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Spatial and Temporal Distribution of Copepods in the Straits of Malacca

Hamid Rezai[1,*], Fatimah Md. Yusoff[1], Aziz Arshad[1], Akito Kawamura[2], Shuhei Nishida[3], and Othman Bin Hj. Ross[4]

[1]*Department of Biology, Faculty of Science and Environmental Studies, University of Putra Malaysia, 43400 Serdang, Selangor D.E., Malaysia*

[2]*Faculty of Bioresources, Mie University, 1515 Kamihama-cho, Tsu, Mie, 514-8507, Japan*

[3]*Ocean Research Institute, University of Tokyo, 1-15-1 Minamida, Nakano-Ku, Tokyo 164, Japan*

[4]*School of Environmental and Natural Resource Sciences, National University of Malaysia, 43600 Bangi, Selangor D.E., Malaysia*

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Hamid Rezai, Fatimah Md. Yusoff, Aziz Arshad, Akito Kawamura, Shuhei Nishida, and Bin Hj. Ross Othman (2004) Spatial and temporal distribution of copepods in the Straits of Malacca. *Zoological Studies* **43**(2): 486-497. The distribution of planktonic copepods was analyzed from samples collected at 13 to 20 stations during 4 oceanographic cruises along the Straits of Malacca (05°59'N, 99°59'E and 01°10'N, 103°29'E). Samples were taken in vertical hauls using a NORPAC net (140 µm mesh size and 45 cm mouth diameter). Univariate (number of species and diversity indices) as well as multivariate (clustering, ANOSIM, and SIMPER) techniques from the PRIMER software package were employed. In total, 117 copepod species were identified. Of these, 9 species are new records for the Straits of Malacca. Thirteen species accounted for 69.7% of the total copepod abundances on average for all cruises. Two characteristic copepod communities in the northern and southern parts of the Straits were distinguished. The shallow southern part was characterized by high abundance values, a low species diversity index (H' of 2.967), and the dominance of a few coastal species such as *Euterpina acutifrons*, *Oithona simplex*, and *Paracalanus parvus* s.l.. The deeper waters of the northern part were characterized by low abundances, a relatively high species diversity index (H' of 3.632), and the presence of epipelagic species belonging to neritic and near-coastal areas of the oceanic communities. Areas of high abundance were the near-coastal waters of Lumut and Port Klang in the northern and the central parts of the straits, respectively. Mean abundance estimates (2927 ± 1085 individuals/m^3) of copepods showed a maximum peak during the pre-southwest monsoon period. Although ANOVA showed no significant differences in copepod abundances between different parts of the straits and among cruises, ANOSIM applied to the average of all 4 cruises revealed that the communities of the northern and southern parts of the straits spatially differed. http://www.sinica.edu.tw/zool/zoolstud/43.2/486.pdf

Key words: Zooplankton, Malaysia, Tropical copepod, Composition, Diversity.

The Straits of Malacca connect the Indian Ocean to the South China Sea. The shallow waters of the Straits provide almost 70% of the fishing resources for Peninsular Malaysia (Chua et al. 1997). Recently the Straits of Malacca has attracted the interest of marine scientists. Notwithstanding the ecological interest in this basin, the literature on its pelagic biological domain is limited. Investigations of copepods of the Straits of Malacca began with the work of Cleve (1901) and Sewell (1933) who described copepod species. Wickstead (1961), Chong and Chua (1973), and Chua and Chong (1975) studied the general distribution of zooplankton and oithonids in particular. Othman et al. (1990) and Othman and Zuraini (1994) contributed to knowledge of the biogeography and distribution of pontellid copepods.

This study gives a general picture of copepods of the Straits of Malacca based mainly on samples collected during 4 cruises carried out from Nov. 1998 to Aug. 2000. The objectives of

*To whom correspondence and reprint requests should be addressed. Tel: 60-638-948-6101. Fax: 60-638-656-7454 E-mail: rezaihamid@hotmail.com

the present study were to determine the composition and species diversity of copepods along the Straits of Malacca and to examine their spatial and temporal distributions from Langkawi Is. in the north to Johor in the south. This investigation forms part of a multidisciplinary research project on the Straits of Malacca.

MATERIALS AND METHODS

Study area

The Straits of Malacca is situated on the western Malaysian Peninsula (05°59'N, 99°59'E and 01°10'N, 103°29'E) (Fig. 1). It is a relatively shallow sea (with an average depth of 35 m) and is partially landlocked. The water depth at the southern entrance of the Straits is approximately 10 m in most places. The water gradually deepens northward to more than 100 m around the entrance to the Andaman Sea. It is located in the tropical zone and supports relatively abundant demersal and pelagic fish species as well as shrimp (Ooi 1990). The surveyed area receives a strong influence from continental effluents draining from the coast, mainly in the form of runoff from the Klang, Selangor, and Perak Rivers. This causes local variations in salinity and temperature and increases the nutrient input, enhancing the general productivity in the area. There are no well-defined seasons in the Straits. Meteorologically, the year is divided into 2 periods of the northeast monsoon (NE) (Dec. to Feb.) and the southwest (SW) monsoon (June to Aug.) and 2 inter-monsoon periods (pre-NE monsoon, Sept. to Nov.; pre-SW monsoon, Mar. to May). Wind and rain can be very local in this area.

