anond Snidvongs.

Physical Characteristics of Watermass in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 1-5.

Musikasung, Waleerat, Mohd Shukri bin Yusoff & Solahuddin bin Abdul Razak.

Primary Production Determination in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 135-146.

Noor A.M. Shazili, Mohamed Kamil Abd Rashid, Mohd Lokman Husain, Asmawi Nordin & Salmah Ali.

Trace Metals in the Surface Sediments of the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 73-85.

Piamthipmanus, Montira.

Temporal changes in the Abundance of Macrobenthos in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 156-171.

Rojana-anawat, Penjan & Anond Snidvongs.

Dissolved Oxygen and Carbonate-Carbon Dioxide in the Sea Water of the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 6-11.

Snidvongs, Anond & Pramot Sojisuporn.

Numerical Simulations of the Net Current in the Gulf of Thailand Under Different Monsoon Regimes. p. 54-72.

Termvidchakorn, Apichart.

Kinds, Abundance and Distribution of the Fish Larvae in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 241-255.

Theparoonrat, Yuttana, Suvimon Seakow & Siriporn Seurungreong.

Biomass Estimation by Hydro-acoustic Methods in the Gulf of Thailand and Peninsular Malaysia. p. 347-366.

Utoomprurkporn, Wilaiwan, Manuwadi Hungspreugs, Saravuth Ratanachongkiat & Anond Snidvongs.

Biogeochemical Implications of Dissolved Trace Metal Concentration and Distribution in the South China Sea, Area 1: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 86-99.

Vidthayanon, Chavalit.

Species Composition and Diversity of Fishes in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p.172-240.

Wongnapapan, Panjarat, Gullaya Wattayakorn & Anond Snidvongs.

Petroleum Hydrocarbon in Seawater and Some Sediments of the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. p. 105-110.

SEAFDEC