Highlights of the

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

AREA II

WATERS OF SABAH, SARAWAK (MALAYSIA) AND BRUNEI DARUSSALAM

SOUTHEAST ASIAN FISHERIES DEVELOPMENT CENTER

BANGKOK

TD/SP/25

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WATERS OF SABAH, SARAWAK (MALAYSIA) AND BRUNEI DARUSSALAM

A Collaborative Research Program
Between

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

and

TRAINING DEPARTMENT
SAMUT PRAKAN, THAILAND

THE SECRETARIAT
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MESSAGE FROM THE CHAIRMAN OF THE SEAFDEC COUNCIL OF DIRECTORS
(1999-2000)

SEAFDEC launched the Collaborative Research Program on Fishery Resources in the South China Sea, with the financial support from the Government of Japan, primarily to assess the current status of the fishery resources and update the database on their sustaining factors, which the national and regional resource managers need and must depend upon in making policy decisions. A program of this type is beneficial to all SEAFDEC member countries, as it collects vital information on fishery oceanographic, environmental and marine biological conditions that give shape to, control and sustain the fishery patterns in the region.

Area I of the Program, in the Gulf of Thailand and the waters off the East Coast of Peninsular Malaysia, covered an interesting maritime zone, the rich and diverse marine resources of which were recently subjected to intense fishing to an extent that their population structure, composition and size changed considerably within a short span of time. Despite the heavy fishing pressure exerted by the efficient modern fishing technologies, the resounding resilience of the marine ecosystem maintained a certain ecological balance, which at the same time also brought about an abundance of 'trash fish' of poor value, as an undesirable consequence of the selective removal of the larger demersal fish that preyed upon them. Despite the development planners' focused attention, no clear indications have emerged so far on how this issue could possibly be tackled in the long term, particularly to alleviate the socio-economic problems of the small-scale subsistence fishermen and to help protect their established traditonal 'rights' in a way to ensure their food, job and income security. The SEAFDEC findings on the structure and composition of the different trophic levels of the marine food chain and their functionally interactive correlations will help in designing and shaping the fisheries development in the region on the long term.

The survey in Area II, covering the waters of Sabah and Sarawak in Malaysia and Brunei Darussalam takes the studies to deeper oceanic waters, whose marine biology and fisheries are less understood. However, there are indications of phenomenal and prolific biological activities in the area that could have consequences to fisheries. Data on the oceanographic features and biological phenomena, discussed in this report, will help fill the existing information gaps on the fishery environment in this area. I fervently hope that the ongoing SEAFDEC Program in the South China Sea will establish a useful database to generate functional indicators of fishery potential in the region of use to fishery planners and managers in designing tangible and viable fisheries development plans.

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, 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 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 covered the Gulf of Thailand and the East Coast of Peninsular Malaysia, and the results from this area have already been published. The second area, covering the waters of Sabah and Sarawak in Malaysia, and Brunei Darussalam was surveyed during two cruises of the Training and Research Vessel, MV SEAFDEC [together with exploratory fishing survey on board the Malaysian Fishery Research Vessel, KK MANCHONG], in July - August 1996 and May 1997. The analyses of research findings were presented at a Technical Seminar held in Kuala Lumpur, Malaysia, during 14 – 15 December 1998 and the proceedings published. This report focuses attention on the major findings of this survey highlighting its implications to the fishery oceanographic phenomena, fish production mechanisms and marine food chain characteristics in the survey area. It is fervently hoped that the findings of this survey and the 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 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 are 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. The fisheries in this region are seriously affected in recent times for lack of adequate background information on fishery oceanographic and environmental conditions that support the fish populations, and insufficient 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 needed to plan sustainable fisheries resource management in the long term, and protection of fisheries environment and habitats that sustain their life-cycle. 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 waters of Sabah and Sarawak in Malaysia, and Brunei Darussalam were designated as Area II under this scheme. The survey area, covering the northwest coast of Borneo, is an open area of about 251,000 sq. km, subjected to the effects of both southwest [SW] and northeast [NE] monsoons. The topographic profile extends from a shallow continental shelf to a deeper zone in the offshore regions of Sarawak with depths of up to 2,900 m. The shelf waters of Sabah and Brunei Darussalam are relatively much narrower. A deep valley is situated just off the coast of Sabah. Oceanography, marine environment and aquatic life of this area are not well known.

The SW monsoon prevails from May to September [summer season of the Northern Hemisphere], while the NE monsoon blows from November to March [winter season of the Northern Hemisphere], and the conditions that they bring about affect the fishery oceanography, fisheries production mechanisms and fish distribution patterns. Both monsoons bring rainfall to the survey area to a greater or lesser extent. Two transitional periods [often referred to as inter-monsoon periods] of about three to seven weeks occur between these monsoons in April – May and October respectively. For a better understanding of these mechanisms and the effects of the SW monsoon on the oceanography, marine environment and the abundance of aquatic life in the area, Survey Area II was studied during two cruises so timed to cover the pre-SW monsoon and the monsoon season proper [the first cruise no. 34-6/1996 from 10 July to 2 August 1996, and the second cruise no. 41-4/1997 from 1 to 24 May 1997, and 79 sampling stations were repeated at the same coordinates, as shown in the station grid map [Fig. 1].

As in the case of Area I, the style applied in planning the survey work was to analyze the situation through static studies on the 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 too lacking in many instances to support any studies on their functions. Under the circumstances, interpretations had necessarily to be restricted to quantitative correlations with different trophic levels, in terms of their significance to fishery production potential. In particular, such an approach ignored the external environmental influences upon the marine ecosystem and

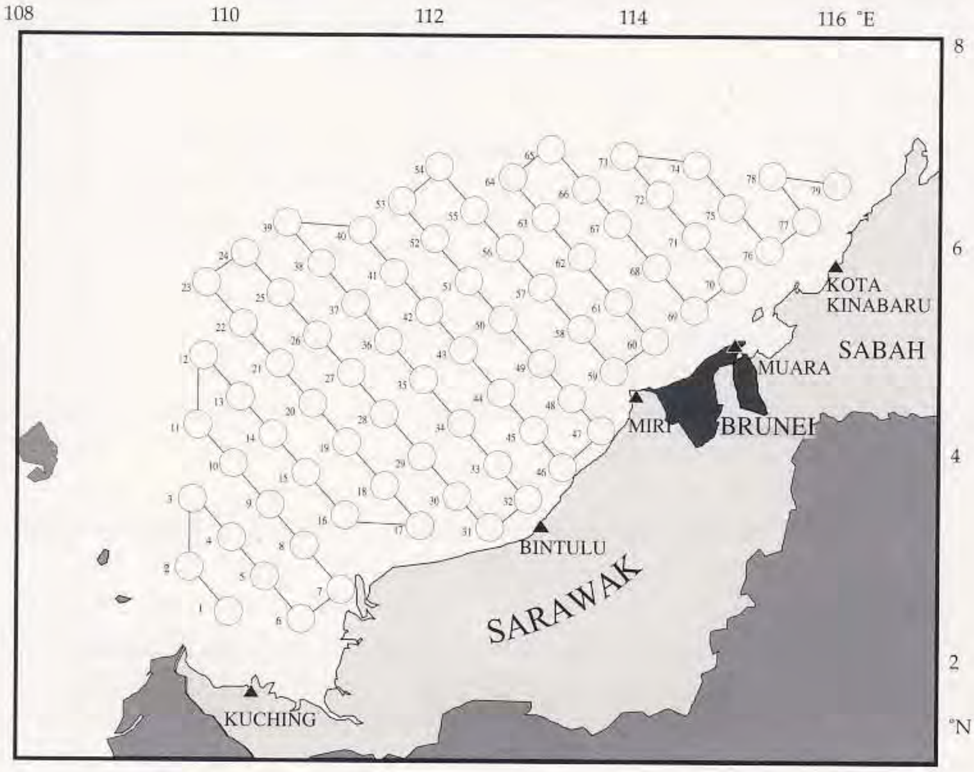


Fig. 1. Map of survey area with cruise track and station grid.

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 plastic and two-dimensional. However, it is hoped that the data and information on community structure brought to light through these studies will provide the foundation for more detailed analysis of their functions and operational dynamics in the future.

Studies in Area III [West Coast of Luzon Island in the Philippines] have already been completed, and studies in Area IV, covering 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 and marine environmental conditions in the entire SEAFDEC region of the South China Sea, as a database for the SEAFDEC Geographic Information System [GIS] that is presently being developed.

2. MATERIALS AND METHODS

Two cruises were conducted on board the Training and Research Vessel, MV SEAFDEC. The Malaysian Fisheries Research Vessel, KK MANCHONG also participated in the survey for exploratory fishing studies. The physical oceanographic parameters were measured by the Falmouth Scientific Integrated Conductivity-Temperature-Depth Sensor Unit [ICTD], 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-acquisition Data Analysis Software at every dbar pressure interval. Density figures were derived from temperature and salinity data using sigma-t computation tables. Currents were calculated by the classical geostrophic method, whereby absolute currents at any depth were calculated, taking areas deeper than 500 m as the layers of no water movement, assuming that the horizontal pressure gradient due to gravity [potential energy] must be counteracted and balanced by Coriolis force through the movement of water in an isobaric medium such as the sea surface [Only 27 stations out of a total of 79 were deeper than 500 m]. Divergence and convergence zones were inferred from the direction of the surface current.

pH was measured using an *in situ* sensor attached to the ICTD unit. [It was also measured on board using the Fisher Scientific Model 1002 pH Meter.] 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. Dissolved carbonate system in seawater was calculated from total alkalinity and pH. Carbonate alkalinity and total carbon dioxide were calculated using the equation: carbonate alkalinity [meq/l] = total alkalinity – 0.05; and total carbon dioxide [meq/l] = 0.96 x carbonate alkalinity.

Light intensity in the water column was measured by Alec Electronics Model SPI-9W Underwater Lux Meter. Continuous oxygen profiles at each station 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 the van Dorn Water Sampler or Rosette Water Sampler. Ortho-phosphate levels were analyzed by the TRAACS 2000 Auto-Nutrient Analyzer, using the colorimetric method. 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 Perkin Elmer Zeeman Graphite Furnace Model 4100ZL Atomic Absorption Spectrophotometer.

Sediment samples were collected by Smith-McIntyre Bottom-grab and/or Gravity Corer. 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 the weight loss after ignition in a furnace at 450°C for three hours or by the potassium chromate wet oxidation method. Acid volatile sulfide levels were measured by using Gastec Model 2011 H_2S-absorbent column after acidifying with sulfuric acid. Pore water samples were analyzed for nitrate-nitrogen, ammonia-nitrogen and phosphate-phosphorus concentrations with a TRAACS 800 Auto-nutrient Analyzer. Total organic carbon and nitrogen content were measured by a Carlo-Erba NA-1500 Elemental Analyzer. For trace metal analysis, they were dried, ground and digested in a mixture of nitric, perchloric and hydrofluoric acids. Dissolved trace metals were co-precipitated with cobalt-APDC, while particulate metals were digested with *aqua regia.* Concentrations of metals were measured using Graphite Furnace Atomic Absorption Spectrophotometer. The first centimeter of the surface sediment was used for taxonomic studies on dinoflagellate cysts, for quantitative analysis and for cyst germination experiments. For practical reasons, benthos was sampled only up to a depth of 240 m, and was collected by washing grab samples through a set of metallic sieves.

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 daylight at their original depths of collection for three hours. The absorbed radioactivity by the exposed phytoplankton in the bottles was determined by GC-9A Model Shimadzu 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 each depth sampled. *In situ* fluorescence recorded at every meter by the SeaTech Submersible Fluorometer and averaged at every dbar interval was converted to chlorophyll values using the standard linear correlation curves of chlorophyll from actual values measured by spectrophotometer at 400 to 750 nm wavelength. This was extrapolated over the water column to obtain the production rate/m^2 and integrated over daylight time using *in situ* biomass, hourly light intensity profile and time-integrated unit production. Using the light intensity available 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 from the surface, seasonal thermocline layer and the depth of sub-pycnocline chlorophyll maxima, 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 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 hauls with the standard larvae net with an opening of 1.3 m and 5 mm mesh size at the mouth part and 330 microns towards the tapering end, hauled for 30 minutes at 2 knots, and also by oblique hauls with the bongo net from a maximum depth of 150 m to the surface. The amount of water filtered was measured by a flow meter.

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 codend, 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. This was supplemented with hand-line sampling, dip-netting and visual recordings, especially of larger species.

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 devises and echoes of rough sea conditions, and were called 'corrected SV values'. Corrected SV values were divided into pelagic [vertical average SV values for all depths except the bottom layer] and demersal fish [average SV values for the bottom layer], and used to estimate the standing stock biomass [called 'calculated SV values'], by correlating with the average standard length and weight of representative species obtained from fishery statistical data of recent fish landings, landing places survey and exploratory fishing data.

3. OCEANOGRAPHY AND MARINE ENVIRONMENT

a. FISHERY OCEANOGRAPHY

Almost every feature of the oceanographic environment in the South China Sea is to a large extent conditioned by the monsoons and its effects. No great variations in temperature, salinity and density values were recorded in the survey area during the two cruises. However, the values varied measurably between coastal and offshore waters, particularly towards the shallower southern parts, brought about by lowered salinity from freshwater runoff and pronounced mixing effect in the surface layers caused mainly by monsoonal turbulence. Surface temperature ranged from 29.12°to 30.06°C and 24.49° to 30.65°C during the pre-SW monsoon and SW monsoon cruises respectively. The horizontal temperature gradient was in the east – west direction during the pre-SW monsoon cruise and in the north – south direction during the SW monsoon. Water temperature decreased with increasing depth, while both salinity and density increased with increasing depth until it stabilized in deeper waters. Sea-surface temperature did not influence the divergence/convergence zone or the vertical movement of the pycnocline.

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 determine the oceanographic situation prevailing in any given area. The southward surface current along the coastline of Vietnam flows cyclonically until it hits the Sunda Straits, and the mid-depth water from the Gulf of Thailand that flows out to Sarawak coast is replenished by these surface waters thereby bringing about a two-layered circulation. During the SW monsoon, the surface current flowed northeasterly from the West Coast of Borneo along the coast of Sarawak, Brunei and Sabah. Monsoonal turbulence increased the depth of the surface mixing, as indicated by the downward movement of the pycnocline from 28 to 41 m during the SW monsoon, and divergence and convergence zones inferred from horizontal circulation patterns matched well with the vertical migration of the pycnocline, which gives a clear indication of the upwelling and downwelling phenomena in the area [Examples of seasonal vertical migration of thermocline, halocline and pycnocline are shown in Fig. 2]. The thickness of the mixed layer clearly reflected the

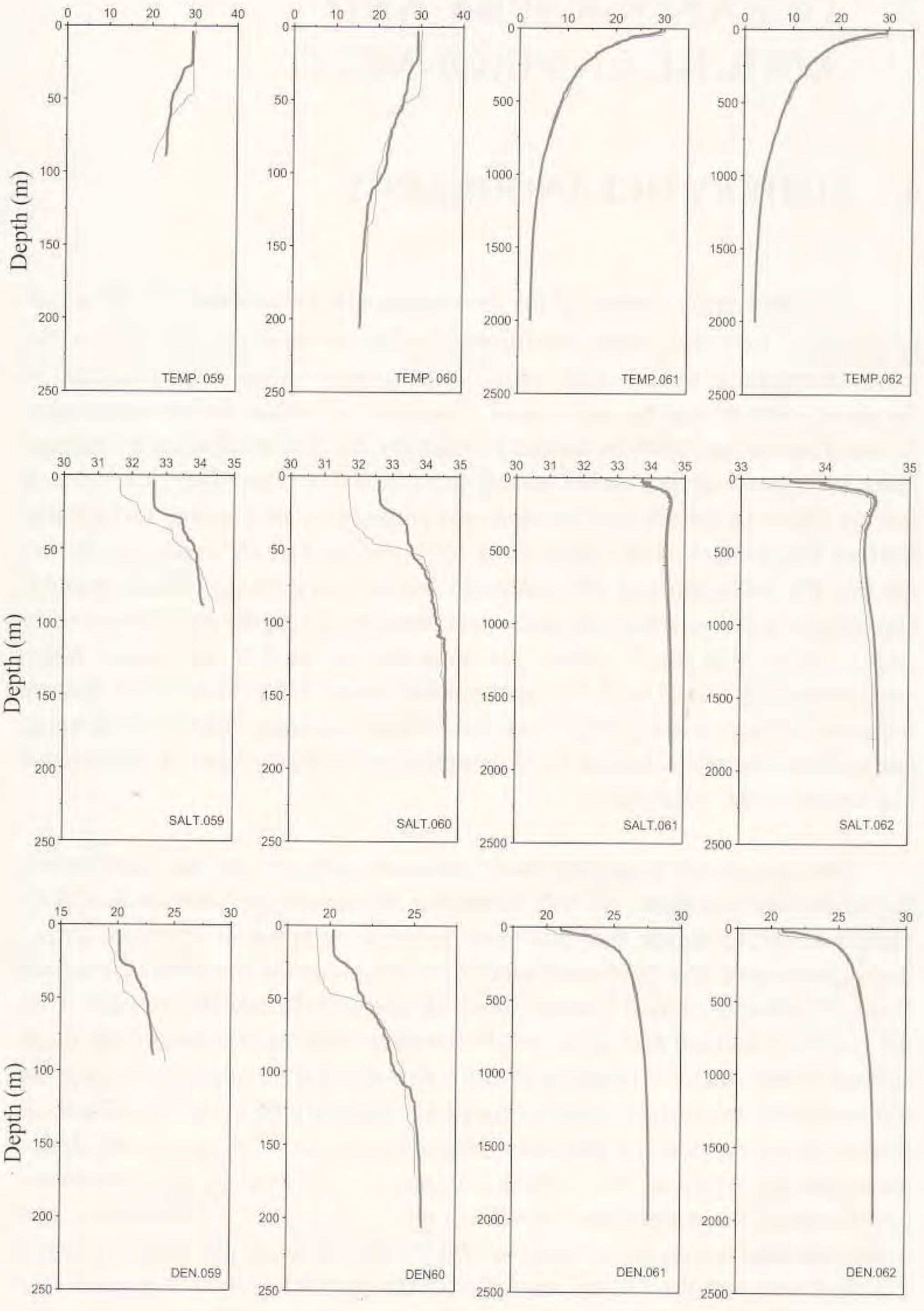
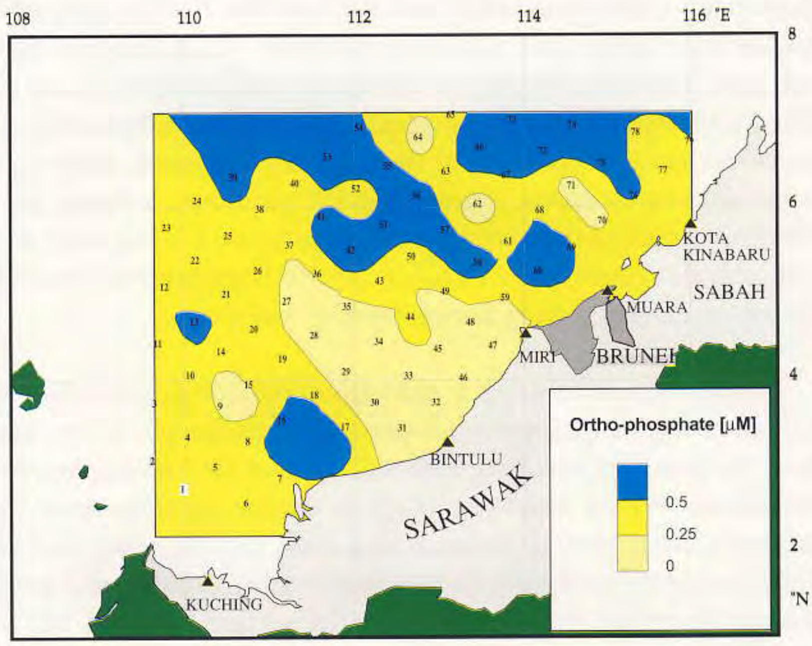


Fig. 2. Temperature, salinity and density profiles at Stations 59 to 62 during the two cruises [Pre-SW monsoon cruise profiles in thicker lines].

