Malaysian Journal of Science **27** (3): 83 - 103 (2008)

Zooplankton of the Straits of Malacca, with Emphasis on Copepods and Fish Larvae in the Vicinities of Jarak, Perak and Sembilan Islands

Chew L.L., Chong V.C.* and Ooi A.L.

Institute of Biological Sciences/ Institute of Ocean & Earth Sciences,
University of Malaya, Kuala Lumpur, Malaysia
* chong@um.edu.my (corresponding author)

ABSTRACT Zooplankton diversity and abundance of the Malacca Straits' waters were assessed in the SESMA I and II research cruises from 4-9 June 2004 and 23-28 November 2007 respectively. In SESMA I, samplings of zooplankton in the waters of Pulau (=island) Jarak, Pulau Sembilan and Pulau Perak, were carried out by oblique tows using 45-cm diameter bongo nets of 180 µm and 363 µm mesh size. From the bongo net catches, the estimated mean wet biomass (± SD, g m^{-3}) of zooplankton at Pulau Jarak, Pulau Sembilan and Pulau Perak were respectively 0.49 ± 0.22, 0.45 ± 0.10 and 0.16 ± 0.10 for the fine net, and 0.14 ± 0.04, 0.14 ± 0.10 and 0.10 ± 0.01 for the coarse net. For the same sites, the mean total zooplankton density (indiv. m^{-3}), as estimated by the fine net, was 2 990 ± 1191, 14 242 ± 3441 and 1722 ± 460, respectively. For fish larvae, the mean density (indiv. 100 m^{-3}) at these sites were 31.7 ± 6.7, 22.9 ± 16.5 and 26.3 ± 2.9, respectively. The main taxa of zooplankton were Copepoda, Urochordata, Ostracoda, Polychaeta and Mollusca. Copepods were represented by 71 identified species from 24 families, which were dominated by the Paracalanidae, Oithonidae, Oncaeidae, Corycaeidae and Euterpinidae. Fish larvae were represented by 24 identified families, the most abundant were from the Carangidae, Engraulidae, Gobiidae and Siganidae. However, the waters around the islands were not as rich in fish larvae (23 – 32 indiv. 100 m^{-3}) as compared to the more open waters in the straits, where along a transect from Pulau Pangkor to Pulau Perak, the fish larval abundance sampled ranged from 38 – 274 indiv. 100 m^{-3}. The light traps deployed in Pulau Jarak and Pulau Sembilan waters during SESMA II were not effective in sampling zooplankton due to swift water conditions during the study period. In Pulau Jarak waters, the main zooplankton attracted to the light traps were copepods (46.9%), followed by isopods (12%), *Lucifer* (9.7%), *Oikopleura* (6.6%), fish larvae (2.3%) and other crustaceans (15.1%). In Pulau Sembilan waters, *Acetes* (54.2%) dominated, followed by copepods (20.8%), ostracods (5.5%) and other crustaceans (13%).

ABSTRAK Taburan diversiti dan kelimpahan zooplankton di perairan Selat Melaka dikaji dalam penyelidikan perlayaran SESMA I dan II dari 4-9 Jun 2004 dan 23-28 November 2007 masing-masing. Dalam SESMA I, persampelan zooplankton di perairan Pulau Jarak, Pulau Sembilan dan Pulau Perak dilakukan secara serong dengan menggunakan sebuah pukat bongo yang bermulut 45 cm diameter, dengan mata jaring yang bersaiz 180 µm dan 363 µm. Dari tangkapan pukat bongo, anggaran min biomass basah (± SD, g m^{-3}) zooplankton di Pulau Jarak, Pulau Sembilan dan Pulau Perak adalah masing-masing 0.49 ± 0.22, 0.45 ± 0.10 dan 0.16 ± 0.10 bagi pukat halus, dan 0.14 ± 0.04, 0.14 ± 0.10 dan 0.10 ± 0.01 bagi pukat kasar. Bagi tempat yang sama, purata densiti jumlah zooplankton (indiv. m^{-3}) adalah 2 990 ± 1191, 14 242 ± 3441 dan 1722 ± 460 masing-masing. Purata densiti larva ikan adalah masing-masing 31.7 ± 6.7, 22.9 ± 16.5 dan 26.3 ± 2.9 bagi tempat tersebut. Taxa zooplankton yang utama adalah Copepoda, Urochordata, Ostracoda, Polychaeta dan Mollusca. Copepoda diwakili oleh 71 spesies dari 42 famili, yang didominasi oleh Paracalanidae, Oithonidae, Oncaeidae, Corycaeidae dan Euterpinidae. Larva ikan diwakili oleh 24 famili, dengan kelimpahan tertinggi daripada Carangidae, Engraulidae, Gobiidae dan Siganidae. Kelimpahan larva ikan di perairan pulau-pulau adalah lebih rendah (23 – 32 indiv. 100 m^{-3}) jika dibandingkan dengan perairan terbuka sepanjang transek daripada Lumut ke Pulau Perak (38 – 274 indiv. 100 m^{-3}). Perangkap cahaya yang digunakan di perairan Pulau Jarak dan Pulau Sembilan semasa SESMA II adalah tidak efektif bagi penyampelan zooplankton disebabkan oleh keadaan arus yang deras semasa pensampelan. Di perairan Pulau Jarak, zooplankton utama yang tertarik kepada perangkap cahaya adalah kopepod (46.9%), diikuti

oleh isopod (12%), *Lucifer* (9.7%), *Oikopleura* (6.6%), ikan larva (2.3%) dan krustasea lain (15.1%). Di perairan Pulau Sembilan, *Acetes* (54.2%) mendominasi, diikuti oleh kopepod (20.8%), ostrakod (5.5%) and krustasea lain (13%).

(zooplankton, copepod, fish larvae, Straits of Malacca)

INTRODUCTION

There are few studies on open-water zooplankton of the Malacca Straits. The handful that are known include those beginning in the early 90s, such as Cleve [1], followed by Sewell [2], Wickstead [3], Chong and Chua [4], Chua and Chong [5] and by more recent ones like Johan et al. [6], Rezai et al. [7], Rezai et al. [8] and Yoshida et al. [9]. All of these studies formed part of the organized oceanographic cruises conducted at that time, and serve to highlight the point that open ocean studies in Malaysia are scarce due to the lack of sea-worthy and well-equipped research vessels. However, such studies are gaining more attention now, not only for the rich treasure of scientific knowledge, but also in light of recent development and national concern such as the country's Exclusive Economic Zone (EEZ) jurisdiction and resources, El Nino-Southern Oscillation (ENSO) and other climate change events, marine food security, trans-boundary migratory fish stocks and bio-prospecting potential.

The study of zooplankton in particular has important applications in fisheries ecology since they are important components of marine food chains [10, 11, 12, 13, 14]. The larvae of many economically-important marine fish and invertebrate species constitute part of the zooplankton [15, 16]. Open-water zooplankton are not only the favored food of adult oceanic species such as sardines, mackerels and baleen whales, but are also food for the larvae of many coastal and neritic species that spawn in off shore waters, e.g. anchovies, snappers, carangids and penaeid shrimps [14, 17, 18].

This study forms part of the first and second Scientific Expeditions to the Seas of Malaysia (SESMA I and SESMA II) to (the islands of) Pulau Jarak, Pulau Sembilan and Pulau Perak, held from 4-9

