

Zooplankton research in Malaysia: Current status and future prospects

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»» Received 17 November 2010; accepted 21 June 2011

Abstract—Malaysia is one of the three mega-diversity countries in the ASEAN region besides Indonesia and the Philippines, making it an important area for marine ecosystem studies. Marine zooplankton research in Malaysia is still comparatively new when viewed globally. In order to identify where the country stands in this field, the scientific developments achieved to date starting from the earliest oceanographic expeditions in the Malaysian waters are introduced. More recent researches span a wide spectrum including taxonomic and biodiversity observations, experiments on the biology and physiology of zooplankton and trophic structure studies in different marine habitats. Research at large and small scales has been limited due mainly to financial and technical difficulties coupled with a critical need to develop expertise in taxonomy. Continued effort in multidisciplinary activities and multilateral collaborations in the region is necessary to enhance communication, outline similar goals and areas of future study, and significantly accelerate the zooplankton research in Malaysia.

Key words: zooplankton, Malaysia, current status, future research

Introduction

The Indo-Pacific region is high in zooplankton biodiversity, covering several high biological productivity areas and important fishing grounds. In recent years, there has been an increasing interest in assessing the productivity of the world oceans and the effect of global warming on these marine ecosystems. Many zooplankton researches have been conducted in temperate waters owing mainly to the long history of scientific interest in marine life coupled with the social and economical importance of fisheries in the region. However, importance of investigations and monitoring of zooplankton in the tropics has also been well recognized in recent years, particularly with reference to the role of zooplankton in aquatic ecosystems and global biogeochemical cycles.

Malaysia is one of the three mega-diversity countries in the ASEAN region besides Indonesia and the Philippines (Myers 1990), surrounded by the Malacca Straits on the west coast and the South China Sea in the east. The shallow water body of the Malacca Straits is characterized by soft-bottom habitats, fringing coral reefs, seagrass beds and mangroves lining the coastline (Chua et al. 2000) while the South China Sea is believed to harbor one-third of the world's marine bio-

diversity (Ng and Tan 2000), making it an important area for the ecosystem. The general feature of tropical zooplankton is that there is little or no seasonality in their biomass and composition (Parsons et al. 1984, Garrison 1993, Levinton 1995) but recent investigations in tropical regions have revealed the significance of zooplankton seasonal variation (Smith et al. 1998, Champalbert and Pagano 2002). Marine zooplankton research in Malaysia is still comparatively new when viewed globally and in order to identify where the country stands in this field requires evaluating the scientific developments achieved to date.

The earliest oceanographic expeditions in the Malayan waters

Zooplankton in Malaysia have historically been examined through the earliest expeditions passing through the Western Pacific including the H.M.S. Challenger in 1874, the Voyage Scientifique dans l'Archipel Malais in 1890, Valdivia in 1898–1899, Siboga and Albatross which made their voyage from 1899–1900 and again in 1904–1905, the Tera Nova in the 1910–1911, Carnegie, Dana and Snellius which made their voyage between 1928–1930, and the Galanthea during 1950–1952. These expeditions have almost invariably worked on areas from the east of Borneo to the West of Sumatra, focusing primarily on taxonomic listing of zoo-

plankton species. However, publications from these expeditions were not continuously done; instead they appeared only from time to time and over an extended period.

Taxonomic records and biodiversity

One of the earliest studies of copepods in Malaysian waters was conducted by Sewell (1933) who collected calanoid copepods from the vicinity of Penang and the Sungai Kurau estuary (Perak) in the Straits of Malacca. He identified 19 species of calanoid copepods. In the mid 1950's (1955–1956) Wickstead (1961) completed a quantitative and qualitative collection of plankton in the Malacca Straits–Singapore Strait–South China Sea areas. In the early 70's Chong and Chua (1973) studied cyclopoid copepods from the family Oithonidae. They found *O. simplex*, *O. attenuata*, *O. plumifera*, *O. rigida*, and *O. nana* to be common in general, and *O. rigida* was especially abundant in the Straits of Malacca. This was followed by Arvin (1977) who published a literature on the marine zooplankton of Malaysia. However, this was a simple guide to the common zooplankton and his description on copepods was very brief. Another study conducted by Othman (1988) at 130 km off Kuala Terengganu in the exclusive economic zone in the South China Sea identified 74 species of copepods in which *Paracalanus denudatus* was dominant followed by *Oithona plumifera* and *Oncaea clevei*. In addition, Othman (1988) published results of his taxonomic research on copepods concentrating on the family Pontellidae, from which *Labidocera jaafari* (Othman 1986) was described as new to science.