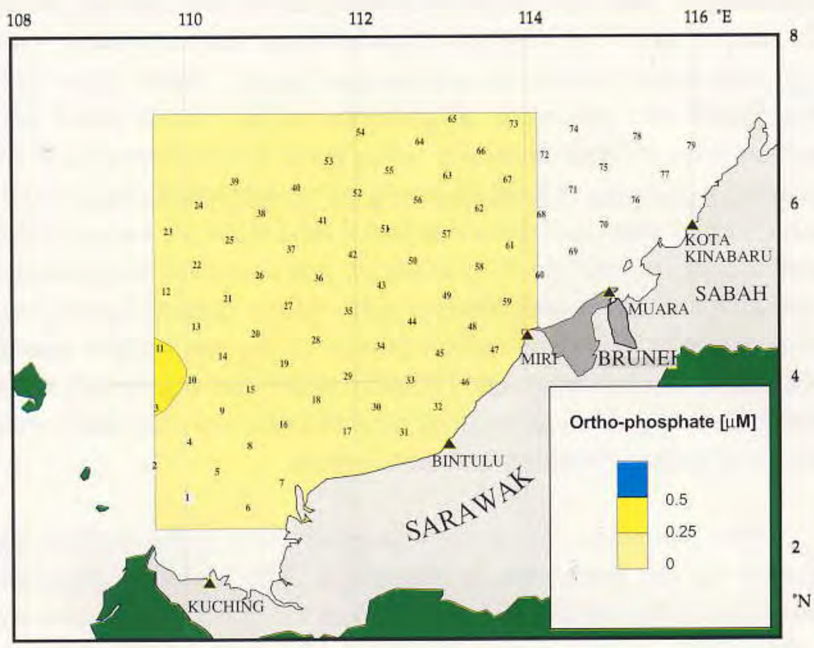
divergence and convergence zones, and was less than 50 m in depth off Sarawak and deeper towards the north before the monsoon, which trend reversed during the monsoon. The mixed layer was thinner in areas of divergence, indicating upwelling. Correspondingly, convergence zones indicated downwelling. Eddies and meanders had a strong effect on the circulation patterns, despite prevailing winds in the same direction. During pre-SW monsoon, a strong but shallow meander was observed from west to east, together with a large and strong anti-cyclonic eddy that penetrated well below 200 m. Two northward surface plumes dominated the current pattern during the SW monsoon.

Concentrations of oxygen and carbon dioxide in seawater are the net result of all biological processes, air-sea surface exchange, lateral transport to and from the area, and reactions with solid phases such as calcium carbonate. Concentrations of total dissolved inorganic carbon are influenced by several factors, particularly partial pressure of carbon dioxide, total and carbonate alkalinity, and physical factors such as temperature, salinity and pressure. pH of seawater decreased from about 8.2 at the surface to 7.7 at 500 m, below which depth it changed only slightly. pH was also low in many near-shore areas, indicating high degree of decay of organic matter, most probably of terrestrial origin. Total alkalinity increased rapidly from 2.2 meq l^{-1} at the surface to 2.35 meq l^{-1} at 150 m, and more gradually in deeper waters, with a more homogeneous distribution in the intermediate layers. Depths below 500 m were undersaturated with respect to magnesium calcite, which could explain the gradual increase in total alkalinity with depth. Freshwater runoff from land brings about a decrease in total alkalinity in the surface layers. Total dissolved inorganic carbon increased from less than 2 mM at the sea surface to more than 2.3 mM at 2,000 m, 88% to 97% of which was dissolved bicarbonate. Higher concentrations in the deeper waters were mainly caused by net respiration. Partial pressure of dissolved carbon dioxide at the sea surface was mostly at equilibrium with the atmosphere. Offshore waters were generally the sinks for atmospheric carbon dioxide, while at river mouths, the near-shore waters were the source of carbon dioxide to the atmosphere.

Ortho-phosphate levels were generally low in the surface layers, but the deeper waters were rich in phosphate. The average ortho-phosphate concentration at the surface [0 - 1 m] during the pre-SW monsoon cruise was 0.24 μM, which increased to 1.15 μM at 100 m and 5.19 μM at 1,000 m. During the SW monsoon cruise, these values decreased to 0.14 μM, 0.5 μM and 2.59 μM respectively [Fig. 3]. Previous studies indicate that the low values of phosphate at the surface may be caused by its uptake by phytoplankton. It accumulates in deeper layers by active remineralization and is brought to the



[a]



[b]

Fig. 3. Ortho-phosphate distribution in the surface layers during [a] pre-SW monsoon; and [b] SW monsoon.

surface layers during upwelling.

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. 38.3% of the survey area was covered with sandy clay, followed by clayey sand [27.66%], clay [19.15%] and sand [14.89%]. Near-shore sediments ranged from sandy to silty loam and were mostly yellowish-grey sandy mud. The nature of the sediment, especially the grain size distribution, changed from fine-grained sand to silt as depth increases [Fig.4]. In general, near-shore sediments were coarsest, more poorly sorted, more positively skewed and most peaked in characteristics as compared to the sediments further offshore [For logistic reasons, samples were collected only up to a depth of 528 m]. Although the survey area was deeper than Area I previously studied, which was located mostly within the continental shelf, sediment characteristics in both the areas were generally similar. Sediments from the pre-SW monsoon cruise were poorly sorted, less symmetrical and less peaked, but surprisingly become better sorted during the monsoon, probably because the heavier particles settled first, while the finer particles remained in suspension due to monsoonal turbulence. When these particles settle down during the calm period after the monsoon, their distribution pattern tends to become more negatively skewed. The sediment characteristics shifted from medium silt to coarse silt during the SW monsoon, while they ranged from fine silt to very fine sand during both the cruises. There are also indications that large volumes of fine sediments are discharged into the sea by the rivers during the monsoon rains, which spread and settle widely in the near-shore areas, mostly around the river mouths.

Information on properties of the sediment-water interface, as well as the kinetics of chemical reactions taking place in the sediments, is essential for understanding the mass transfer processes between seawater and marine deposits at the sediment-water interface. Release of nutrients from bottom sediments also affects the seawater quality directly, influencing organic production levels and organic pollution in the sea. Levels of nitrate and phosphate concentrations in the pore water of sediments ranged between 0.05 to 77.12 μg of NO_3-N/l [mean value of 29.09 μg NO_3-N/l] and 0.07 to 13.31 μg of PO_4-P/l [mean value of 3.73 μg PO_4-P/l]. Nitrate concentrations had no apparent correlation with surface layers during upwelling.

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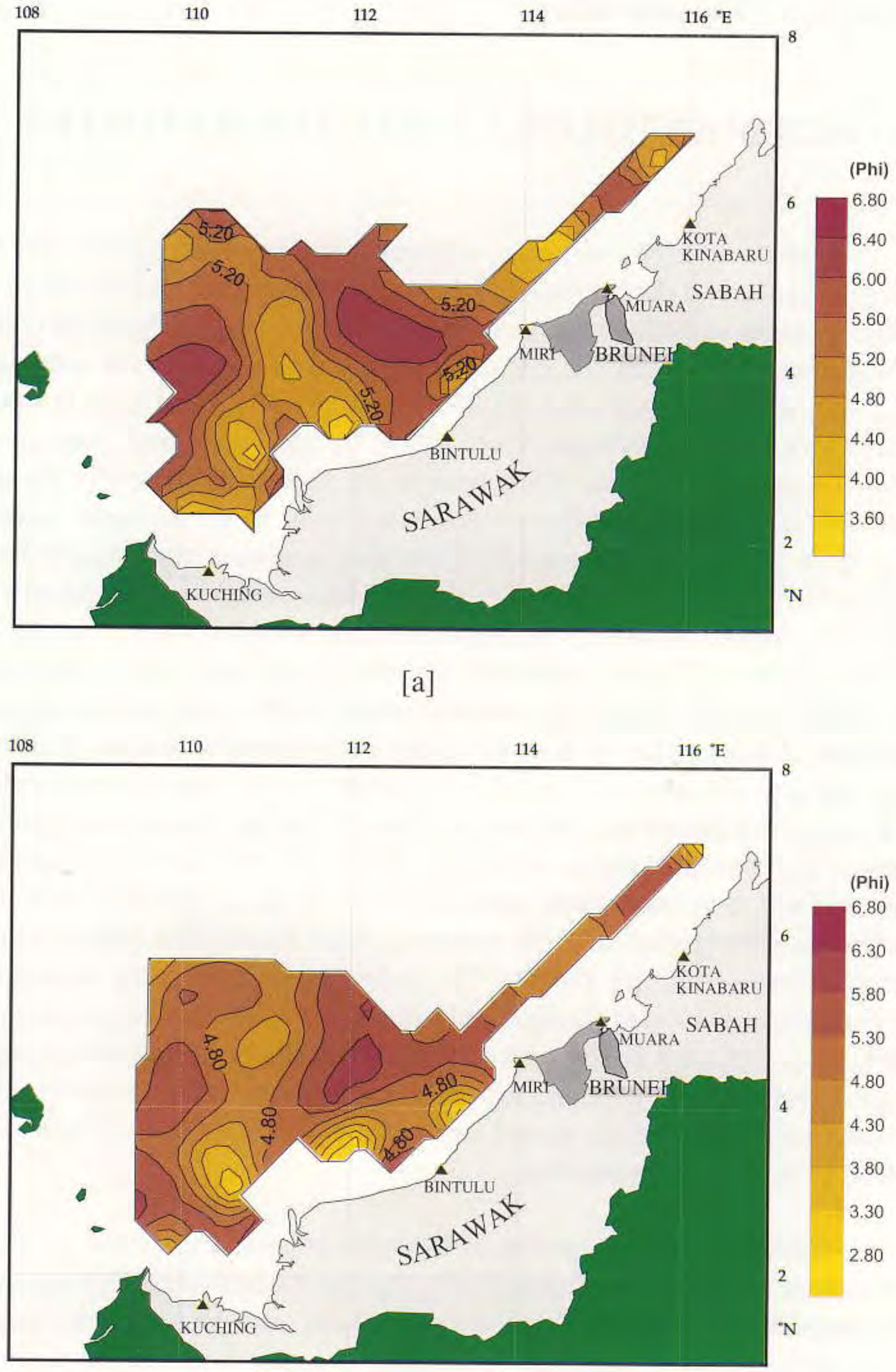


Fig. 4. Sediment size distribution patterns during [a] pre-SW monsoon; and [b] SW monsoon.

the depth of water, but were generally low at near-shore stations and comparatively high at offshore stations. Nitrate levels therefore reflect the net result of organic loading in each area and oxygen availability in the sediments to oxidize them. Tidal currents in near-shore areas also have an inhibitory effect on sedimentary denitrification. Irregular vertical distribution patterns of nitrate-nitrogen profiles at some stations may be explained as reflecting the physico-chemical functions of inhibition of nitrate reduction or stimulation of nitrification as the case may be. Phosphate concentrations were generally low except at some deeper stations, which reflect the oxidized condition of the sediments, and vertical profiles of phosphate concentrations in most of the cores were relatively constant. Ammonia is released by the decomposition of detritus and nitrified by bacteria under aerobic conditions. Ammonia concentrations in the survey area ranged between 0 – 81.76 µg NH_4-N/l, with a mean value of 15.58 µg NH_4-N/l and were particularly high in near-shore organically enriched areas, with very high upward fluxes of nearly 10 times those of nitrates and phosphates. Ammonia was not found in one-third of the area studied, showing the well-oxidized conditions there, but its levels generally increased with depth. Sedimentary organic levels were comparatively high in the shallow near-shore regions of Sarawak and the deep offshore regions of Sabah and Brunei Darussalam. Vertical distribution pattern of all nutrients indicates a constant depositional process of sediments in the area.

Organically enriched bottom sediment is important either as habitat and direct food source for benthic production or as potential nutrient source for biological productivity of the water column. Levels of organic contents of sediments correlate quite well with the type and nature of bottom deposits. Distribution of organic carbon and nitrogen contents also showed a similar pattern. Total organic carbon content [TOC] was low in near-shore waters and higher in the offshore deeper waters of Sabah. TOC was lowest [<1.00 mg/l] in sandy zones and highest [17.39 mg/l] in silty clayey sediments, with an average of 5.91 mg/l. Total organic nitrogen [TON] showed a very similar pattern of distribution to that of TOC and ranged between <0.20 and 2.00 mg/l, with an average of 0.97 mg/l for the whole area. The pattern of organic matter distribution in near-shore areas, and especially near river-mouths, reflects the effects of freshwater discharge upon the marine environment. This is also indicated by the high carbon:nitrogen ratios of more than 10 in such areas, as compared to an average ratio of 6 – 8 in other areas unaffected by outside intrusions. Total organic matter content also showed increases by over 50% – 160% during the monsoon that could only be explained by terrestrial inputs brought about by rainwater runoff and freshwater discharges. This does not, however, explain the common reduction in total organic matter in some near-shore areas during the monsoon that might have been caused by their transport away from the area by monsoonal wave action. Only 3-dimensional numerical models that reflect the important role of residual current flow characteristics in the area could clarify this aspect.

In water quality management, estimation of nutrient upward fluxes is often beneficial in understanding their recycling system and prediction of the effects of changes such as enhanced nutrient loading beneficial to the productivity of the overlying water column. Fairly high rates of nutrient upward fluxes are indicated in the survey area, comparable to other very highly productive geographical regions. Fluxes of pore water nitrate-nitrogen averaged at 26.5 mg NO_3-N/m^2/day at near-shore stations and were about one order of magnitude higher than that of phosphate. At the offshore stations, the flux varied between 5.6 and 88.4 mg N/m^2/day. Negative fluxes at many stations suggest that the overlying waters might be a possible source of nitrogen to denitrification processes in the surface sediment. Average phosphate-phosphorus upward fluxes were generally low at 2.8 mg P/m^2/day throughout the survey area, except for the high values in the deeper waters off Sabah. This may possibly be explained by the high rates of organic decomposition under comparatively oxidized conditions of the sediment. Ammonia-nitrogen upward fluxes ranged widely from 0 to 388.0 mg N/m^2/day, and the higher values were one order of magnitude higher than those for nitrate and phosphate. Variations reflect the effects of microfaunal activity, detrital inputs and oxygen content of the bottom water. Correlation between the rates of nutrient upward fluxes and sedimentary organic levels indicate that the accumulated organic matter tends to be biogenically metabolized and thus enhance the exchange between the sediments and water interface, bringing about a nutrient enrichment of the water column.

c. MARINE POLLUTION

Trace elements in the water are derived from continental rocks by weathering, leaching, desorption, cation exchange, and also increasingly from human activities, of the influence of which, some of them could often be taken as an indicator. They are removed from the system by biological processes and geochemical reactions such as adsorption, precipitation and cation exchange. Concentrations of dissolved cadmium, copper, lead and nickel ranged at more or less the same level normally found in relatively unpolluted coastal waters, except for high concentrations of cadmium at some offshore stations. Levels of iron ranged between 47 – 1,672 nM during July – August 1996 and 92 –

2,020 nM during May 1997, which were about 20 times higher than the earlier recorded levels in the Gulf of Thailand. It is suspected that these metals might have originated from Indonesian waters that flow north during the SW monsoon season. Surface distribution of copper, iron, lead and nickel showed the influences of freshwater discharges from land during the SW monsoon season. Cadmium, copper, lead and nickel were mostly in dissolved form, while iron was mostly in particulate form. Dissolved iron content was high only at some stations where total iron concentrations were also high.

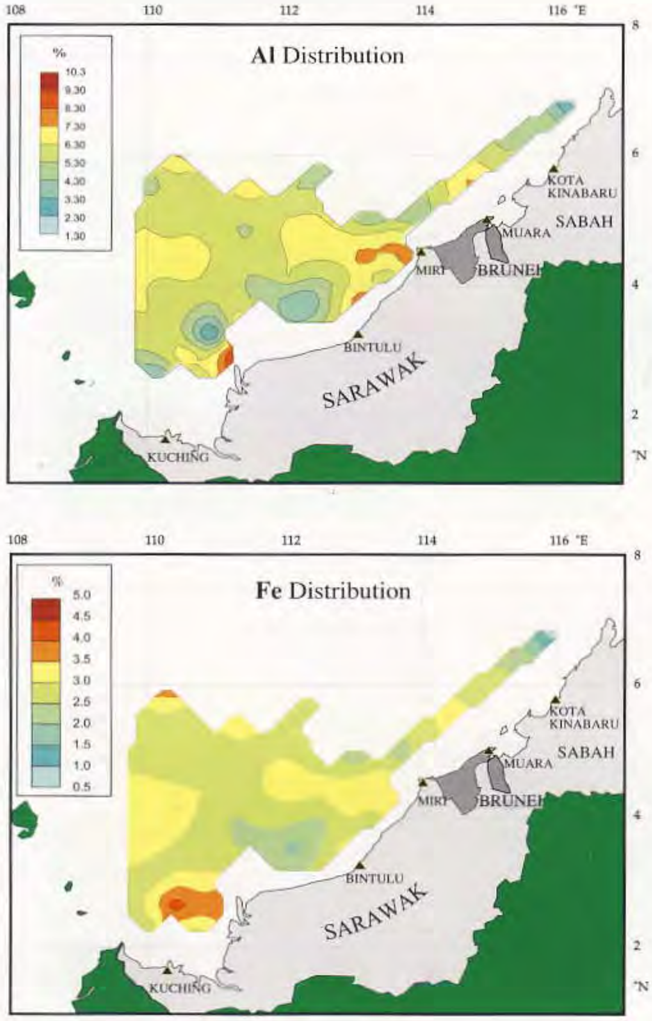


Fig. 5. Distribution pattern of trace metals in bottom sediments during pre-SW monsoon.