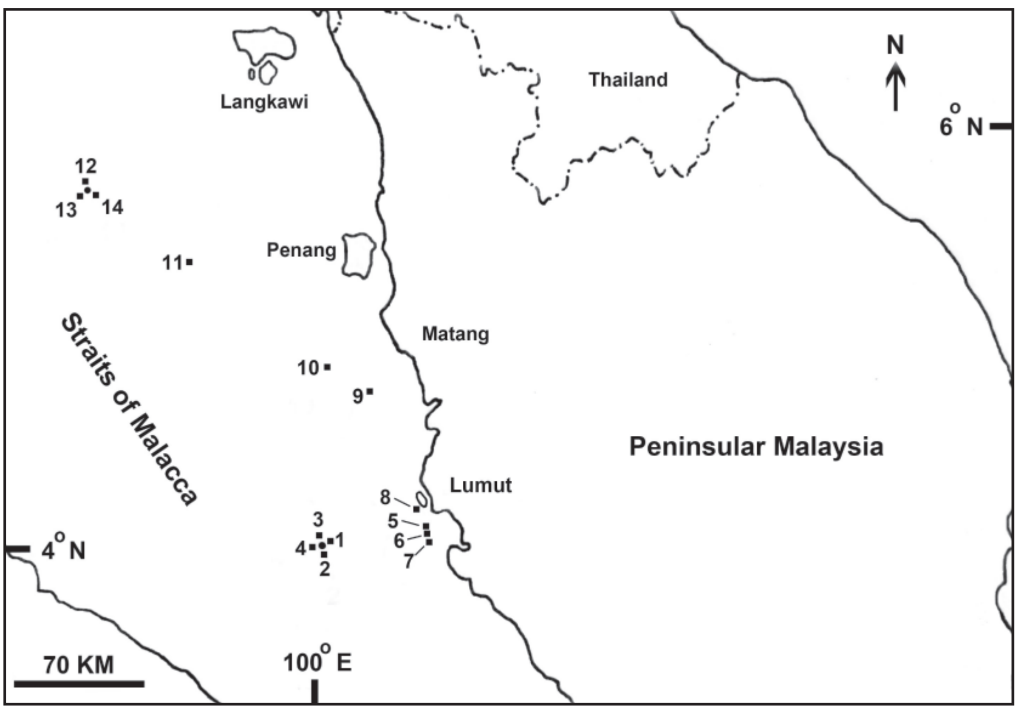


Figure 1. Map showing sampling stations during SESMA cruise, Straits of Malacca, from 4-9 June 2004. Sampling stations, 1-4 at Pulau Jarak, 5-6 at Pulau Sembilan, and 12-14 at Pulau Perak, are exploded to show their relative positions.

June 2004 and 23-28 November 2007 respectively. The expedition studies had the objective of determining the species composition and abundance of zooplankton, particularly the copepods and fish larvae around these islands.

MATERIALS AND METHODS

SESMA research cruises

The first SESMA ocean research cruise by MV Reef Challenger was carried out from 5-9 June 2004 (SESMA I). The research cruise included the following stop-overs: Port Klang – Pulau Jarak – Pulau Sembilan – Pulau Pangkor – Pulau Perak – Pulau Pangkor – Port Klang (Figure 1). Plankton samplings were carried out at Pulau Jarak (Stations 1-4), Pulau Sembilan (Stations 5-7), along an inshore-offshore transect that included four stations from Pulau Pangkor towards Pulau Perak (Stations 8-11), and at Pulau Perak (Stations 12-14). Except the last transect station which was sampled during night time, all others were sampled during day (Table 1). The second SESMA cruise (SESMA II) was conducted by the Kaleepso in waters around Pulau Jarak and Pulau Sembilan from 23-28 November 2007. Only night samplings were carried out.

Field method

Plankton samplings during SESMA I were carried out using MARMAP Bongo Nets of 45-cm mouth diameter, and twin nets of 180 µm and 363 µm mesh sizes. Triplicate oblique tows to a depth of 30 m were carried out around the station, except in Pulau Jarak where 4 oblique tows were taken. Each net was fitted with a calibrated flowmeter to estimate the amount of water filtered; tow duration varied between 3 – 6 minutes each, with filtration volumes that ranged between 13 to 50 m^3 (Table 1). Collected plankton samples were immediately preserved in 10% buffered formaldehyde until laboratory analysis.

Table 1. Location, towing time and filtration volume of zooplankton tows in SESMA 1 cruise, Straits of Malacca, 5-9 June 2004

Location	Date	Station	Position	Time	Mesh size (mm)	Towing Time	Volume (m^3) filtered
Pulau Jarak	5-Jun-04	1	3° 58’ 26.6”	3:00 pm	363	4’ 30”	32.2
			100° 06’ 39.1”		180		30.8
		2	3° 58’ 10.7”	3.30 pm	363	3’ 28”	33.1
			100° 06’ 21.6”		180		25.5
	6-Jun-04	3	3° 58’ 57.8”	1.25 pm	363	4’ 15”	50.0
			100° 05’ 44.6”		180		45.6
		4	3° 58’ 58.5”		363	5’ 39”	37.3
			100° 05’ 33.8”		180		25.3
Pulau Sembilan	7-Jun-04	5	4° 01’ 19.4”	9.55 am	363	3’ 02”	33.4
			100° 33’ 14.8”		180		36.6
		6	4° 01’ 16.2”	10.08 am	363	3’ 09”	20.0
			100° 33’ 16.7”		180		23.5
		7	4° 01’ 11.1”	10.20 am	363	3’ 27”	25.4
			100° 33’ 24.3”		180		29.6
Straits of Malacca Transect (P. Pangkor to P. Perak)	8-Jun-04	8	4° 08’ 27.8”	7.45 am	363	4’ 09”	34.3
			100° 36’ 8.8”		180		34.2
		9	4° 39’ 37.4”	12.36 pm	363	4’ 23”	15.4
			100° 14’ 28”		180		33.7
		10	4° 48’ 19.15”	3.26 pm	363	4’ 08”	28.5
			100° 03’ 52.5”		180		22.9
		11	5° 19’ 28.8”	10.57 pm	363	5’ 02”	13.2
			99° 23’ 53.3”		180		33.1
Pulau Perak	9-Jun-04	12	5° 41’ 17.7”	9.30 am	363	3’ 53”	14.1
			98° 55’ 54.9”		180		17.6
		13	5° 40’ 51.7”		363	4’ 47”	16.5
			98° 56’ 03.4”		180		18.7
		14	5° 40’ 39.8”		363	4’ 08”	16.5
			98° 56’ 19.4”		180		17.1

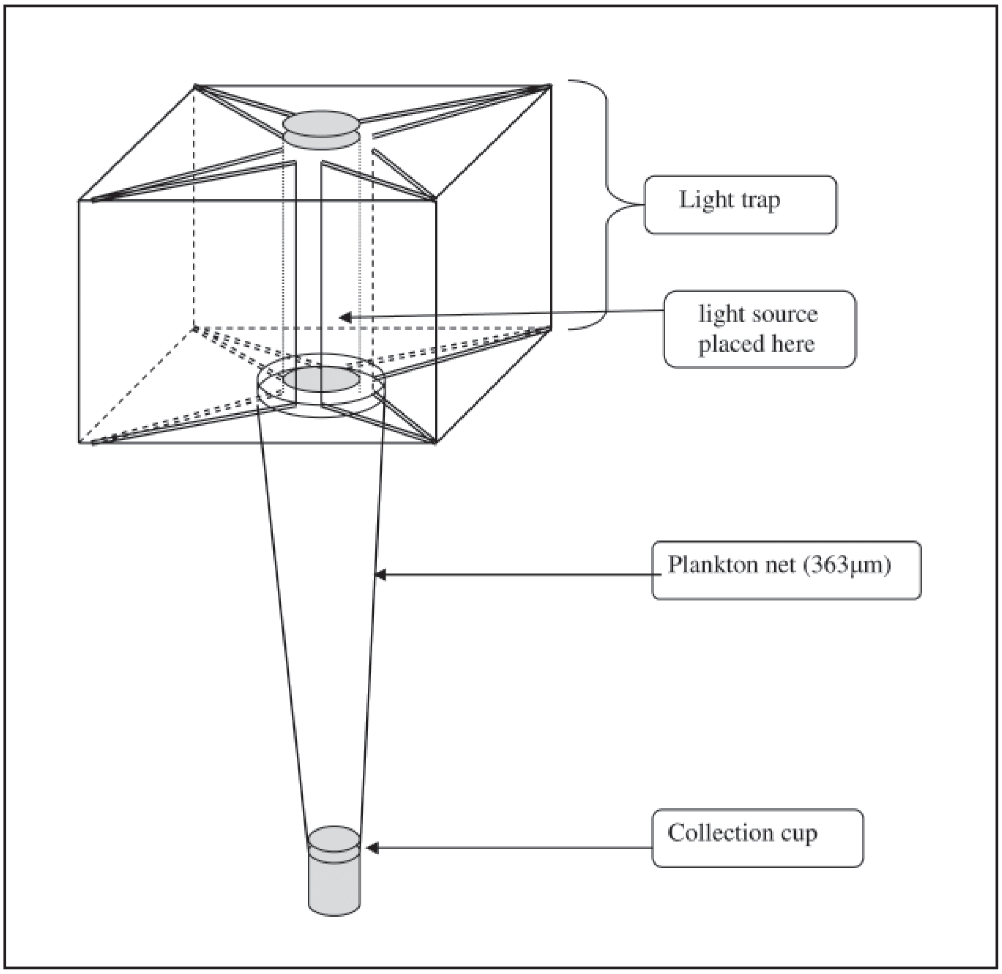


Figure 2. Diagram of light trap with plankton net as used in SESMA II.