In the early 1990's, Salim (1993) conducted a study in seagrass areas located off Pulau Sibul, Johor. He identified 12 copepod genera including *Eucalanus*, *Eucheta*, *Centropages*, *Paracalanus*, *Oithona*, *Oncaea*, *Corycaeus*, *Clytemnestra*, *Euterpina*, and *Macrosetella*. He also reported that Calanoida was the most dominant group contributing to 35–45% of all copepods, followed by Cyclopoida (23–33%), Harpacticoida (15%) and others (18%) which consisted mostly of nauplii and immature copepodids. Idris et al. (1995) reported five species of planktonic harpacticoid copepods from four genera, all of which were found in the Straits of Malacca. Another study conducted in seagrass and coral reef areas identified 30 species of calanoid copepods representing 15 genera and 13 families (Idris and Mohd Affandy 1998). Amphipods were recently studied by Azman and Othman (2006), Othman and Morino (1995, 2006), Othman and Azman (2007) and Lim et al. (2010), adding new taxonomic records to the growing list of species found on the east coast of Malaysia. Preliminary notes on a collection of amphipods were made for Redang Island (Azman and Othman 2006) while a taxonomic list of Melitoid amphipods was created for the South China Sea (Lim et al. 2010). A new species of Liljeborgiidae and Talitridae was described from the Malacca Straits (Othman and Morino 2006) and Tioman Island (Othman and

Azman 2007), respectively.

Zooplankton ecology and distribution

While studies on taxonomic records and diversity were common in the 1980–90s, zooplankton research has advanced further into the investigation of ecology and distribution. Towards the end of the 90's Idris et al. (1999) conducted a twelve-month study on the population dynamics of planktonic copepods in the coastal waters off Port Dickson, where a total of 36 species were identified. The copepod density showed an increasing trend from the northeast (NE) monsoon (October–February) to southwest (SW) monsoon (April–August) with the highest peak during the SW monsoon period. In addition, four distinct populations were observed throughout the 12-month period. The first group comprised the dominant genera such as *Paracalanus*, *Euterpina*, *Acrocalanus* and *Oithona* which maintained a high density throughout the year. The second group consisted of *Acartia* and *Microsetella* with moderately high densities. The third group comprised of less dominant genera *Acrocalanus*, *Clausocalanus*, and *Corycaeus* with low densities throughout the year. The fourth group consisted of rare genera *Subeucalanus*, *Labidocera*, *Candacia* and *Temora* which occurred only in restricted periods of the year. Another study conducted in the coastal waters off Port Klang, Selangor, identified 35 species of copepods of which the family Paracalanidae was dominant (Johan et al. 2002). Another study conducted by Rezai (2002) in the coastal waters off Port Dickson identified 80 species of copepods, of which *Paracalanus parvus*, *Parvocalanus elegans*, *Oithona simplex*, *O. oculata*, *Euterpina acutifrons*, *Corycaeus andrewsi*, *Acrocalanus gibber* and *Acartia pacifica* were most abundant.

An ecological study of zooplankton was carried out in the east coast of Peninsular Malaysia from 2002 to 2005 where samples were collected from a total of 105 stations along 19 transects laid 60 km seaward around the coasts of Terengganu, Pahang and Johor (Zaleha et al. 2006a). The observed temporal variation in zooplankton density and composition was not entirely attributed to the monsoon season and the importance of harpacticoid copepods in the zooplankton biomass was suggested. Zaleha et al. (2006b) examined further the harpacticoid copepods from these areas and found 12 species belonging to eight families and ten genera. The harpacticoid copepods were significantly less abundant in Terengganu and Johor than in Pahang coast. The copepod species composition and distribution were also studied in the estuarine mangroves of Pahang (Zaleha et al. 2008) where 25 species from 17 families were identified. The influence of seawater input into the estuaries was suggested to cause differences in the species composition and copepod groups with similar distributional patterns were related to salinity regimes. Results also indicated the importance of estuaries as a shelter for coastal species.

