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Vertical Distribution of Zooplankton and Copepod Community Structure in the Straits of Malacca

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Abstract
Vertical distribution of zooplankton biomass and abundance, copepod taxonomic composition and species diversity were analyzed at eight stations during an oceanographic expedition along the Straits of Malacca. Samples were collected in vertical hauls (140 µm mesh using 45 cm diameter NORPAC net) from four depth strata. Zooplankton biomass was higher at 10-20 m depth in the central and southern parts of the Straits compared to the other depth layers, but the differences were significant ($p<0.05$) only in the southern part. A total of 96 species of planktonic copepods belonging to 35 genera were identified in the surveyed area. Except for the 10-20 m depth layer in the northern part of the Straits, copepods were the major fraction of the total zooplankton at all depths. In the northern and central parts of the Straits, the deeper layers had higher species diversity indices than in the surface waters, mainly due to higher evenness in the deeper layers. The lower species diversity in the deeper layers of the southern region was attributed to the dominance of a few species.

Keywords: *Biomass, Copepods, Vertical distribution, Diversity, Malaysia*

1. Introduction

The Straits of Malacca is situated off the Western Malaysian Peninsula; it is a relatively shallow sea and partially landlocked. In spite of the fact that the Straits of Malacca is an important fishing ground producing more than 50% of the fish catch for West Malaysia (Razali, 2000), information concerning biological community structure is lacking. Previous five-year oceanographic surveys conducted in the Straits of Malacca between 1998 and 2002 provided much of the information on the zooplankton biomass, species composition and spatio-temporal distribution of different components of zooplankton assemblages (Rezai et al., 2003; 2009).

Zooplankton populations, which are dependent on the phytoplankton production, form the major link in the marine food chain. In fact, zooplankton biomass is often the basis for estimating biological production and carrying capacity of the sea. Zooplankton distribution is closely related to environmental factors such as light level, temperature, abundance of food and mixed layer depth (Hirota and Hasegawa, 1999; Andersen et al., 2004). Rezai et al. (2003a) reported that zooplankton biomass was generally higher in waters near the coastal areas, indicating the importance of food in determining the zooplankton distribution. The aim of this paper is to provide information on the vertical distribution of total

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zooplankton biomass, abundance, composition and species diversity in different parts of the Straits of Malacca.

2. Materials and Methods

Zooplankton samples were collected in vertical hauls (140 µm mesh and 45 cm diameter NORPAC net) during an oceanographic expedition between 20 March and 6 April 1999, along the Straits of Malacca (05° 59’ N, 99° 59’ E and 01° 10’ N, 103° 29’ E) (Fig. 1).

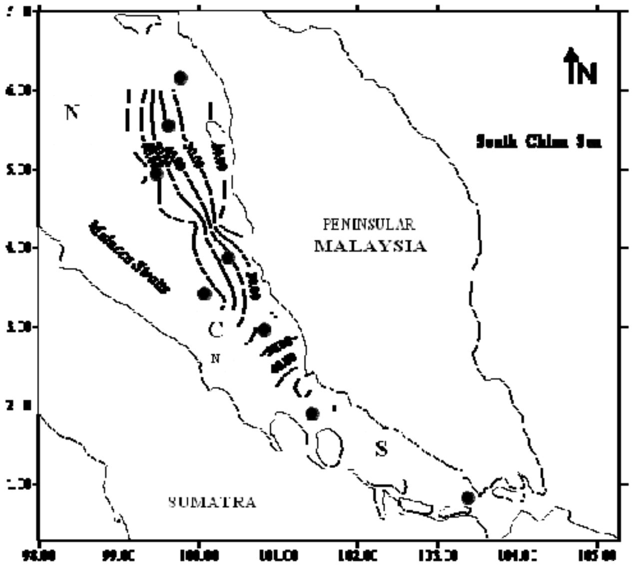

Fig. 1. Location of the sampling stations (●) and depth contours (m). N, C, and S are northern, central and southern parts of the Straits respectively.