During SESMA II, three light traps were used to collect nocturnally-active zooplankton in Pulau Sembilan waters. The Perspex-made light trap was rectangular in shape, 33.8 cm in length, 31.8 cm in width and 25.8 cm in height, with a 363 µm conical net and collecting bucket (Figure 2). LED white light emitted from a small torch light placed inside the light-trap was used to attract the zooplankton which entered it through the trap's doorways. The light traps with their floats were deployed at a depth of 1 m below surface from the sides of the ship using a rope tether. They were set for 3 hourly periods from 2000 - 0600 hr. The trapped zooplankton were collected from its net bucket and preserved as described above.

Laboratory Analysis

Sampled zooplankton was processed by first sieving the entire contents through a stacked array of four Endecott sieves of 500 µm, 250 µm, 125 µm and 53 µm mesh size, under running tap water. Particles with sizes smaller than 53 µm were discarded. The zooplankton fractions were then separately transferred onto pre-weighed steel gauze and excess moisture was blotted dry before they were weighed together by analytical balance (g, four decimal places). Wet weight (g) of the zooplankton fraction was then estimated by subtraction. The zooplankton fractions were then resuspended in 85% alcohol in separate 100 ml plastic containers for subsequent examination.

All fish larvae were completely sorted out from the plankton samples collected by the 363 µm net, identified and enumerated. Other zooplankton from the 183 µm net were examined under a compound microscope after suitable splits (of between 2 to 8 times) were made using a Folsom plankton splitter.

Table 2. Mean total biomass, density and diversity indices for zooplankton and fish larvae in the Straits of Malacca, SESMA I.

		Pulau Jarak	Pulau Sembilan	Pulau Perak	Transect stations			
		Stn 1-4	Stn 5-7	Stn 12-14	Stn 8	Stn 9	Stn 10	Stn 11
Biomass (g m-3 ± SD)	180 µm 363 µm	0.491±0.2180 0.1392± 0.0408	0.445±0.0973 0.1414±0.0953	0.1564±0.0197 0.0998± 0.0053	1.083 0.1726	0.857 0.3455	1.7384 0.2656	0.1888 0.2674
Mean total density (±SD)	Zooplankton (Indiv. m^{-3})	2990.1±1190.6	14242.4±344.1	1722.2±460.1	-	-	-	-
	Fish larvae (Indiv. m^{-3})	31.7±6.7	22.9±16.5	26.3±2.9	212.8	194.8	273.7	37.9
H' (Shannon-Weiner index)	Zooplankton Fish larvae	3.13 2.46	3.04 1.85	3.16 1.48	- 1.69	- 2.05	- 2.20	- 1.33
J' (Pielou's index)	Zooplankton Fish larvae	0.72 0.87	0.67 0.89	0.74 0.92	- 0.74	- 0.94	- 0.88	- 0.96

Homogenous subsamples were then taken using a 1 ml Stempel pipette and transferring its contents onto a 1 ml Sedgewick-Rafter cell. Zooplankton diversity and abundance of the transect samples were not enumerated and reported here.

The fish larvae and other zooplankton were identified to the lowest possible taxa [19, 20, 21, 22, 23, 24, 25] and enumerated in term of density per unit volume; individual (indiv.) 100 m^{-3} for fish larvae and indiv. m^{-3} for the other zooplankton.

RESULTS AND DISCUSSION

Biomass and density

Estimated mean biomasses (±SD) of total zooplankton (g m^{-3}) collected by the fine net (180 µm) in marine waters of Pulau Jarak, Pulau Sembilan and Pulau Perak were 0.49 ± 0.22, 0.45 ± 0.10 and 0.16 ± 0.10, respectively. For the coarse net (363 µm), zooplankton biomasses were more consistent at respectively 0.14 ± 0.04, 0.14 ± 0.10 and 0.10 ± 0.01.

Corresponding mean total density (indiv. m^{-3}) excluding fish larvae for the above sites were 2990 ± 1191, 14242 ± 3441 and 1722 ± 460, respectively. The mean density (indiv.100 m^{-3}) of larval fish for the same sites were 31.7 ± 6.7, 22.9 ± 16.5 and 26.3 ± 2.9, respectively.

None of the biomass and density of zooplankton collected at Pulau Jarak, Pulau Sembilan and Pulau Perak had higher values than those collected from the first 3 transect or open-water stations between Pulau Pangkor and Pulau Perak (i.e. Stations 8-10), which ranged from 0.86 - 1.74 g m^{-3} for the fine net and 0.17 – 0.27 g m^{-3} for the coarse net (Table 2). Larval fish density was also highest along these 3 transect stations, with densities of 195 – 274 indiv. 100 m^{-3}. Stations 8, 9 and 10 were located about 2, 35 and 50 km due west of the mainland, with the latter two located off the Matang Mangrove Forest Reserve which is well known as an important nursery area for marine fishes [26]. The last station on the transect, Station 11, which was located 87 km due west of Penang Island, had very much poorer catches of fine net zooplankton (0.19 g m^{-3}) including fish larvae (38 indiv. 100 m^{-3}).

Zooplankton abundance in the Pulau Sembilan (25 km offshore) waters was very high compared to the waters around Pulau Jarak (68 km offshore) and Pulau Perak (160 km offshore). This was attributable to the high numbers of small copepodites and appendicularians. Their abundance was likely related to the greener water observed here as compared to the much clearer water in Pulau Jarak and Pulau Perak. It has been reported that the riverine discharges from Perak River reach the Sembilan group of islands (Station 8) where there are coral reefs; degradation of the coral reefs [27] may be due to sedimentation as well as eutrophication of its waters as evidence from its greener water [28]. Similarly, plumes of riverine discharges from the Matang river estuaries in Perak do jet out into offshore waters in the vicinities of Stations 9 and 10, as indicated by satellite images (personal observation). Chlorophyll *a* concentrations are reported to be higher nearer to shore [28] which could explain the richer zooplankton found here in terms of abundance.

Species diversity and composition

Zooplankton species diversity based on Shannon-Wiener index, H' was the highest in Pulau Perak (3.16), followed by Pulau Jarak (3.13) and Pulau Sembilan (3.04). Larval fish diversity (H') was 2.46 for Pulau Jarak, 1.85 for Pulau Sembilan and 1.48 for Pulau Perak. There were more than 140 zooplankton taxa identified including larval (meroplankton) and adult forms.

Copepoda

The holoplankton was dominated by copepods both in terms of species and numbers. Copepods dominated at all locations comprising 70% of the total zooplankton in Pulau Perak, 57% in Pulau Sembilan and 56% in Pulau Jarak.

A total of 71 identified copepod species from 24 families were recorded from both SESMA cruises. The identified species belonged to the Calanoida, 44 species, 15 families; Cyclopoida, 22 species, 4 families; Harpacticoida, 4 species, 4 families; and Monstrilloida, 1 species, 1 family (Table 3). In terms of abundance (indiv. m^{-3}), calanoids were the most abundant copepod in Pulau Sembilan (63%) whereas cyclopoids were found to be higher than other copepods in more offshore waters at Pulau Jarak (50%) and Pulau Perak (59%). Harpacticoids comprised <12% of copepod abundance of the three island waters.

In all island waters, copepods were generally dominated by smaller species (<0.5mm) such as Paracalanidae, Oithonidae, Oncaeidae, Corycaeidae and Euterpinidae (two examples given in Plate I, a-b). Similar families have also been reported to be abundant and important food source for larval fish elsewhere [18]. The Paracalanidae (particularly *Parvocalanus crassirostris*) and Oithonidae (*Oithona attenuata, O. brevicornis*) were very dominant in the Pulau Sembilan waters, with total numbers (excluding copepodites) that exceeded 1,000 indiv. m^{-3}. Corycaeidae, dominated by *Corycaeus andrewsi*, were more abundant at Pulau Jarak and Pulau Sembilan, with total numbers close to 150 indiv. m^{-3}. Pulau Perak waters had the least number of identified oithonid species (2). Oncaeidae (*Oncaea clevei*) were the most abundant in Pulau Perak waters (>300 indiv. m^{-3}). *Euterpina acutifrons* and *Microsetella norvegica* were the two most dominant harpacticoid species in Pulau Sembilan waters but Pulau Perak was dominated by a larger species, *Macrosetella gracilis*. The three harpacticoid species were almost equally abundant in Pulau Jarak (Table 3).

Although light trap catches were poor in terms of abundance, due to the swift tidal currents, a total of 40 identified species of copepods were recorded, of which 7 species had not been recorded during SESMA I. These included the monstrilloid copepod, *Cymbasoma bullatus*, and the only representative of the Pseudodiaptomidae*, Pseudodiaptomus bowmani*. Copepods dominated the nocturnal zooplankton in Pulau Jarak with 46.9% composition. In Pulau Sembilan, the nocturnal copepod density constituted 21%, being surpassed only by the unusual abundance of *Acetes* protozoea which indicates their reproductive season at the time of sampling.

