Community Structure and Abundance of Epipelagic Copepods in a Shallow Protected Bay, Gulf of Thailand

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ABSTRACT

The community structure and abundance of epipelagic copepods in a shallow protected bay (Manao Bay, Gulf of Thailand) were studied twice a week from September 2006 to August 2007. Copepod samples were collected by vertical hauling using a conical 0.6 m diameter plankton net with 200 µm mesh size. Twenty-eight species from 19 genera were recorded. The mean abundance was 4,064 ± 263 individuals. m^{-3}. The dominant species were *Acartia erythraea* Giesbrecht (7.16%), *Corycaeus asiaticus* Dahl (4.72%), *Pseudodiaptomus aurivilli* Cleve (4.17%) and *Euterpina acutifrons* (Dana) (3.85%). Copepodid stages were more dominant than the other stages, consisting of 64.19% of the total copepod abundance. The carnivores were the most abundant at 17.55%, followed by the omnivores (13%) and the herbivores (3.33%). Total abundance of the copepods showed a temporal variation. The Shannon – Wiener diversity index ranged from 1.66 to 2.49. But the detected similarities to temporal variability showed no difference in species composition. The epipelagic copepod community in this bay was low in diversity but high in abundance throughout the year.

Key words: epipelagic copepods, community structure, Gulf of Thailand

INTRODUCTION

Epipelagic copepods play a key role in pelagic food webs by shaping primary production and providing food sources for planktivorous fish such as anchovy and herring. Due to their vast abundance, the dynamics of copepod populations have significant potential to controlling fish stocks (Runge, 1988; Uye *et al*., 2000; Renz *et al*., 2008). Also, they support the microbial community and phytoplankton production in terms of nitrogen regeneration (Richardson, 2008). Many studies have described the copepod community structure in many parts of the world (Woodd-Walker *et al*., 2002; Rodrigo *et al*., 2003; Hooff and Peterson, 2006; BÖttger-Schnack *et al*., 2008;); however, there have been few studies in the Indo-West Pacific regions (Lan *et al*., 2008; Tseng *et al*., 2008).

The Gulf of Thailand is an important area for fishery resources in the South China Sea (Longhurst, 1998). This area is a shallow basin with depths ranging from 50 to 80 m and is a high primary production

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area (SEAFDEC, 1999). In the Gulf of Thailand, the main small fish resources are anchovy, herring and mackerel (Pauly and Chuenpagdee, 2003). Unfortunately, studies about trophic structure and the function of the pelagic ecosystem to support these fish stocks are very limited, especially on copepod production and community structure. A few published papers deal with aspects of species composition and abundance that were mainly restricted to the inner Gulf (Fleminger,1963; Suwanrumpha, 1980a; 1984; Pinkaew, 2003). Therefore, our objective was to investigate temporal variation of epipelagic copepods in terms of abundance and community structure in a shallow protected bay in the upper western coast of the Gulf of Thailand.

MATERIALS AND METHODS

Study sites

The Manao Bay (11º 49' N, 99º 50' E) is a shallow protected bay in Prachuab Khiri Khan Province which is located in the upper western coast of the Gulf of Thailand (Figure 1). As this area is under the jurisdiction of the Royal Thai Air force, it is relatively undisturbed by fisheries, freshwater runoff and transportation (Jansang *et al*., 1999). It is a famous location for sight-seeing due to its beautiful scenery. It is classified as a small semi-enclosed bay with an approximate surface area of 15 km^2 and a mean depth of 7 m. In the Gulf of Thailand, the tide is of a mixed type, and circulation of coastal water is affected by tidal currents. Surface current (0-10 m) is strongly influenced by prevailing monsoons and this area is affected by two heavy monsoons: the southwest monsoon from May to October and the northeast monsoon from October to February. The surface vector field is northeastward in the Gulf from the South China Sea during the northeast monsoon and the opposite direction in the southwest monsoon (Robinson, 1963; Snidvongs and Sojisuporn, 1999).

