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Seasonal variation of zooplankton community in the coastal waters of the Straits of Malacca

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Abstract—The seasonal and annual variation of zooplankton community was investigated at a fixed station in the coastal waters of the Straits of Malacca. Sampling was carried out monthly by vertical hauls of a 140 μm plankton net from June 2002 to May 2004. Zooplankton were identified and grouped into respective taxonomic groups and 23 genera of copepods were identified. Copepods dominated the zooplankton community and among them, the genera *Acartia, Acrocalanus, Paracalanus, Euterpina, Corycaeus* and *Oithona* were dominant. They accounted for approximately 90% of the total copepod population throughout the year, emphasizing the importance of small species in tropical zooplankton communities. Zooplankton biomass generally peaked at the beginning of each monsoon and gradually decreased toward the intermonsoon periods. Biomass seemed to increase with increasing ambient chlorophyll-*a* concentration. Cluster analysis of zooplankton abundance showed two distinct groups relative to the SW and NE monsoons. The population of *Acartia pacifica* and *A. spinicauda,* the two most abundant species in the genus *Acartia* (>90 %), showed alternating peaks throughout the year, with *A. pacifica* appearing primarily during the NE monsoon and *A. spinicauda,* during the SW monsoon. The presence of the effect of monsoon on zooplankton community in tropical waters is suggested.

Key words: zooplankton, biomass, seasonal variation, tropical coastal waters, monsoon

Introduction

The Straits of Malacca is located in the tropical zone between the east coast of Sumatra Island in Indonesia and the west coast of Peninsular Malaysia. It is one of the most important trade routes linking the Indian Ocean via the Andaman Sea to the South China Sea and Pacific Ocean. The widest section of the Straits is found at its northwest entrance, narrowing gradually to 12 km near the southeast entrance. It is a unique, tropical environment rich in renewable and non-renewable natural resources such as fishery products, oil, gas and tin (Burbridge 1988). Due to its economic and polictical importance, the Straits has always been an interest for biological oceanographic studies.

Zooplankton in the Straits of Malacca have historically been examined by various studies, with early investigations focusing primarily on taxonomic listing of zooplankton species (Sewell 1933, Wickstead 1961), and more recent studies concentrating on zoogeography of most of the groups and species of zooplankton (Chua and Chong 1975, Othman et al. 1990, Johan et al. 2001, Hamid et al. 2004). The general feature of tropical zooplankton is that there is little or no seasonality in their biomass (Parsons et al. 1984b, Garrison 1993, Levinton 1995). However, recent studies on some tropical areas have revealed that zooplankton biomass and species composition indicate seasonal variation (Smith 1995, Smith et al. 1998, Champalbert and Pagano 2002). Continual observation of the seasonal variation of zooplankton in the Straits of Malacca is limited to a study by Idris et al. (2000) which only studied the copepod community. They observed that the biomass of copepods was relatively higher during the SW monsoon season and that small sized species dominate the copepod community. The aim of this study is to examine the qualitative and quantitative seasonal changes of zooplankton from 2002 to 2004 in the coastal waters of the Straits of Malacca.

The seasonal variation in plankton communities is very apparent in boreal to temperate waters due to distinct hydrographic variation. Compared with boreal and temperate regions, the Straits of Malacca does not experience such seasonal climate variations. Howerver, seasonality can also be observed in tropical waters; the most evident being the monsoon seasons. The weather in Malaysia is characterised by two monsoon regimes, namely, the SW Monsoon from late May to September, and the NE monsoon from early Novem-