The current systems of the Straits of Malacca are influenced by the monsoons. There is a light upwelling near One-Fathom Bank, in water west of Port Klang (Wyrtki 1961). The dominant direction of the surface currents in the Straits of Malacca is westward from the SE entrance (from the South China Sea) to the narrowest entrance (to the Andaman Sea) in all monsoon periods (Chua et al. 1997). One of the main causes of this is the bottleneck formed during both monsoons across the neck of water at the junction of the South China Sea and the Java Sea (Wickstead 1961).

Water temperatures in the Straits of Malacca are generally constant from the surface to the bottom, except in deep areas in the northern region; this is due to the strong tidal currents that cause complete vertical mixing of the water (Wyrtki 1961). The average ranges of water-column temperature were 27.6 to 28.7, 26.1 to 29.0, 28.0 to 28.5, and 27.9 to 32.7°C during cruises I to IV, respectively. Average salinities ranged from 29.6‰ to 34.0‰, 31.7‰ to 36.3‰, 28.7‰ to

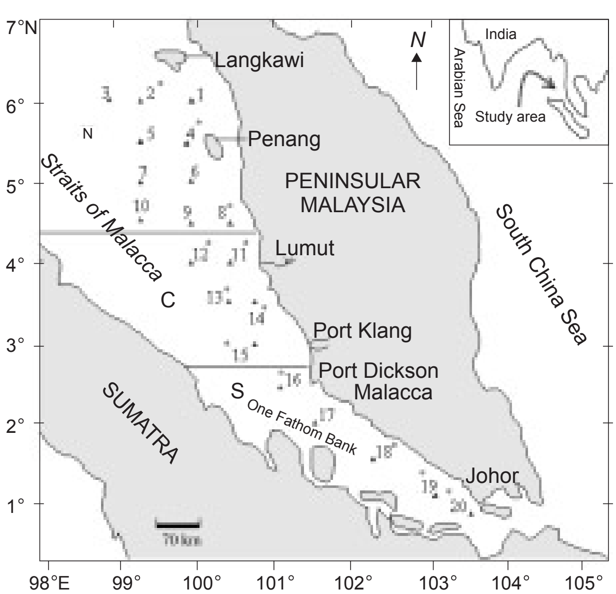

Fig. 1. Location of sampling stations (Δ). Divisions referred to in the text are N, north; C, center and S, south. An asterisk (*) indicates stations that were sampled during all 4 cruises.

Table 1. Sampling stations

Station	Position		Depth of haul (m)
1	06°00.00'N	99°59.79'E	31.0
2	06°00.03'N	99°30.05'E	68.0
3	06°00.09'N	98°59.88'E	96.0
4	05°30.04'N	99°59.98'E	37.0
5	05°30.07'N	99°30.00'E	68.0
6	04°59.97'N	99°58.60'E	59.0
7	05°00.00'N	99°30.00'E	60.0
8	04°30.04'N	100°30.03'E	13.0
9	04°30.13'N	100°00.01'E	60.7
10	04°30.00'N	99°30.00'E	50.0
11	04°00.02'N	100°30.02'E	44.8
12	03°59.98'N	100°00.03'E	76.2
13	03°29.95'N	100°29.95'E	64.5
14	03°29.94'N	101°00.11'E	10.5
15	02°59.94'N	100°59.95'E	15.4
16	02°29.83'N	101°30.10'E	68.0
17	02°10.00'N	102°00.10'E	35.0
18	01°40.66'N	102°38.67'E	50.0
19	01°29.29'N	103°03.63'E	38.0
20	01°15.82'N	103°26.34'E	34.6

32.0‰, and 28.8‰ to 33.2‰ during the same cruises, respectively.

Sampling techniques

Zooplankton sampling and general oceanographic surveys were conducted at 17, 19, 13, and 20 stations during cruises I (23 Nov.~2 Dec.1998), II (20 Mar.~6 Apr. 1999), III (20~29 August 1999), and IV (29 July~8 Aug. 2000) along the Straits of Malacca, respectively (Fig. 1, Table 1). Samples were taken in vertical hauls using a NORPAC net (with a mesh aperture of 140 μm, and a net opening of 0.159 m^2) from near the bottom to the surface at each station. Plankton samples were removed from the nets and immediately fixed in 4%~5% neutral formalin, buffered to a pH of 8 with sodium tetraborate (borax).

Adult copepods were counted after removal of large organisms. Samples were subsampled using a Folsom plankton sample divider, and varied from 1/2 to 1/16 of the total sample. From this, three 10 ml subsamples were obtained using a Stemple pipette. Then, each subsample was transferred into a Bogorov plate, counted, and identified under a dissecting stereoscope. At least 100~150 individuals were counted per sample (Postel et al. 2000).

Data analysis

To simplify data analysis, the straits was divided into 3 parts on the basis of the geography and hydrography of the region (Namba and Yusoff unpubl. data). A mixed-model two-way ANOVA was performed to examine the influence of the random factor (location: northern, central, and southern parts of the Straits) and the fixed factor treatment (cruise) on the univariate measures. Data were transformed using [$\log_{10}$ (x + 1)] to conform to the assumption of ANOVA (Zar 1984). The Bray-Curtis similarity index (Ludwig and Reynolds 1988) was used to cluster stations. Species diversity was calculated using the Shannon-Weaver diversity index (Shannon and Weaver 1963) and Pielou's evenness (Pielou 1969). The regional distribution of planktonic copepods was calculated using SURFER (software vers. 6; Golden Software Inc. 1995).

To compare plankton communities during each cruise, non-metric cluster analysis was used in conjunction with the Bray-Curtis similarity index. Significance levels and sources of differences among copepod assemblages were tested using the analysis of similarity (ANOSIM) and similarity percentage (SIMPER) programs of the Plymouth Routines in Multivariate Ecological Research (PRIMER, Clarke and Warwick 1994) computer package.