Twenty stations were established for oceanographic survey, but only eight of these were used for the study of vertical distribution of biomass. Samples were collected from four depth layers (0-10 m, 10-20 m, 20-40 m, and > 40 m down to the maximum depth of approximately 60 m). The period of the cruise coincided with the pre-Southwest (pre-SW) monsoon. Two replicate samplings were performed at each depth. One sample was measured for biomass analysis, while the other was used for quantitative counting and for microscopic analysis. Details of sampling stations are described elsewhere (Rezai et al., 2004). Temperature and salinity were measured synchronously with the zooplankton samplings using a Hydrolab Model 40215.

Hydrographic conditions in the southern part of the Straits were characterised by the homogeneous surface layer with a temperature of 28.0°C and a salinity of 33.0 psu reaching down to 36 m depth.

3. Results

The vertical distribution of total zooplankton biomass varied at different geographic locations of the Straits. Zooplankton biomass in the northern part exhibited a gradual decline from the surface to deeper waters (Fig. 2, a). However, in the central part, zooplankton biomass increased from the surface to 20 m, and thereafter, declined slightly in deeper layers (Fig. 2, b). On the other hand, in the southern part, the zooplankton biomass presented a pronounced increase at 10-20 m (Fig. 2, c), followed by a sudden decline in deeper waters. Significant differences ($p< 0.05$) in zooplankton biomass were found amongst different depth layers. Mean zooplankton biomass of the water column for the combined stations was 65.80 ± 15.37 mg m^{-3}.

The quantitative composition of the zooplankton differed considerably according to the depth layers sampled. Although most of the zooplankton groups showed near-surface maximum abundances, many avoided the upper 10 m. Total zooplankton showed maximum relative abundances at the10-20 m layer in the northern and southern parts of the Straits (Fig. 3 a, c), whereas the minimum abundances were recorded at > 40 m. The situation was quite different in the central part, where the zooplankton abundances declined gradually with depths (Fig. 3, b). Significant differences ($p<0.05$) were found in total zooplankton abundances amongst different depth layers (0-10 m, 10-20 m, 20-40 m, and >40 m), suggesting uneven vertical distribution patterns. In the northern part of the Straits, zooplankton groups were more prominent and more diverse, particularly at the10-20 m depth layer. The main groups of zooplankton in the upper layer of the Straits were crustaceans, appendicularians and tunicates.