The zooplankton in the Malacca Straits have been extensively studied by Rezai et al. (2003a, 2003b, 2004, 2005, 2009). The patterns of zooplankton distribution were studied using samples collected in vertical hauls (140- μm mesh) during four oceanographic cruises in the Straits of Malacca from November 1998 to August 2000 (Rezai et al. 2003a). The average zooplankton biomass was higher during the SW monsoon than the NE monsoon. Higher zooplankton biomass occurred in the central region of the Straits although the spatial and temporal variations in biomass were not significant. Rezai et al. (2004) further examined the distribution of planktonic copepods and identified 117 species, of which 9 species were new records for the Straits of Malacca. Two copepod communities each characteristic to the northern and southern areas of the Straits were distinguished. The shallow southern area was characterized by the community with high abundance and low species diversity index with the dominance of a few coastal species such as *Euterpina acutifrons*, *Oithona simplex*, and *Paracalanus parvus*. The deeper waters of the northern area were characterized by low abundances, high species diversity index, and the presence of epipelagic species belonging to oceanic communities. An analysis of similarity (ANOSIM) indicated differences in communities between monsoon periods (Rezai et al. 2005). Copepods were the most important constituents of the zooplankton in all areas and accounted for 58–71% of the total zooplankton populations during consecutive cruises (Rezai et al. 2009). The study of mercury concentrations in mixed zooplankton from the Straits was also carried out by Rezai et al. (2003). They found total mercury levels ranging from 1.12 to 4.68 ng dry weight g^{-1} with a mean of 2.08 ± 0.25 ng dry weight g^{-1} and showed a decreasing trend from nearshore to offshore areas. Although the total mercury content was higher in the southern part of the Straits it was concluded that the zooplankton in the Malacca Straits were not heavily contaminated with mercury.

Another study involved investigating the seasonal variation of zooplankton community at a fixed station in the Straits of Malacca where sampling was carried out monthly by vertical hauls of a 140- μm plankton net from June 2002 to May 2004 (Yoshida et al. 2006). The copepods of the genera *Acartia*, *Acrocalanus*, *Paracalanus*, *Euterpina*, *Corycaeus* and *Oithona* accounted for approximately 90% of the total copepod population throughout the year, indicating the importance of small species in tropical zooplankton communities. Zooplankton biomass generally peaked at the beginning of each monsoon and gradually decreased toward the intermonsoon periods and showed a weak correlation with increasing ambient chlorophyll-*a* concentrations. Cluster analysis of zooplankton abundance showed two distinct groups corresponding to the SW and NE monsoons. The populations of *Acartia pacifica* and *A. spinicauda* showed alternating peaks throughout the year, with *A. pacifica* appear-

ing primarily during the NE monsoon and *A. spinicauda* during the SW monsoon.

Zooplankton in coral reefs was studied extensively in recent years by Nakajima et al. (2006, 2008, 2009). Observation of size-fractionated zooplankton indicated predominance of larger zooplankton, which showed stronger diel vertical migration than smaller ones, and the possibility of coral mucus as a potential food source for reef zooplankton (Nakajima et al. 2006). Increases in the biomass of larger zooplankton later at night (3 a.m.) in the coral reefs of Redang and Tioman Island may have been caused by the advection of pelagic species into the reef (Nakajima et al. 2008, 2009). These studies have demonstrated that changes in zooplankton communities over coral reefs take place on a scale of hours. Nakajima et al. (2010) also examined the bias in the estimation of zooplankton biomass in net-samples in coral reef waters by measuring seston weight containing non-living matter and net-phytoplankton in addition to zooplankton. Seston weight was on average 2.2 times higher than net-zooplankton biomass, and non-zooplankton content (detritus/phytoplankton) contributed on average 49.2% to the seston weight, indicating the measurement of net-plankton seston weight is inadequate due to the possibility of over-estimation of zooplankton biomass.

Experimental zooplankton biology and physiology

Physiological responses of organisms to the environment dictate tolerance limits and define favorable conditions for the optimal energy balance of the species. Due to increasing importance of copepods as live feed for tropical aquaculture, research on the biology and physiology has become increasingly important. The effect of experimental environmental parameters on the reproduction and development of a tropical marine harpacticoid copepod *Nitocra affinis* f. *californica* Lang was observed by Matias-Peralta et al. (2005). The highest ($p < 0.05$) overall reproduction and fastest development time were achieved by copepods reared under the salinity of 30–35 and the optimum temperature required for the maximum reproduction was 30°C. The overall reproduction was highest ($p < 0.05$) and development rate of *N. affinis* was shortest ($p < 0.05$) under lowest experimental light intensity (25 $\mu\text{mol m}^{-2} \text{s}^{-1}$). Although *N. affinis* is tolerant to a wide range of environmental conditions, prolonged exposure to subnormal environments affects its reproduction and development. The possibility of mass culture for commercial purposes and use in toxicity studies is promising due to its high reproduction, fast development and tolerance to a wide range of environmental conditions.