RESULTS

Composition and spatiotemporal distribution

In total, 117 copepod species belonging to 37 genera and 25 families were found during the present investigation (Table 2). Among these, 9 species were new records for the Straits. Thirteen species accounted for 69.7% of the total copepod population on average for all cruises. Of the species found, more than 79.0% occurred sporadically or in small numbers (< 1.0%). Five of the families, including the Paracalanidae (27.3%), Oithonidae (26.2%), Euterpinidae (10.5%), Corycaeidae (2.3%), and Oncaeidae (11.7%), comprised 79.1% of the total copepod population on average for all cruises.

The relative abundances of dominant copepod species varied among cruises. However, dominant species always included *Oithona simplex*, *Euterpina acutifrons*, and *Paracalanus parvus* s.l.. As to copepod groups, Calanoida was the most species-rich (76), followed by Poecilostomatoida (27), Cyclopoida (9), and Harpacticoida (6) on average for all cruises.

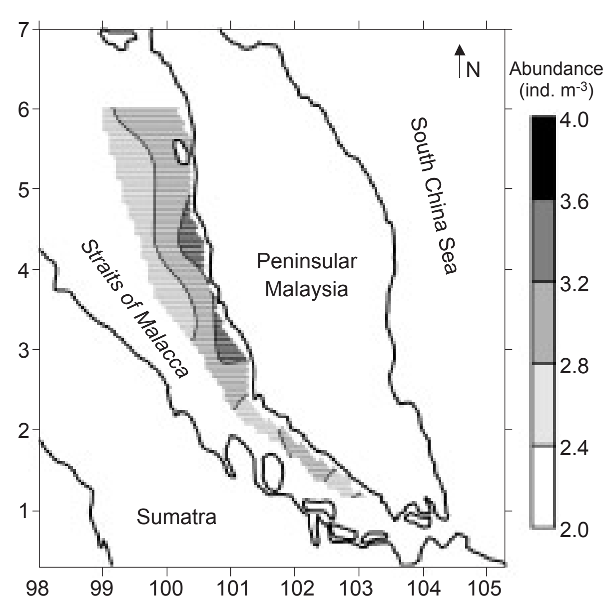

Fig. 2. Distribution of copepods ($\log_{10}$-transformed), averaged for the 4 cruises.

Oithona simplex, representing 13.9% of the total abundance, was the most abundant species. The order of abundance of the next most common species was *Euterpina acutifrons* (at 10.5%), *Paracalanus parvus* s.l. (at 9.1%), *Oncaea media* (at 6.7%), *O. clevei* (at 5.0%), and *Oithona oculata* (at 4.8%). These contributed about 50.0% to the copepod population on average for all cruises.

Individual copepod species did not seem to exhibit consistent seasonal patterns in numerical abundance in similar geographic locations in the northern, central, and southern parts of the straits (Table 3). However, there were differences in numerical abundances among the northern, central, and southern parts of the straits.

The copepod distribution in the straits based on the mean number of specimens collected during the average of all cruises revealed 4 abundance areas (Fig. 2) having mean abundance ratio values of about 11: 3: 2: 1. The areas of high abundances included the near-coastal waters of the northern and central parts of the Straits, near Lumut and northwest of Port Klang, respectively. The lowest-abundance areas included the offshore waters of the northern/central and southern parts of the straits. Mean abundance estimates of copepods reached a maximum value during the pre-SW monsoon period (2927 ± 1085 individuals/m^3); minimum abundances occurred during the NE monsoon (2238 ± 890 ividuals/m^3). However, no marked differences were shown for other monsoon periods ($p > 0.05$). Moreover, no significant differences ($p > 0.05$) were observed in copepod abundances among various geographic locations (Table 4).

Mixed model two-way ANOVA indicated that cruise and geographical location (northern, central, and southern parts of the straits) had significant ($p < 0.05$) effects on the univariate community indices (Table 4), but their interactions (cruise x location) were not significant ($p > 0.05$).

The distribution of copepods varied markedly

Table 2. List of observed copepod species in the Straits of Malacca

CALANOIDA
ACARTIIDAE
1. *Acartia* sp. 1
2. *Acartia* sp. 2
3. *Acartia amboinensis* Carl
4. *Acartia erythraea* Giesbrecht
5. *Acartia pacifica* Steuer
6. *Acartia spinicauda* Mori

PARACALANIDAE
7. **Paracalanus aculeatus* Giesbrecht
8. **Paracalanus denudatus* Sewell
9. **Paracalanus parvus* s.l. (Claus)
10. *Paracalanus* sp.
11. **Parvocalanus crassirostris* Dahl
12. **Parvocalanus elegans* Andronov
13. **Acrocalanus gibber* Giesbrecht
14. *Acrocalanus gracilis* Giesbrecht
15. *Acrocalanus longicornis* Giesbrecht
16. *Acrocalanus monachus* Giesbrecht
17. **Bestiolina similis* (Sewell)
18. *Delius nudus* (Sewell)

CENTROPAGIDAE
19. *Centropages dorsispinatus* Thompson and Scott
20. *Centropages furcatus* (Dana)
21. *Centropages orsinii* Giesbrecht
22. *Centropages* sp.
23. *Centropages tenuiremis* Thompson and Scott

CLAUSOCALANIDAE
24. *Clausocalanus arcuicornis* (Dana)
25. *Clausocalanus furcatus* (Brady)
26. *Clausocalanus jobei* Frost and Fleminger√
27. *Clausocalanus pergens* Farran√

