JARQ 41 (2), 163 – 172 (2007) http://www.jircas.affrc.go.jp

Diversity and Community Structure of Macrobenthic Fauna in Shrimp Aquaculture Ponds of the Gulf of Thailand

Yoshimi FUJIOKA[1]*, Toru SHIMODA[2] and Chumpol SRITHONG[3]

[1] Fisheries Division, Japan International Research Center for Agricultural Sciences (JIRCAS) (Tsukuba, Ibaraki 305–8686, Japan)
[2] Ishigaki Tropical Station, Seikai National Fisheries Research Institute (Ishigaki, Okinawa 907–0451, Japan)
[3] Faculty of Fisheries, Kasetsart University (Chatuchak, Bangkok 10900, Thailand)

Abstract

To compare the diversity and community structure of macrobenthic fauna inhabiting shrimp aquaculture ponds, quantitative samplings using a multilayer cylinder were carried out in culture experimental ponds at Samut Songkhram, along the innermost part of the Gulf of Thailand. A total of 25 species/taxa of macrobenthic organisms were identified from the six aquaculture ponds; four ponds used for active shrimp (*Penaeus monodon* Fabricius) culture and two ponds planted with mangrove stands (*Rhizophora mucronata* Lamarck). The dominant species belonged to three taxonomic categories; that is, (1) sedentary, tube-dwelling spionid, *Polydora* sp., free-living nereid, *Perinereis* sp., and some other polychaetes (Annelida), (2) gastropods such as *Cerithidea cingulata*, *Cerithium coralium*, *Thiara riqueti*, and *Stenothyra* spp. which live on the surface or in the shallow layer of the substratum (Mollusca), and (3) barnacles, *Balanus* sp., and some small arthropods such as ostracods, copepods, harpacticoids, amphipods, and dipterans (Arthropoda). Maximum density and biomass exceeded 10,000 individuals/m^2 and 600 g/m^2, respectively, and gastropods were the most dominant and representative taxa in most of the ponds. Species composition was clearly distinguished between the shrimp culture ponds and the mangrove planted ponds. Population density, species richness and species diversity indices of macrobenthic organisms in the bottom of the mangrove planted ponds were significantly higher than those of the shrimp culture ponds, suggesting that mangrove was important for maintaining and increasing the biodiversity. There was a tendency that epibenthic mollusks and arthropods decreased evidently as the depth increased from the surface to the deeper layers, while annelids were found not only in the surface layer but also in the moderately deeper layer. A possibility that *Penaeus monodon* fed on some macrobenthic organisms under the cultured conditions was discussed.

Discipline: Fisheries
Additional key words: benthos, field survey, giant tiger prawn, invertebrate, mangrove, *Penaeus monodon*

Introduction

Coastal aquaculture in mangrove swamps has developed rapidly during the two decades since the middle of the 1980's, and the production of cultured prawns has increased greatly in the Kingdom of Thailand as well as in other Southeast Asian countries. The over-intensive utilization of brackish water areas has resulted in the destruction of many mangrove ecosystems and in water pollution affecting the culture ponds and adjacent coastal areas[1–3,15]. In order to develop rational and sustainable utilization of mangrove ecosystems, it is necessary to carry out studies relating to the practical use of coastal aquaculture systems that are compatible with the preservation of the environment. For this purpose, we are studying the benthic organisms inhabiting in brackish mangrove swamps as a potential food source for fisheries products.

This paper reports the results obtained by the Japan International Research Center for Agricultural Sciences (JIRCAS) Research Project "Studies on sustainable production systems of aquatic animals in brackish mangrove areas" (2001–2005, Kasetsart University, Thailand).
*Corresponding author: e-mail fujioka@affrc.go.jp
Received 22 August 2005; accepted 15 August 2006.

A lot of pieces of research have been conducted concerning the macrobenthic fauna in mangrove ecosystems[1,7,8,10,12]. However, research concerning the benthic fauna inhabiting aquaculture ponds has rarely attracted attention except for commercial species, nevertheless benthic organisms play important roles in the maintenance of conditions for aquaculture[2,9,13,19] and adjacent coastal ecosystems[1,4,5,7,8,10–12]. Adequate knowledge of trophic interactions among food webs within the aquaculture ponds, rates of detrital decomposition by benthos, estimates of secondary production including commercial species such as prawns and fishes is still lacking, despite the fact that such knowledge is necessary to properly assess the energetic role of benthos in aquaculture ecosystems.