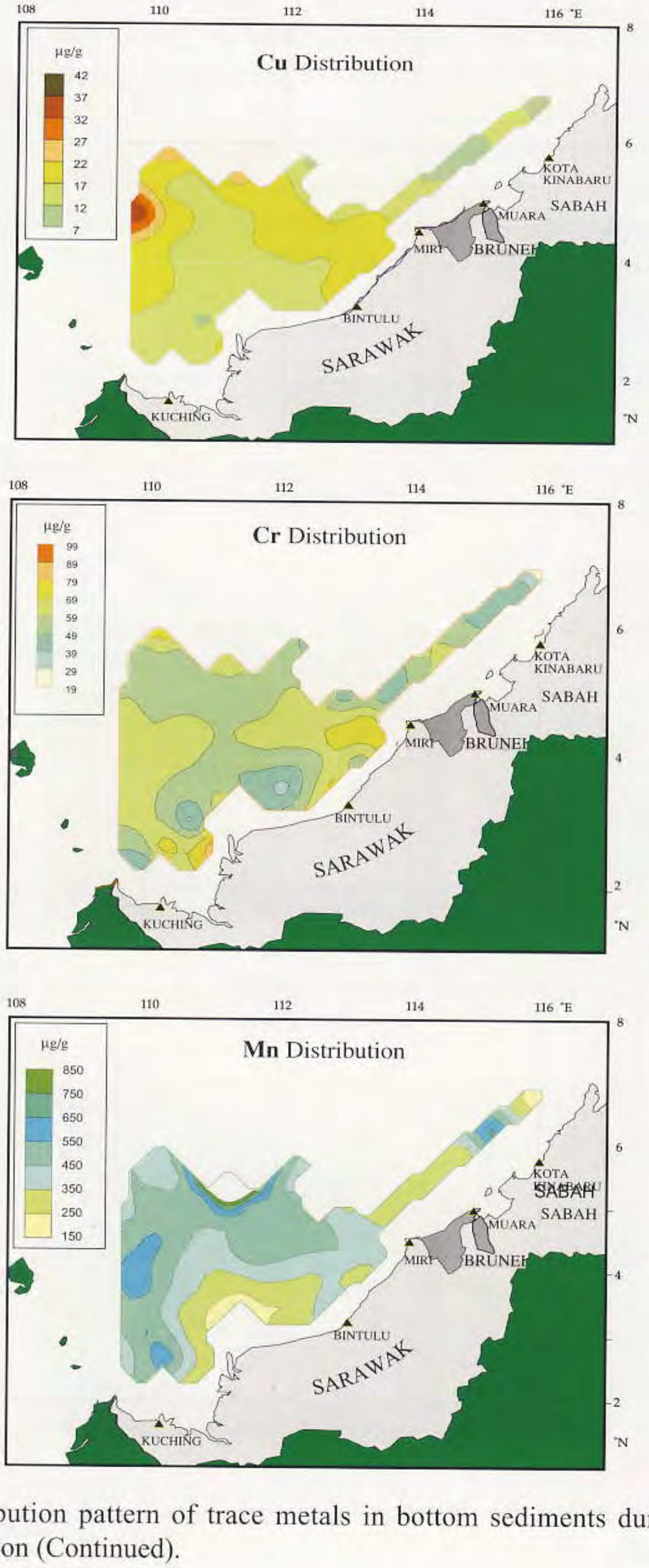


Fig. 5. Distribution pattern of trace metals in bottom sediments during pre-SW monsoon (Continued).

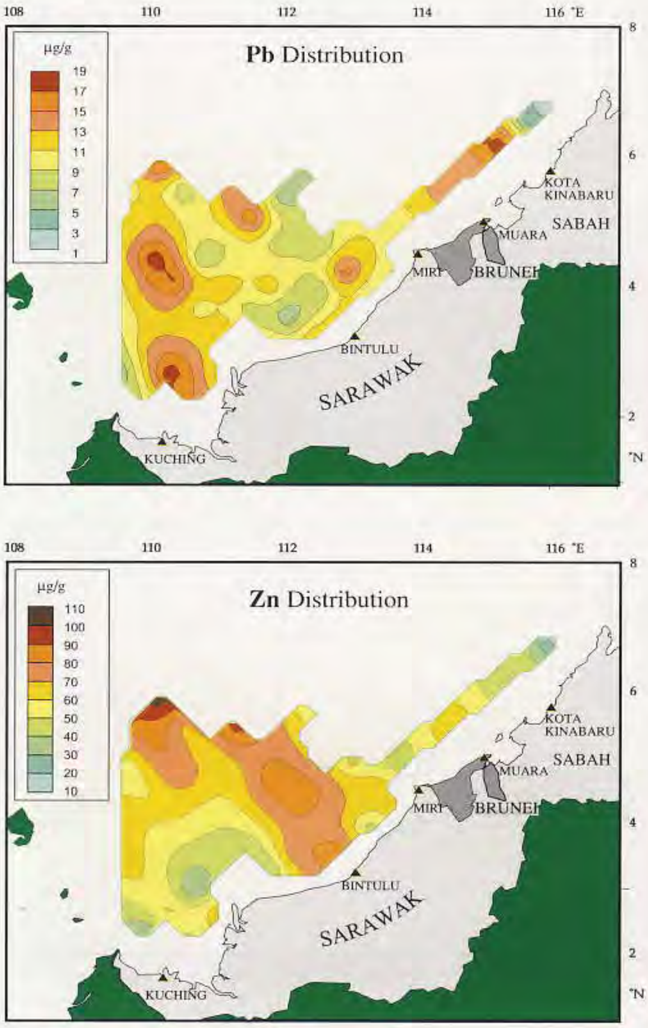


Fig. 5. Distribution pattern of trace metals in bottom sediments during pre-SW monsoon (Continued).

It is known that freshwater discharges from the rivers in the area influence the sedimentary characteristics of the seabed over a wide area and previous studies have indicated that distribution of some metals in the sediments is related to the depth of the water column. During the pre-SW monsoon season, aluminum, chromium, iron, zinc, and to a lesser extent, lead were lowest at the mouth of the Rajang river, extending northwards to the deeper stations [Fig. 5]. Manganese concentrations increased gradually with depth. The pattern of trace element distribution was very similar during the SW monsoon cruise, except for high copper concentrations recorded at the Rajang river mouth and some shifts in metallic ratios with aluminum, clearly indicating a correlation

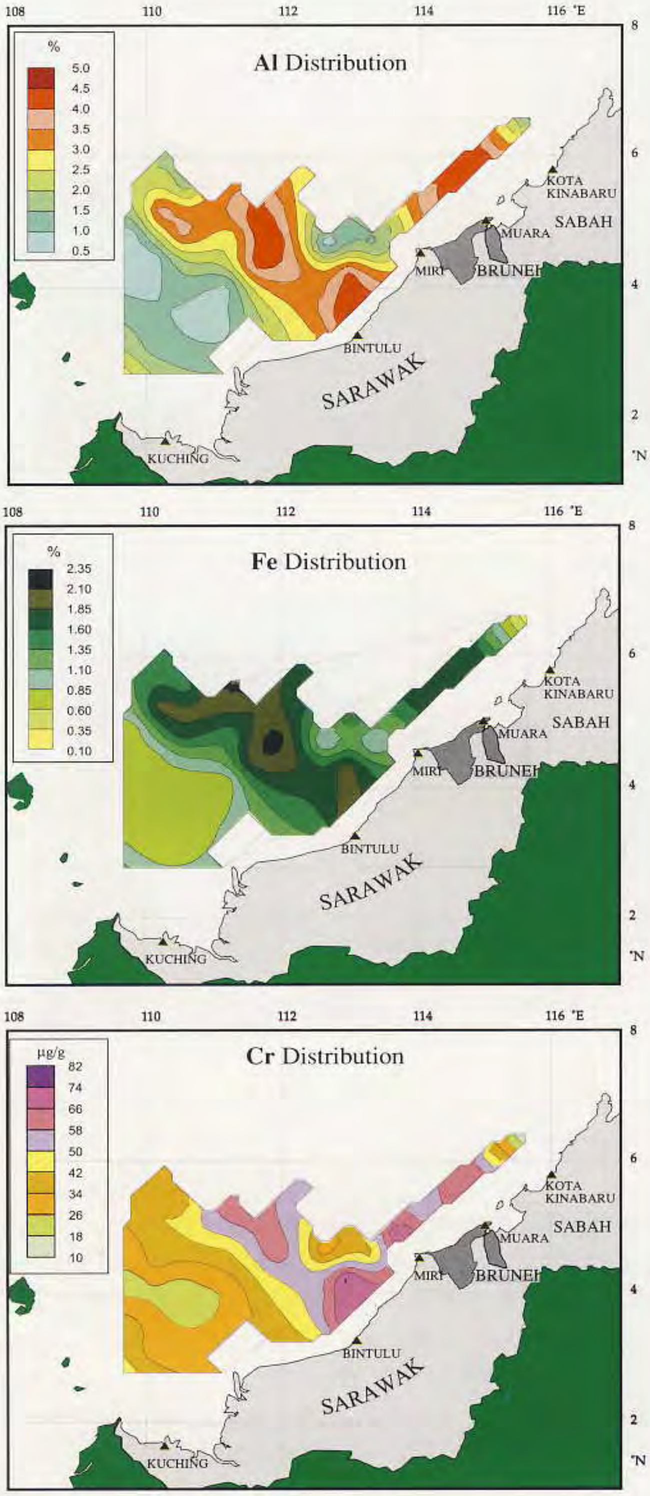


Fig. 6. Distribution pattern of trace metals in bottom sediments during SW monsoon.

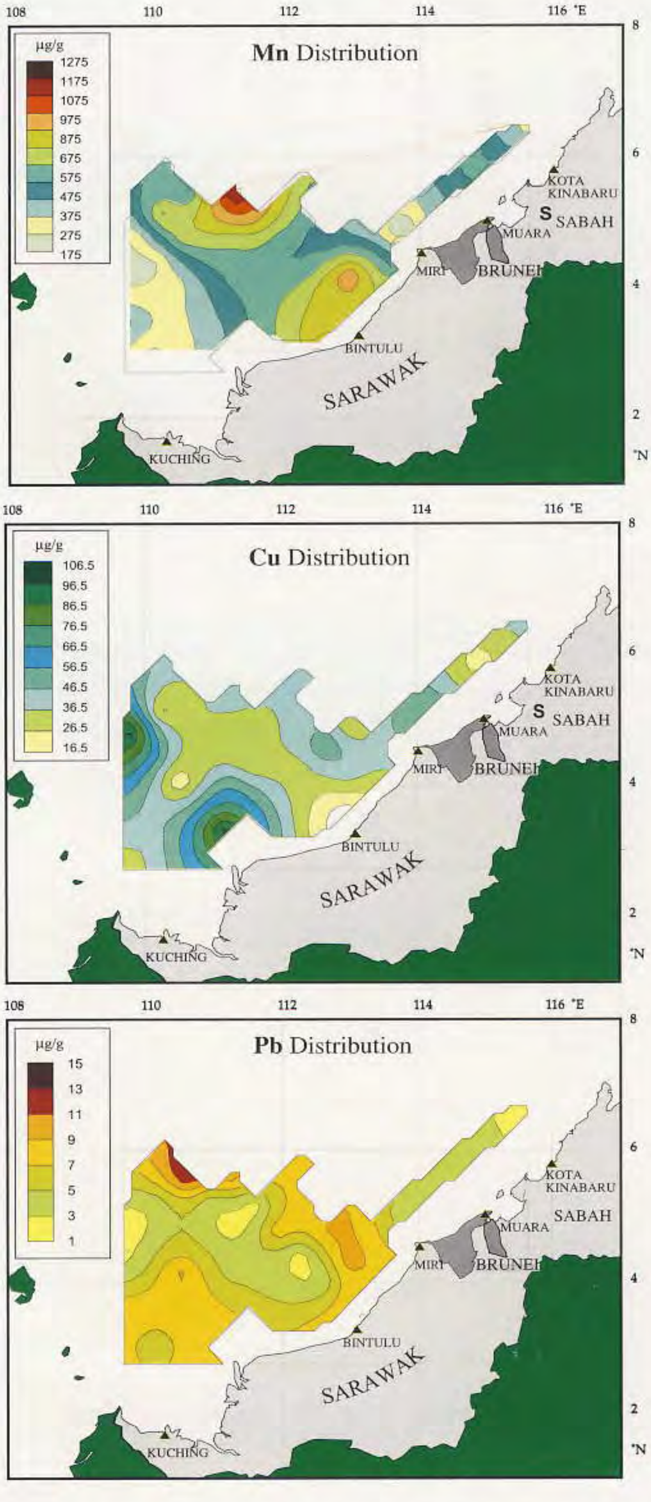


Fig. 6. Distribution pattern of trace metals in bottom sediments during SW monsoon (Continued).

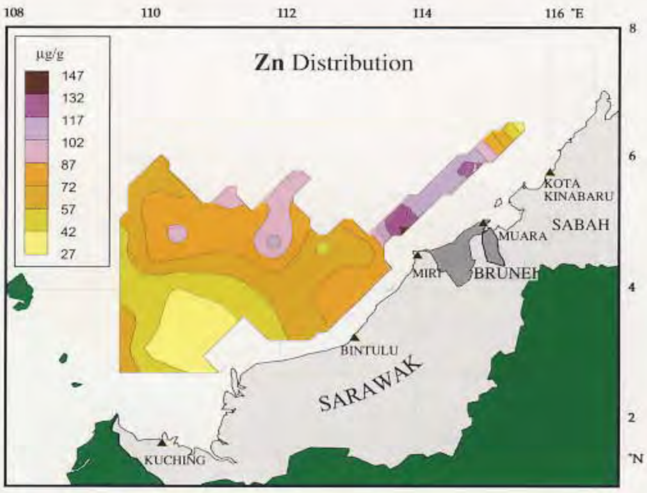


Fig. 6. Distribution pattern of trace metals in bottom sediments during SW monsoon. (Continued)

with river discharges [Fig. 6]. In general, concentrations of iron and lead are similar to natural values, while ratios of copper, chromium, lead and nickel and to a lesser extent manganese to aluminum are lower than natural values by a factor of two.

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. Depth-integrated primary production rates in the survey area during the SW monsoon period varied between 0.13 – 0.88 gC/m^2/day in the coastal shallow areas and 0.23 – 0.89 gC/m^2/day in the open sea [Fig. 7]. The production rates were highest in the northern areas off Brunei Darussalam and Sabah, which gradually decreased with increasing depth. The rates were generally high in the surface mixed layers and in the layers of sub-pycnocline chlorophyll maxima, and showed a direct correlation with light attenuation curves and to a lesser extent with the chlorophyll distribution patterns [Fig. 8].

Variations in photosynthetic pigments are being commonly used as a convenient indicator of phytoplankton biomass in aquatic environments, through

Fig. 7. Distribution of depth-integrated primary production rates [gC/m^2/day] during SW monsoon.

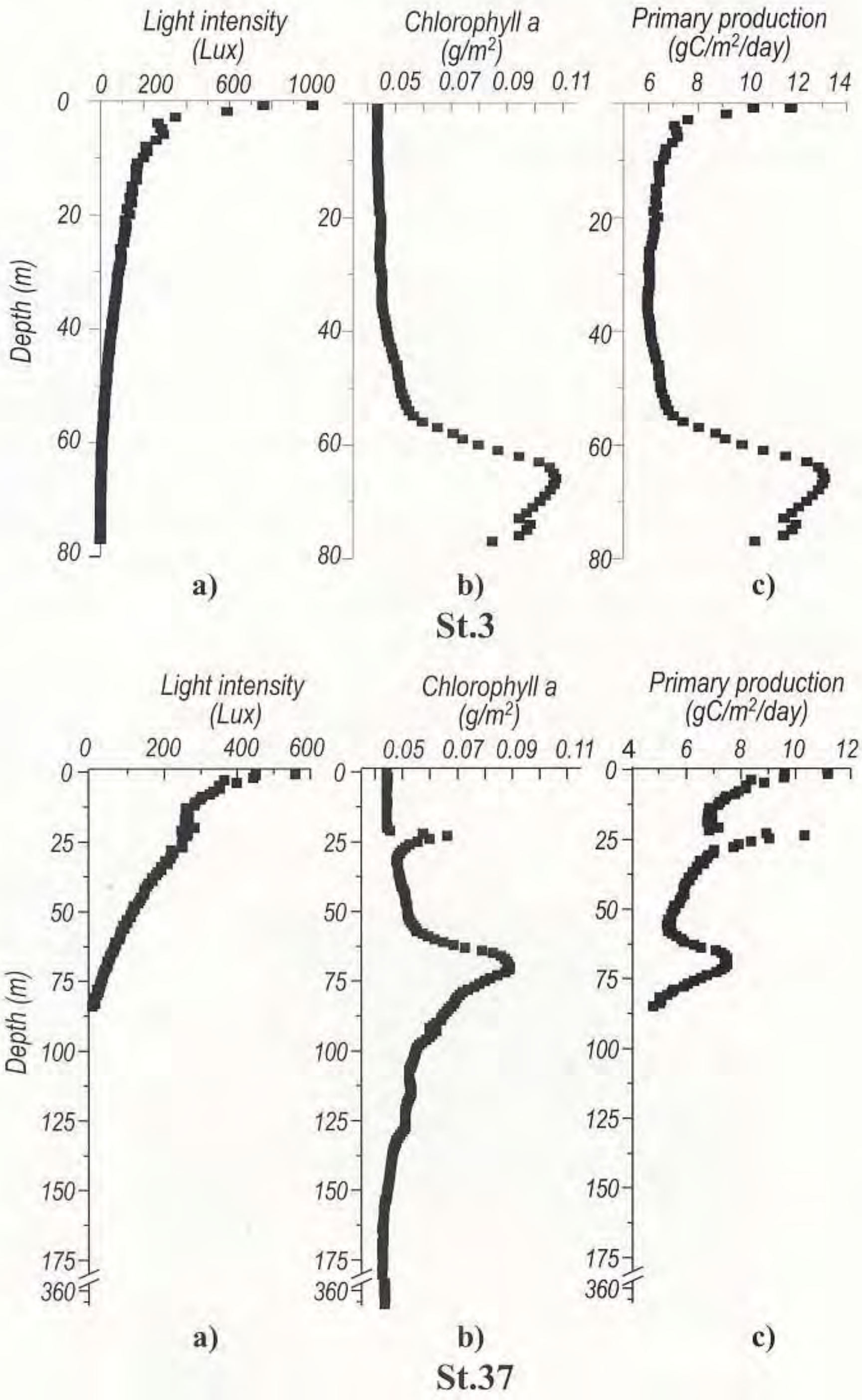
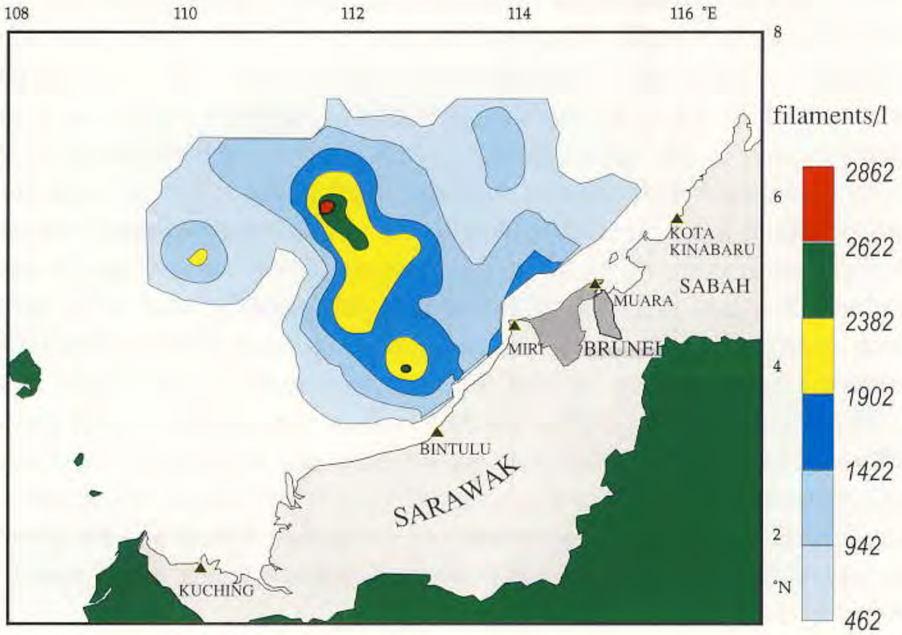