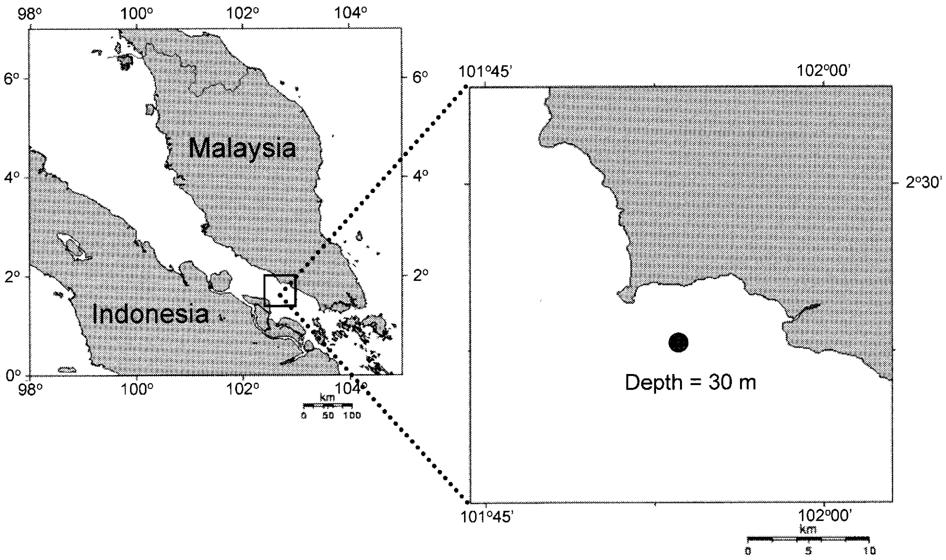

Fig. 1. Location of sampling site.

ber to March. The NE monsoon usually brings heavy rainfall, whereas the SW Monsoon normally signifies relatively drier weather. The transition period in between the monsoons is known as the intermonsoon period. Water movement and hydrographic parameters in the Straits are strongly influenced by the monsoon trade winds (Wyrtki 1961, Namba and Saadon 1999, Chua et al. 2000). Thus, monsoonal effects on zooplankton community variation is also discussed.

Materials and Methods

The sampling site is situated at 2°24′N, 101°54′E in the coastal waters of the Straits of Malacca (Fig. 1). Zooplankton samples were collected monthly for two years from June 2002 to May 2004 by vertical tows from the bottom to the surface by a plankton net. The 140 μm mesh size net has a mouth diameter of 0.5 m, 2.0 m in length and was equipped with a flow meter and a 500 ml cod-end bucket. The depth of the study site is 30 m.

Water temperature, salinity and chlorophyll-*a* concentration were measured at 0, 5, 10, 20 and 30 m depths, respecively. Chlorophyll-*a* concentration was obtained by extraction of phytoplankton pigment in 90% acetone solution and the absorbance was measured with a spectrophotometer (Parsons et al. 1984a). Mann-Whitney U-test was carried out to find any charactersitic differences between the monsoon seasons.

Samples for taxonomic identification were immediately preserved in 5% buffered formalin seawater upon collection. All groups of zooplankton were identified from appropriately split aliquots to the genus level as far as possible under a dissecting microscope. To compare plankton communities with respect to the monsoon seasons, non-metric cluster analysis was used to find the average linkage between groups of zooplankton composition with SPSS® software (SPSS Inc., USA). The genus *Acartia* was identified to species (Carl 1907, Chihara and Murano 1997). Investigation of resting eggs of *Acartia* in the sediment was conducted bi-weekly during March to June 2005. Sediment samples were taken using a Ponar grab sampler. Three centimeter of the surface sediment was collected and stored at 4°C upon returning to the laboratory. After a few days, any eggs in sediment were separated by the sugar floatation method (Marcus 1990) and counted.

In order to examine the spatial distribution of one of the dominant copepods *Acartia* spp. along the Straits, zooplankton samples were observed from 20 stations during 2 cruises carried out in July 2000 and late October 2002, which was performed as a part of a multidisciplinary research project on the Straits of Malacca.