PONTELLIDAE
28. *Labidocera minuta* Giesbrecht
29. *Labidocera acuta* (Dana)
30. *Labidocera bengalensis* Krishnaswamy
31. *Labidocera rotunda* Mori√
32. *Labidocera euchaeta* Giesbrecht√
33. *Labidocera pectinata* Thompson and Scott
34. *Labidocera kroyeri* (Brady)
35. *Labidocera* sp. 1
36. *Labidocera* sp. 2
37. *Pontella* sp. 1
38. *Pontella* sp. 2
39. *Pontella* sp. 3
40. *Pontellina plumata* Dana
41. Unidentified Pontellidae
42. *Calanopia elliptica* Dana
43. *Calanopia* sp.
44. *Calanopia minor* Scott
45. *Calanopia thompsoni* A.Scott

EUCALANIDAE
46. *Eucalanus pileatus* (Giesbrecht)
47. *Eucalanus attenuatus* (Dana)
48. *Eucalanus subtenuis* Giesbrecht
49. *Eucalanus crassus* Giesbrecht
50. *Eucalanus* sp.

Table 2. (Cont.)

51. *Eucalanus subcrassus* Giesbrecht

EUCHAETIDAE
52. *Euchaeta concinna* (Dana)
53. *Euchaeta marinella* Bradford

LUCICUTIIDAE
54. *Lucicutia gaussae* Grice
55. *Lucicutia flavicornis* (Claus)

ARIETELLIDAE
56. *Metacalanus* sp.[√]

PSEUDODIAPTOMIDAE
57. *Pseudodiaptomus aurivilli* Cleve
58. *Pseudodiaptomus* sp.

SCOLECITHRICIDAE
59. *Scolecithricella* sp.
60. Unidentified Scolecithricidae

TEMORIDAE
61. *Temora discaudata* Giesbrecht
62. *Temora stylifera* (Dana)
63. *Temora turbinata* (Dana)

CALOCALANIDAE
64. *Calocalanus styliformis* Giesbrecht
65. *Calocalanus pavo* (Dana)
66. *Calocalanus* sp.

CANDACIIDAE
67. *Candacia bradyi* Scott
68. *Candacia curta* (Dana)
69. *Candacia discaudata* Scott
70. *Candacia ethiopica* (Dana)
71. *Candacia pachydactyla* (Dana)

CALANIDAE
72. *Canthocalanus pauper* Giesbrecht
73. *Nannocalanus minor* (Claus)
74. *Undinula vulgaris* (Dana)

TORTANIADAE
75. *Tortanus forcipatus* (Giesbrecht)
76. *Tortanus gracilis* Brady

CYCLOPOIDA
OITHONIDAE
77. *Oithona attenuata* Farran
78. *Oithona brevicornis* Giesbrecht
79. *Oithona nana* “Plumosa form” Giesbrecht
80. *Oithona oculata* Farran
81. *Oithona plumifera* Baird
82. *Oithona rigida* Giesbrecht
83. *Oithona similis* Claus
84. *Oithona simplex* Farran
85. *Oithona* sp.

POECILOSTOMATOIDA
CORYCAEIDAE
86. *Corycaeus affinis* McMurrich
87. *Corycaeus agilis* Dana
88. *Corycaeus andrewsi* Farran
89. *Corycaeus asiaticus* F. Dahl
90. *Corycaeus catus* F. Dahl
91. *Corycaeus dahli* Tanaka
92. *Corycaeus dubius* Farran
93. *Corycaeus erythraeus* Cleve
94. *Corycaeus lautus* Dana
95. *Corycaeus limbatus* Brady
96. *Corycaeus pacificus* F. Dahl
97. *Corycaeus speciosus* Dana
98. *Corycaeus subtilis* M. Dahl
99. *Farranula* (*Corycaeus*) *rostratus* (Claus)
100. *Farranula gibbula* (Giesbrecht)

ONCAEIDAE
101. *Oncaea clevei* Früchtl
102. *Oncaea media* Giesbrecht
103. *Oncaea paraclevei* sp. nov.[√]
104. *Oncaea scottodicarloi* Heron & Bradford-Grieve[√]
105. *Oncaea venusta* f. *typica* Philippi

SAPPHIRINIDAE
106. *Copilia mirabilis* Dana
107. *Copilia quadrata* Dana
108. *Sapphirina metallina* Dana
109. *Sapphirina angusta* Dana
110. *Sapphirina gastrica* Giesbrecht

MACROCHIRONIDAE
111. *Pseudomacrochiron* sp.[√]

HARPACTICOIDA
CLYTEMNESTRIDAE
112. *Clytemnestra scutellata* Dana

EUTERPINIDAE
113. *Euterpina acutifrons* (Dana)

ECTINOSOMATIDAE
114. *Microsetella norvegica* Dana
115. *Microsetella rosea* (Dana)

MIRACIIDAE
116. *Distioculus minor* (Scott)[√]
117. *Macrosetella gracilis* Dana

[√] New records for the study area.
* One of the 20 most abundant species in the entire collection.

throughout the sampling periods according to 2 distinct spatiotemporal patterns. First, the near-coastal area showed high abundances in the vicinity of Lumut, Port Klang, and the Penang area during cruises I and II (Fig. 3). Second, during cruise III, 2 high-abundance areas were apparent in the central and northern parts (Fig. 3); for the rest of the survey (cruise IV), copepods presented an increased distribution range from the northern to the central part, then another increase at the southern end (Fig. 3) of the straits.