Fig. 8. Correlation between vertical distribution of [a] light penetration curves; [b] chlorophyll-a values; and [c] primary production rates at Station 3 [shallow station] and Station 37 [offshore station] respectively during the SW monsoon, showing the production peaks at the depths of chlorophyll maxima.

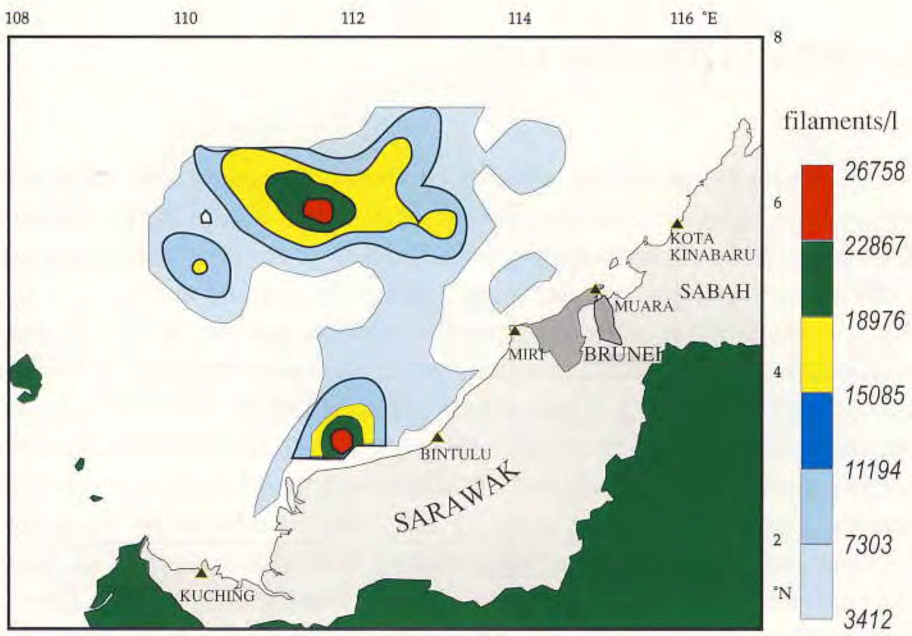
real time measurements of fine variations in vertical chlorophyll profiles. Studies during the Collaborative Research Program have clearly shown the common occurrence of sub-surface chlorophyll maxima at around 18 - 70 m in the coastal areas and 45 - 80 m at the deeper stations, despite very low pigment concentrations in the surface layers [Values varied by a factor of up to 10]. A minor chlorophyll accumulation was also often found at 10 – 25 m in the sub-surface mixed layer. Spatial distribution of depth-integrated total biomass of phytoplankton as shown by *in situ* fluorescence clearly showed unique patterns of plume distribution during the two cruises, although the total values were not much different quantitatively. Total calculated biomass of chlorophyll *a* for an estimated survey area of 243,000 sq. km was computed to be of the order of 2,070 mt and 1,870 mt during the two cruises respectively, which showed a difference of barely 10% between the two seasons. Biomass per unit area did not correlate well with the surface mixed layer, which might be because of the time lag between nutrient enrichment of the surface layers and the growth of phytoplankton. Yet, high biomass values at some stations could possibly be related to the effects of upwelling.

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. The only previous phytoplankton study in the survey area was on red tides. During the present survey, 310 taxa of phytoplankton were collected from the surface and the depths of seasonal thermocline and sub-pycnocline chlorophyll maxima, composed of 139 species [belonging to 55 genera] of diatoms, 150 species [37 genera] of dinoflagellates and three species [2 genera] of blue-green algae. The genera *Chaetoceros, Bacteriastrum, Rhizosolenia* and *Ceratium* were found to have a wide range of species. The phytoplankton standing crop was dominated by 16 species of diatoms and one blue-green alga during both the cruises. The diatoms, *Chaetoceros lorenzianus* and *Thalassionema frauenfeldii,* and the blue-green alga, *Trichodesmium erythraeum* were abundant at all the layers sampled. The diatoms, *Proboscia alata, Pseudosolenia calcar-avis* and *Thalassionema nitzschioides* were predominant in the surface layers, while *Asteromphalus elegans, Chaetoceros curvisetus, C. densus, C. distans* and *Thalassiosira thailandica* occurred exclusively at the surface during the SW monsoon. The diatoms, *Bacteriastrum comosum, B. elongatum, Chaetoceros affinis, C.*



[a]



[b]

Fig. 9. Distribution of *Trichodesmium* spp. [filaments/l] during [a] pre-SW monsoon; and [b] SW monsoon.

compressus, C. messanensis, C. radicans, Fragilariopsis doliolus, Leptocylindrus mediterraneus and *Planktoniella sol* were abundant only at the depths of chlorophyll maxima. *Planktoniella sol,* which is a well known 'shade species', sometimes predominated at this depth, especially at the offshore stations during the pre-SW monsoon cruise. 14 diatom species found at the thermocline and chlorophyll maxima layer, were not recorded from the surface. *Chaetoceros didymus* and *Thalassionema frauenfeldii* were dominant in the surface layers near the coastal areas, while two species of the blue-green alga, *Trichodesmium* abounded in the offshore surface waters, particularly during the pre-SW monsoon cruise, reaching concentrations of up to 2.24 x 10^6 filaments/m^3 [20% of total cell density] [Fig. 9]. The overall dominance of this species reached over 30% in some areas. An elongated narrow strip of *Thalassionema nitzschioides* bloom was observed along the coast of Sarawak during the SW monsoon, while two small patches of the same species, together with a bloom of *Rhizosolenia alata*, were seen before the SW monsoon. Smaller patches of various species of *Bacteriastrum, Chaetoceros* and *Thalassionema* were also recorded during both the cruises. Dinoflagellates were found to be common only in the thermocline layers. But *Alexandrium fraterculus, A. leei, Amphidinium* spp., *Amphisolenia globifera, Ceratium arietinum, C. lumulus, C. symmetricum and Phalacroma rapa* were recorded in the surface layers. *Protoperidinium* sp. was sometimes found in large concentrations in some areas during the SW monsoon. *Amphisolenia* and *Ceratocorys* were often common at the near-shore stations. 35 species were found below the mixed layer. Marked differences in the phytoplankton standing crop between the two cruises was noticed only in the sequence of dominance of species, but not in general species composition. In the offshore waters of Sarawak, the total cell density during the pre-monsoon cruise was only 28% of that during the SW monsoon.

A maximum cell density of 2,068 cells/l was recorded during the pre-SW monsoon, while the highest cell counts increased to 3,658 cells/l during the SW monsoon. But the SW monsoon seems to have an effect on phytoplankton growth only in the coastal areas, as the cell densities at the offshore stations during this period were very low. As is to be expected, phytoplankton standing crop was most abundant at the depths of chlorophyll maxima, which was particularly outstanding in Sarawak waters, especially during the SW monsoon. Diversity and evenness indices of phytoplankton in this layer were also highest during both the cruises. The highest indices of species richness were recorded at the offshore stations, although it ranged widely. Turbulence caused by the strong southwesterly winds during the SW monsoon brings up nutrients to the surface layers, which trigger phytoplankton growth, as shown by the high cell densities especially near the coast. High diversity indices recorded during this period also indicate the suitability of monsoonal conditions for the growth of a large number of phytoplankton species. In contrast, the weak currents before the onset of the SW monsoon result in low phytoplankton concentrations especially in the offshore areas.

Considered on the station cluster analysis, at least 7 species associations were identified, on the basis of their preference for specific environmental conditions. Such associations are constantly acted upon by various physical and biological factors in different ways, which eventually precipitate changes in their patterns of dominance in response to such effects. These changes are usually at a maximum when predominance of one or more species occurs during blooms.

Red tides caused by the dinoflagellate, *Pyrodinium bahamense* var. *compressum,* which is associated with paralytic shellfish poisoning [PSP], have been often recorded in the recent past in the coastal areas of Brunei Darussalam, and to a lesser extent off Sabah, and also in the Philippines [almost annually] and Eastern Indonesia. The outbreaks occur very regularly during June – July and December - January in Brunei Bay, Kimanis Bay, and off Kota Kinabalu. Over 300 cases of illness, including 30 deaths have been reported, mostly attributed to the consumption of contaminated shellfish, and to a lesser extent, the fishes, *Sardinella* spp. and *Decapterus* spp. During the present survey, some toxic dinoflagellate species were recorded in small numbers. *Alexandrium tamiyavanichi* occurred in the highest density [36 cells/l] at the surface during the SW monsoon [Fig. 10]. However, the toxic species, *Pyrodinium bahamense* was not recorded at any of the stations during the survey.

Life cycles of dinoflagellates alternate between a vegetative stage [motile cells in the phytoplankton] and a resting stage [non-motile cells or cysts mostly in the sediments] produced during the sexual phase. The potential danger of the cysts lies in that they could act as the seed population to trigger toxic red tides at any time. 18 species of dinoflagellate cysts belonging to Gonyaulacaceae [6 species], Protoperidiniaceae [9 species], Pyrophacaceae [1 species] and an unidentified family [2 species] were collected from the survey area. The cell density ranged between 6 to 278 cysts/cm^3, with *Spiniferites bulloideus* [cyst of *Gonyaulax scrippsae,* recorded at 30 out of a total of 47 stations, 63.8% of total abundance] as the dominant species [Fig.11], closely followed by *Spiniferites ramosus* [cyst of *Gonyaulax spinifera* complex, recorded at 27 stations, 57.4% of total abundance] [Fig. 12]. *Spiniferites cf. mirabilis* [cyst of *Gonyaulax spinifera* complex] was a distant third [recorded at only 5 stations, 10.6% of total abundance]. Many unidentified species of *Protoperidinium* were

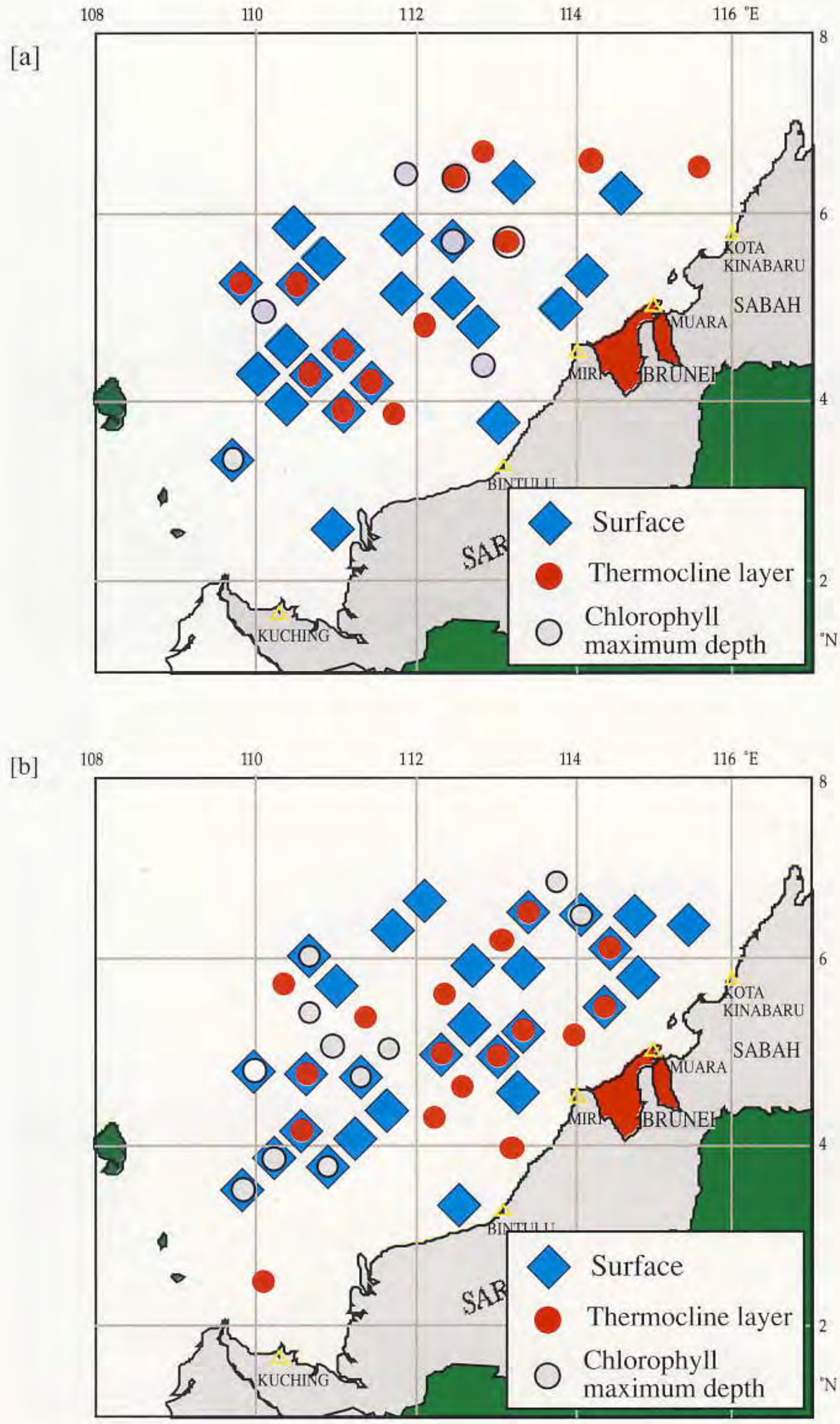


Fig. 10. Distribution of the toxic dinoflagellate species, *Alexandrium* spp. during [a] pre-SW monsoon; and [b] SW monsoon.

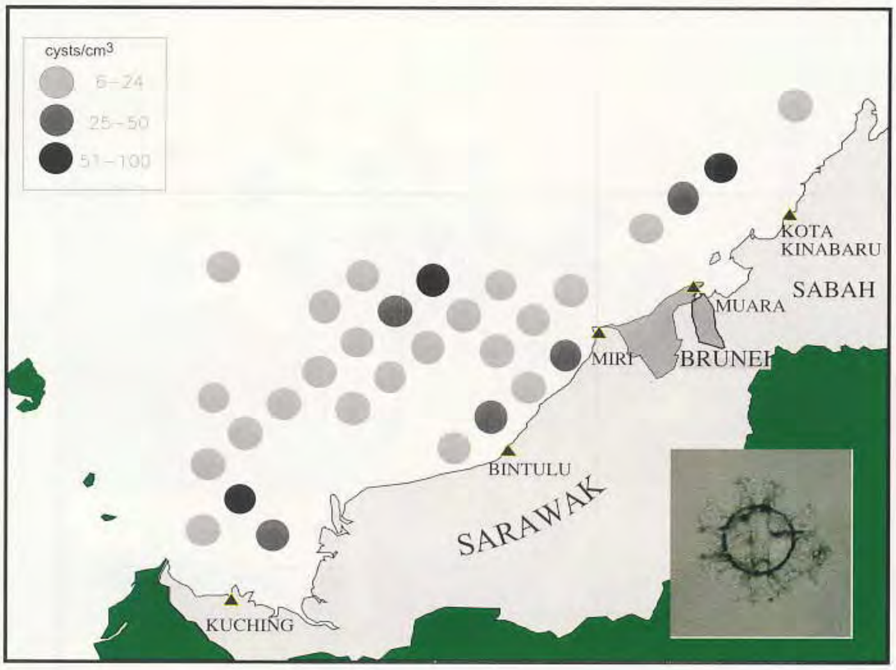


Fig. 11. Distribution and abundance of cysts of the dinoflagellate *Spiniferites bulloideus*.