Results and Discussion

During the study period, average temperature in the water column ranged between 26.0 and 31.0°C and the salinity between 28.0 to 32.0 PSU. Maximal temperature values were registered during the SW monsoon and minimal in January–February of each year (Fig. 2). Temperature showed a significant difference between the SW and NE monsoons ($p<0.001$, Fig. 3). In contrast, salinity values were significantly higher ($p<0.05$) during the NE monsoon than the SW monsoon. Chlorophyll-*a* concentrations generally increased during both the SW and NE monsoon seasons but did not show a significant difference between the two monsoon seasons. Differences in physical hydrography were observed with respect to the monsoon seasons. Water temperature in

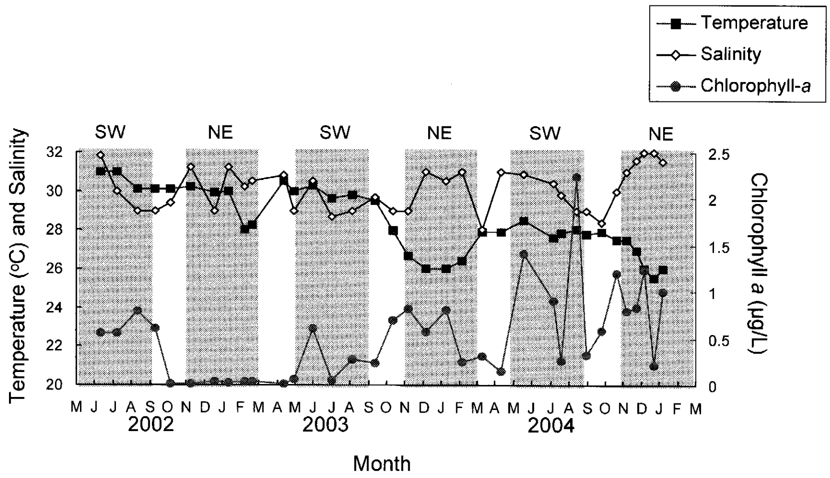

Fig. 2. Seasonal variation of environmental parameters at the study site (0–30 m average).

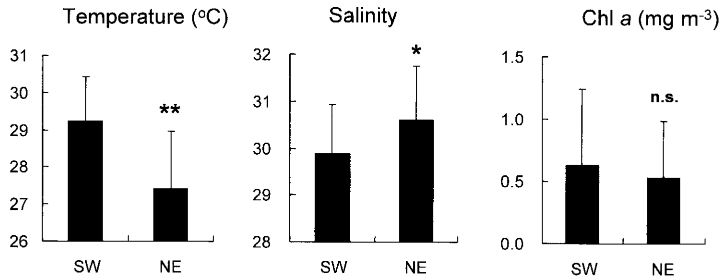

Fig. 3. Environmental parameters at the study site between SW and NE monsoon (0–30 m average; Significance level: $**p<0.001$; $*p<0.05$; n.s., not significant).

the Straits is affected by atmospheric temperatures due to its shallow depth. The greatest depth is about 90 m in the north and ranges between 60 to 85 m off Port Kelang, stepping up abruptly to a depth of less than 40 m towards the south. Therefore, water temperatures generally increase as atmospheric temperatures increase during the SW monsoon season. Wind generated mechanism for the intrusion of the saline waters of the Andaman Sea into the Straits during the SW monsoon has been proposed by various studies (Namba and Saadon 1999, Chua et al. 2000, Ibrahim et al. 2003). But this intrusion of seawater rarely reaches the southern sector of the Straits due to the sudden shelving of the seabed off Kelang (Parry 1995), preventing further influence of the Andaman Sea into the Straits. The situation is reversed during the NE monsoon when there is a net flow of highly saline seawater from the South China Sea which penetrates at least into the southern sector of the Straits. Therefore, the southern sector experiences higher salinity values during the NE monsoon. Vertical profiles of the measured environmental variables did not show any stratification, indicating a well mixed homogenous water column regardless of the season (Fig. 4).

A total of 23 genera of copepods and zooplankton taxa including Amphipoda, Cheatognatha, Cladocera, Appendicularia, Polychaeta, Hydrozoa, Echinodermata, fish eggs and larvae were identified and their occurrence patterns are summarized (Fig. 5).