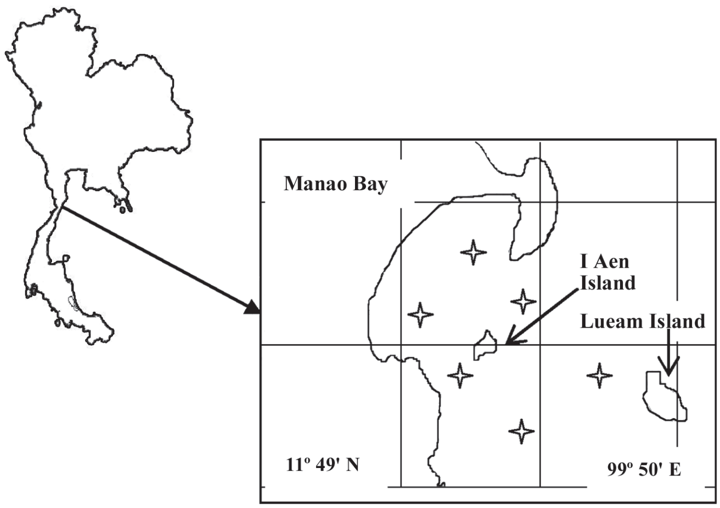

Figure 1. Geographic location of Manao Bay (11º 49' N, 99º 50' E), showing position of sampling stations in the inner, middle and outer area of the bay

Environmental variables

Salinity and water temperature were measured using a refractometer and a YSI 550A, respectively. Water samples were collected at 30 cm below surface level for analysis of total Chlorophyll *a* concentration using the spectrophotometric method (Strickland and Parson, 1968).

Sampling techniques

Copepod samples were collected by vertical hauling using a conical 0.6 m diameter plankton net with 200 µm mesh size, with 2 replications per station. The net was fitted with a flow meter to determine the amount of water filtered during each tow. Six sampling stations of two transect lines were set up in the inner, middle and outer areas of the bay along the transect lines. Net samples were immediately preserved in 5 % buffered formaldehyde solution. The abundance and community structure were studied twice a week from September 2006 to August 2007.

Data analysis

Preserved copepod specimens were sorted and identified by species under a microscope in the laboratory. Abundance (ind. m^{-3}) and species composition were determined using the methods of Postel *et al*. (2000). Adults were separated into four pelagic orders: Calanoida, Cyclopoida, Harpacticoida and Poecilostomatoida, following the works of Huys and Boxshall (1991) and Bradford-Grieve (1999). Nauplii and copepodid stages were counted separately to determine stage composition. In order to determine the trophic position, all observed species were classified into three trophic groups, namely, carnivores, herbivores, omnivores and using the criteria of morphological feeding apparatuses. Information on concerned feeding behaviors was also reported by Anraku and Omori (1963); Suwanrumpha (1980b); Ohtsuka *et al*., (1996) and Turner (2004).

Bray – Curtis similarity was calculated using a similarity analysis program to differentiate the copepod community. Prior to calculation, data were log transformed to standardization. The Shannon-Wiener equation was used to calculate the copepod diversity index to describe a quality of a community (Field *et al*., 1982). Pearson correlation analysis was used to determine the relationship between the environmental variables, total abundance and three trophic categories of epipelagic copepods.

RESULTS

Environmental variables

Water temperature ranged between 26.02 and 31.43ºC. The maximum value was recorded in June 2007 and the minimum was recorded in January 2007 (Figure 2a). Salinity values varied from 21 to 31 psu (Figure 2b). Total chlorophyll *a* concentrations ranged between 0.24 and 2.67 mg. m^{-3}. Chlorophyll *a* values regularly changed with two peaks in concentration: a small one (2.14 mg. m^{-3}) in October 2006 and a large one (2.67 mg. m^{-3}) in June 2007 (Figure 2c). Pearson correlation analysis indicated that the total chlorophyll *a* concentration was negatively correlated to salinity ($r=0.57$, $P<0.05$) but positively correlated to water temperature ($r=0.51$, $P<0.05$).