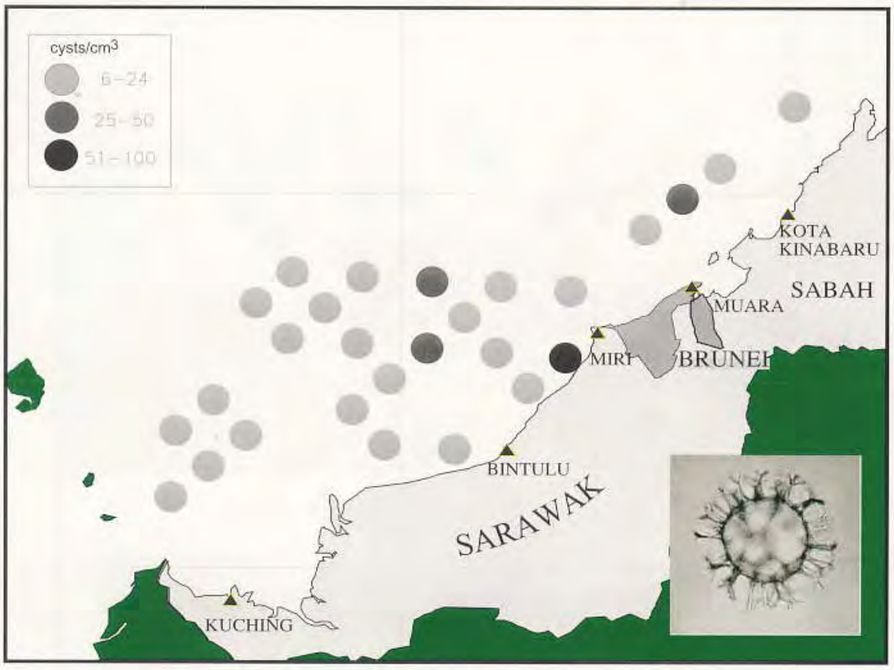


Fig. 12. Distribution and abundance of cysts of the dinoflagellate *Spiniferites ramosus*.

also common, each at up to 7 stations [a total abundance of 55.4%]. The values were higher than those earlier found in the Gulf of Thailand and the East Coast of Peninsular Malaysia [12 – 84 cysts/cm^3], but were very low when compared to such areas as the Southern Indian Ocean [200 – 50,000 cysts/cm^3]. Protoperidiniacean cyst abundance has been associated with areas of high levels of dissolved nutrients and diatom productivity, such as the upwelling areas. None of the harmful species were collected, except for a small number of *Alexandrium* sp. at one station near Sarawak coast. The pattern of abundance and distribution were not much different between the two cruises, and there was no apparent relationship between the physical properties of sediments and the distribution of cyst densities, mainly because these parameters were not much different throughout the survey area. It would appear that *Spiniferites bulloideus* is widely distributed in Southeast Asian waters, as it was also abundant in Area I previously studied.

c. ZOOPLANKTON

Zooplankton plays a key role in marine food chain as they transfer energy from phytoplankton to higher trophic levels, and very particularly as larval fish food. Especially, the transfer of trophic energy to the fish stocks through their food supply is of particular interest to the fisheries in the region. It has been hypothesized that variations in the availability of zooplankton are related to the survival of fish larvae and the degree of their subsequent recruitment to adult stages. 38 groups of zooplankton were identified from the survey area, dominated by Copepoda [average 52%] [Fig. 13], Ostracoda [average 10%] and Chaetognatha [average 7.8%] during both the cruises. Copepods were abundant throughout. Gastropod veliger [57.9%], bivalve larvae [14.6%] and Thecosomata [23.4%] accounted for the majority of planktonic molluscs, mostly in neritic waters. Total zooplankton biomass varied from 0.09 – 1.76 ml/m^3 [average 0.45 ml/m^3] and 0.11 – 1.54 ml/m^3 [average 0.44 ml/m^3] respectively during the two seasons [Fig. 14]. Total zooplankton abundance varied from 35 – 1,383 nos./m^3 [average 251 nos./m^3] and 72 – 681 nos./m^3 [average 232 nos./m^3] respectively during the two cruises [Fig. 15]. Waters of Sarawak were richer in abundance than the more northerly areas and the coastal waters were richer than the offshore areas. Some groups such as the Gymnosomes [naked Pteropods] were mostly distributed in the oceanic waters off Brunei and Sabah, but were very rare in Sarawak waters. Fish eggs were most abundant in the coastal waters and near-shore stations of Sarawak [Fig. 16]. In general, zooplankton abundance was lower than in the Gulf of Thailand

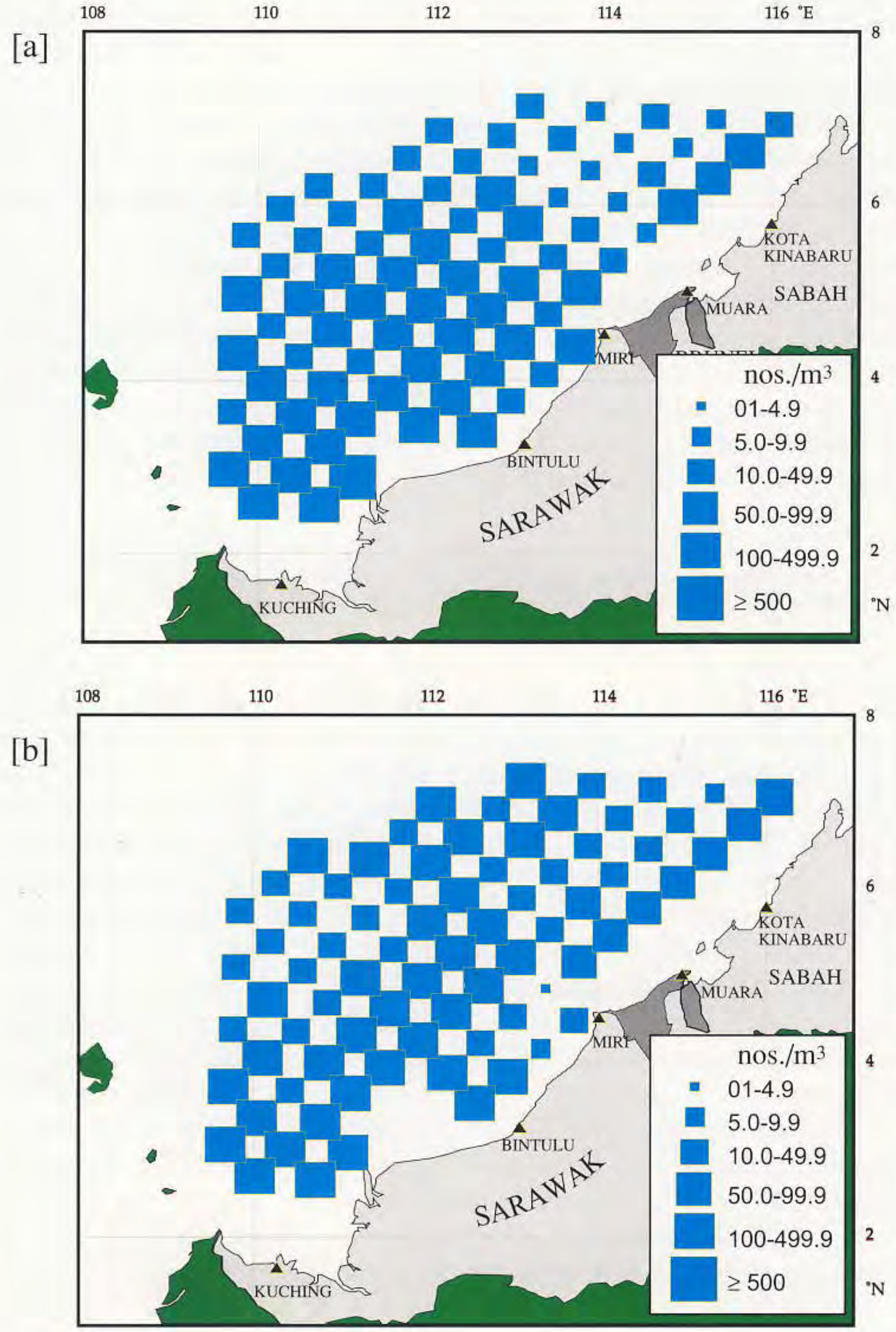
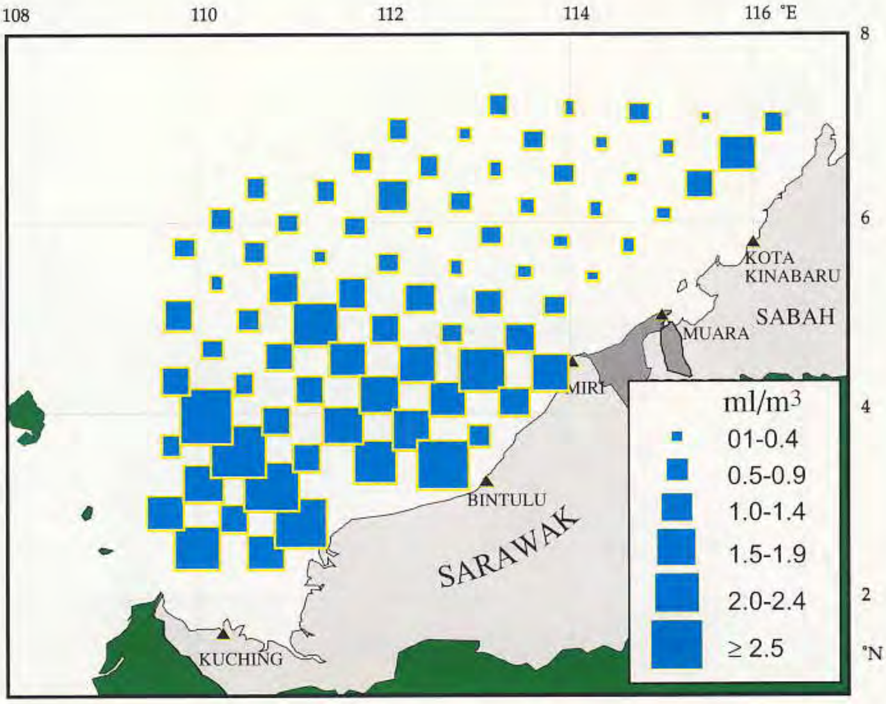


Fig. 13. Abundance and distribution of copepods during [a] pre-SW monsoon; and [b] SW monsoon.

[a]



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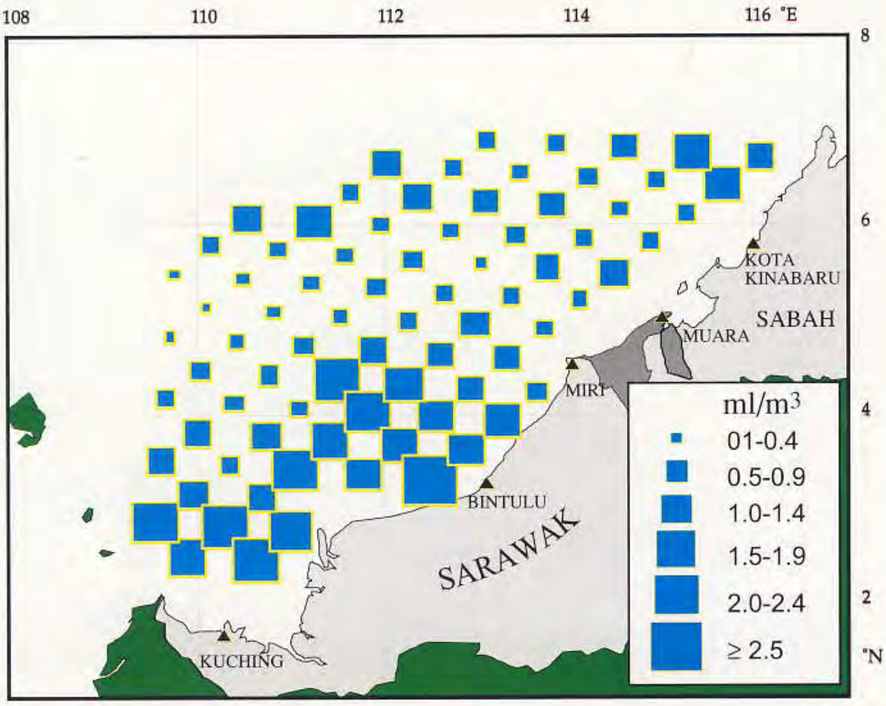


Fig. 14. Distribution of total zooplankton biomass during [a] pre-SW monsoon; and [b] SW monsoon.

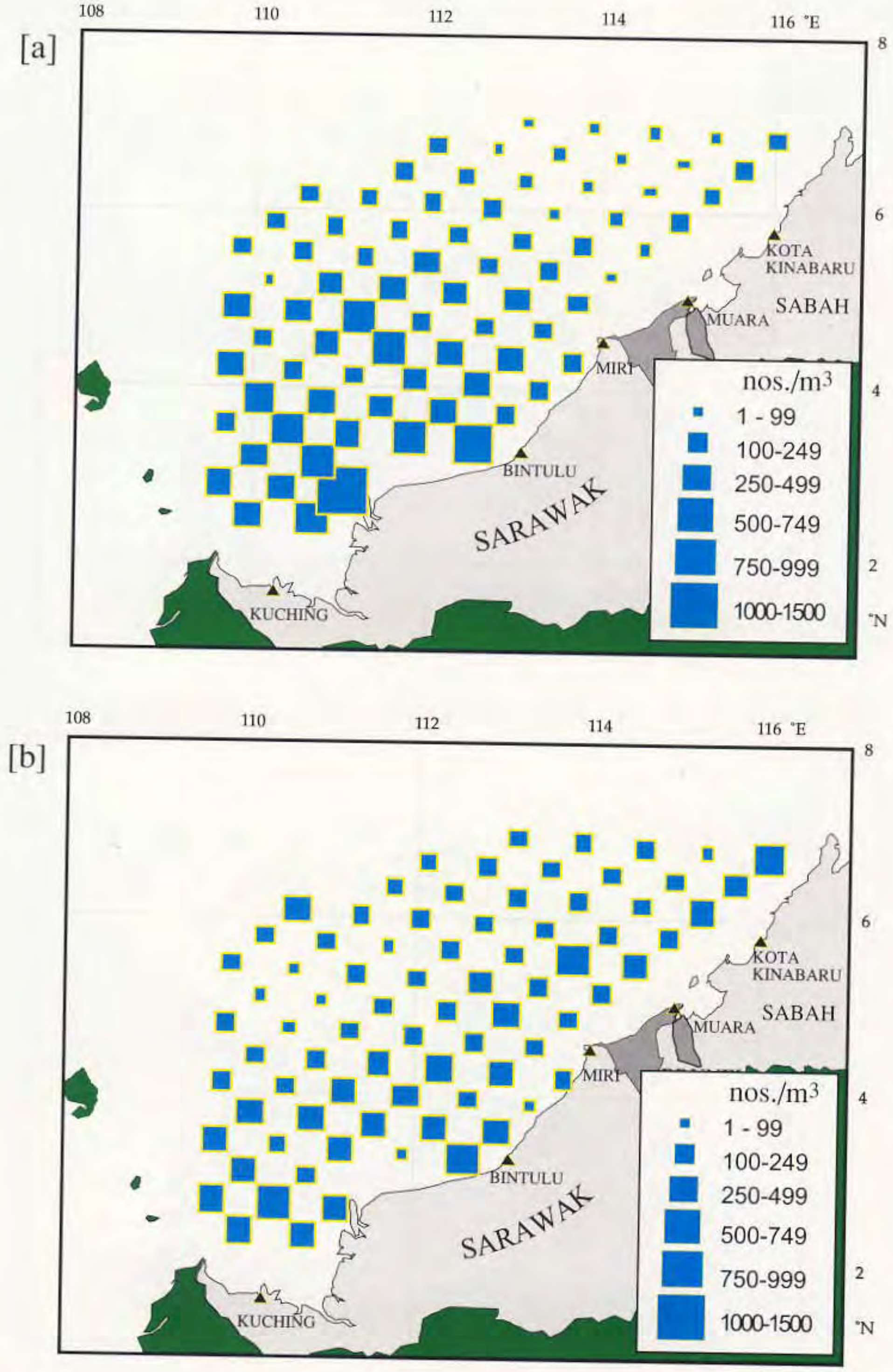
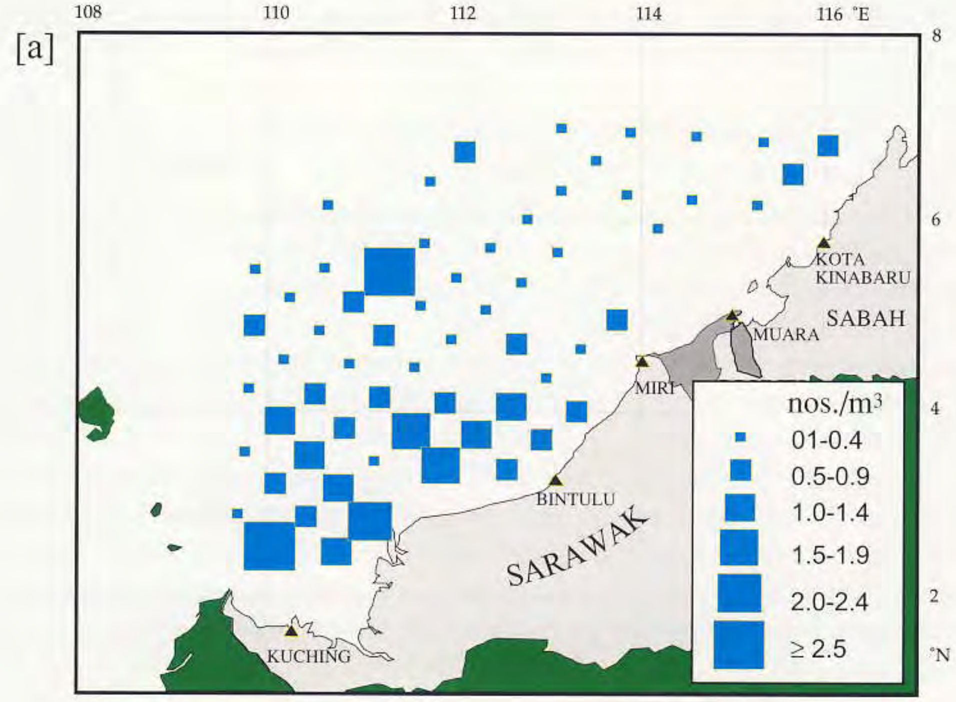


Fig. 15. Distribution of total zooplankton abundance during [a] pre-SW monsoon; and [b] SW monsoon.