The most recent and comprehensive copepod study in the Straits of Malacca is that by Rezai et al. [7] which is based on four cruises from 1998-2000. This study involved vertical tow samplings of 13-96 m depth along the entire length of the straits (20 stations) using 0.159 m^2 NORPAC net of 140 µm mesh size. The study recorded a total of 117 copepod species from 25 families for the whole straits. The present study which covered the middle one-third of the total straits area, recorded 1 family and 46 species fewer than the above study. In comparison to Rezai et al. [7]'s observations, the three families that were absent in the present study were Clausocalanidae, Macrochironidae and Arietellidae. However, the present study obtained two families not obtained by them, namely, Phaenidae and the Monstrilloida family, Monstrillidae. Species not recorded by them and probably new records were *Pontella fera, Pontellopsis tenuicauda, Pseudodiaptomus bowmani, Phaena spinifera, Corycaeus pumilus, Oncaea similis* and *Cymbasoma bullatus*. Except for these exceptions, the dominant five families of Paracalanidae, Oithonidae, Oncaeidae, Corycaeidae and Euterpinidae are similar in both studies. Also in agreement, is the relatively higher copepod abundance in the coastal waters as compared to offshore waters (> 60 km offshore).

This study, in agreement with Rezai et al. [7] and Chong and Chua [4], found the common cyclopoid species to be *Oithona plumifera, O. simplex and O. attenuata*, but surprisingly did not encounter any *Oithona nana*, reported to be common by both. On the other hand, *O. brevicornis* was also found to be common in this study, but not so from their studies. Since we did not examine the transect samples, this could suggest that *O. nana* prefers more open offshore waters while *O. brevicornis* may prefer offshore island waters. Interestingly, the latter species was rare in the adjacent coastal waters of the Matang mangrove estuary where there is significant freshwater input [29].

Table 3. Composition and abundance of zooplankton in the Straits of Malacca, June 2004 and November 2007.
Zooplankton abundance estimated in SESMA I in term of individuals m^{-3}; SESMA II, in term of individuals $trap^{-1}$ 3 hr^{-1}

	SESMA I (2004): Sampling by Bongo Traps							SESMA II (2007): Sampling by Light Traps	
	P. Jarak	P. Sembilan	P. Perak	Transect Stations					
Taxa	Stn. 1, 2, 3	Stn. 4, 5, 6	Stn. 11, 12, 13	Stn. 7	Stn. 8	Stn. 9	Stn. 10	P. Jarak	P. Sembilan
CRUSTACEA									
COPEPODA									
Copepod nauplius	310.0±262.3	554.3±25.5	62.1±21.8					0.33	0.13
CALANOIDA									
Acartiidae									
Acartia erythraea	23.0±13.0	29.4±16.1	4.5±1.9					0.00	0.50
A. spinicauda	5.8±5.1	7.2±3.1						0.22	0.00
Acartia sp.			1.0±1.7						
Acartia copepodid	144.8±83.9	286.9±22.1	17.6±15.4						
Acartia amboinensis								2.22	0.00
A. pacifica								1.00	0.50
Calanidae									
Canthocalanus pauper	1.6±2.8	0.9±1.6						21.89	6.50
Canthocalanus copepodid								0.33	0.00
Undinula vulgaris			0.2±0.02					2.44	0.00
Undinula copepodid			15.8±4.7					0.56	0.00
Calocalanidae									
Calocalanus copepodid			1.2±2.0						
Candaciidae									
Candacia catula			0.02±0.03						
Candacia discaudata	6.3±8.7	1.0±1.6	2.6±2.7					0.11	0.00
Candacia copepodid	1.9±2.0	56.8±24.1	4.7±5.8					0.11	0.00
Centropagidae									
Centropages furcatus	0.1±0.1	12.8±19.8						4.78	3.88
Centropages orsinii	0.9±1.5		1.6±1.4					0.33	0.00
Centropages copepodid	25.5±19.3	41.5±9.2							
C. dorsispinatus								0.00	0.50
Eucalanidae									
Eucalanus attenuatus			0.02±0.03						
Eucalanus subcrassus	0.6±1.0	0.1±0.1						9.89	6.38

Eucalanus subtenuis			7.0±3.2						
Eucalanus copepodid								5.78	3.75
Euchaetidae									
Euchaeta concinna	0.01±0.02	0.3±0.1	0.2±0.4					2.78	1.75
Euchaeta wolfendeni			0.02±0.03						
Euchaeta copepodid	0.6±1.0	1.5±1.4	1.9±3.2					30.56	10.13
Lucicutiidae									
Lucicutia gaussae	4.3±7.5	3.1±2.8						3.67	1.13
Paracalanidae									
Acrocalanus gibber	15.1±13.5	36.0±53.3						8.22	6.38
Acrocalanus gracilis	0.5±0.9	0.9±1.6	2.7±4.6					0.33	0.00
Acrocalanus longicornis	5.4±7.9		1.0±1.7					11.67	0.88
Bestiolina similis		1.8±3.1							
Paracalanus aculateus	3.2±3.6	101.9±55.2						1.00	2.00
Paracalanus denudatus	54.7±75.0		81.3±66.7						
Parvocalanus crassirostris	7.8±13.6	1108.8±132.9						0.11	0.00
Parvocalanus elegans	8.7±9.9		40.1±7.3						
Paracalanidae copepodid	130.9±112.0	1798.6±286.3	98.5±61.1						
Pontellidae									
Calanopia minor			3.7±3.2						
Labidocera acuta	0.1±0.1							0.33	0.25
Labidocera kroyeri		0.01±0.02						0.11	0.00
Labidocera sp.								0.00	0.13
L. pectinata								0.00	0.38
Pontella fera	0.01±0.01								
Pontella sp.		0.1±0.1						0.00	0.13
Pontellina plumata			0.02±0.03						
Pontellopsis tenuicauda		0.5±0.8							
Pontellidae copepodid	3.4±4.1	27.2±35.8						1.33	0.50
Temoridae									
Temora discaudata			0.8±1.3					6.33	0.25
Temora stylifera			5.4±7.0						
Temora turbinata		104.2±88.2						3.56	5.00
Temora copepodid	33.7±23.2	613.7±88.8	9.2±15.9						

Tortanidae									
Tortanus forcipatus		1.4±2.4						0.00	1.63
Tortanus copepodid		18.0±28.8						0.00	0.00
Pseudodiaptomidae									
Pseudodiaptomus bowmani								0.00	1.25
Phaenidae									
Phaena spinifera		0.9±1.6	1.4±2.5						
Scolecithricidae								0.00	0.00
Scolecithricella mior		1.8±3.1							
Scolecithrix nicobarica								0.11	0.00
Unidentified Calanoid copepodid	105.2±54.4	622.6±185.8	130.3±73.2					0.56	0.00
CYCLOPOIDA									
Corycaeidae									
Corycaeus affinis	14.3±12.6								
Corycaeus agilis			8.1±7.3						
Corycaeus andrewsi	29.2±24.8	86.8±50.4	0.9±1.5					0.00	0.13
Corycaeus asiaticus	3.4±3.5	6.2±8.6	2.8±4.9						
Corycaeus catus			21.0±18.9						
Corycaeus dahli		2.7±4.7							
Corycaeus erythraeus	19.1±18.8	6.2±8.6	4.2±4.0						
Corycaeus lautus		2.7±2.7							
Corycaeus limbatus			28.6±12.6						
Corycaeus pumilus	5.3±9.1								
Corycaeus speciosus	4.9±7.2								
Corycaeus spp.	74.3±70.9	40.5±70.2	2.0±3.4						
Corycaeus copepodid	66.6±44.1	60.8±66.1	20.1±7.2						
Oncaeidae									
Oncaea clevei	17.1±14.8	83.0±33.5	108.6±12.5						
Oncaea media	0.8±1.4							0.33	0.00
Oncaea scottodicarloi	0.8±1.4								
Oncaea similis	0.8±1.4								
Oncaea venusta	0.9±1.5		62.6±5.8						