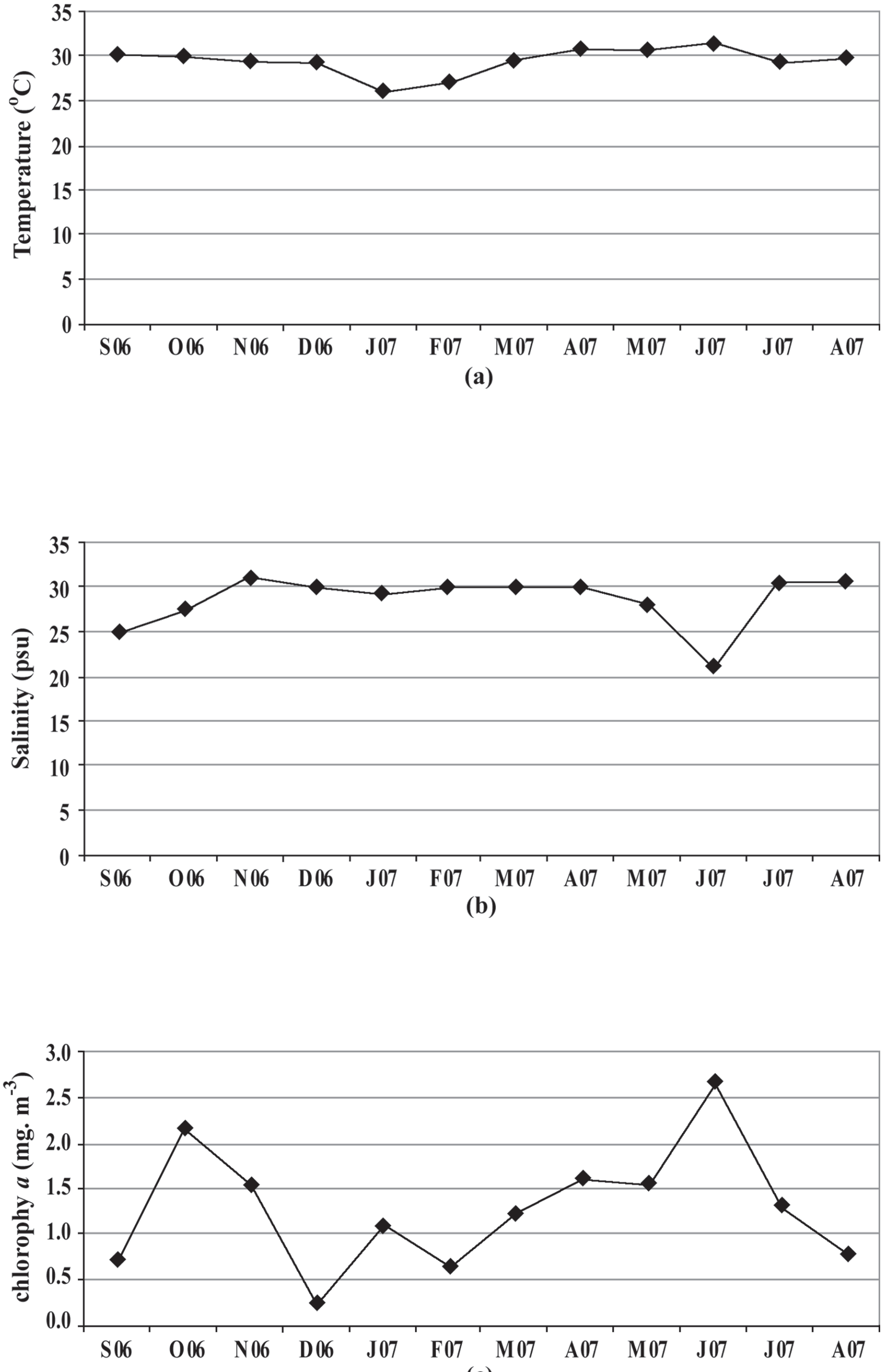

Figure 2. Temporal variations in water temperature (a), salinity (b) and total chlorophyll *a* concentration (c) in Manao Bay, the upper western Gulf of Thailand

Diversity, species composition and abundance

Twenty-eight species from 19 genera were recorded. The most diverse group was Order Calanoida which comprised of 17 species, followed by Order Poecilostomatoida with 5 species and Order Harpacticoida with 4 species (Table 1). The least diverse group was Order Cyclopoida with 2 species. The number of species ranged from 12 in September 2006 to 21 in October 2006.