Considering the environment of artificial and/or semi-artificial aquaculture ecosystems to maintain sustainable production, it is of principal importance to understand and describe the species richness, abundance of each species and community structure of macrobenthic fauna inhabiting aquaculture farms. As the first step for this study, we detail here the initial results on the biodiversity and community structure of macrobenthic fauna inhabiting aquaculture farms by quantitative sampling in the Samut Songkhram shrimp culture ponds.

Materials and methods

To compare the diversity and community structure of the macrobenthic fauna inhabiting the shrimp aquaculture ponds, quantitative field investigations were carried out on February 9–12, 2004. This period was the middle of the dry season in Thailand. Samplings were performed in six experimental ponds of the Samut Songkhram Fisheries Research Station (13°26.3′N, 100°03.5′E), Faculty of Fisheries, Kasetsart University. Samut Songkhram Province is situated along the innermost part of the Gulf of Thailand, and the station is located at about 90 km westward from Bangkok and about 3 km onshore from the coastal area. In this area, most of the original mangrove forests had been reformed and converted to shrimp ponds, and the replanted mangrove forests are developed on the seaward mudflat[11].

The experimental ponds were 40 m × 20 m in the upper level and 35 m × 15 m in the lower level with a depth of about 1.5 m (Fig. 1). Giant tiger prawns (*Penaeus monodon* Fabricius) were cultured in four ponds (Ponds 1–4) during about five months before this survey, and about 400 mangrove stands (*Rhizophora mucronata* Lamarck) were planted in the two other ponds (Ponds 5–6) in July, 2002. Shrimps were not cultured in the mangrove planted ponds (Ponds 5–6), but the ponds were used to purify the waste water of shrimp culture ponds for prior experiments[6]. The shrimp culture ponds were filled with water to a depth of 100 cm. In the mangrove ponds, the water was repeatedly allowed to dry up and then once a week re-submerged up to about 50 cm in depth. Thereby, the environment of the shrimp culture ponds (Ponds 1–4) might be similar to that of the so-called "intensive culture system[14,18] (high-density shrimp culture system with artificial feed)", while the environment of the mangrove planted ponds (Ponds 5–6) are partly comparable to that of the so-called "extensive culture system[14] (low-density shrimp culture system with natural feed)" or natural mangrove swamps.

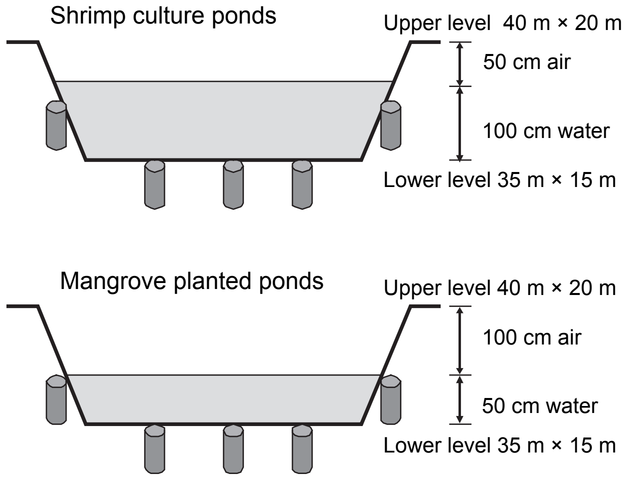

Fig. 1. Diagram showing sampling points in the Samut Songkhram experimental ponds
Cylindrical markers indicate the sampling positions.

Sampling positions in the ponds are shown in Fig. 1. For quantitative sampling of macrobenthic organisms in each pond, replicate samples from three parts of the bottom (northern, central and southern part of every pond) and at two locations on the slope (*ca.* 50 cm height from the bottom) of each pond were collected. Soils and sediments were collected from the surface to the depth of 15 cm with three layers each of 5 cm; that is, 0–5 cm, 5–10 cm, and 10–15 cm, using a multilayer PVC cylinder with an inner diameter of 8 inches (20.4 cm) and cross-sectional area of *ca.* 327 cm^2.

Collected soils and sediments were preserved with 10% neutralized formalin solution and sieved using a 500 µm mesh sieve. Macrobenthic specimens were identified to the possible lowest taxonomic category. The total weight of each species was measured using an electric balance after being picked out from the residue under a dissecting stereo microscope.