Tunicata

Appendiculata, Doliolida and Salpida were present. *Oikopleura* spp. were the dominant appendicularians in the study area. They occurred throughout the year, but were most abundant during the SW monsoon with an average value of 62.7±58.1 inds. m^{-3} throughout the study period. Doliolida appeared only during August–September.

Protoctista

Foraminiferida was present all year round mostly in small numbers but in large numbers as many as 122.2 inds. m^{-3} in September 2003.'The next common protoctistan present thorughout the study period was Rotifera which did not seem to have a marked seasonality. Tintinnids, Radiolarians and *Noctiluca* appeared sparsely often in very low numbers throughout the year.

Cnidaria

Several species of medusae belonging to Hydroida and Siphonophora occurred in the plankton samples. They were present almost throughout the year, but their abundance was significantly higher in May 2004 compared to the other months (maximum, 105.3 inds. m^{-3}). Abundances generally

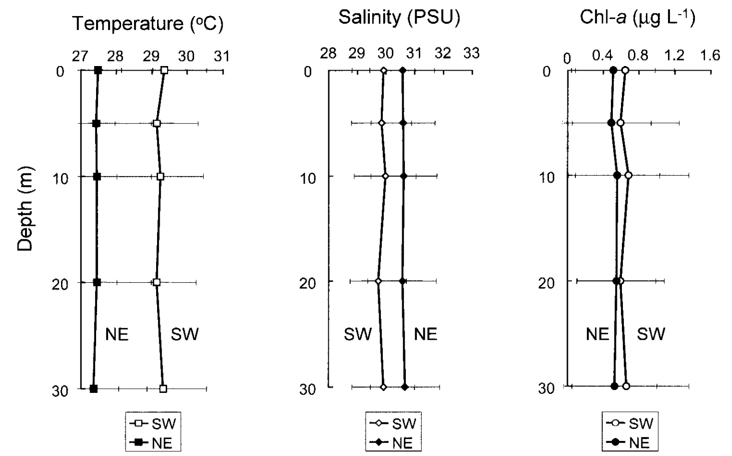

Fig. 4. Mean vertical profiles of environmental parameters during SW and NE monsoon at the study site.

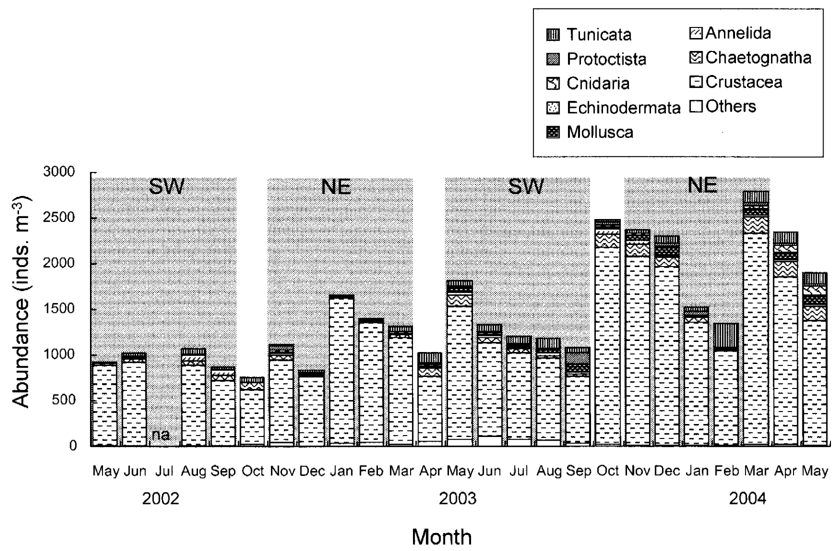

Fig. 5. Seasonal variation in zooplankton abundance at the study site.

increased during both the monsoon seasons with Siphonophora accounting for most of the cnidarian density (60.1%).

Echinodermata

Echinoderm and ophiuroid larvae were observed only sporadically. Peaks showed echinoderm numbers in the range 2.7 to 10.9 inds. m^{-3} in alternate months from April to November 2003 and the highest peak in March 2004.