Total abundance of epipelagic copepods fluctuated during the study period. The values varied from a minimum of 2,342 ind. m^{-3} in December 2006 to a maximum of 6,446 ind. m^{-3} in February 2007 (Figure 3). The mean abundance was 4,064 ± 263 ind. m^{-3}. The peak abundance was reached in February 2007, which coincided with the abundance of *Acartia erythraea* Giesbrecht, *Pseudodiaptomus aurivilli* Cleve, *Euterpina acutifrons* (Dana), *Oithona* sp. and *Corycaeus asiaticus* Dahl. This peak was positively correlated to the abundance of the copepodid stage. Three minimum values were found in December 2006, July and August 2007.

The larval stages (copepodid) of copepods dominated other stages, contributing 64.19% to total abundance; the mean abundance was 2,608 ± 130 ind. m^{-3}. Percentage and mean abundances of other groups in descending order were as follows: 16.01% (650 ± 83 ind. m^{-3}) calanoids, 9.59% (390 ± 423 ind. m^{-3}) poecilostomatoids, 4.58% (186 ± 41 ind. m^{-3}) harpacticoids and 3.71 % (151 ± 94 ind. m^{-3}) cyclopoids (Figure 4). In terms of percentage abundance, the four dominant species were *Acartia erythraea* (7.16%), *Corycaeus asiaticus* (4.72%), *Pseudodiaptomus aurivilli* (4.17%) and *Euterpina acutifrons* (3.85%). Subdominant species were *Oithona* sp. 1 (3.09%), *Acrocalanus gibber* Giesbrecht (2.61%), *Corycaeus catus* Dahl (2.35%) and *Oncaea conifera* Giesbrecht (1.60%). All frequently occurring species were present throughout the year (Table 1). The Pearson correlation analysis indicated that copepod abundance was positively correlated to total chlorophyll *a* concentration ($r = 0.35$, $P<0.05$) but was not correlated with salinity or water temperature.

Community structure

The carnivorous copepods are predominant throughout the year. Total abundance ranged between 339 and 1,212 ind. m^{-3} in November 2006 and February 2007, respectively. The average value was 713 ± 286 ind. m^{-3} or 17.55 % of the total copepods (Figures 5 and 6). They belonged to the following families: Candaciidae, Corycaeidae, Labidoceridae, Oithonidae, Oncaeidae, Pseudodiaptomidae, Sapphirinidae and Tortanidae. Omnivorous copepods comprised 13 % of the total copepods. The mean value was 528 ±254 ind. m^{-3}, the maximum value was 1,042 ind. m^{-3} in June 2007 and the minimum value was 200 ind. m^{-3} in July 2007. They were composed of many neritic species of genera *Acartia*, *Calanopia*, *Centropages*, *Clytemnestra*, *Euterpina*, *Macrosetella* and *Microsetella*. Herbivorous copepods were present in low density (mean 135 ± 93 ind. m^{-3}), contributing 3.33 % of the total copepods. They varied from 33 ind. m^{-3} in July 2007 to 354 ind. m^{-3} in November 2006 and included four genera, namely, *Acrocalanus*, *Canthocalanus*, *Paracalanus* and *Subeucalanus*. The contribution of the three categories of epipelagic copepods demonstrated a sharp temporal pattern as shown in Figure 7.