Community structure and differences

Distinct variations in the number of copepod species were observed, both geographically along the north-south axis, and seasonally. The number of species (Table 5) and proportion of different species fluctuated from cruise to cruise and depended on their locations in the northern, cen-

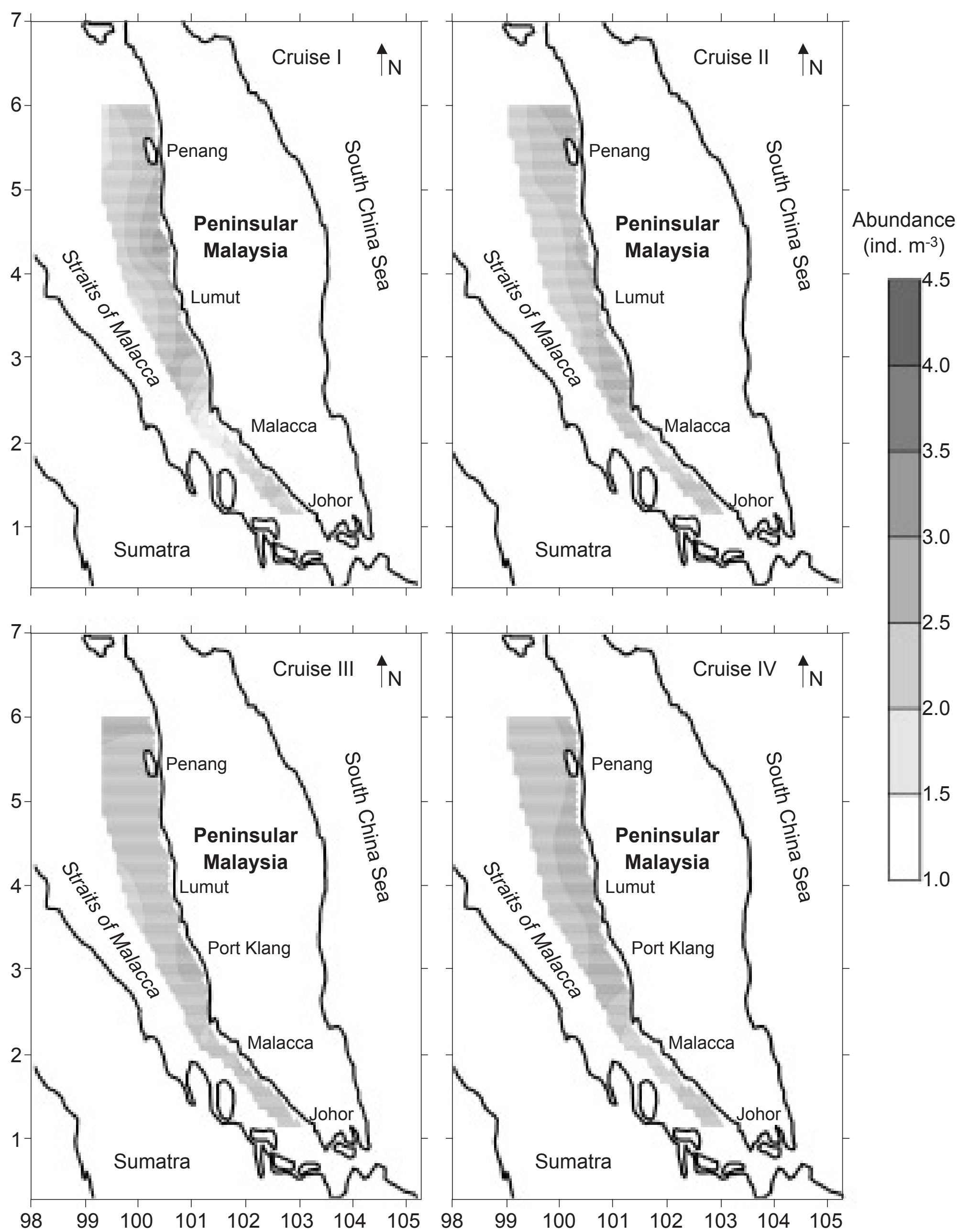

Fig. 3. Distribution (log_{10}-transformed density) of copepods during the 4 cruises.

Table 3. Seasonal and regional abundance (individuals/m^3) of numerically important species (> 2.0% of the population) in the Straits of Malacca. (N, north; C, center; S, south)