Mollusca

The genus *Lamellibranchia* was predominant followed by *Janthinida*. *Lamellibranchia* was generally abundant during the monsoon seasons with an annual average of 17.2±21.7 inds. m^{-3} and was low in numbers only during the pre NE monsoon periods. However, two maximum peaks of 78.8 and 74.7 inds. m^{-3} were observed in September and December 2003, respectively. *Janthinida* populations averaged at 11.7±12.8 inds. m^{-3} throughout the study period with a peak abundance in the 2004 intermonsoon period. Pteropoda was present only in June 2002 and December 2003 in very low numbers.

Annelida

Annelids consisted alomst entirely of planktonic Polychaeta. Density was significantly higher during the SW monsoon season with the highest peak in August 2002 (70.6 inds. m^{-3}). A small population of *Tomopteris* was observed in May 2004 (1.4 inds. m^{-3}).

Crustacea

Various crustaceans such as Copepoda, Malacostraca and Cirripedia were collected. Among these, copepod numbers (including copepodites) dominated with an average of 81.7±7.5% of total crustaceans, ranging between 95.6 and 67.4%. The percentage number of copepods in crustaceans dropped abruptly from 89.3% in March to 69.3% in April 2003 and increased again to 80.2% in May, maintaining high

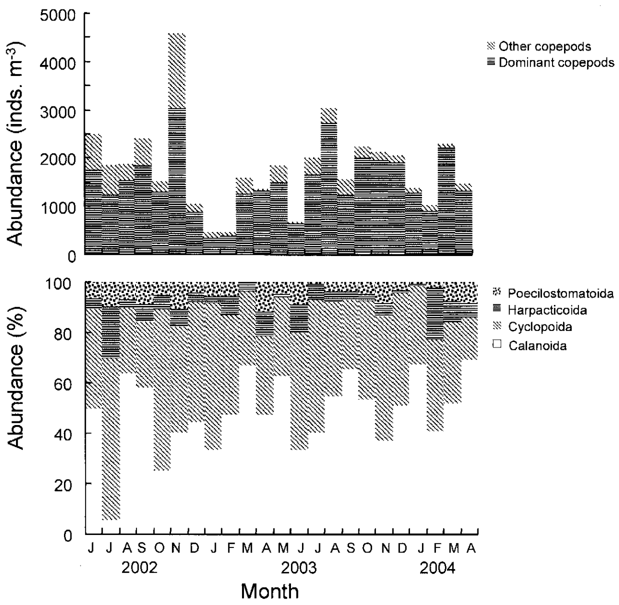

Fig. 6. Seasonal variation in absolute and relative abundances of the dominant copepod groups.

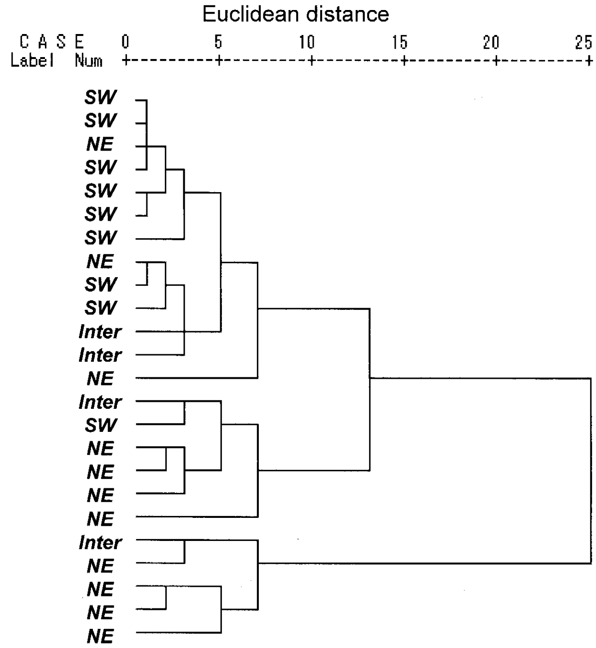

Fig. 7. Dendrogram using average linkage (between groups) of zooplankton composition.

percentage numbers throughout the SW monsoon.