Oncaea spp.	41.1±24.5	10.9±18.9	145.3±17.5						
Oncaea copepodid	89.9±39.3	73.3±64.6	53.7±36.6					0.11	0.00
Oithonidae									
Oithona attenuata	4.4±7.6	494.5±112.6							
Oithona brevicornis	43.3±17.7	345.4±269.8							
Oithona plumifera	44.4±26.8	35.2±28.3	88.4±49.8					0.11	1.88
Oithona rigida		20.6±35.7							
Oithona simplex	2.2±3.8	155.0±53.4	6.3±5.8						
Oithona copepodid	225.8±92.9	480.3±165.2	124.4±16.6						
Sapphirinidae									
Copilia mirabilis f. platyonyx			0.04±0.03						
HARPACTICOIDA									
Clytemnestridae									
Clytemnestra scutellata			1.1±2.0						
Euterpinidae									
Euterpina acutifrons	38.8±27.8	759.0±116.5	2.8±2.5						
Ectinosomatidae									
Microsetella norvegica	33.3±29.2	189.7±109.6	4.5±5.5					0.11	0.00
Miraciidae									
Macrosetella gracilis	38.2±14.9	2.7±2.7	22.3±12.4						
Unidentified Harpaticoid sp.			2.5±4.3						
Monstrilloida									
Cymbasoma bullatus								0.00	0.13
MALACOSTRACA									
Mysidae									
Achialina sp.		0.05±0.04						1.56	0.13
Siriella sp.								0.33	0.25
Acanthomysis sp.								0.11	0.00
Euphausiacea									
Euphausiid larvae								0.00	3.25

DECAPODA									
Sergestidae									
Acetes protozoea		21.6±21.1						0.33	145.88
Acetes mysis/juvenile		3.2±2.8						0.11	0.13
Unidentified Sergestidae protozoea								0.00	0.13
Luciferidae									
Lucifer protozoea	22.2±27.9	166.9±169.0						9.56	8.00
Lucifer mysis/juvenile	13.6±11.7	14.5±9.6	14.2±9.6					24.56	7.25
Lucifer hanseni		0.3±0.2						0.89	1.38
Lucifer penicillifer	0.1±0.1	0.1±0.04	0.02±0.03					1.78	0.00
Penaeidae									
Penaeidae protozoea	0.8±1.4	2.7±2.7						0.00	0.63
Penaeidae mysis		4.5±1.5						0.00	0.13
Unidentified Penaeid nauplius		13.5±23.4							
Unidentified shrimp juveniles								0.11	0.00
Caridea									
Alpheidae zoea		6.0±3.4							
Palaemonidae zoea		1.8±3.1							
Pasiphaeidae juveniles		0.1±0.1							
Unidentified caridean zoea	0.1±0.1	0.6±0.7						3.11	0.50
Unidentified caridean juveniles								0.11	0.00
Brachyura									
Brachyuran zoea		17.9±19.0						2.22	2.88
Brachyuran megalopa		0.1±0.1						0.00	0.25
Anomura									
Hermit crab juveniles		0.5±0.8							
Porcellanidae zoea								0.00	0.25
Thallasinidae									
Thallasinidae zoea		1.1±1.6	1.0±1.7					0.11	4.63
STOMATOPODA									
Stomatopod larvae (Alima type)		1.4±1.4	0.04±0.1					0.67	0.13

Stomatopod larvae (Erichthus type)	0.6±0.9								
OSTRACODA								0.00	8.50
Cypridina spp.	0.8±1.4	168.8±98.1						1.11	14.88
Euconchoecia spp.	28.4±30.4	364.9±54.1	2.5±4.3					3.33	0.38
	2.2±3.8								
ISOPODA									
Isopods	6.5±11.2	28.0±25.9						30.56	0.50
CIRRIPEDIA									
Cirripede nauplius	13.0±22.5	151.0±134.1	2.8±4.9					0.11	2.75
Cypris cirripedia								0.22	0.13
Cladoceran									
Edvane sp.								7.89	0.00
AMPHIPOD								0.00	0.13
Hyperiidae								0.22	0.25
Unidentified amphipods								4.56	0.00
Cumaceae								0.56	1.00
CNIDARIA									
Anthodmedusa	0.5±0.9	0.9±1.6	1.8±1.5					1.33	0.88
Trachymedusa	0.6±0.9	0.1±0.03						0.22	0.00
Siphonophora	23.4±0.8	4.3±2.5	7.6±5.0					5.67	1.13
Unidentified Cnidaria larvae	7.6±5.5		1.2±2.0						
Letomedusa								1.00	0.25
Obelia sp.								0.00	0.13
CTENOPHORA									
Pleurobranchia sp.								0.22	0.00
POLYCHAETA									
Nereidae larvae	0.4±0.8								
Spionidae larvae	7.3±10.6	160.3±79.6						0.33	0.38
Terebellidae larvae		28.4±47.9						0.22	0.38
Rostraria type polychaete larvae	10.3±17.8	0.9±1.6						0.44	0.00
Unidentified polychaete	0.8±1.5	10.9±18.9	0.9±1.5					0.56	0.38

Unidentified polychaete larvae	26.9±3.7	238.5±84.4	6.3±2.3					0.11	0.13
Phyllodocidae								0.00	0.13
Polychaete trochophore								0.00	0.13
Unidentified gelatinous zooplankton								0.00	0.13
CHAETOGNATHA	11.0±19.0								
Chaetognaths	38.6±28.3	107.7±29.0	24.1±8.7					0.11	0.00
Flaccisagitta enflata								0.89	1.38
Sagittidae								0.89	1.25
MOLLUSCA									
GASTROPODA									
Gastropods	13.3±19.1	100.5±46.4	14.3±10.9						
Creseis spp.	15.3±13.6	6.4±11.0	11.4±9.2					3.22	0.00
Atlanta sp.								0.89	0.00
Limacina sp.								0.56	0.50
BIVALVIA									
Bivalves	38.4±49.4	221.1±163.0	10.2±12.1					0.11	0.00
CEPHALOPODA									
Cephalopods		0.01±0.02							
ECHINODERMATA									
Echinopluteus larvae			0.8±1.3						
Ophioluteus larvae	29.0±33.3	359.2±53.0	7.5±13.0					1.22	0.13
Ophiuroidea post-larvae	12.2±11.8	0.03±0.05	13.7±12.1						
Holothuroidea larvae								0.22	0.00
CHORDATA									
UROCHORDATA									
Salpinae			0.1±0.1						
Thalia sp. (solitary zooid)								0.00	0.75
Thalia sp. (aggregate zooid)								0.00	4.63
Oikopleura spp.	672.9±437.8	3106.3±2955.8	149.3±52.4					16.78	4.13
Fritillaria spp.	121.1±49.3		14.7±8.1					0.44	0.00
CEPHALOCHORDATA									

Unidentified species			0.1±0.003						
Bryozoa larvae								0.44	0.00
Unidentified eggs	179.0±132.9	552.2±144.0	232.6±44.0						
FISH LARVAE									
Ambassidae	0.8±1.6			2.9					
Apogonidae						7			
Amplyopinae									
Ammyotidae	0.7±1.3				19.5	38.6			
Atherinidae				2.9					
Bothidae					6.5	17.5			
Bregmacerotidae				23.3					
Carangidae	1.3±1.5				64.9	21.1			
Callionymidae		1.3±2.3							
Carangidae (Caranx)	0.5±1.0								
Carangidae (Decapterus)	0.7±1.3								
Carangidae (Scomberoides)	4.1±5.9	2.0±3.5	3.0±4.3						
Cepolidae							7.6		
Cynoglossidae	0.8±1.6	2.0±3.5	6.6±0.7	2.9		3.5			
Engraulidae	6.2±2.1		3.0±4.3	37.9	6.5	42.1	7.6		
Gobiidae	2.5±3.0	8.6±9.0	10.1±5.7	93.3	39	73.7	15.2		
Haemulidae	0.7±1.3								
Leiognathidae				8.7					
Nemipteridae	0.7±1.3	2.0±3.5			19.5				
Sciaenidae		5.0±8.7		26.2	13	10.5	7.6		
Scombridae (*Rastrelliger*)						45.6			
Scorpaenidae				2.9					
Siganidae	6.0±2.7								
Sparidae	1.3±2.7		3.5±5.0						
Synontidae	2.0±4.0					10.5			
Tetrapontidae	0.8±1.6					3.5			
Trichonotidae	2.3±2.9				26				
Unidentified	0.5±1.0	2.0±3.5		11.7					
Fish larvae								0.00	0.38
Fish eggs		1.0±1.7			19.5	14		5.67	0.38
PROTOZOA									
Foraminiferan		85.3±147.7							

Other Crustaceans

Besides the Copepoda, the other maxillopodans comprised two common taxa, the Cirripedia and Ostracoda (Plate I, e) which were particularly more abundant (> 100 indiv. m^{-3}) in the waters around Pulau Sembilan and Pulau Jarak.