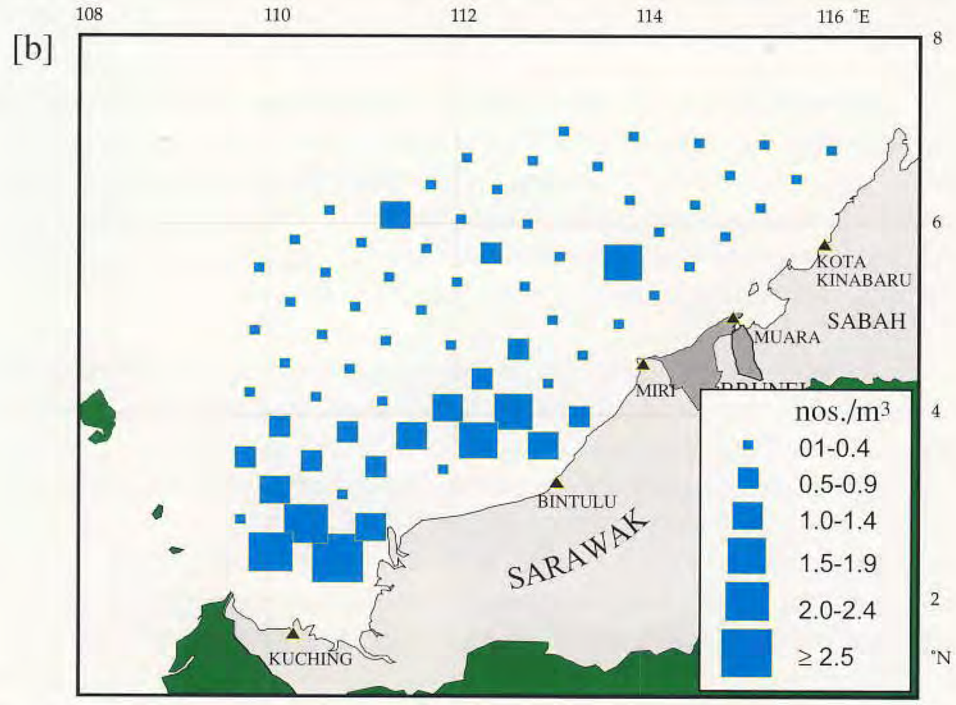


Fig. 16. Abundance and distribution of fish eggs during [a] pre-SW monsoon; and [b] SW monsoon.

and the East Coast of Peninsular Malaysia, which was surveyed earlier in Area I, mainly because of the more oceanic nature of the waters.

During the pre-SW monsoon, zooplankton biomass fluctuated from 0.09 – 1.76 ml/m^3 [average 0.45 ml/m^3] and abundance 35 – 1,383 nos./m^3 [average 251 nos./m^3], predominated by Siphonophora, Medusae, Chaetognatha, Copepoda, *Lucifer* spp. and bivalve veliger. Ctenophora, Cladocera, Appendicularia, Thaliacea, Thecosomata and Heteropoda, as well as larvae of many taxonomic groups, such as Phyllosoma larvae, Brachyura larvae, Gastropod veliger and fish eggs were also common. During the SW monsoon, total zooplankton biomass varied between 0.11 to 1.54 ml/m^3 [average 0.44 ml/m^3] and total abundance, 72 – 681 nos./m^3 [average 232 nos./m^3], composed mainly of Siphonophora, medusae, Cladocera, salps and Thecosomata. Zooplankton concentrations were highest in the neritic zone along the coastline of Sarawak during the pre-SW monsoon, but their distribution pattern did not show much variation during the monsoon, such as in the case of Thecosomata, probably because of the effects of monsoonal turbulence. Between the two cruises, biomass values were higher at 36.71% and lower at 46.84% of the stations, while the abundance was higher at 40.51% and lower at 46.84% of the stations sampled during the pre-SW monsoon period. T-test showed no significant differences in biomass and abundance between the two seasons.

Microplankton in the survey area consisted of more than 20 groups and was dominated by copepod nauplii [which constituted more than half of the total microplankton counts], Chaetognath larvae [5%], Ciliophora [4%, mostly tintinnids], Foraminifera [2-3%], Radiolaria and other Protozoa, which were mostly concentrated in the near-shore waters. Microplankton concentrations showed an increase in abundance during the SW monsoon.

Survival rates of larval fish are controlled by many biotic and abiotic factors, such as predators. Such large carnivorous zooplankton as medusae, Siphonophora Ctenophora and Chaetognatha are macroplanktonic predators of fish larvae. The present study indicates a clear-cut inverse correlation between the abundance of Chaetognatha and fish larvae in the survey area. Their abundance could thus have a deleterious effect on the recruitment of larval fish. On the other hand, fish larvae tend to accumulate in areas of high copepod concentrations, which constitute their main food. Being abundant in copepods, the area thus holds promise as a good grazing ground for the growth of fish larvae, whose abundance in its turn is kept in check by their predators. Eggs, larval crustaceans and molluscs, ciliates, small zooplankton and unicellular organisms also constitute larval fish food. Studies in many other geographical areas have shown that peak seasons of commercial fisheries coincide with periods of high zooplankton production, indicating their influence upon and importance to fisheries.

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 in the nutrition of bottom-feeders. In addition, they could also be used as good biological indicators of marine pollution. Certain macrobenthic species themselves are also of commercial value. Studies on the seasonal changes in the faunistic composition and diversity of macrobenthic organisms identified over 90 species of organisms from 47 stations in the survey area, composed mostly of carnivores and scavengers [62.59%], followed by deposit feeders [35.2%], suspended detrital particle feeders [2.31%] and herbivores [0.08%] during both the seasons.

The benthic fauna is mainly composed of Polychaeta, Crustacea, Mollusca and Echinodermata. The overall average density of organisms was 167 nos./m^2 during the pre-SW monsoon cruise [ranging from 20 to 670 nos./m^2] and 100 nos./m^2 during SW monsoon [10 – 320 nos./m^2] [Fig. 17]. Crustaceans were predominant during the pre-SW monsoon [58.7% of total abundance, at an average of 98 nos./m^2, varying from 0 – 500 nos./m^2], followed by Polychaeta [35.9%, at an average of 60 nos./m^2, varying from 10 to 180 nos./m^2] which situation reversed during the monsoon, when Polychaeta was dominant with 53% abundance [average, 53 nos./m^2, ranging from 10 – 230 nos./m^2, mostly in near-shore areas], and Crustacea 37% [at an average of 37 nos./m^2, varying from 0 – 170 nos./m^2]. Among the Crustaceans, Amphipoda was abundant at all the stations sampled, while a total of 32 families of Polychaeta were identified, with family Capitellidae the most widely distributed. Brittle stars were the most common Echinoderms. Between the two cruises, abundance of Polychaeta and Crustacea showed a marked difference at 85% and 90% of the stations sampled. Polychaeta showed a decrease in abundance at 47% of the stations during the SW monsoon, while it showed an actual increase at 38% of the survey area. Abundance of Crustacea decreased at 66% of the survey area, while it increased at 23% of the stations sampled. Echinodermata differed at half of the stations and the abundance of Molluscs showed no difference between the two seasons. On the whole, benthic fauna

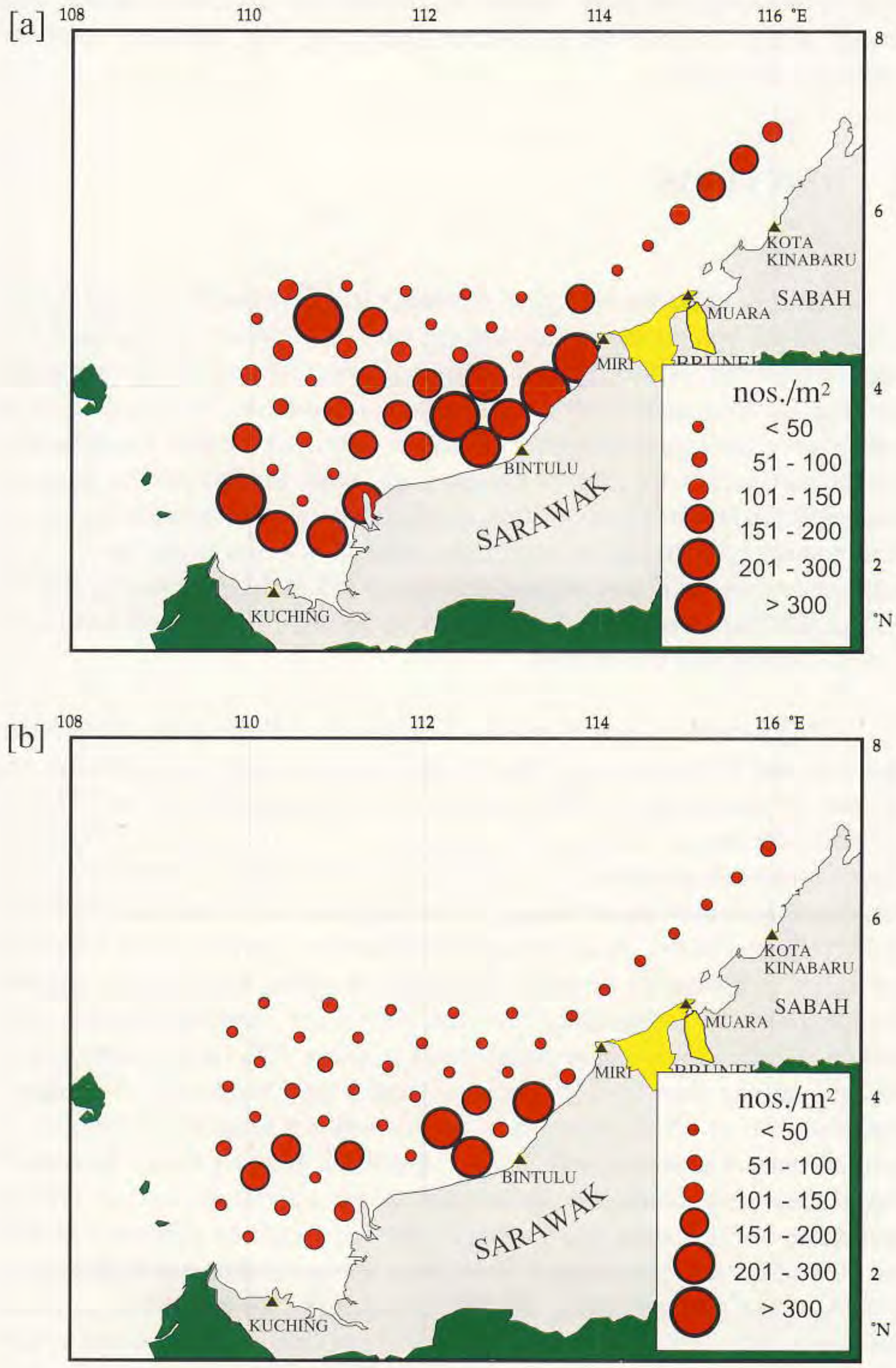


Fig. 17. Distribution and abundance of macrobenthic fauna [nos./m^2] during [a] pre-SW monsoon; and [b] SW monsoon.

showed a marked difference in 98% of the survey area, but aberrations in averages are caused mainly by abnormally high or low values at a handful of stations.

Diversity index showed an increase during the SW monsoon, which never exceeded 3.56 during both the cruises. Evenness index also increased during the SW monsoon, and as many as 21 species contributed to the bulk of the abundance, as compared to 7 species before the monsoon. These changes are brought about mainly because different species react diversely to changes in environmental conditions. It has been suggested that low diversity and high concentrations of only a few selected species usually denote major stress conditions on the benthic environment that could eliminate many species by promoting the proliferation of only a few favored 'bulk species'. This would indicate that the onset of the SW monsoon actually reduces the stress on the sea-bottom, probably by weakening the stagnant conditions. 0 – 60 m deep zone in the coastal areas of Sarawak was the richest in abundance of benthic organisms during both the cruises. Polychaeta occurred at all depths sampled [maximum depth sampled was 240 m] during both the cruises, while distribution of Crustacea was restricted up to 180 m only during the pre-SW monsoon. Mollusca and Echinodermata were also not found beyond this depth. Waters of Sabah and Brunei are poorer in benthic fauna, mainly because of the much deeper areas there, as it has been suggested that depth is an important factor in controlling the population density of benthic fauna.

5. FISHERY RESOURCES

a. FISHERY BIOLOGY

Studies on the species composition, abundance and distribution of fish larvae in the survey area identified 186 species of larvae belonging to 112 families. The oblique hauls during pre-SW monsoon were the richest yielding 158 species belonging to 94 families. Based on their ecological characteristics, three basic groups of pelagic, mesopelagic and demersal types of larvae were identified. Larvae of Gobiidae [29.44%], *Bregmaceros rarisquamosus* [16.26%], *Nemipterus* sp. [2.86%], *Hygophum* sp. [2.78%] and *Callionymus* sp. [2.49%] were the most abundant in the oblique hauls, while *Stolephorus* sp. [10.49%], *Myripristis* sp. [8.83%], *Holocentrus* sp. [8.04%], *Upeneus* sp. [8.04%] and Gobiidae [5.38%] were abundant in the surface horizontal hauls [Fig. 18]. During the SW monsoon, Gobiidae [32.04%], *Bregmaceros rarisquamosus* {8.68%], *Decapterus* sp. [4.74%], *Apogon* sp. [3.56%], *Lutjanus* sp. [2.7%], *Callionymus* sp. [2.57%], *Benthosema* sp. [2.13%] and *Nemipterus* sp. [2.12%] were abundant in the oblique hauls, while *Sardinella* sp. [10.22%], *Upeneus* sp. [9.74%], Gobiidae [7.6%], *Myripristis* sp. [6.21%] and *Diaphus* sp. [5.68%] were common in the surface horizontal hauls [Fig. 19]. Larvae of eight Scombrid genera, *Rastrelliger, Scomber, Scomberomorus, Acanthocybium, Euthynnus, Auxis, Katsuwonus* and *Thunnus* were collected during both the cruises. Fish larvae belonging to 107 families of fishes have been recorded from the area during previous studies.

Larvae of *Sardinella* sp. were most abundant at the surface during the SW monsoon cruise, while *Stolephorus* sp. predominated during the pre-SW monsoon cruise, and their pedominance at the surface was particularly outstanding in the samples collected during the night and on overcast days, indicating phototactic behavior. 75% of all Gobiid larvae caught were in the oblique hauls, closely followed by *Bregmaceros rarisquamosus* larvae. Larvae of mesopelagic species, *Benthosema* sp., *Diaphus* sp., *Hygophum* sp., *Myctophum* sp., *Pollicthys* sp. and *Lampadena* sp. were common at the deeper stations. Family Myctophidae with 13 genera, including one specimen each of *Centrobranchus* sp. and *Lobianchia* sp., were the most widely represented. Two mesopelagic genera belonging to Argentinidae, *Argentina kagoshimae* and *Glossanodon* sp. [only one specimen] were also collected at the deeper stations. Larvae of mesopelagic species were always more common in the

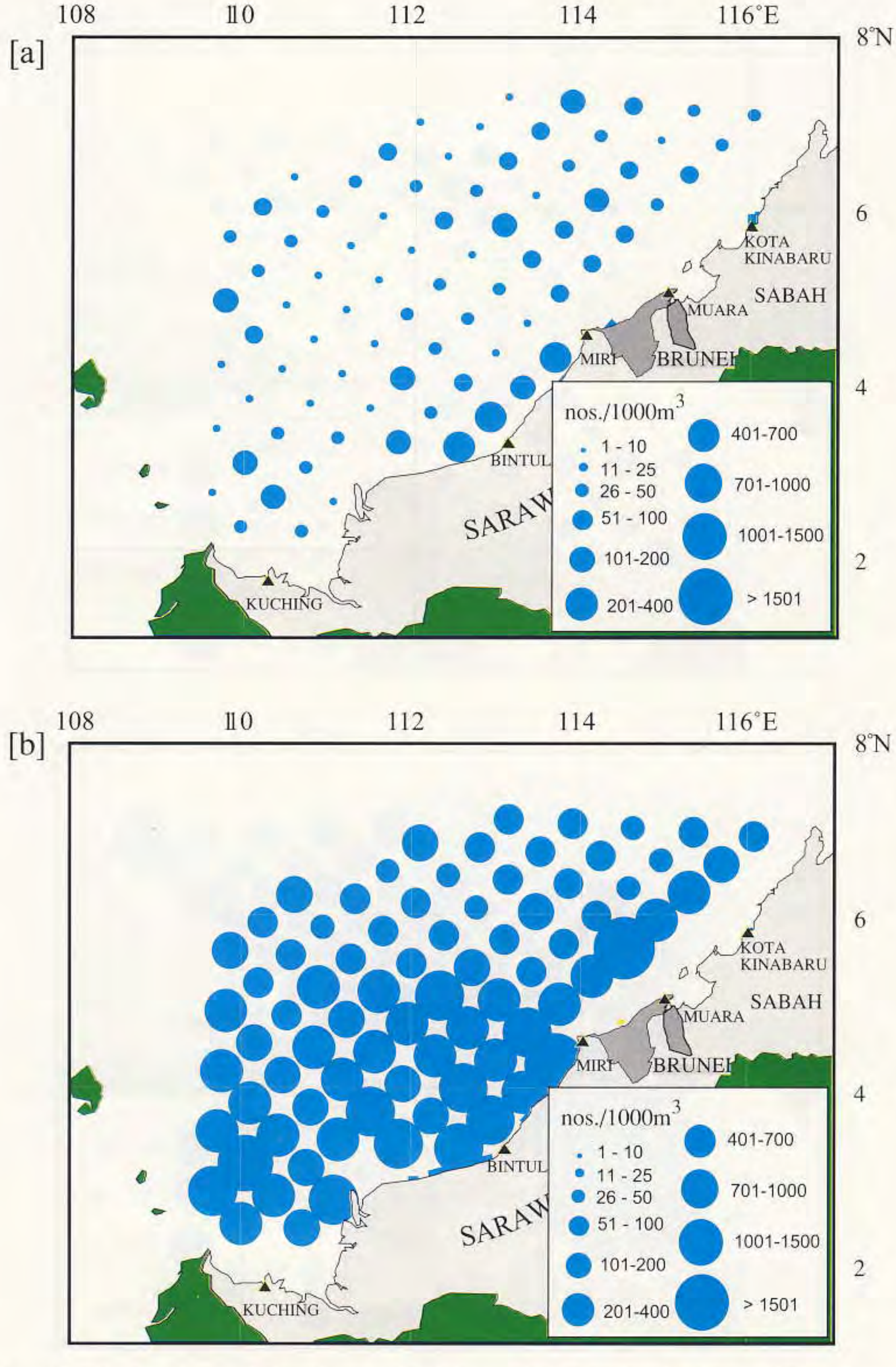


Fig. 18. Distribution and abundance of fish larvae in [a] surface hauls; and [b] oblique hauls, during pre-SW monsoon.