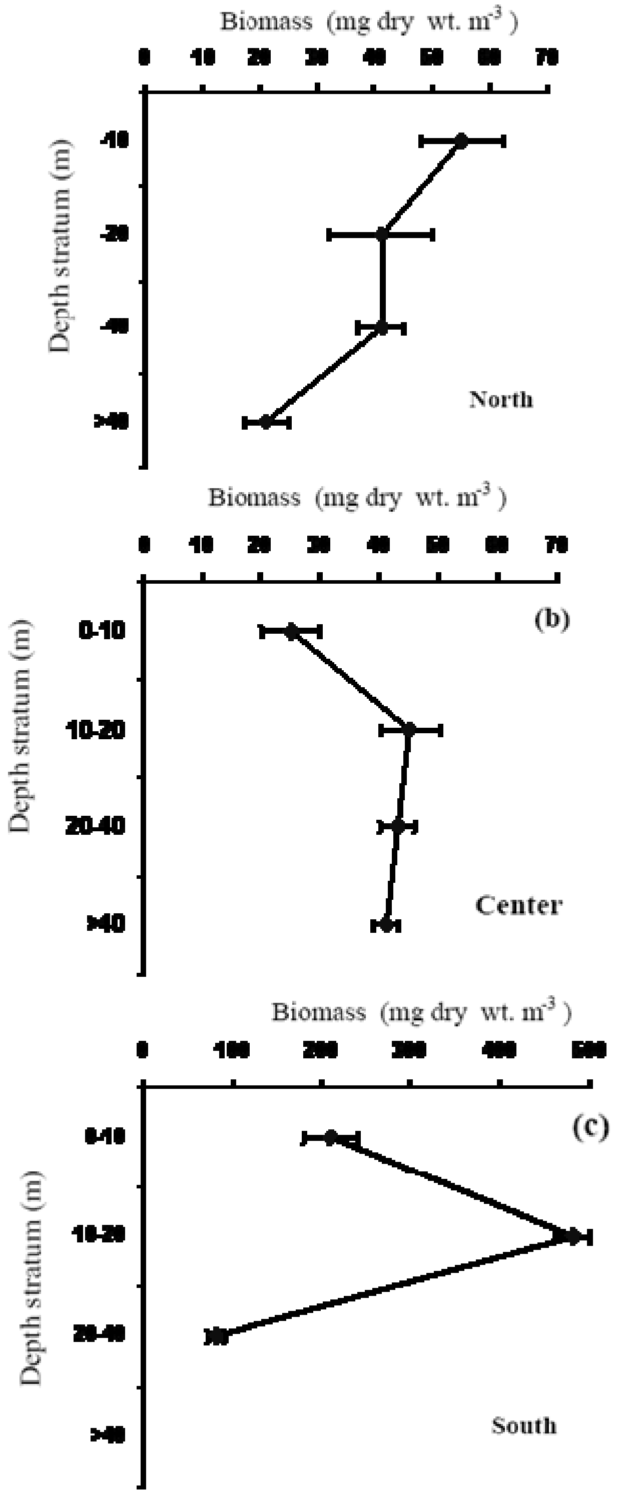

Fig. 2. Vertical distribution of total zooplankton biomass (mg dry wt. m^{-3}) in the northern (a), central (b) and southern (c) parts of the Straits of Malacca. The horizontal bars are the standard errors of the mean.

Amongst the zooplankton, copepods (including copepodite stages) constituted 71.2% (9202 ± 4712 ind. m^{-3}) of the total zooplankton of the water column in all combined stations. Except for the 10-20 m depth layer in the northern part (Fig. 3, a), copepods were the major fraction of the total zooplankton at all depth layers. In the northern part, the relative abundance of copepods increased after the 10-20 m depth layer, from 11.2% in the upper waters to 64.3% in deeper waters; in the central part, it decreased from 96.2% to 38.9%; and in the southern part, it decreased from 88.1% to 84.1%.