The potential utilization of the copepod *Apocyclops den-gizicus* as live feed has been tested by Farhadian et al. (2007, 2008, 2009a, b). First, the species was found to be a suitable live feed for *Penaeus monodon* larvae (Farhadian et al. 2007) as the shrimp ingested *Apocyclops* selectively over *Artemia*

and the body dry weight of larvae fed the former was higher than those fed the latter. Second, a feeding experiment using various diets including monoalgal, mixed algal and non-algal diets revealed that the type and density of diet had significant effects on the growth and density of *A. dengizicus* (Farhadian et al. 2008). Of the tested diets, *Tetraselmis tetrahele* and a mixture of *Chaetoceros calcitrans*+*T. tetrahele* proved to be optimum with higher density and growth rate of *A. dengizicus* than other diets. Third, the survival rate and nutritional composition of the copepod was found to meet the requirements of fish and shrimp larvae. Coupled with the ease for mass culture, *Apocyclops* makes an economically viable replacement of *Artemia* cysts (Farhadian et al. 2009a, b).

Studies on the physiology on *Acartia* spp. were carried out in an effort to understand its contribution to zooplankton biomass in the Straits. Prey size and concentration of food particles on the egg production of *A. pacifica* was examined experimentally by Eio et al. (2007). Their results revealed the copepods' preference for larger prey size indicated by significantly higher ingestion rates. Egg production, however, was not related to prey size and carbon demand by the copepod could be met by metabolic regulation of carbon transfer to eggs. The vertical distribution of *A. erythraea* was observed by Liong et al. (2007), where underwater light intensity did not show significant relationship with the vertical distribution of copepods in the Straits. It is discussed that this could be characteristic of shallow coastal waters where turbidity levels and vertical mixing are high and variable. The effort required to orientate with underwater light variation in such conditions may be of little advantage to offset predation risk and acquisition of foods.

Other zooplankton research

Stable isotopes of carbon and nitrogen are increasingly used in ecological and environmental studies. Iwasaki et al. (2001) used stable isotope to identify food web integrators which helped in elucidating the structure of trophic webs in the tropical coral reef ecosystem of Tioman Island, Malaysia. They found that the main carbon sources for organisms at higher trophic levels such as reef fishes and macrobenthos were zooxanthellae and seaweeds, with minor contribution from the plankton and terrestrial plants. In order to understand the role of zooplankton contribution in such environmental studies, future works on stable isotope identification in various marine ecosystems (e.g. seagrass and mangrove areas) is encouraged. Stable isotopes, as experimental tracers, allow the study of many aspects of nitrogen and carbon cycles at the scale of a single species or at the scale of the whole ecosystem.

Conclusions

The importance of researches on tropical zooplankton in understanding processes in the marine ecosystem has in-

creasingly been recognized, which is particularly the case in Malaysia which encompasses a 'hotspot' of marine biodiversity. Research at both large and small scales has been limited due mainly to technical difficulties but recent technological developments are expanding the horizons of researches at these scales. Some of the principal issues on future advances in tropical zooplankton research include (1) determination of how environmental variability, rather than mean conditions, affects physiology and behavior; (2) relation of growth rates and production to environmental conditions; (3) determination of nutritional sources and requirements; (4) long term observations of population and community dynamics which would permit analysis of inter-annual variability and effects of climate change; (5) a critical need to maintain expertise in taxonomy; and (6) development of mathematical models encompassing biological, chemical and physical parameters. Zooplankton research is being conducted by individual investigators working largely independently with a wide range of perspectives. Continued efforts in multidisciplinary activities and multilateral collaborations in the region is necessary to enhance communication, outline similar goals and areas of future study, and significantly accelerate the zooplankton research in Malaysia.

Acknowledgments

We thank the many people who contributed to the material presented in this paper. Thanks are also due to the Multilateral Core University Program "Coastal Marine Science" (2001–2010) of the Japan Society for the Promotion of Science (JSPS), which supported many recent collaborative researches on marine zooplankton in Malaysia as reviewed in this paper. Thanks are extended to the project members for their collaboration through the project, and encouragements and useful information for the preparation of this review.

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