	Species	Cruise I (Nov.~Dec. 1998)			Cruise II (Mar.~Apr. 1999)			Cruise III (Aug. 1999)			Cruise IV (July~Aug. 2000)			Total
		N	C	S	N	C	S	N	C	S	N	C	S	(%)
1	*Oithona simplex*	578	644	101	59	425	764	63	379	1095	110	592	144	13.9
2	*Oithona oculata*	354	178	32	27	+	530	38	263	51	+	174	40	4.8
3	*Parvocalanus crassirostris*	259	338	+	+	+	89	+	0	+	0	62	+	2.5
4	*Euterpina acutifrons*	212	659	61	87	728	468	221	244	56	172	838	59	10.5
5	*Parvocalanus elegans*	199	177	11	69	252	253	84	156	91	+	+	19	2.7
6	*Paracalanus parvus* s.l.	194	231	125	69	192	241	197	300	610	162	716	131	9.0
7	*Metacalanus* sp.	93	15	+	+	0	+	+	+	+	+	+	+	0.5
8	*Bestiolina similis*	75	43	+	28	115	504	46	24	27	+	+	+	2.2
9	*Pseudodiaptomus* sp.	63	+	+	0	45	0	0	0	0	0	0	0	0.3
10	*Oncaea media*	60	+	0	57	50	1111	600	72	+	283	106	0	6.7
11	*Paracalanus aculeatus*	58	118	28	38	89	+	32	100	+	30	+	19	1.9
12	*Oithona similis*	+	+	+	+	0	+	+	+	+	+	300	54	1.6
13	*Oncaea clevei*	+	+	0	39	+	790	551	+	0	176	138	+	5.0
14	*Macrosetella gracilis*	+	+	+	50	+	+	67	+	+	124	57	+	1.8
15	*Oithona plumifera*	+	+	+	46	+	+	65	54	+	145	83	+	2.2
16	*Microsetella norvegica*	+	+	0	40	+	+	+	+	0	63	+	+	1.2
17	*Acrocalanus gibber*	32	74	44	65	107	312	28	25	+	81	196	72	3.1
18	*Canthocalanus pauper*	+	+	23	25	+	90	42	57	97	68	55	19	1.7
19	*Eucalanus subcrassus*	+	+	16	55	+	+	+	+	+	+	+	+	1.1
20	*Corycaeus andrewsi*	+	32	68	33	+	198	36	35	56	85	71	112	2.3
21	*Oithona nana*	+	31	+	+	+	70	57	160	109	+	90	39	1.6
22	*Paracalanus denudatus*	+	103	5	134	306	506		69	121	+	+	61	3.9
23	*Oithona rigida*	+	50	+	+	+	200	79	+	+	+	+	19	1.0
24	*Acartia pacifica*	+	+	+	+	+	+	61	+	+	+	+	+	0.6
25	*Acrocalanus gracilis*	+	0	+	26	38	74	+	+	+	39	67	16	1.1
26	*Acartia erythraea*	+	+	+	+	73	+	85	+	+	+	+	+	1.1
27	*Tortanus forcipatus*	+	+	+	+	127	+	+	+	+	+	+	+	0.9
28	*Oithona attenuata*	+	+	+	+	+	93	52	77	+	34	92	33	1.2
29	*Paracalanus* sp.	0	0	0	+	+	0	0	80	0	0	0	0	0.2
30	*Oithona brevicornis*	+	+	+	+	+	+	+	+	+	+	100	+	0.7
31	*Eucalanus crassus*	+	+	+	+	+	+	+	+	+	+	113	+	0.6

\+ Species comprising less than 2% of the population during each cruise.

tral, and southern part of the straits.

The Shannon-Weaver species diversity index was generally low during the NE monsoon (cruise I) and high during the SW monsoon (cruise IV) (Table 5). At the same time, an increase in abundance towards the coast occurred. The number of species and the evenness values were generally high (Table 5). Regardless of the cruise, evenness was inversely related to the abundance of the copepod population. It was generally low during the NE monsoon (cruise I), and somewhat higher values were recorded during the pre-SW monsoon and SW monsoon periods. The species diversity index and number of species on average for all cruises were higher at stations located in the northern part than in the southern part of the straits (Table 6).

The dendrogram resulting from the cluster analysis of the average of the 4 cruises (Fig. 4) shows the similarity of the stations based on the abundance and species composition. The presence of 2 major groups of stations (clusters) was apparent: group "A" comprising near-coastal stations (8, 14, 15, and 20) with high abundances, and group "B" which included the 2 subclusters of B_1 comprising stations in the south with moderate abundances, and B_2 including stations in the north and central part of the straits with relatively low abundances. Sensitivity of the cluster analysis when tested and applied to those species with relative abundances of more than 1% (thus excluding rare species) gave similar clusters, although there were minor changes in ordination of stations within the same clusters.

The results of one-way analysis of similarity (ANOSIM) performed on each cruise showed that except for cruise IV, there were no significant differences among communities of the northern, central, and southern parts of the straits during other cruises. During cruise IV, there was a significant difference (R = 0.92, p < 0.01) between copepod

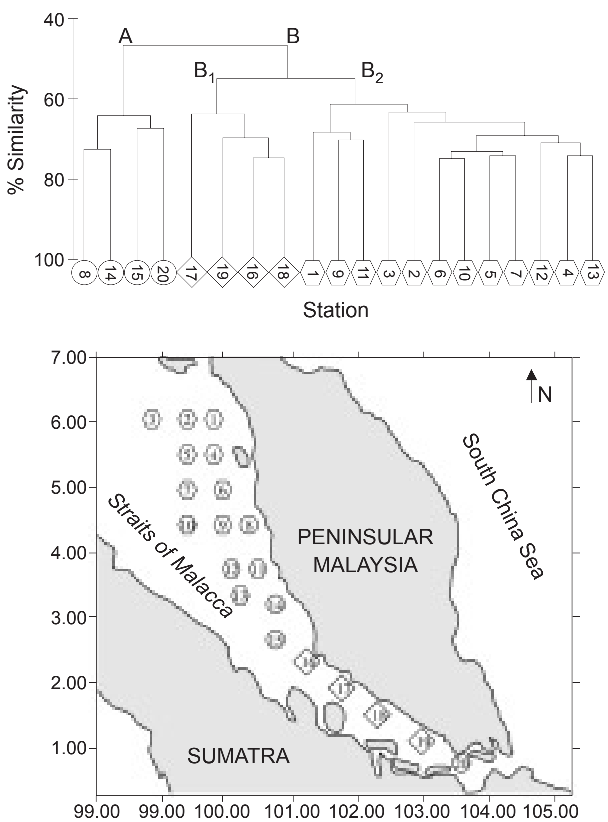

Fig. 4. Dendrogram of group classification by stations for the average of 4 cruises in the Straits of Malacca. A, stations with high abundances, and B, stations with low (B_1) or moderate abundances (B_2).