Copepod numbers were relatively lower during the transition periods between the NE and SW monsoons. Copepods of the genera *Acartia*, *Acrocalanus*, *Paracalanus*, *Euterpina*, *Corycaeus* and *Oithona* were dominant and they accounted for approximately 80–90% of the total copepod population throughout the year (Fig. 6). The high abundance of these small-sized copepods suggests the importance of this size fraction of zooplankton in the biological production in coastal tropical waters. The relative abundance of the dominant copepod groups seem to show no clear seasonal pattern despite the differences in absolute numbers. This suggests that the dominant copepods are relatively stable and occur throughout the year in the coastal waters of the Straits of Malacca.

Ostracoda appeared almost throughout the year at less than 40 inds. m^{-3} but the population bloomed in June 2003 (203.7 inds. m^{-3}). Brachurian larvae averaged at 22.8 inds. m^{-3} in the zooplankton but were most common during early SW and NE monsoons (57.0 and 67.9 inds. m^{-3}, respectively). Euphausiids, mysids and luciferids were present rather uniformly throughout the year but never exceeded 10 inds. m^{-3} combined. Other taxa such as Cirripedia, *Balanus*, Isopoda and Amphipoda were encountered infrequently at very low numbers.

Zooplankton abundance generally peaked at the beginning of each monsoon season, gradually decreasing towards the intermonsoon periods and was generally high with increasing ambient chlorophyll-*a* concentration. Periods of increased chlorophyll-*a* concentrations commonly coincided with both the SW and NE monsoon seasons and seemed to decrease during the intermonsoon periods. This could be due to an increase in nutrients as a result of upwelling in this region (One Fathom Bank, Wyrtki 1961, Parry 1995) from increased vertical mixing as a result of strong winds and surface currents by the monsoons. Hamid et al. (2004) observed spatial differences in the copepod community between the northern and southern sectors of the Straits but found no significant temporal difference between the SW and NE monsoon season during their study period. In this study however, cluster analysis of the zooplankton community seem to show significant similarity within the respective monsoon groups (Fig. 7), emphasizing a characteristic seasonal pattern in zooplankton community variation in the Straits of Malacca. During a one year study on copepods, Idris et al. (2000) found that individual numbers were generally higher during the SW monsoon which conforms to the observation obtained in this study and thus contribute to the increase in total zooplankton abundance.

The population of *Acartia pacifica* and *A. spinicauda*, the two most abundant species in the genus *Acartia* (>90 %), showed alternating peaks throughout the year, with *A. pacifica* appearing primarily during the NE monsoon and *A. spinicauda*, during the SW monsoon (Fig. 8). The time lag between their peaks suggests temporal succession as a consequence of temperature and salinity differences between the two monsoons, and each species appearing during periods of its preferred survival optimum range. Both *A. pacifica* and *A. spinicauda* are considered characteristically estuarine. However, the distribution of some *Acartia* species is known to be affected by temperature and salinity regimes (Ueda 1987, Cervetto et al. 1999, Gaudy et al. 2000). In this study, *A. pacifica* seem to reside in waters of higher salinities and

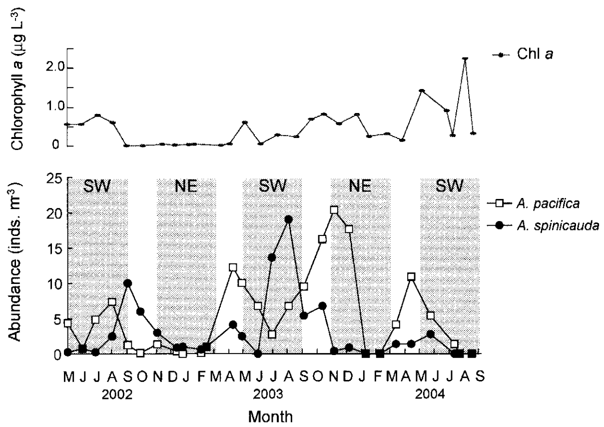

Fig. 8. Seasonal variation of *Acartia pacifica* and *A. spinicauda* abundance at the study site.