Table 1. Taxonomic list of copepods with mean, maximum and minimum values of abundance (ind. m^{-3}), mean value for contribution (%) to total abundance of each taxon and its trophic category*

Taxa	Abundance (ind. m^{-3})			Mean %	Trophic category*
	Mean	Max	Min		
Order CALANOIDA					
Acartia erythraea Giesbrecht	291	559	49	7.16	O
Candacia catula Giesbrecht	0.15	1.75	0	0.004	C
Centropages furcatus (Dana)	38	103	9	0.93	O
Centropages orsinii Giesbrecht	10	37	0	0.26	O
Centropages tenuiremis Thompson &Scott	4	24	0	0.10	O
Calanopia thompsoni A. Scott	0.37	4.5	0	0.01	O
Labidocera bipinnata Takaba	0.19	2.35	0	0.005	C
Labidocera minuta (Giesbrecht)	2	7	0	0.06	C
Labidocera pectinata Thompson &Scott	1	9	0	0.02	C
Pseudodiaptomus aurivilli Cleve	155	351	0	3.82	C
Pseudodiaptomus clevei A. Scott	8	37	0	0.21	C
Tortanus forcipatus (Giesbrecht)	4	29	0	0.11	C
Tortanus gracilis (Brady)	2	15	0	0.06	C
Canthocalanus puaper (Giesbrecht)	2	11	0	0.04	H
Acrocalanus gibber Giesbrecht	106	233	31	2.61	H
Paracalanus aculeatus Giesbrecht	17	183	0	0.42	H
Subeucalanus subcrassus (Giesbrecht)	10	48	0	0.26	H
Order HARPACTICOIDA					
Macrosetella gracilis (Dana)	9	75	0	0.22	O
Microsetella norvegica (Boeck)	1	5	0	0.03	O
Clytemnestra scutellata Dana	16	75	0	0.47	O
Euterpina acutifrons (Dana)	157	552	32	3.85	O
Order CYCLOPOIDA					
Oithona plumnifera Baird	25	70	3	0.62	C
Oithona sp.	126	303	19	3.09	C
Order POECILOSTOMATOIDA					
Oncaea conifera Giesbrecht	65	192	4	1.60	C
Corycaeus asiaticus Dahl	192	557	48	4.72	C
Corycaeus catus Dahl	96	387	13	2.35	C
Corycaeus speciosus Dana	37	67	9	0.91	C
Sapphirina stellata Giesbrecht	0.16	2	0	0.004	C
Nauplii	78	281	0	1.93	
copepodites	2608	4333	1212	64.19	

* C = Carnivore, H = Herbivore, O = Omnivore

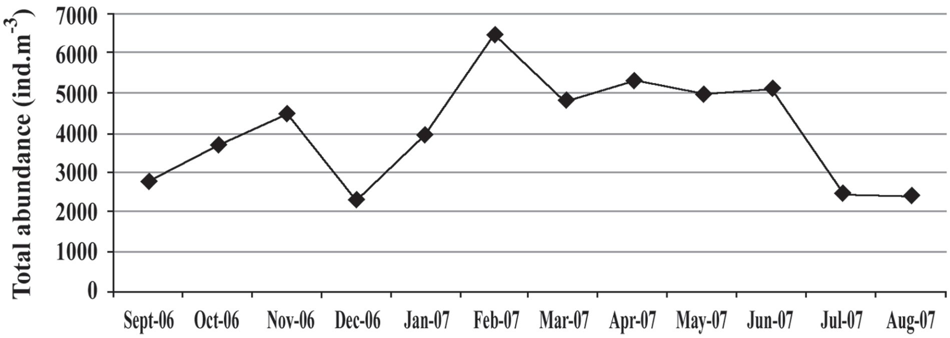

Figure 3. Total abundance of epipelagic copepods in Manao Bay, the upper western Gulf of Thailand.