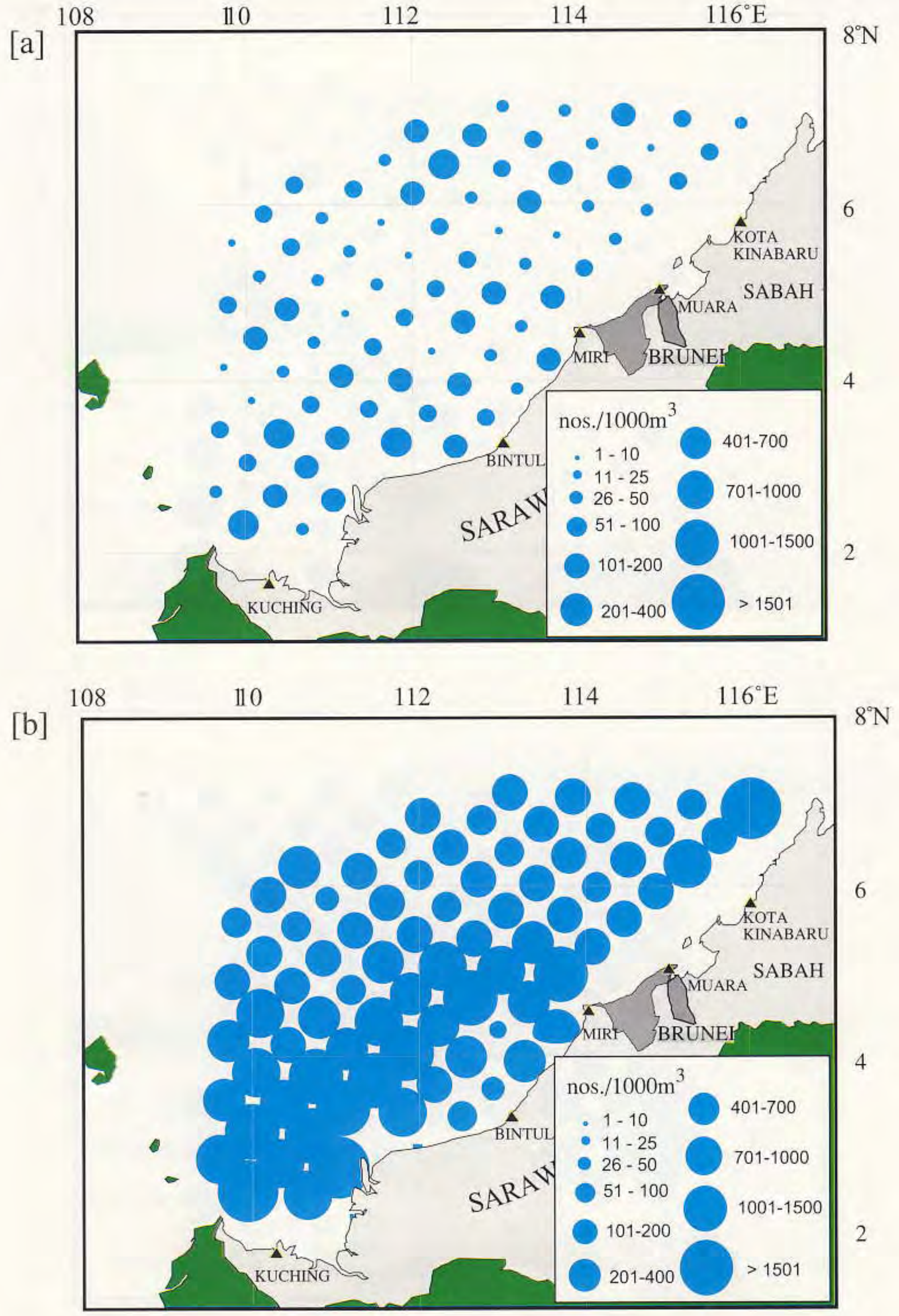


Fig. 19. Distribution and abundance of fish larvae in [a] surface hauls; and [b] oblique hauls during SW monsoon.

oblique hauls because of their phototactic behavior. Larvae of species belonging to Carangidae and Nomeidae were often found clinging to floating debris. Based on the distribution patterns, larvae of *Sardinella* sp., *Stolephorus* sp., *Myripristis* sp., *Holocentrus* sp., *Upeneus* sp., *Decapterus* sp., *Euthynnus* sp., and *Diaphus* sp. were found to be pelagic in character, while Gobiidae, *Bregmaceros rarisquamosus, Decapterus* sp., *Apogon* sp., *Nemipterus* sp., *Callionymus* sp., *Hygophum* sp., *Myctophum* sp. and *Benthosema* sp. were more demersal in character.

Studies on species composition, diversity and distribution of fish species, identified a total of 523 species of fishes belonging to 24 orders and 108 families, out of which 103 economically valuable species were obtained from the trawl catches and 160 species from the landing places and fish markets surveyed. During the pre-SW monsoon cruise, 454 species from 88 families were collected from the trawl samples and 97 species from the local fish markets. *Saurida undosquamis* [most abundant], *Abalistes stellatus, Synodus hoshinonis, Fistularia petimba, Pentaprion longimanus, Priacanthus macracanthus, Seriolina nigrofasciata, Parupeneus cinabarinus* and *Nemipterus nemurus* were the most widely distributed. 359 species belonging to 87 families were collected during the SW monsoon cruise. Of these, *Priacanthus macracanthus* [most abundant], *Saurida undosquamis, S. micropectoralis, Parupeneus cinabarinus, Gymnocranius griseus, Fistularia petimba, Pentaprion longimanus, Seriolina nigrofasciata* and *Abalistes stellatus* were the most widely distributed. 7 species were common to both the cruises. The coastal waters of Sarawak had the maximum species diversity of up to 70 species per haul. 37 species were collected by handline fishing, of which *Lutjanus malabaricus, Gymnocranius griseus, Cephalopholis miniatus, C. sonnerati, Diagramma pictum, Lethrinus lentjan* and *Arius bilineatus* were the most commonly caught. Many more species, caught mainly from coral reefs by small-scale fishing, using traps, gill nets and handlines, and also from offshore trawl catches, were observed at the local fish markets. The third recorded specimen of the rare deep-sea fishes, *Hepalogenys analis* and *Pomadasys auritus* from the Southeast Asian waters were collected during the survey.

Most species-rich families were Carangidae with 40 species, Serranidae with 30 species and Nemipteridae with 26 species. Central areas of Sarawak were found to be most rich in terms of species diversity, yielding up to 70 species per haul. Most of the species along the southwest corner of the Sarawak coastline were estuarine, belonging to Ariidae, Clupeidae and Scianidae. Deep-sea species belonging to Moridae, Caproidae and Argentinidae were recorded along the northeastern areas of the Sarawak coast. A total of 2,500 species of bony fishes, belonging to 45 orders and 228 families have previously been reported from the South China Sea region.

b. FISHERY SITUATION

Out of a total marine fish production of 1,108,430 mt in Malaysia in 1995, 99,255 mt were landed in Sarawak and 166,460 mt in Sabah, out of which approximately 61,960 mt and 49,100 mt were demersal fish in the two areas respectively. Exploratory trawl fishing yielded a maximum catch per unit effort [CPUE] of 196 and 144 kg in the coastal waters of Sarawak. CPUE, during the pre- SW monsoon cruise, varied between 4.7 to 144 kg. The most common five species during this cruise were *Ariomma indica, Priacanthus macracanthus, Saurida undosquamis, Upeneus moluccensis* and *Priacanthus tayenus. Loligo duvoucelli* was also common in every haul. During the SW monsoon cruise, CPUE ranged widely from 3.5 – 196 kg/hr, out of which 31.48% – 90.11% were commercially valuable fishes [61.02% of the richest haul was composed of commercially valuable species].

Exploratory trawl fishing conducted by the Department of Fisheries of Thailand in the 10 - 100 m deep zone along the Sarawak coast yielded CPUE values ranging between 186 kg in 1968, 442 kg in 1969, 286 kg in 1970 and 214 kg in 1972, out of which 53% – 72% were commercially valuable species. Subsequent Malaysian surveys yielded average CPUE values of 210 kg in 1973, 200 kg in 1975, 149 kg in 1977, 142 kg in 1979, 154 kg in 1980 and 141.9 kg in 1981, out of which 47 - 73% were commercially valuable species. It is not clear whether the trend in lower catches during the latter phase is in any way related to the degree of fishing efforts in the area, especially as the percentage of commercially valuable species in the catches remained more less the same throughout, which does not seem to indicate any overfishing trend. Particularly, the relatively low catches of 3.5 – 196 kg/hr during the current survey also does not give any clear indication of the trends, although the values obtained are considerably lower [almost one-fourth] of the averages obtained during the previous such exploratory surveys. *Saurida undosquamis, Synodus hoshinonis, Fistularia* spp., *Seriolina nigrofasciata, Pentaprion longimanus, Nemipterus furcosus, Parupeneus cinnabarinus, Abalistes stellatus* and *Gymnocranius griseus* were caught at almost every station. On the whole, highest catches were restricted to the southwestern corner of Sarawak coastline before the SW monsoon. During the SW monsoon, it was more spread out along the shallow coastal areas.

Exploratory trawl fishing conducted during the survey showed that CPUE fluctuated between 10.9 – 90.5 kg/hr, at an average of 50.2 kg/hr before the SW monsoon, and 3.5 – 194 kg/hr, at an average of 55.9 kg/hr during the SW monsoon [Fig. 20]. Catches during the pre-SW monsoon cruise were mainly composed of Nemipteridae [12.7%], Carangidae [8.7%], Mullidae [7.1%], Lutjanidae [4.9%] and Priacanthidae [2.2%], at an average of 34.4 kg [68.7%], with a maximum of 62.9 kg/hr fish of market value. The most common species were *Loligo* spp [5.7%], *Nemipterus bathybius* [4.2%], *N. memurus* [3.8%], *Abalistes stellaris* [4%], *Upeneus moluccensis* [3.8%], *U. bensasi* [2.4%], *Gymnocranius griseus* [3.2%], *Carangoides malabaricus* [3.2%] and *Plectorhynchus pictus* [3.1%]. During the SW monsoon cruise, 41.5% of the catches was trash fish [average CPUE, 23.3 kg], and 58.5% species of market value [average, 32.6 kg, with a maximum of 119.3 kg/hr], which were composed mainly of Priacanthidae [14.1%], Nemipteridae [10.8%], Carangidae [5%], Lutjanidae [3.7%] and Mullidae [2.1%]. The most common species were *Priacanthus macracanthus* [13.2%], *Nemipterus bathybius* [3.3%], *N. metamophorus* [2.2%], *Abalistes stellaris* [2.8%] and *Arius* spp. [2.5%]. Trash fish registered an average catch rate of 15.7 kg/hr before the SW monsoon, dominated by *Upeneus sulphureus, Pentaprion longimanus* and *Saurida* spp. During the SW monsoon, trash fish averaged 23.3 kg/hr, with a maximum of 74.4 kg/hr, and was dominated by *Pentaprion longimanus, Leiognathus* spp., *Upeneus* spp. and *Saurida micropectoralis.*

Total Allowable Catch [TAC], as defined under the United Nations Convention on the Law of the Sea, has the attainment and maintenance of the Maximum Sustainable Yield [MSY] level as one of its important goals. Using the average catch of selected major species in 1996 and 1997, MSY is estimated at 83,000 mt of pelagic fish and 31,000 mt of demersal fish for the survey area. Based on these estimates, the average catches during these two years were 22% and 51% of MSY for the two fish groups respectively. However, recent interpretations of this approach have suggested more conservative goals, the biological reference point of which should be less than MSY, such as 2/3 of this value applied in such countries as New Zealand. Similarly, more exploratory surveys are necessary in order to fully realize the significance of relatively large percentage of trash fish in the catches. This may not be readily taken as an indicator of overfishing, as the percentage of commercially valuable fish in the catches have not shown any significant decrease in the meantime.

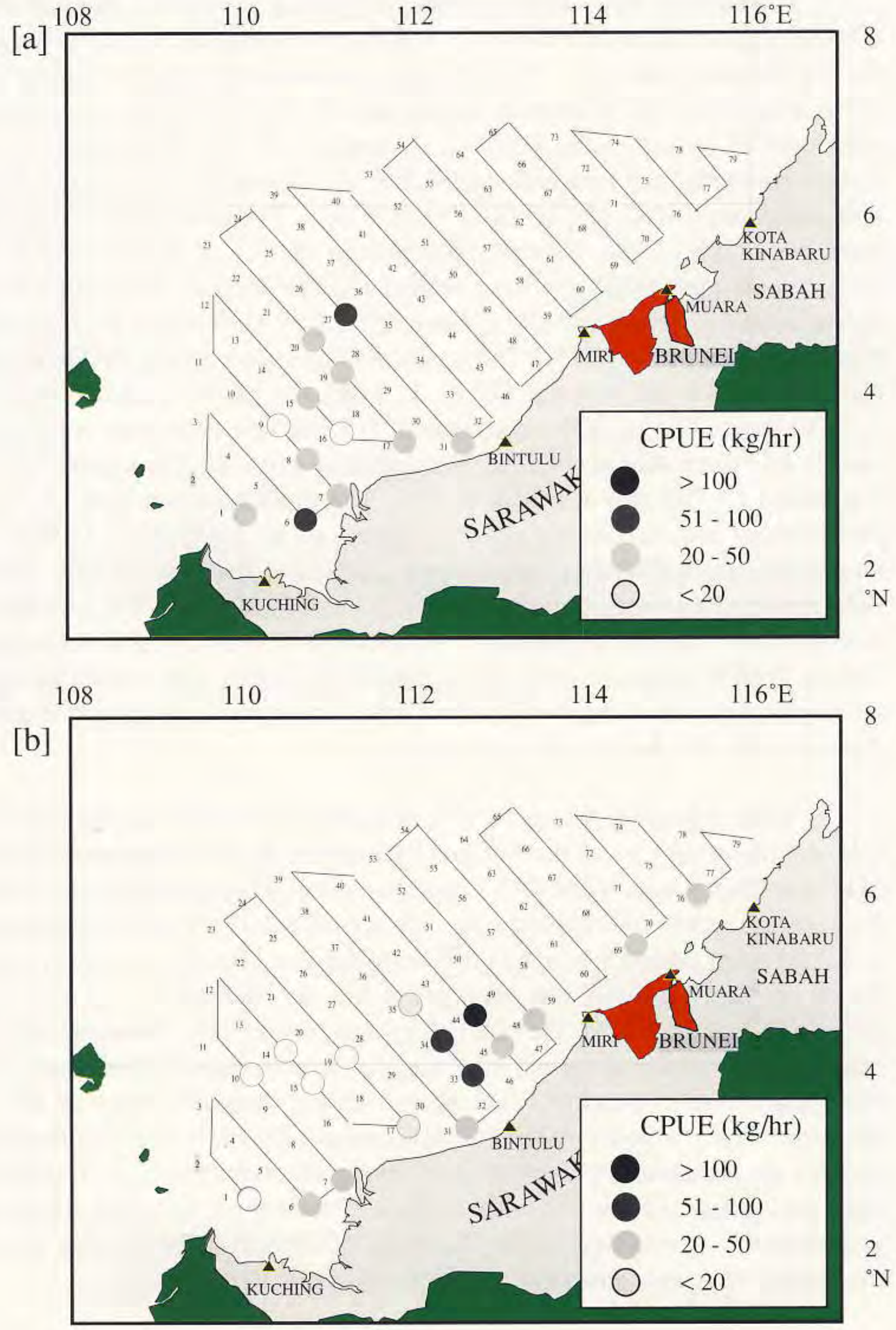


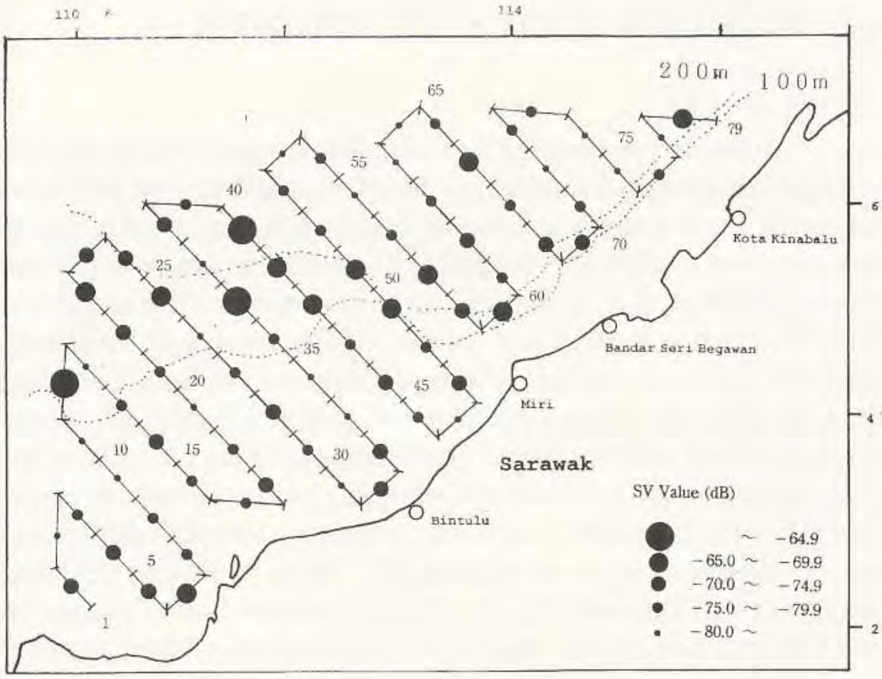
Fig. 20. Distribution of CPUE [kg/hr] of Exploratory Fishing Survey during [a] pre-SW monsoon; and [b] SW monsoon.

c. FISHERY ACOUSTIC STUDIES

Biomass estimates of fish abundance from volume back-scattering strength recordings [SV values] at 50 kHz and 200 kHz of the Furuno FQ-70 Scientific Echo Sounder 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. Distribution of SV values for pelagic fish showed a distinct difference between the two cruises, with the largest concentrations in the zone of depths between 100 – 200 m on the continental shelf during both seasons [Only recordings at 200 kHz were utilized for this analysis to minimize outside interference]. During the pre-SW monsoon cruise, the highest SV values for pelagic fish were recorded in this zone off Sarawak [Fig. 21]. This pattern was further emphasized during the SW monsoon cruise, when it also extended to offshore waters of Sabah [beyond 200 m depth]. SV readings for demersal fish were restricted almost exclusively to the waters of Sarawak [mainly because of the extent of its shallower waters] during both the cruises, and equally abundant both in the coastal [<100 m] and offshore areas [100 – 200 m] during the pre-SW monsoon cruise, but more so in the offshore areas during SW monsoon [Fig. 22]. The SV values within the 100 – 200 m zone alone accounted for 49.8% and 92.4% of total abundance recorded during pre-SW monsoon and SW monsoon respectively.