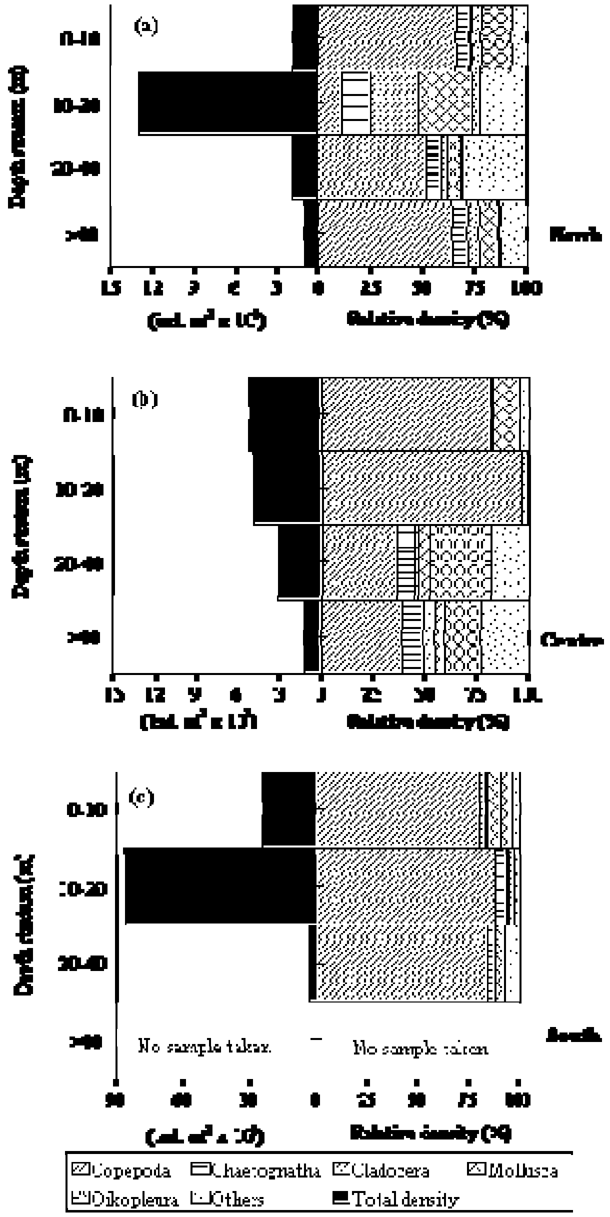

Fig. 3. Vertical distribution of total zooplankton abundances in the northern (a), central (b) and southern (c) parts of the Straits of Malacca.

A total of 96 species of planktonic copepods belonging to 36 genera were identified in the surveyed area: 57 calanoids, 9 cyclopoids, 25 poecilostomatoids and 5 harpacticoids. The composition of copepod orders varied according to different depth layers and geographical locations within the Straits. Except for the 0-10 m layer in the northern part of the Straits, members of the order Calanoida were abundant at all depth layers (Fig. 4) and they formed 34.0% to 67.0% of copepod population.

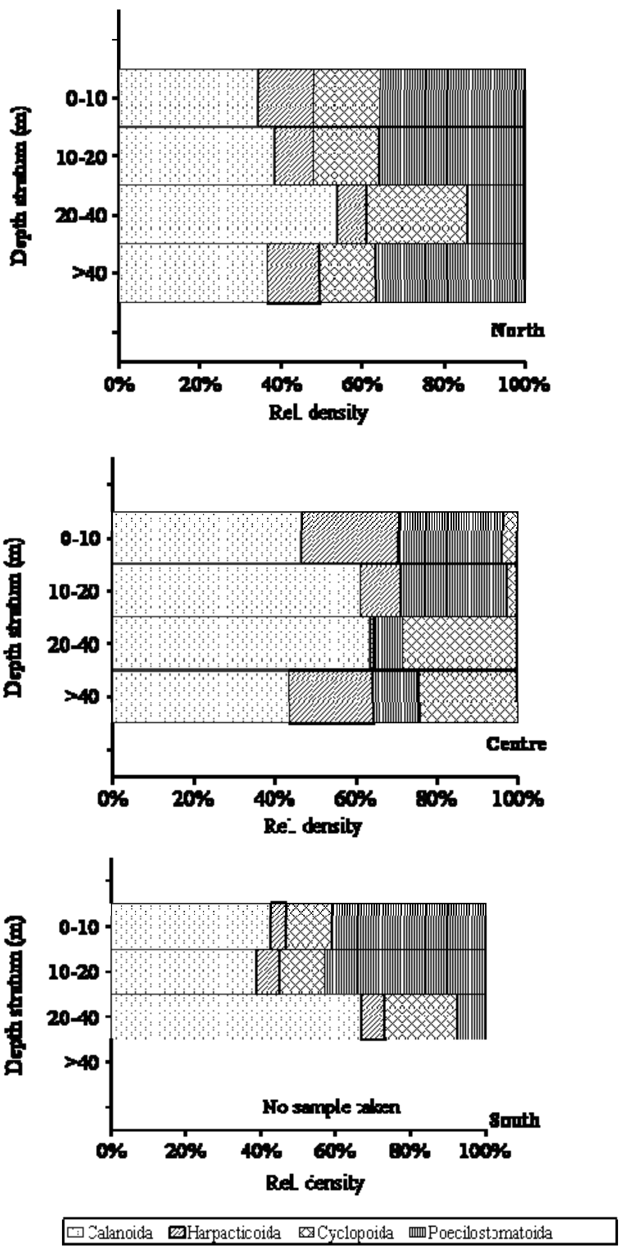

Fig. 4. Percentage composition of copepod orders at different depth layers in the northern (a), central (b) and southern (c) parts of the Straits of Malacca.