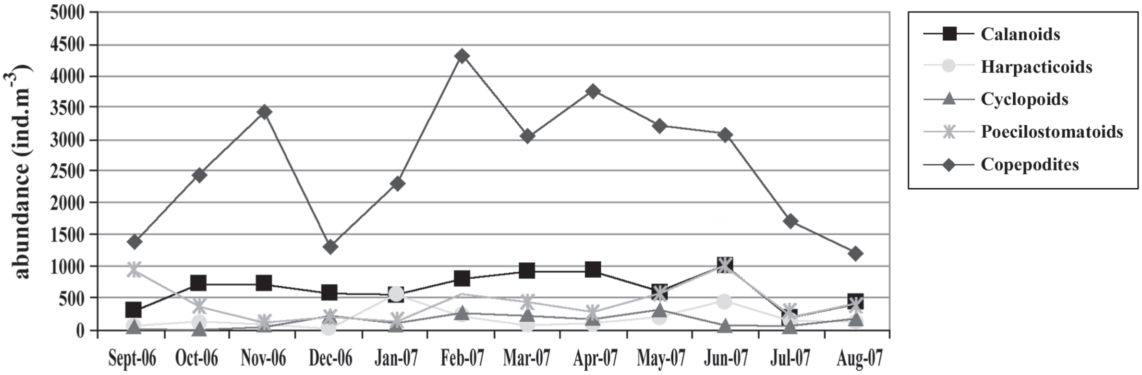

Figure 4. Temporal variations in abundance of copepodid stage and adult epipelagic copepods

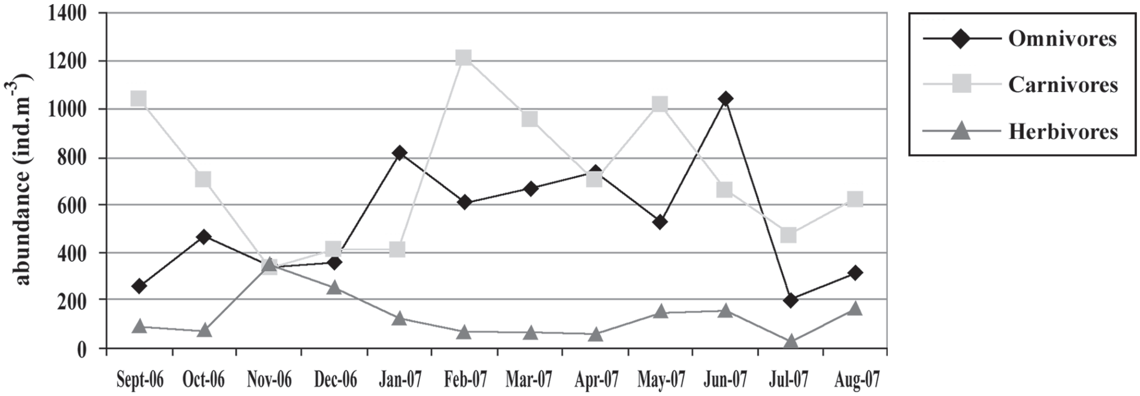

Figure 5. Temporal variations in abundance of three categories of adult epipelagic copepods