The Malacostraca were the next important zooplankton group found, and included in them were the holoplanktonic shrimps, *Acetes* and *Lucifer* spp. and isopods, and the larvae of penaeid and caridean shrimps, crabs, anomurans, thalassinids and stomatopods. The meroplanktonic crustacean larvae that mainly comprised shrimp nauplii and crab zoeae (Table 3) were found to be more abundant in Pulau Sembilan as compared to Pulau Jarak and Pulau Perak. This suggests that the area encompassing the Sembilan group of islands could serve as important breeding grounds for commercially-important shrimps and crabs.

Additional crustacean taxa not reported in SESMA I but found in the light traps during SESMA II included the Amphipoda (Plate I, g), Cumacea, Isopoda (Plate I, c), porcellanid zoea and euphausiid larvae. The first two taxa comprise many known nocturnal species.

Other Invertebrate Taxa

Included in the zooplankton were species that belonged to Cnidaria, Polychaeta, Chaetognatha, Mollusca, Echinodermata, Urochordata and Cephalochordata (see examples in Plate I, j-q). The larvae of polychaetes (>200 indiv. m^{-3}), gastropods (>100 indiv. m^{-3}) and bivalves (>200 indiv. m^{-3}), and the ophiopluteus (> 300 indiv. m^{-3}) were especially abundant around Pulau Sembilan. Night catches by light traps included additional representatives from the Bryozoa (Plate I, i), Ctenophora (*Pleurobrachia* sp.) and salps (*Thalia* spp.) (Plate I, r).

Fish Larvae

Twenty-four families of larval fish were recorded from the entire cruise (Table 3). The number of taxa recorded from Pulau Jarak, Pulau Sembilan and Pulau Perak were 17, 8 and 8 families respectively. The most dominant taxa were Carangidae (*Scomberoides*, *Decapterus* and *Caranx* spp), Engraulidae, Siganidae and Gobiidae around the islands, while Gobiidae, Carangidae, Engraulidae and Sciaenidae were distinctly abundant in the open waters (Plate I, s-x). The relatively higher abundance of fish larvae in the open waters vis-à-vis the island waters is related to the spawning behavior of many marine fish species. The recruitment of mainly larvae and early juveniles into estuarine nursery areas from offshore is a common feature of the life cycle of many marine species [see 30 and 13]. Such is the case for the present study area which is located off the important nursery area of the Matang Mangrove Reserve [31], where it was found that many marine fish spawns offshore and migrated into the mangrove waters either at the post-flexion or early juvenile stage [32].

CONCLUSIONS

Zooplankton biomass of island waters is lower than in the more open waters of the Straits of Malacca. However, in the open waters, zooplankton biomass significantly decreases in offshore waters. More than 140 taxa of zooplankton were recorded from the middle region of the Straits of Malacca, which comprised of mainly Copepoda, Urochordata, Ostracoda, Polychaeta and Mollusca. Copepods were dominated by the Paracalanidae, Oithonidae, Oncaeidae, Corycaeidae and Euterpinidae. Probably new records of copepods are *Pontella fera, Pontellopsis tenuicauda, Pseudodiaptomus bowmani, Phaena spinifera, Corycaeus purnilus, Oncaea similis* and *Cymbasoma bullatus*. Fish larvae were represented by 24 identified families, the most abundant were from the Carangidae, Engraulidae, Gobiidae and Siganidae, with the highest numbers recorded in the open waters of not more than 60 km offshore, due west of the main fish nursery areas of the Matang mangrove. This feature is consistent with the observed abundance of zooplankton.

ACKNOWLEDGEMENTS

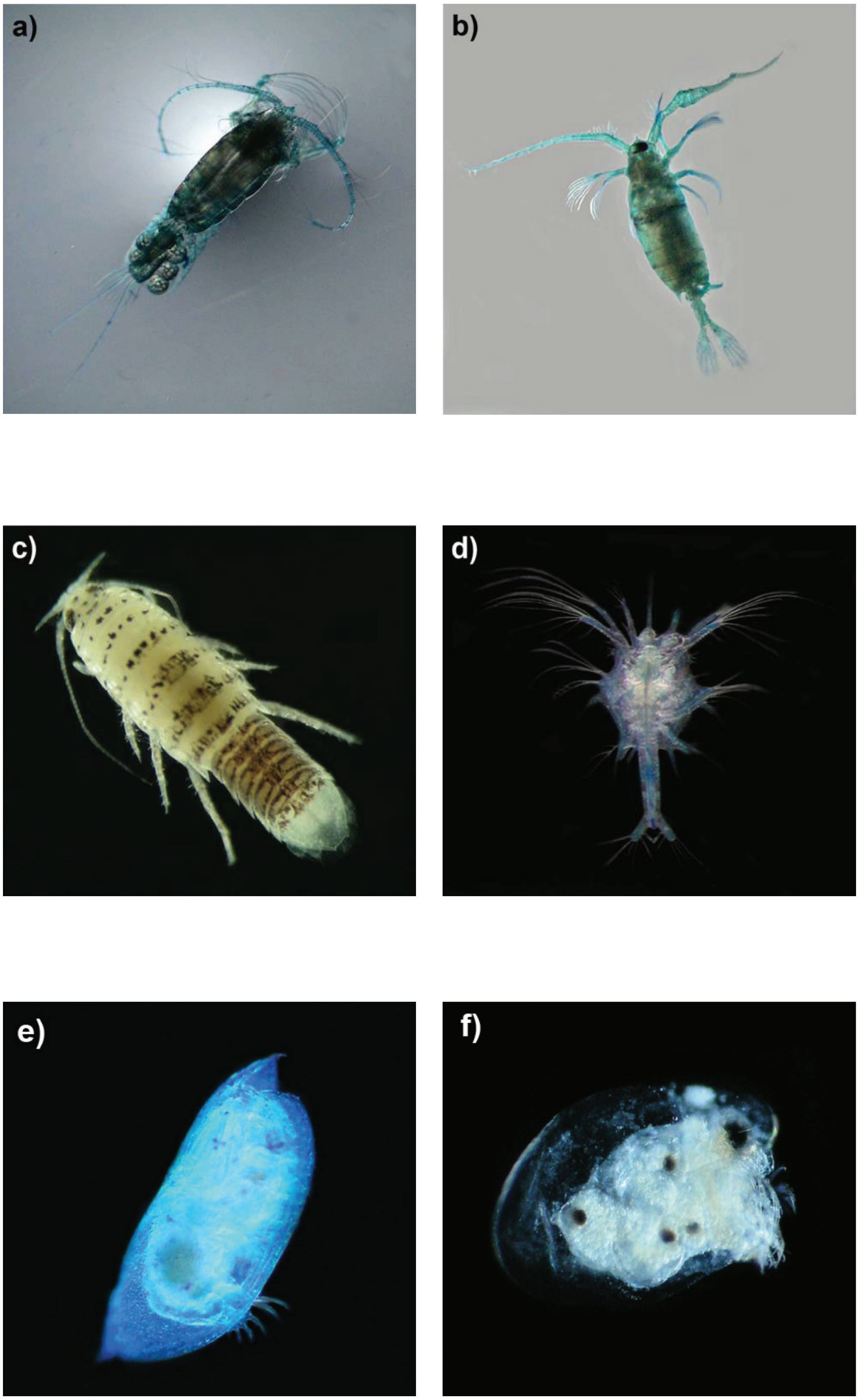
We thank the University of Malaya for funding the SESMA research cruises and providing research facilities. The Royal Malaysian Navy and the Marine Police are gratefully acknowledged for providing logistical support and security.