In general, calanoids showed maximum relative abundances at the 20-40 m depth layer regardless of the locations in the Straits (Fig. 4). The study also revealed the presence of non-calanoid copepods including poecilostomatoids (Corycaeus spp., Oncaea spp. plus a few *Copilia* spp. and *Sapphirina* spp.), cyclopoids (*Oithona* spp.) and harpacticoids (*Euterpina acutifrons*, *Macrosetella gracilis*). Poecilostomatoids showed slightly higher abundances than calanoids in the northern part compared with other areas, whereas harpacticoids showed lower relative abundances in the southern part compared with other parts of the Straits.

Spatial variations in the vertical distribution of copepod community were complex since this community included species associated with different depths. Table 1 lists the 26 most abundant copepod species with more than 2% relative abundance, and summarizes data on their relative abundance during the cruise for the northern, central, and southern parts of the Straits. Clearly the highest copepod abundances were recorded in the 10-20 m depth layer, followed by a gradual decline in abundances with increasing depth. An impoverished population was recorded below 40 m where the number of species also greatly declined. However, the Kruskal-Wallis analysis showed no significant difference ($P>0.05$) in copepod abundances amongst different depth layers when stations were pooled within each geographic location (northern, central, southern parts).

Different trends of diversity indices were observed for copepods at successive depth layers in different geographic locations within the Straits (Fig. 5). The northern and central parts showed totally opposite trends of diversity from the surface to deeper layers. The decrease in diversity index was accompanied by an increase in abundance (Fig. 5). A small peak in species diversity at 40 m in the northern part of the Straits was probably resulted from the reduced dominance of any one species at that depth layer. In the southern part, the diversity index gradually decreased from the surface to deeper layers.

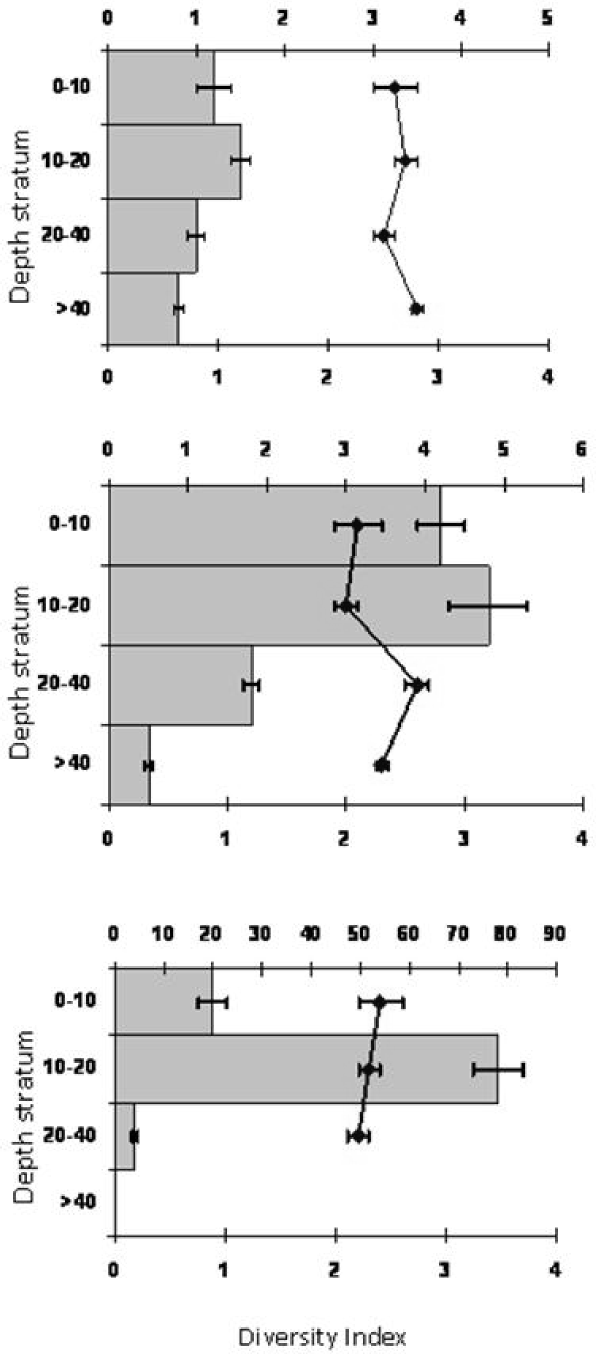

Fig. 5. Vertical distribution of the mean copepod abundances along with corresponding diversity index (H') at the different depth layers in the northern, central and southern parts of the Straits of Malacca. The horizontal bars are the standard errors of the mean.