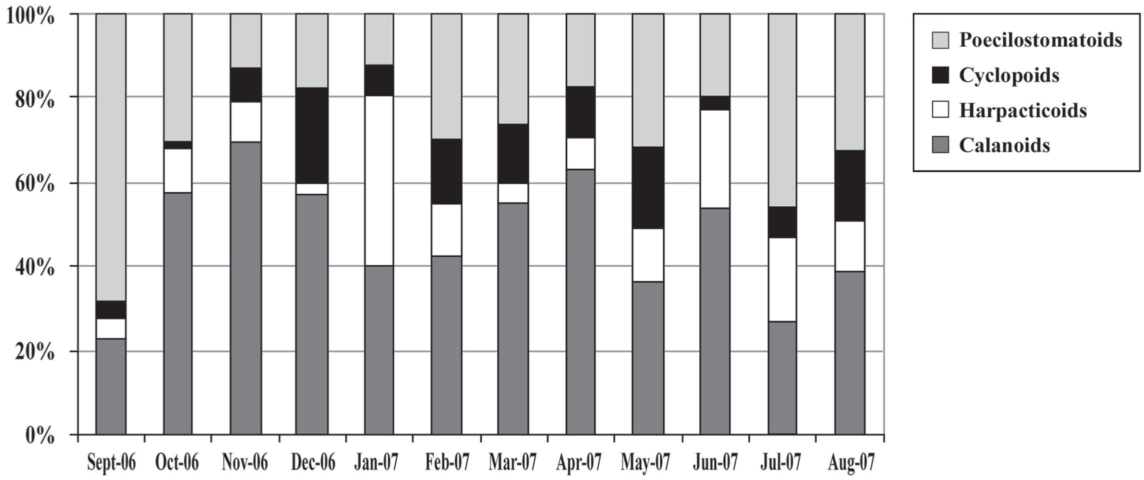

Figure 6. Temporal contribution percentages of adult epipelagic copepods

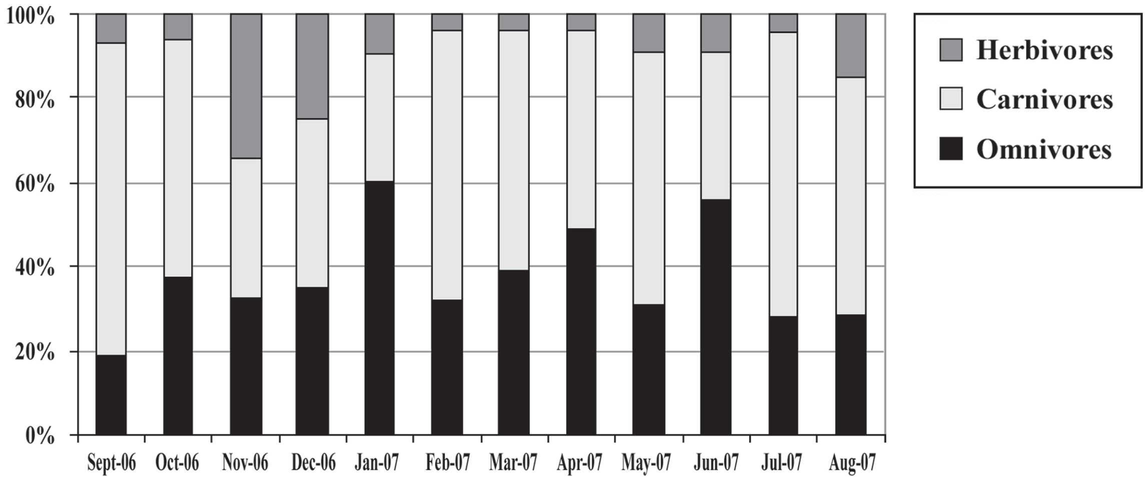

Figure 7. Percentage composition of three categories of adult epipelagic copepods

The correlation analysis showed that omnivores were positively correlated to total chlorophyll *a* concentration ($r = 0.51$, $P < 0.05$) but carnivores and herbivores were not.

Numerical analysis

Bray-Curtis similarity was used to observe the annual difference in species composition of the copepod community. Results of the analysis showed no difference in species composition of the epipelagic copepod community in this study site although the total abundance showed temporal variations. The Shannon-Wiener diversity value was highest in August 2007 ($H' = 2.49$) and lowest in September 2006 ($H' = 1.66$).

DISCUSSION

Environmental variables

Important factors affecting both horizontal and vertical water column mixing in the Gulf of Thailand are shallow depth (< 10m), strong coastal winds and mixed type of tidal currents (Nasir *et al*., 1999). The well mixed water in the present study exhibited slight temporal variations in salinity and water temperature excluding the annual cycle in chlorophyll *a* concentration. These results agreed with previous findings by Nasir *et al*. (1999) in the South China Sea area. During the southwest monsoon season, chlorophyll *a* concentration was higher than during the northeast monsoon season. It could be explained by seasonal changes in coastal circulation patterns, phytoplankton density and nutrient loading during the rainy season in this bay (Boonyapiwat, 1999). Nutrients are stirred up and transported to the northern part of the Gulf by strong south-westerly winds and opposite from the northern Gulf during the north-easterly winds (Robinson, 1963; Snidvongs and Sojisuporn, 1999).