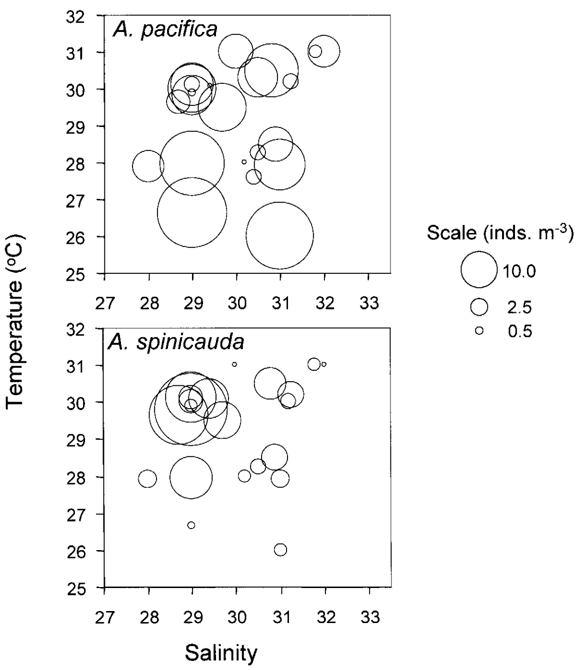

Fig. 9. *Acartia pacifica* and *A. spinicauda* population distribution with temperature and salinity.

lower temperatures than *A. spinicauda* (Fig. 9). Distinctive temperature-salinity preferences shown by the two species indicate that their spatial distribution is heterogenous to each other with some overlap. Distributional patterns of *A. pacifica* and *A. spinicauda* along the Straits show a well-defined divergence between the two populations (Fig. 10). The central sector of the Straits has several large rivers (mainly Perak, Bernam, Selangor and Klang-Langat Rivers) and the importance of freshwater inflow is noted to maintain salinity in this region relatively low (Ibrahim et al. 2003). As the cooler and highly saline Andaman Sea waters flow into the Straits due to predominant current movement in the southeast direction during the SW monsoon, the *A. pacifica* population experiences a distribution extension from the north towards the south. However, the population distribution ceases in the southern end of the Straits possibly due to the sudden shelving of the seabed off Kelang which prevent further water intrusion from the north (Parry 1995). The warmer and less saline waters of the southern sector during this period (Ibrahim et al. 2003) also present a physiological barrier to the species. On the other hand, during the NE monsoon, the net flow of cooler and highly saline water from the South China Sea into the Straits creates a preferable hydrographic environment for *A. pacifica*, thus extending the population distribution into the shallow southern sector of the Straits. The situation is reversed for *A. spinicauda*: During the SW monsoon, the population distribution extends to the southern end of the Straits due to the physiological preference to higher temperatures and lower salinity waters. During the NE monsoon, the population becomes confined to the central sector of the Straits as a consequence of the inflow of low temperature, high salinity waters from the South China Sea. Similar hydrographic conditions prevalent in the northern sector hinder the population from flourishing in this region.

Ecological differentiation between the congeners is of biological significance as it prevents competition for food and habitat niche between two similar species. One of the strategies in which copepod population is maintained is through the production of diapause or resting eggs. Resting eggs have been found in *A. pacifica* and *A. spinicauda* in a few investigations in temperate (eg. Inland Sea of Japan, Uye 1985) and subtropical waters (Xiamen Bay, China, Marcus 1996) and none have been found in tropical waters. In this study, no resting eggs of *Acartia* have been found in the sediment during the bi-weekly samplings from March to June 2005. Production of resting eggs may not be one of the major life history strategies or *Acartia* copepods in tropical waters where constant high temperatures promote egg hatching and shorter generation times. Temporal succession by *Acartia pacifica* and *A. spinicauda* in the study area is suggested to be a consequence of the variation in temperature-salinity regime of the SW and NE monsoons which may be coupled with influences of physical transport by the resultant monsoonal water movement. The same mechanism is thought to effect zooplankton community variation in the tropical coastal waters of the Straits of Malacca.