As the fisheries in the area is restricted only to the coastal waters up to a depth of 60 m, it is impossible to obtain information on the fisheries background situation for offshore waters, and only the fishery statistics from the coastal waters of Sarawak were used for the purpose of biomass estimations. *Decapterus macrosoma* and *Priacanthus macracanthus,* two of the most dominant species in the area were used as representative biomass target species for pelagic and demersal fish respectively. Target strength [TS] of these species were calculated using the formula: TS = 20 $_{log}$[SV] – 66. Based on the characteristics of SV recordings, the estimated multi-species biomass of total fish in the survey area were 470,000 mt during the pre-SW monsoon cruise and 120,000 mt during SW monsoon, out of which, 360,000 mt [5.87 mt/sq. km] and 100,000 mt [1.61 mt/sq. km] were pelagic fish, and 110,000 mt [1.83 mt/sq. km] and 20,000 mt [0.3 mt/sq. km] were demersal fish during the two seasons respectively. Previous fishery acoustic studies had arrived at an estimated biomass of 108,070 mt of demersal fish and 216,300 mt of pelagic fish for the

[a]



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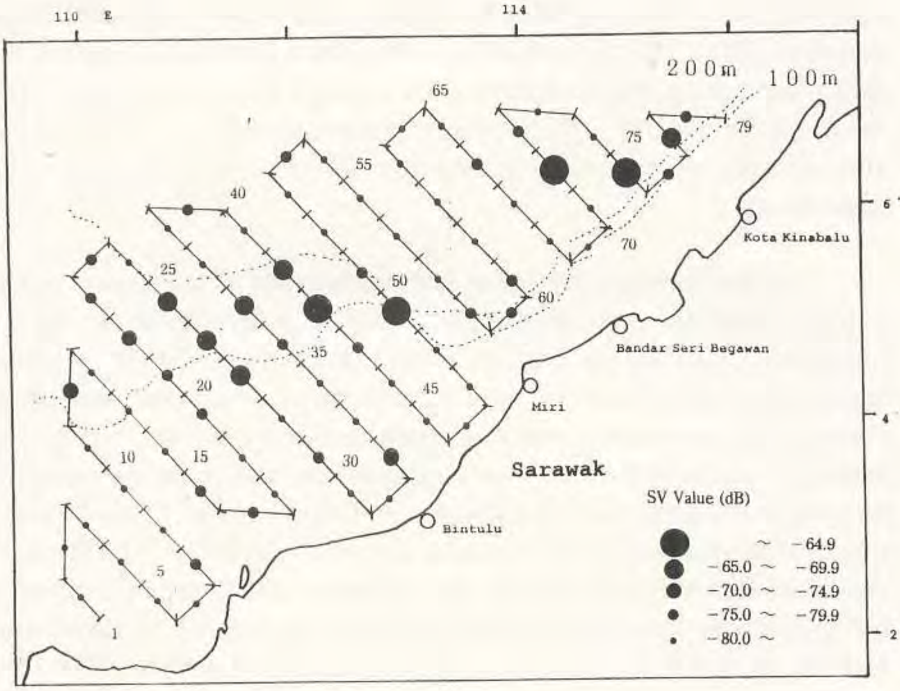
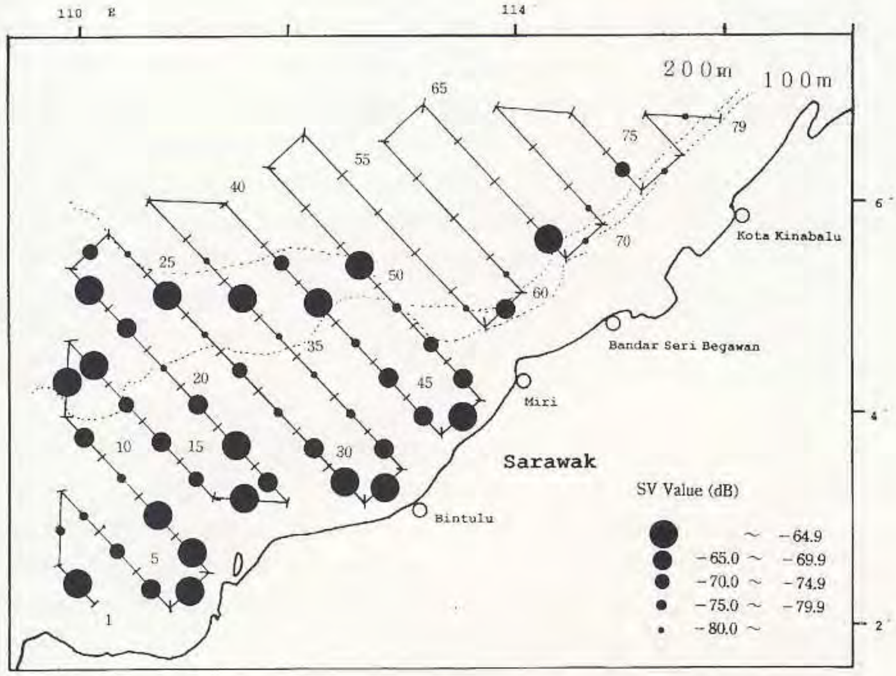


Fig. 21. Back-scattering strength recording [SV values] at 200 kHz for pelagic fish: [a] pre-SW monsoon; and [b] SW monsoon.

[a]



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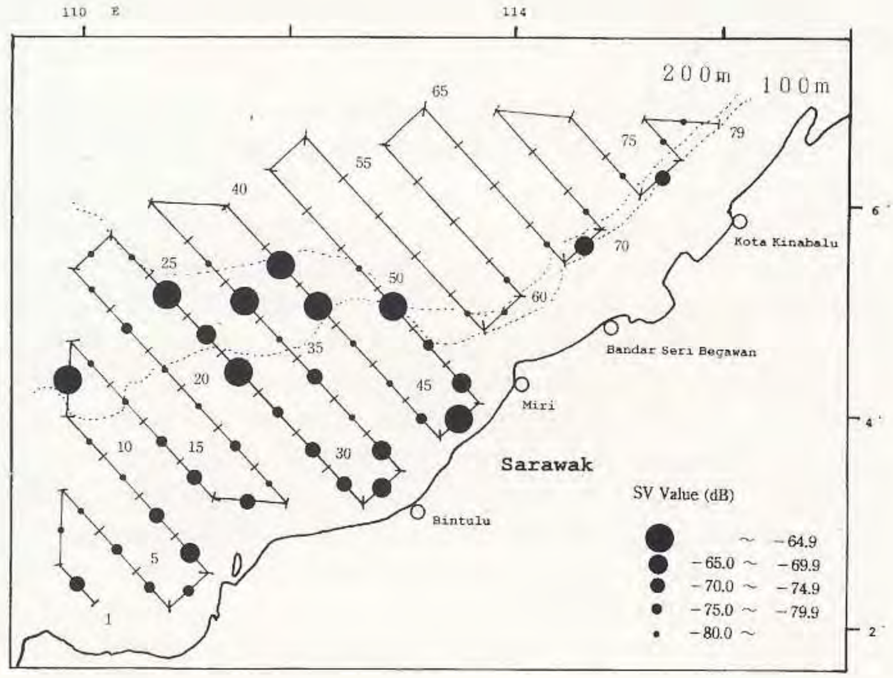

Fig. 22. Back-scattering strength recording [SV values] at 200 kHz for demersal fish: [a] pre-SW monsoon; and [b] SW monsoon.

same study area, at an average density of 1.74 mt/sq. km. Another study in 1986 had arrived at a density of 2.41 mt/sq. km of pelagic fish for the same area during the SW monsoon. Using Cadima's model, this would amount to a MSY of 83,000 mt of pelagic fish and 31,000 mt of demersal fish in the area surveyed. Even if the more conservative biological reference point of 2/3 MSY were applied, the sustainable fishery potential would amount to 55,000 mt and 21,000 mt of pelagic and demersal fish respectively. 1996 – 1997 fish landings in the area would thus amount to 33% and 77% of this biological reference point, which still shows a reasonable potential for increasing the fishery production in the survey area.

Another simultaneous estimate, using the sardine, *Sardinella gibbosa* as the representative species for determining TS, arrived at a total estimated biomass of 1,717,850 mt and 956,400 mt of fish in the survey area during the pre-SW and SW monsoon cruises respectively. The total biomass estimated separately for shallow areas less than 100 m, 100 – 200 m zone and deeper waters beyond 200 m, were 314,750 mt [32.9%], 476,450 mt [49.8%] and 165,200 mt [17.3%] during the pre-SW monsoon cruise, and 105,950 mt [6.2%], 1,587,590 mt [92.4%] and 24,310 mt [1.4%] during the SW monsoon, showing that the 100 – 200 m deep zone is the most potentially productive of the three areas for fisheries.

Although the hydro-acoustic method is a practical and positive approach for estimating the order of magnitude of fish stocks in the region, the need for an unusually large number of assumptions and generalizations raises questions on their accuracy and reliability, especially when applied to multi-species evaluations, such as those occurring in the tropical regions. Further, SV values collected during the survey have been used without specific echo identification. The most suitable representative fish species for obtaining the average length-weight-age data for calculating the TS values and biomass estimations of fish stocks also has to be correctly identified. In-depth statistical analysis is also necessary to improve the confidence level of all these data. Considering the significant seasonal fluctuations in fish abundance, closely spaced periodic surveys would also be needed to address their significance for formulating appropriate fisheries management strategies at the localized level. There are also some indications that vertical abundance and accumulation of phytoplankton, different groups of zooplankton, and fish larvae recorded at different layers of the water column at different times of the day during the survey might be contributing to exaggerated echo values and denser SV readings recorded at 50 kHz, that could create problems in the calculation of corrected SV values. Interference from plankton deep scattering layer, frequently recorded in the area, is another important factor that should be taken into consideration. The method should, therefore, be considered as experimental at the most.

5. CONCLUSIONS

Large amount of fishery 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 area covered, and considering the geographical extent of the survey 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 populations in the region, should be expected to be understood only gradually. The profile of features, events and processes occurring during any full season could also not be fully characterized through the findings of a single cruise.

The survey has revealed that almost every parameter of the oceanographic environment and its biological processes is to more or less extent conditioned and altered by SW monsoon and its effects, and more particularly, its influences on biological productivity and marine food chain in the region, that affect fish production mechanisms and fish distribution patterns. Monsoon-generated turbulence increased the depth of the mixed layer causing a downward movement of the pycnocline, and the divergence and convergence patterns give a clear indication of the upwelling and downwelling phenomena taking place during this season. Low levels of dissolved nutrients in the surface layers indicate their active uptake by phytoplankton photosynthesis, and monsoon-induced upwelling refertilizes these layers with remineralized nutrients from deeper layers. Offshore waters were the sinks for atmospheric carbon dioxide, while the near-shore waters were the source of carbon dioxide to the atmosphere, giving an indication of the net level of biological activities going on in these areas.

Freshwater runoff from the rivers discharge large quantities of silt into the near-shore areas, while the monsoonal turbulence keeps the finer particles in suspension, that settle down under more calmer stable conditions, which brings about changes in the characteristics and distribution patterns of sediments.

Total organic matter in the sediments showed an increase of up to 160% during the monsoon, caused mainly by freshwater runoff from rivers. Nutrient levels in the sediments reflect the net result of organic loading in each area and availability of oxygen to oxidize them, but general indications are that the sediments are well oxidized in the area, particularly in the shallow waters. Correlation between the rates of nutrient upward fluxes and sedimentary organic levels indicate that the accumulated organic matter tend to be biogenically metabolized and thus enhance the exchange between the sediments and the water interface, bringing about nutrient enrichment of the water column. Vertical distribution patterns of all nutrients indicate a constant depositional process of sediments. 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 during the SW monsoon indicating the influence of the monsoonal conditions in stimulating its growth, more particularly in the coastal areas. Depth-integrated spatial distribution of chlorophyll concentrations as shown by *in situ* fluorescence clearly showed unique patterns of plume distribution, which could be generally related to the effects of upwelling. The persistent occurrence of the productive chlorophyll maxima at around 18 – 70 m in the coastal areas and 45 – 80 m at the deeper stations is another aspect that has been highlighted during the Collaborative Research Program. The rates of primary production in this layer, which also display high species diversity, is, however, determined by the amount of light available for photosynthesis at that depth. Overall cell densities of phytoplankton were generally low, particularly in the offshore areas, when compared to Area I previously studied. Toxic dinoflagellate species were recorded only in small numbers during the two cruises, although occurrence of red tides, causing paralytic shellfish poisoning, have occasionally been reported from the area in the recent past. Abundance and variability of zooplankton were also related to the effects of the monsoon, and their distribution patterns showed a significant covariance with that of phytoplankton.

The area holds promise as a good grazing ground for larval fish because of the abundance of copepods, but their abundance is kept in check by the larger zooplanktonic predators, bringing about a delicate balance between the two. Thus, a clear-cut inverse correlation is seen between the abundance of Chaetognatha and fish larvae. Geographical diversity gradients of zooplanktonic groups obtained from their composition and distribution studies at the primary sorting level will broaden the information base on the basic significance of geographical distribution patterns of faunistic communities in the region. As regards the benthic community in the survey area, the variety of organisms that constitute the bulk of benthos increases considerably with the onset of the SW monsoon, indicating that the monsoon reduces the environmental stress on the habitat of the sea-bottom and stabilizes its ecological equilibrium. Studies have shown that the abundance of some commercially important pelagic fish, particularly plankton feeders, is related to the amount of available nutrients and phytoplankton.

Biomass estimates of fish based on hydro-acoustic studies indicate that the values recorded within the zone of 100 – 200 m depth account for 49.8% and 92.4% of the total calculated abundance for the whole area during the pre-SW and SW monsoon cruises respectively. The potential values per unit area are invariably higher for both pelagic and demersal fish during the pre-SW monsoon period. Even going by the conservative approach of 2/3 of MSY for the area, the current fish landings amount to 33% of pelagic and 77% of demersal sustainable fisheries levels, which would indicate a reasonable potential for increasing the fisheries production in the area surveyed.

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 United Nations Convention on the Law of the Sea], and special areas of interest to fisheries resources, and their seasonal fisheries production mechanisms, food-chain dynamics and life-cycles. 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. The studies have also established a firm foundation of mainly qualitative reference baseline information on various trophic levels of organisms which would be of great use in investigating their future fluctuations and other changes brought about by marine pollution and other environmental stress factors. In addition, the studies have highlighted the areas in need of additional data and information for an in-depth understanding of fisheries production, abundance, distribution patterns and sustenance of life cycle.

BIBLIOGRAPHY

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

MAIN REFERENCE

Southeast Asian Fisheries Development Center [SEAFDEC]

PROCEEDINGS OF THE SECOND TECHNICAL SEMINAR ON MARINE FISHERY RESOURCES SURVEY IN THE SOUTH CHINA SEA, AREA II: WEST COAST OF SABAH, SARAWAK AND BRUNEI DARUSSALAM. 14-15 DECEMBER 1998, KUALA LUMPUR, MALAYSIA. SEAFDEC, Samut Prakan, March 1999, 370p.

RESEARCH PAPERS

Boonyapiwat, Sopana

Distribution, Abundance and Species Composition of Phytoplankton in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam, p. 177-196.

Chareonpanich, Charumas, Siriporn Seurungreong & Shettapong Meksumpun

Nutrient Diagenesis in Sediments of the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam Waters, p. 111-128.

Hadil bin Rajali, Albert Chuan Gambang, Idris Abdul Hamid, Raja Bidin bin Raja Hassan, Daud Awang, Kunimune Shiomi & Shunji Fujiwara

Stock Assessment by Hydro-Acoustic Method in the South China Sea, Area II: Sabah, Sarawak, Brunei Darussalam, p. 338-352.

Jivaluk, Jutamas

Distribution, Abundance and Composition of Zooplankton in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam Waters, p. 288-309.

Lirdwitayaprasit, Thaithaworn

Distribution of Dinoflagellate Cysts in the Surface Sediment of South China Sea, Area 2: Off Sabah, Sarawak and Brunei Darussalam, p. 310-322.

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

Microplankton Distribution in the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters, p. 197-223.

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

Sedimentological Characteristics of Sediments of the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters, p. 95-110.

Musikasung, Waleerat, Mohd Shukri bin Yusoff, Solahuddin bin Abdul Razak & Anond Snidvongs

Primary Production Determination in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam Waters, p. 165-176.

Nasir Saadon, Lim Phaik Kin, Anond Snidvongs & Penjan Rojana-anawat

Physical Characteristics of Watermass in the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters, p. 1-22.

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

Trace Metals in Surface Sediment of the South China Sea, Area II: Sarawak, Sabah and Brunei, p. 146-155.

Piamthipmanus, Montira

Temporal Changes in the Abundance of Macrobenthos in the South China Sea, Area II: Sarawak, Brunei and Sabah, p. 323-337.

Rumpet, Richard, Daud Awang, Jamil Musel & Rooney Biusing

Distribution, Abundance and Biological Studies of Economically Important Fishes in the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters, p. 353-361.

Snidvongs, Anond

Geostrophic Current, Divergence and Convergence in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam Waters, p. 23-31.

Ibid.

Dissolved Carbonate-Carbon Dioxide in Sea Water of the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam, p. 62-94.

Ibid.

Distribution and Composition of Photosynthetic Pigments in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam Waters, p. 156-164.

Tengku Rozaina Bt. Tengku Mohamad, & Mohd. Shukri b. Yusoff

Ortho-phosphate in the Sea Water of the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam, p. 32-61.

Termvidchakorn, Apichart

Kind, Abundance and Distribution of the Fish Larvae in the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam, p. 243-287.

Theparoonrat, Yuttana

Biomass Estimation by Hydro-acoustic Methods in the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam, p. 362-370.

Utoomprurkporn, Wilaiwan & Anond Snidvongs

Trace Metal Concentrations and Distributions in Sea Water of the South China Sea, Area II: Off Sabah, Sarawak and Brunei Darussalam, p. 129-145.

Vidthayanon, Chavalit

Species Composition and Diversity of Fishes in the South China Sea, Area II: Sarawak, Sabah and Brunei Darussalam Waters, p. 224-242.