Table 4. Results of two-way ANOVA based on abundances of adult copepods, copepod orders, species richness, and diversity index (Shannon-Weaver). The random factor is location (northern, central, and southern parts of the Straits of Malacca), while the fixed factor is the cruise (I, II, III, and IV) (n = 69)

Univariate measure	Source of variation	F-ratio	p
Copepods	Location	1.286	0.361
	Cruise	1.201	0.308
	Location x cruise	1.952	0.087
Species richness	Location	13.535	0.000*
	Cruise	4.838	0.048*
	Location x cruise	0.560	0.759
Diversity	Location	24.961	0.000*
	Cruise	5.376	0.038*
	Location x cruise	0.784	0.585

* Significant at the 0.05 level.

Table 5. Characterization of the copepod community for different cruises

Cruise (no. of stations)	Mean abundance ± SE (individuals/m^3)	No. of species	Evenness (J')	Diversity index (H')
I (n = 17)	2238 ± 890	88	0.665	2.978
II (n = 19)	2927 ± 1085	99	0.710	3.263
III (n = 13)	2612 ± 650	75	0.691	2.983
IV (n = 20)	2597 ± 583	97	0.757	3.464

SE, standard error.

communities in the northern and southern parts of the straits on one hand, and between the 2 communities of the central and southern parts (R = 0.60, $p < 0.01$) on the other (Table 7). This shows that the communities in the northern and southern parts were distinct, and thus well separated (R > 0.75), while those from the central and the southern parts overlapped but differed (R > 0.50). That is to say that the most similar communities were the northern-central groups with an average dissimilarity value of 44.1%, whereas the most dissimilar groups were the northern and southern ones with an average dissimilarity of 52.7%.

A similar analysis for the average of all 4 cruises (Table 7) showed that unlike cruise IV, only the communities of the northern and southern parts of the straits differed (R = 0.63, $p < 0.01$). These groups did not appear to be well defined since the separation between them was not very high (38.7%). On the other hand, communities of the central and southern parts (R = 0.17, $p > 0.05$), and the northern and central parts (R = 0.17, $p > 0.05$) were barely separable at all.

Similarity analyses based on community estimates for cruises I, II, and III were redundant, as there were no community differences among the northern, central, and southern parts of the straits during those cruises. However, similarity analyses during cruise IV identified the following discriminator species which primarily accounted for the assemblage difference between the northern and southern parts of the Straits. These were *Oncaea media*, *O. clevei*, *Macrosetella gracilis*, *Oithona plumifera*, *Centropages furcatus*, *Lucicutia flavicornis*, *Parvocalanus crassirostris*, and *P. elegans*; while for the assemblage difference between the central and the southern part, the following species were distinguished: *Macrosetella gracilis*, *O. media*, and *Microsetella norvegica*.

In addition, for the average of all 4 cruises, SIMPER identified the following major species which accounted for assemblage differences between the northern and southern parts of the straits: *Lucicutia flavicornis*, *O. venusta*, *Temora turbinata*, *Oithona plumifera*, *Clausocalanus arcuicornis*, *Corycaeus erythraeus*, *T. stylifera*, *T. discaudata*, and *Macrosetella gracilis* (Table 8).

DISCUSSION

The distribution of copepods in the Straits of Malacca reflects the dual structure of this basin. The deep northern part showed a notable species diversity index (H' of 3.632) and the presence of

Table 6. Characterization of the copepod community on average for all 4 cruises in different parts of the Straits of Malacca

Station	No. of species	Evenness (J')	Diversity index (H')
North (stns. 1~3, 5~7, 8~10)	112	0.768	3.632
Center (stns. 11~15)	97	0.693	3.172
South (stns. 16~20)	80	0.677	2.967

Table 7. Summary of results of one-way ANOSIM. Values of the ANOSIM statistic (R) are given for the global test of differences between groups (in the northern, central, and southern parts) in each matrix during the 4 cruises in the Straits of Malacca

	Cruise I		Cruise II		Cruise III		Cruise IV		Average of the 4 cruises	
	(global R = 0.216)		(global R = 0.243)		(global R = 0.143)		(global R = 0.647)		(global R = 0.376)	
Groups	*R*	*p* (%)	*R*	*p* (%)	*R*	*p* (%)	*R*	*p* (%)	*R*	*p* (%)
N, C	0.05	27.3	0.08	24.2	-0.17	78.6	0.37	1.2	0.17	9.6
N, S	0.33	1.4	0.44	0.3	0.48	3.6	**0.92**	0.1	**0.63**	0.1
C, S	0.24	4.0	0.08	23.0	0.10	20.6	**0.60**	0.8	0.19	11.1

Bold face type indicates separable communities. N, north; C, center; S: south.
The pairwise R value gives an absolute measure of how separated the groups are R > 0.75, groups well separated; 0.75 > R > 0.5, groups overlapping but clearly different; 0.5 > R > 0.25, groups barely separable at all.

neritic and near-coastal species that comprise relatively uniform but quantitatively poor populations. The shallow southern part was characterized by a low species diversity index (H' of 2.967), high-abundance values, and the dominance of a limited number of species comprising the near-coastal community.

The total number of copepod species identified in this study was higher than those previously reported from the same area (Wickstead 1961, Chua and Chong 1975, Othman et al. 1986 1990); at least 9 new records for the region were found. This can be partially attributed to the sampling gear, as well as the sampling design employed in the present survey.