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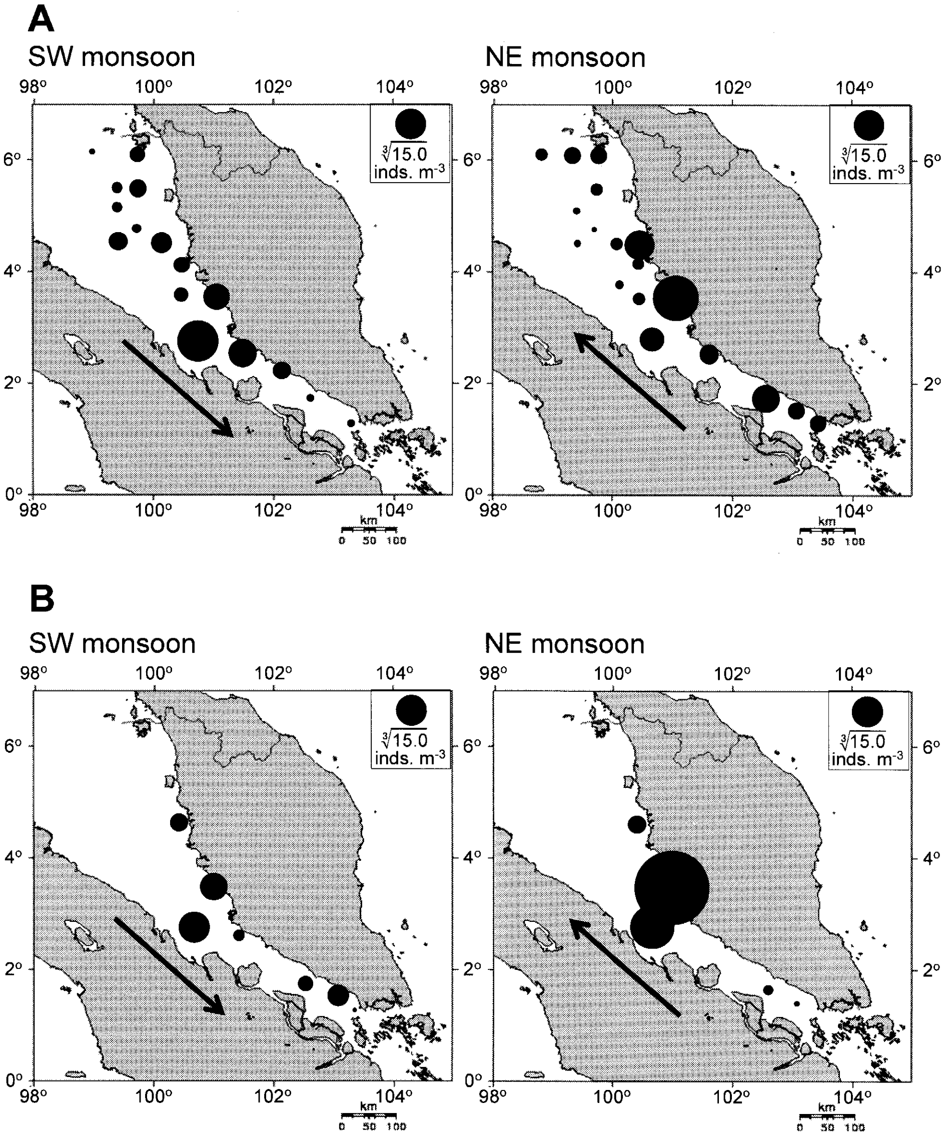

Fig. 10. Spatial distribution of (A) *Acartia pacifica* and (B) *A. spinicauda* in the Straits of Malacca during the SW (Jul 2000) and NE (late Oct 2002) monsoon season. Arrows indicate predominant direction of water flow.

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