One-way ANOSIM showed no significant difference (P> 0.05) between copepod communities at different depth layers in the Straits (Table 2). However, the copepod communities of 0-10 m and > 40 m were more separable (but overlapping; R> 0.25) than any other paired depth layers (R<0.25). Similarity percentage analysis (SIMPER) revealed that eight discriminator species (Pontellidae, *P. parvus*, *F. gibbulus*, *O. simplex*, *E. marinella*, *O. media*, *P. denudatus* and *O. plumifera*), were mostly responsible for the separation of communities between the paired depth layers of 0-10 m and > 40 m (mean dissimilarity = 71.1%).

4. Discussion

The data presented here describe the vertical distribution of zooplankton biomass and abundance, and the copepod community structure in terms of species composition and diversity during the pre-SW monsoon in the Straits of Malacca. The intra-variation in biomass content among different depth layers at each station was higher than the inter-variation between stations. The present results on the vertical distribution of zooplankton biomass are in close agreement with Wickstead (1961) who showed that there is a greater zooplankton biomass towards the surface layer.

Studies of vertical distributions of zooplankton have shown that particle grazers are closely associated with subsurface chlorophyll-a layers in many parts of the world (Longhurst, 1976). The higher zooplankton biomass and abundances at 10-20 m may be attributed to a well-defined subsurface chlorophyll-a at about 10 m (Yusoff et al., 2001). On the other hand, the apparent reduction of biomass in the northern part at 10-20 m could be due to higher predation. The relatively low mean zooplankton biomass in deeper water (>40 m) probably reflects the paucity of biota at deeper waters in all parts of the Straits, and may be related to gradual decline of chlorophyll-a with depth (Yusoff et al., 2001). This trend is distinct in the southern part of the Straits where the water was more turbid than in the northern region.

The reduction in zooplankton biomass with depth is similar to that of most tropical ocean regions. Low biomass values near the bottom of the Straits waters are not necessarily the outcome of inefficient resources for plankton communities but could result from low surface organic production and poor vertical flux of organic material from overlaying layers. Because of the shallowness of the Straits, no distinct boundary was evident between the distribution limit of each species. The dominant species such as *P. parvus* and *E. acutifrons* were distributed from the surface to bottom.

Table 1- Vertical proportion of adult copepod species at four depth layers in combined stations in the northern (N), central (C) and southern (S) parts of the Straits of Malacca. Only species with a relative abundance of ≥ 2.0% of the total abundance of adult copepods in a given layer, were selected.