Table 8. Major species, ranked in order of importance, contributing to the average dissimilarities between samples from the northern and southern parts of the Straits of Malacca on average for all 4 cruises, as determined by SIMPER analyses based on 4th-root-transformed estimates and the Bray-Curtis measure of similarity

Groups North and South Species	Group N Mean abundance (individuals/m^3)	Group S Mean abundance (individuals/m^3)	Dissimilarity /SD	Contribution (%)
Oncaea media	178	224	1.5	2.2
Lucicitia flavicornis	13	0	4.6*	2.1
Oithona simplex	167	488	1.5	2.0
Oncaea venusta	16	0	2.2*	2.0
Oncaea clevei	130	159	1.4	1.9
Temora turbinata	14	0	2.4*	1.7
Oithona plumifera	81	4	2.7*	1.7
Centropages furcatus	18	6	1.9	1.7
Paracalanus denudatus	48	149	1.6	1.6
Farranula rostrata	11	0	1.4	1.6
Clausocalanus arcuicornis	12	0	2.0*	1.5
Oithona oculata	82	137	1.6	1.5
Farranula gibbulus	6	0.0	1.8	1.5
Acartia spinicauda	1	14	1.5	1.5
Corycaeus erythraeus	19	1	2.0*	1.5
Temora stylifera	7	0	2.1*	1.5
Microsetella norvegica	42	5	1.8	1.4
Temora discudata	4	0	2.9*	1.4
Corycaeus dahli	6	0	1.8	1.4
Lucicutia gaussae	16	0	1.2	1.4
Paracalanus parvus s.l.	122	265	1.4	1.3
Oithona similis	23	20	1.3	1.3
Macrosetella gracilis	73	9	2.1*	1.3
Average percentage dissimilarity			38.7%	

SD, standard deviation; * species which appeared as excellent discriminators between groups; N, north; C, center; S, south.

Our results on copepod abundances are in close agreement with those reported by Chong and Chua (1973) in that adults and young of the family Oithonidae were numerically the largest single family among the total zooplankton. Indeed, the family Oithonidae and in particular *Oithona simplex* constituted around 27.0% and 13.9%, respectively, of the total copepod abundance.

The high zooplankton abundances observed at stns. 14 and 15 may be attributed to the enrichment of the water caused by heavy rainfall, river runoff, and a relatively higher level of ammonium near Klang, Selangor, Penang, and Langkawi, especially during the SW monsoon (Law et al. 2001) and NE monsoon. It seems that the combination of several factors including river runoff, rain, distance from the shore, and sediment discharge (land drainage) might be responsible for the apparent increase in zooplankton abundances in these areas through enrichment of the coastal waters with nutrients. The high-abundance data as observed at stn. 8 could not be attributed to the runoff from the Perak River alone, but may also have been due to the presence of mangrove forests in the vicinity of Lumut, which undoubtedly increases the zooplankton population in the area.

Furthermore, the local upwelling at One-Fathom Bank, which affects the general circulation of the area as well as bringing up nutrients to the surface, has been largely ignored. Last is the effect of the seabed topography of the straits which shows a sharp rise, particularly in the Klang and Penang areas (Nasir 2001), and which affects mixing of the water mass with deeper waters rich in nutrients combining with surface waters.

The higher numbers of species and values of diversity indices in the central and northern parts of the straits compared with the southern part may be attributed to several factors. First, there is intrusion of more-oceanic species from the Andaman Sea into the straits, thus increasing the number of species in the northern part. Next, deeper water in the northern part of the straits contains a much-higher volume of water than the southern part, thus providing more-diverse habitats and space for occupation by copepods (and other planktonic organisms). Third, the land-locked feature of the straits in the south limits the arrival of species from the South China Sea which enter with more-saline water thus creating intense advection in the south, and this creates less-stable conditions for the organisms that thrive there. Additionally, in this region considerable year-to-year variations in runoff occur. Such variations influence local salinities and, potentially, species composition. However, the reduction in number of species found during cruise III (Table 5) might have been due to lower coverage of the area by that cruise compared with other cruises than to a year-to-year variation in runoff.

Results of multivariate analyses painted a very different picture from those derived from analyses based on univariate community measures. The clear-cut separation of communities between the northern and southern parts of the straits was evident by the cluster analysis, implying that there were in fact differences in copepod assemblages found between these geographic locations. The nature of the distributions of genera/species as reflected in clusters (Fig. 4) clearly showed a high degree of correlations among stations with considerable homogeneity in copepod composition in the area investigated. Most of the frequently occurring species did not show significantly higher abundances on any particular cruise. Oceanic species occurred in very low numbers and did not appear to influence the linkage.

The results of ANOSIM tests on copepod communities applied to the average of all cruises confirmed that the straits can be divided into 2 zones (northern and southern parts). The separation of copepod communities in the northern and southern parts of the straits was in close agreement with hydrographical data provided by Liong (1973) who show the presence of 2 water bodies north and south of One-Fathom Bank. Law (1994) also distinguished 2 water bodies: a shallow-water portion and a deep-water portion in the straits. Although *Labidocera kroyeri* is a good water-mass indicator and important to understanding current systems, its role was not investigated in the present survey.

The present results emphasize the view that progress in understanding the ecological systems of the Straits of Malacca requires recognition and elucidation of the ecological diversity of its subregions. Additional sampling is required to assess the potential effects of small-scale and seasonal variabilities on the present results.

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