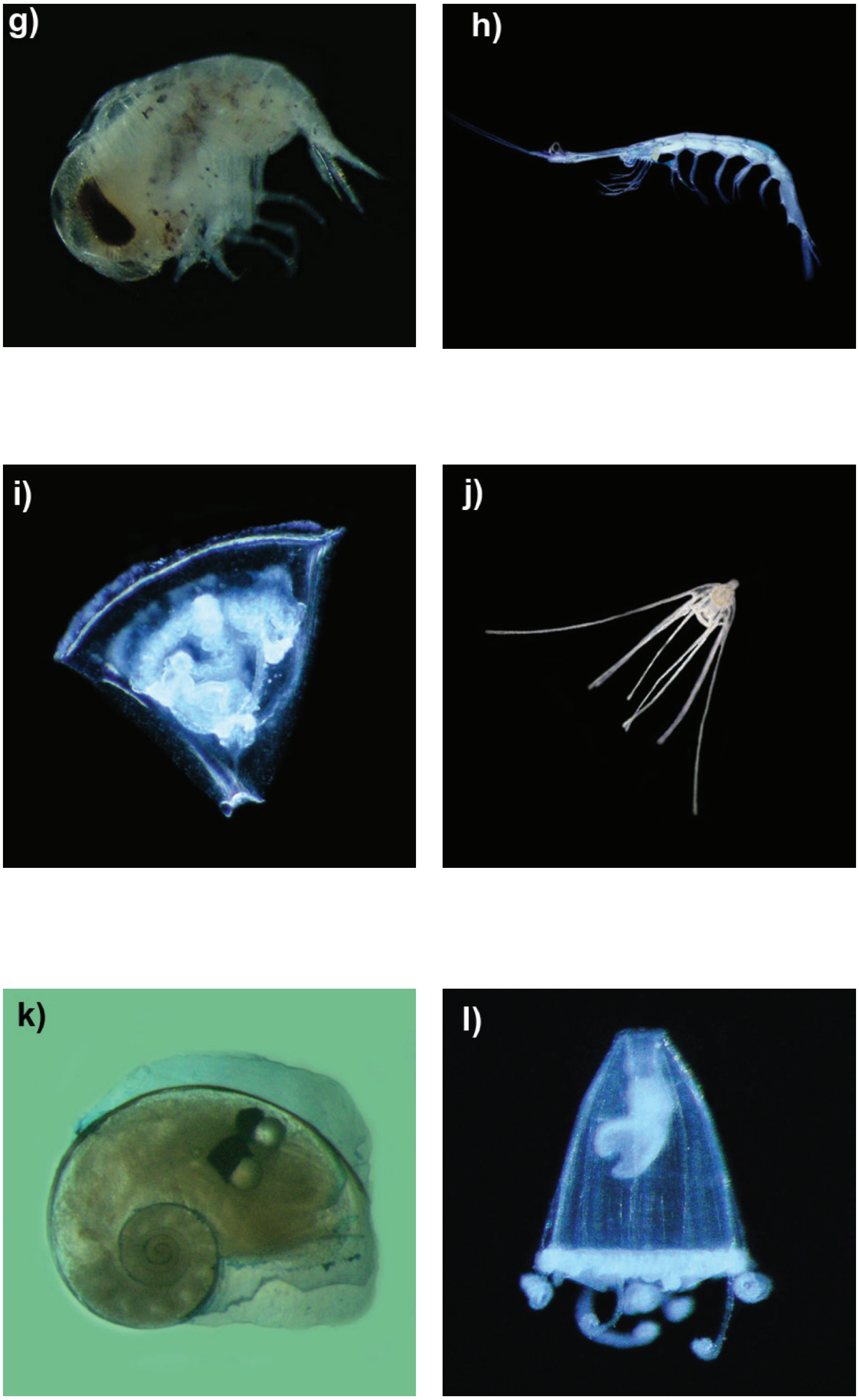
REFERENCES

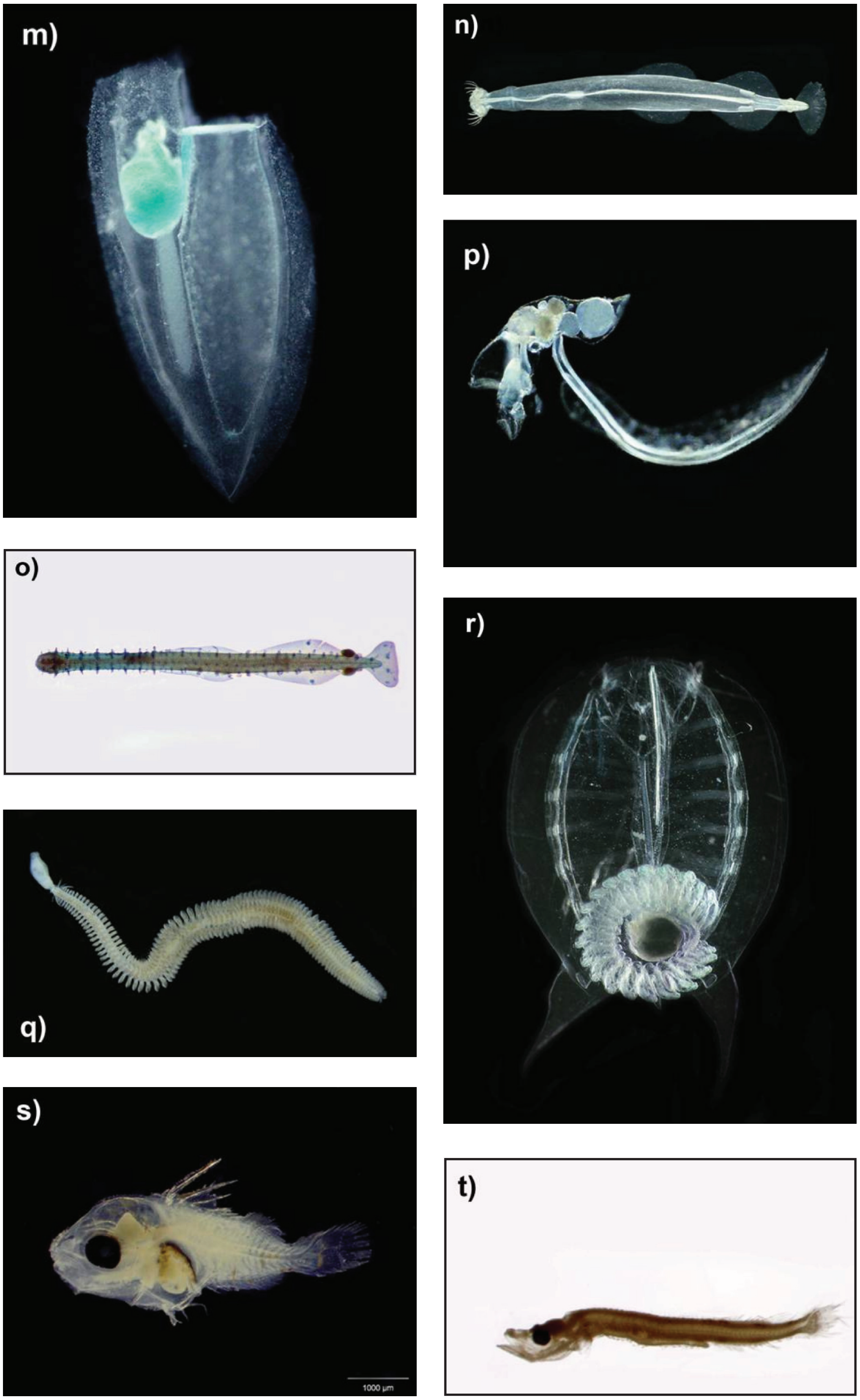
1. Cleve, P.T. (1901). Plankton from the Indian Ocean and the Malay Archipelago, Kongol. Svenska. *Vetenskaps-Akademiens. Handl.* **35**: 5.
2. Sewell, S.R.B. (1933). Note on a small collection of marine copepods from the Malay states. *Bulletin of Raffles Museum* **8**: 25-31.