Diversity, species composition and abundance

Species diversity data and species numbers obtained from Manao Bay during this study were lower than those reported in the western Gulf of Thailand by Suwanrumpha (1984). The lower values recorded from this study area were probably due to the collecting area which was small and restricted in a shallow bay and did not include the offshore areas. However, compared to the previous record of Suwanrumpha (1984), 17 new additional species were recorded. At present, the proximate species diversity of epipelagic copepod is 50 species in the upper western coast of the Gulf of Thailand. However, the new additional species were based on only a sample collected by one mesh size of 200 µm. Using different mesh sizes for sampling undoubtedly influences the data obtained for diversity, species composition and abundance of copepods. In this regard, the copepodites were found to be the most common in all samples and contributed to the highest numbers throughout the study period.

The dominant species of epipelagic copepods were *Acartia erythraea*, *Corycaeus asiaticus*, *Euterpina acutifrons* and *Pseudodiaptomus aurivilli*. They are important contributors to the total abundance in coastal waters (Suwanrumpha 1980a; 1984). These species are considered to be eurythermal and euryhaline and are widely distributed in the Gulf (Suwanrumpha, 1984).

The variation in copepod abundance showed a slightly positive correlation with chlorophyll *a* concentration during this study ($P<0.05$) but no correlation with water temperature or salinity. This result agrees with the previous study of Suwanrumpha (1984) where she also indicated that the epipelagic copepod community was of the brackish water species in this area.

The abundance of total copepods was greater during the post monsoon season (February-June) than during the monsoon season in this bay. This pattern is in agreement with the previous study of Suwanrumpha (1980a; 1984) in the Gulf of Thailand and can be explained by the warmer summer months which result in increased breeding rate of marine organisms including copepods (Froneman, 2004; Hooff and Peterson, 2006).

Furthermore, results of many studies showed that the high contribution of copepod abundance was restricted to near shore areas (Rodrigo *et al*., 2003; Krumme and Liang, 2004; Putland and Iverson, 2007), thus a high number of neritic species were present rather than offshore species.

The high abundance of copepods was not accompanied by a low diversity index. In addition, the Pearson correlation analysis showed that no correlation existed between abundance and Shannon-Wiener diversity index. It could then be assumed that the copepod community was restricted to this bay and not affected by tidal currents or the monsoon season. Therefore, the species composition did not vary and there was no mixing with the offshore species in the samples.

Community structure

The proportion of epipelagic copepods in Manao Bay in the upper western coast differed from that of the inner Gulf. Moreover, the proportion of carnivores was higher than herbivores and omnivores in this area. Carnivores were almost highly dominant throughout the study period. Omnivores were more abundant in January and June 2007 whereas herbivore abundance increased in November and December 2006. Our results did not correspond with the findings of Suwanrumpha (1980) who found herbivores in high numbers (41.5%) throughout the year in the inner Gulf. The abundance of carnivores and omnivores were 36.85 and 21.5 %, respectively. As this study was based on plankton samples collected by only one mesh size (200 µm), it could not be compared with the previous study conducted by Suwanrumpha (1980) where a larger mesh size (330 µm) was used. Her study did not include small size copepods such as *Oithona* and *Oncaea*. In addition, the near shore species composition certainly differed from that of the offshore species. The species composition was significantly limited by horizontal and vertical distribution (Suwanrumpha, 1984).

This bay is a protected area so it can be assumed to be an oligotrophic coastal water. Chlorophyll *a* concentration was relatively low in this bay during the study period. Also, the low primary production provided not enough food sources for herbivores and omnivores (Uye *et al*., 2000; Turner, 2004; Morgado *et al*., 2007). The copepodites were also found in high numbers throughout the annual cycle. They are assumed to be a main predator of phytoplankton in tropical oligotrophic waters (Calbet, 2008). These conditions resulted in a higher proportion of carnivores than herbivores and omnivores in this study.

From this study, it can be concluded that the epipelagic copepod community in Manao Bay is low in species diversity but high in abundance throughout the year. The copepod community is restricted to this bay with no mixing with offshore species, and it is not affected by temperature, salinity or monsoon seasons.

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