		0-10 m			10-20 m			20-40 m			>40 m		
	Species	N	C	S	N	C	S	N	C	S	N	C	S
1	*Oncaea media*	19.88	+	13.21	13.00	0	15.17	+	14.28	+	13.73	5.77	-
2	*Oithona plumifera*	13.45	0	+	13.36	0	0	+	7.14	+	2.46	8.97	-
3	*Paracalanus parvus*	12.87	32.16	22.14	15.52	39.74	27.24	20.88	24.67	37.08	10.21	26.28	-
4	*Centropages furcatus*	9.94	0	+	+	+	+	+	+	+	+	+	-
5	*Euterpina acutifrons*	7.60	19.38	3.57	6.86	9.61	5.30	3.30	9.09	4.94	5.99	17.30	-
6	*Oncaea clevei*	7.60	0	18.93	15.16	+	17.91	10.99	5.19	3.37	5.28	8.97	-
7	*Corycaeus andrewsi*	4.68	3.52	5.71	3.25	2.18	8.22	+	6.49	3.14	11.27	7.69	-
8	*Microsetella norvegica*	4.09	+	0	2.53	+	0	3.30	+	+	3.87	+	-
9	*Canthocalanus pauper*	2.92	+	3.57	+	3.06	+	+	5.19	2.02	+	+	-
10	*Eucalanus subcrassus*	2.92	0	+	5.05	+	+	13.19	4.54	+	+	+	-
11	*Oithona simplex*	2.92	5.07	3.21	2.53	17.47	2.38	15.93	0	14.83	10.92	+	-
12	*Macrosetella gracilis*	2.34	3.74	+	+	0	+	+	+	0	2.82	+	-
14	*Acrocalanus gibber*	+	2.64	6.07	2.89	+	4.75	+	+	5.62	9.86	+	-
16	*Oithona oculata*	0	19.82	2.14	+	7.42	4.94	7.14	3.25	3.82	+	+	-
17	*Paracalanus aculeatus*	+	3.08	+	+	5.68	+	2.20	+	+	+	+	-
18	*Paracalanus elegans*	0	2.64	5.71	+	6.33	+	+	+	13.70	+	+	-
19	*Oithona rigida*	0	0	3.57	+	+	4.02	+	+	+	+	+	-
20	*Corycaeus subtilis*	0	+	+	+	+	+	+	2.0	+	+	+	-
21	*Lucicutia gaussae*	0	+	+	+	+	+	3.30	+	+	+	11.53	-
23	*Euchaeta marinella*	0	+	+	2.17	2.18	+	4.40	+	2.92	3.17	+	-
24	*Eucalanus subtenuis*	+	+	+	+	+	+	+	+	+	+	+	-
25	*Temora turbinata*	0	+	+	+	+	+	+	3.25	+	4.93	+	-
26	*Lucicutia flavicornis*	0	0	+	+	+	+	4.95	+	+	+	+	-

- : No sample was taken

Table 2- Results of one-way ANOSIM for testing the difference in copepod communities between different depth layers.

Groups	R statistic	SSignificance (%)
0-10 m, 10-20 m	- 0.259	90
0-10 m, 20-40 m	0.000	50
0-10 m, > 40 m	0.417	30
10-20 m, 20-40 m	0.222	30
10-20 m, > 40 m	0.333	20
20-40 m, > 40 m	- 0.167	70

Bold type indicates separable but overlapping communities.
(Global R = 0.036)

A significant problem is that variations in vertical population structure are probably related to an environmental mosaic that varies on vertical scales smaller than our vertical sampling scales (20-40 m). Although, variations in copepod numbers in the deeper waters must to some extent be related to events in the upper waters, other phenomena, such as the movement of water masses in this region, could also be involved. Except for some northernmost stations that may experience thermal stratification, there are neither temperature nor salinity barriers that could limit the distribution of species at different depth layers. In accordance with near uniformity of temperature and salinity, there was no significant spatial variation in zooplankton biomass between groups of stations in the northern, central and southern parts of the Straits.

The comparison of copepod species in the surface and deeper layers in the northern part of the Straits showed that a considerable number of paracalanid individuals occurred in the surface layers. This uneven species proportion within each depth stratum was probably the main reason for the lower diversity indices in the surface waters. The decrease in diversity index at 10-20 m accompanied by an increase in the copepod abundance, in the central and southern parts of the Straits (Fig. 5) could be attributed to the higher abundance of one or two species such as *P. parvus* and *E. acutifrons* contributing to the overall copepod abundance.

In the northern part, the proportions of copepod species were more evenly distributed in the deeper layers than in the upper ones, thus relatively higher diversity indices in former were found. This is in contrast to the uneven proportion of copepod species in the southern part of the Straits, especially in the deeper layers due to the domination by three species. This study illustrated that there are two characteristic copepod communities in the northern and southern parts of the Straits. The deeper waters of the northern part were characterised by low-abundance, but relatively higher species diversity index, whereas the shallow southern area was characterised by high-abundance, but a low species diversity index.

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