3. Wickstead, J.H. (1961). A Quantitative and Qualitative Study of some Indo-West-Pacific Plankton, Colonial Office Fishery Publications, No. 16, Her Majesty's Stationery Office, London.
4. Chong, B.J. and Chua, T.E. (1975). A preliminary study of the distribution of the cyclopoid copepods of the family Oithonidae in the Malaysian waters. In Anon. (ed), Proceedings of the Pacific Science Association of Marine Science Symposium, Hong Kong: 32-36.
5. Chua, T.E. and Chong, B.J. (1975). Plankton distribution in the Straits of Malacca and its adjacent waters. In Anon. (ed), *Proceedings of the Pacific Science Association of Marine Science Symposium, Hong Kong*: 17-23.
6. Johan, I., Idris, B.A.G., Ismail, A. and Hishamuddin, O. (2002). Distribution of planktonic calanoid copepods in the Straits of Malacca. In: Yusoff, F.M., Shariff, M., Ibrahim, H.M., Tan, S.G., Tai, S.Y. (eds) *Tropical Marine Environment: Charting Strategies for the Millennium,* MASDEC-UPM, Serdang: 393–404.
7. Rezai, H., Yusoff, F.M., Arshad, A., Kawamura, A., Nishida, S. and Othman, B.H.R. (2004). Spatial and Temporal Distribution of Copepods in the Straits of Malacca. *Zoological Studies* **43**: 486-497.
8. Rezai, H., Yusoff, F.M., Arshad, A. and Othman, B.H.R. (2005). Spatial and temporal variations in calanoid copepod distribution in the Straits of Malacca. *Hydrobiologia* **537**: 157-167.
9. Yoshida, T., Toda, T., Yusoff, F.M. and Othman, B.H.R. (2006). Seasonal variation of zooplankton community in the coastal waters of the Straits of Malacca. *Coastal Marine Science* **30**: 320-327.
10. Hamner, W.M., Jones, M.S., Carleton, J.H., Hauri, I.R. and Williams, D.M. (1988). Zooplankton, planktivorous fish and water currents on a windward reef face, Great Barrier Reef, Australia. *Bulletin of Marine Science* **42**: 459-479. Leakey, R.J.G., Burkhill, P.H. and Sleigh, M.A. (1992). Planktonic ciliates in Southampton water: abundance, biomass, production and role in pelagic carbon flow. *Marine Biology* **114**: 67-83.
11. Trathan, P.N., Eversen, I., Miller, D.G.M., Watkins J.L. and Murphy, E.J. (1995). Krill biomass in the Atlantic. *Nature* **373**: 201-202.
12. Blaber, S.J.M. (2000). *Tropical Estuarine Fishes. Ecology, Exploitation and Conservation.* Blackwell Science Ltd. France: 372pp.
13. Chew, L.L., Chong V.C. and Hanamura, Y. (2007). How important are zooplankton to juvenile fish nutrition in mangrove ecosystems? *JIRCAS Working Report* **56**: 1-18.
14. Heinle, D.R. (1981). *Zooplankton, in Functional Adaptations of Marine Organisms*, Vernberg, F.J. and Vernberg, W.B. Eds., Academic Pres, New York: 85pp.
15. Omori, M. and Ikeda, T. (1984). *Methods in Marine Zooplankton* Ecology, John Wiley & Sons, New York.
16. Chong, V.C. and Sasekumar, A. (1981). Food and Feeding Habits of the White Prawn *Penaeus merguiensis*. *Marine Ecology Progress Series* **5**: 185-191.
17. Turner, J.T. (2004). The Importance of Small Planktonic Copepods and Their Roles in Pelagic Marine Food Webs. *Zoological Studies* **43**: 255-266.
18. Chen Q. C. and Zhang, S.Z. (1965). *The planktonic copepods of the Yellow Sea and the East China Sea.* I. Calanoida: 131pp, 53 plates.
19. Nishida, S. (1985). *Taxonomy and distribution of the family Oithonidae* (Copepoda, Cyclopoida) *in the Pacific and Indian Oceans.* Ocean Research Institute, University of Tokyo, Tokyo: 167pp.
20. Okiyama, M. (1988). *An atlas of early life stage fishes in Japan.* Tokai Univ. Press: 2254pp.
21. Leis J.M. and Trnski T. (1989). *The Larvae of Indo-Pacific Coral Reef Fishes*. NSW University Press, Australia and University of Hawaii Press, USA: 269 pp.
22. Chihara, M. and Murano, M. (1997). *An Illustrated Guide to Marine Plankton in Japan.* Tokai University Press, Tokyo: 1479pp.
23. Neira, F.J., Miskiewicz and Trnski, T. (1998). *Larvae of Temperate Australian Fishes. Laboratory Guide for Larval Fish Identification.* University of Western Australia Press: 474pp.
24. Leis J.M. and Carson-Ewart, B.M. (2000). The larvae of Indo-Pacific coastal fishes. *An identification guide to marine fish larvae. Fauna Malesiana handbook.* Brill, Netherland: 850pp.
25. Chong, V.C. (2008). Fifteen years of mangrove fisheries research in Matang: What have we learnt? In: Shaharuddin M.L., Azahar M., Razani U., Kamaruzzaman A.B., Lim K.L., Suhaili R., Jalil M.S., and A. Latiff (eds), Forest Biodiversity Series 4: *Sustainable Management of Matang Mangroves: 100 Years and Beyond.* Forestry Department, Peninsular Malaysia, Intiprint,

Selangor: 443-451.
26. Mohd. Ibrahim H. M. and Zaharuddin B. (1990). The morphology and ecology of the west coast island groups of Peninsular Malaysia. In: Othman, B.H.R. (ed) ASEAN Australia Cooperative Program on Marine Sciences: Coastal Living Resources Project, Phase I Final Report. UKM, Malaysia: 53-66.
27. Lee, C.W. and Bong, C.W. (2008). Bacterial production and production, and their relation to primary production in tropical coastal waters of Peninsular Malaysia. *Marine and Freshwater Research* **59**: 10-21.
28. Chew, L.L. and Chong, V.C. (2008). Copepod community structure and abundance in a tropical mangrove estuary, with comparisons to coastal waters. (manuscript to Hydrobiologia).
29. Day, J.W., Blaber, S.J.M. and Wallace, J.H.(1981). Estuarine fishes. In: *Estuarine ecology with Particular Reference to Southern Africa* (ed. Day, J.H.), A.A. Balkema, Rotterdam, pp. 197-218.
30. Chong, V.C. (2007). Mangroves-fisheries linkages-the Malaysian perspective. *Bulletin of Marine Science* **80**: 755-772.
31. Ooi, A.L., Chong, V.C., Hanamura, Y. and Konishi, Y. (2007). Occurrence and recruitment of fish larvae in Matang Mangrove Estuary, Malaysia. JIRCAS Working Report **56**: 1-6.


a)
b)
c)
d)
e)
f)


g)
h)
i)
j)
k)
l)


m)
n)
p)
o)
r)
q)
s)
1000 µm
t)

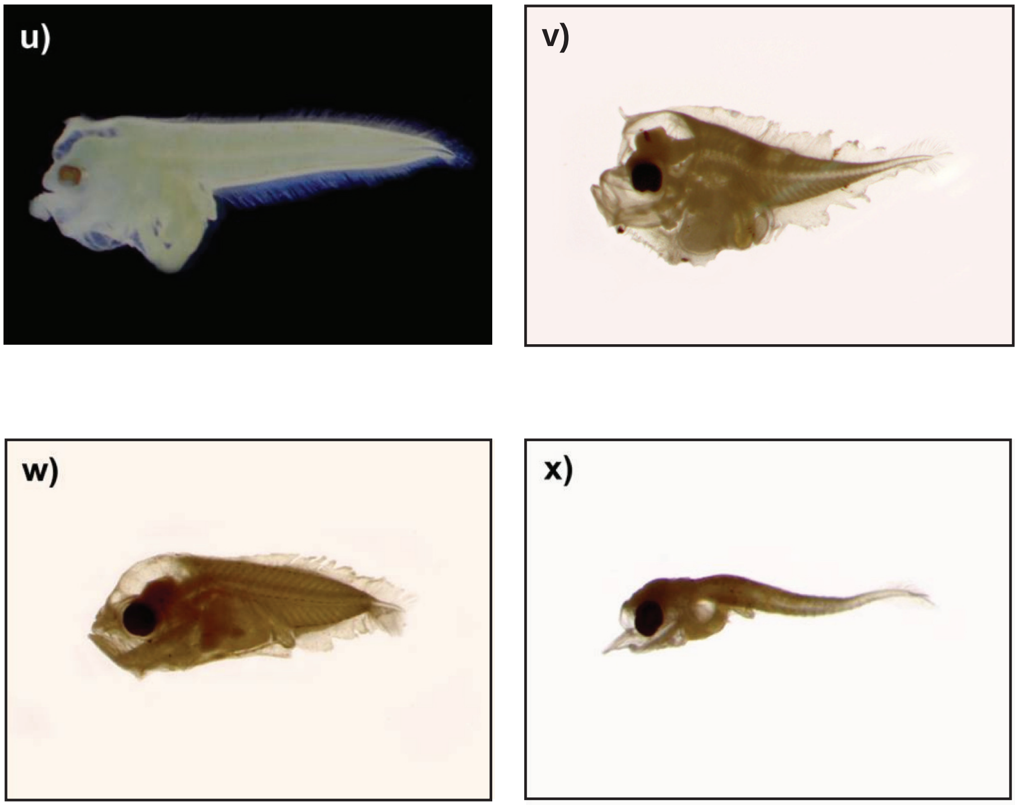


Plate I.
a) Copepod, *Euchaeta concinna*
b) copepod, *Labidocera acuta*
c) isopod
d) sergestid protozoea
e) ostracod, *Euconchoecia* sp.
f) cladoceran
g) amphipod, Hyperiidae
h) sergestid shrimp, *Lucifer penicillifer*
i) Bryozoa larva
j) ophiupluteus larva
k) heteropod, Atlanta sp
l) anthomedusa
m) siphonophoran
n) chaetognath, Sagittidae
o) chaetognath, Sagittidae
p) appendicularian, *Fritillaria* sp.
q) errantia polychaete
r) salp, *Thalia* sp.
s) fish larva, Siganidae
t) fish larva, Gobiidae
u) fish larva, Cynoglossidae
v) fish larva, Bothidae
w) fish larva, Carangidae
x) fish larva, Scombridae