Population density and biomass were calculated as the number of individuals (n/m^2) and the wet weight (g/

m²) per square meter, respectively, for each species/taxon. Species richness (number of species) and species diversity index were calculated for every pond. Species diversity was calculated using the Shannon-Weaver Index $H' = -\sum(n/N)\log(n/N))$, which uses logarithmic base 2, where 'n' is the number of individuals for each species, and 'N' is the total number of individuals. Similarity of species composition was calculated using the Jaccard Index CC (coefficient of community) = $c/(a + b - c)$, where 'a' and 'b' are the number of species in each sample, and 'c' is the common number of species. Cluster analysis based on similarity of species composition was calculated by the unweighted pair-group method using arithmetic average (UPGMA) by means of the application software "Statistica (Statsoft Inc.)". The results were expressed as a dendrogram among all samples.

The identification of the species of the phylum Annelida was based on comments by E. Nishi (personal communication). The taxonomic study on the species of the phylum Mollusca has been described in detail in another publication (Fujioka & Kurozumi, in preparation).

Results

A total of 25 species/taxa of macrobenthic organisms (including nematodes) were identified from the shrimp aquaculture ponds (Ponds 1–4) and the mangrove planted ponds (Ponds 5–6) as shown in Table 1. A total of 6–12 species were recorded in the shrimp culture ponds, while 17–19 species were found in the mangrove planted ponds. They consisted of four major taxa; that is, the phyla Nematoda, Annelida, Mollusca, and Arthropoda. All species of annelids belonged to the class Polychaetes and all

Table 1. Faunal list of macrobenthic organisms collected from Samut Songkhram shrimp aquaculture ponds

	Pond 1 Aquaculture	Pond 2 Aquaculture	Pond 3 Aquaculture	Pond 4 Aquaculture	Pond 5 Mangrove	Pond 6 Mangrove
Nematoda	○	○	○	○	○	○
Annelida						
Polydora sp.	○	○	○	○	○	○
Perinereis sp.	○		○	○	○	○
Sigambra phuketensis	○				○	○
Mediomastus sp.						○
Laonome sp.					○	
Capitellidae			○	○	○	
Mollusca						
Cerithium coralium	○			○	○	○
Thiara riqueti	○		○		○	○
Melanoides tuberculata	○		○			
Cerithidea cingulata	○	○	○	○	○	○
Rissoina sp.	○				○	
Assiminea brevicula	○			○	○	○
Stenothyra ovalis	○	○	○	○	○	○
Stenothyra glabrata					○	○
Stenothyra sp.						○
Mactra cuneata						○
Arthropoda						
Ostracoda					○	○
Copepoda					○	
Harpacticoida		○		○	○	○
Balanus sp.	○	○	○	○	○	○
Amphipoda			○			
Isopoda					○	
Tanaidacea				○		
Chironomus sp.					○	○
	12	6	10	11	19	17

Replicate samples were collected quantitatively five times using a multilayer PVC cylinder with 8 inch inner diameter.

species of mollusks except for *Mactra cuneata* (Gmelin) belonged to the class Gastropoda.

Representative species/taxa observed in all the ponds from Pond 1 to Pond 6 were *Polydra* sp. (spionid polychaeta), *Cerithidea* (*Cerithideopsilla*) *cingulata* (Gmelin) (gastropod snail), *Stenothyra ovalis* Brandt (ditto), and *Balanus* sp. (barnacle), in addition to some unidentified nematodes. *Perinereis* sp. (nereid polychaeta), *Thiara* (*Sermyla*) *riqueti* (Grateloup) (gastropod snail), *Cerithium coralium* Kiener (ditto), and *Assiminea brevicula* (Pfeiffer) (ditto) were also common species as well as harpacticoids observed from four or five out of the six ponds. Only a few meiobenthic Nematoda and Ostracoda remained in the residue as most of the specimens passed through the 500 µm mesh sieve.

Thus, the dominant macrobenthic organisms living in the Samut Songkhram aquaculture ponds were classified into the following three categories; that is, (1) sedentary, tube-dwelling spionid, *Polydora* sp., free-living nereid, *Perinereis* sp., and some other polychaetes (Annelida), (2) gastropods such as *Cerithidea cingulata*, *Cerithium coralium*, *Thiara riqueti*, and *Stenothyra* spp.

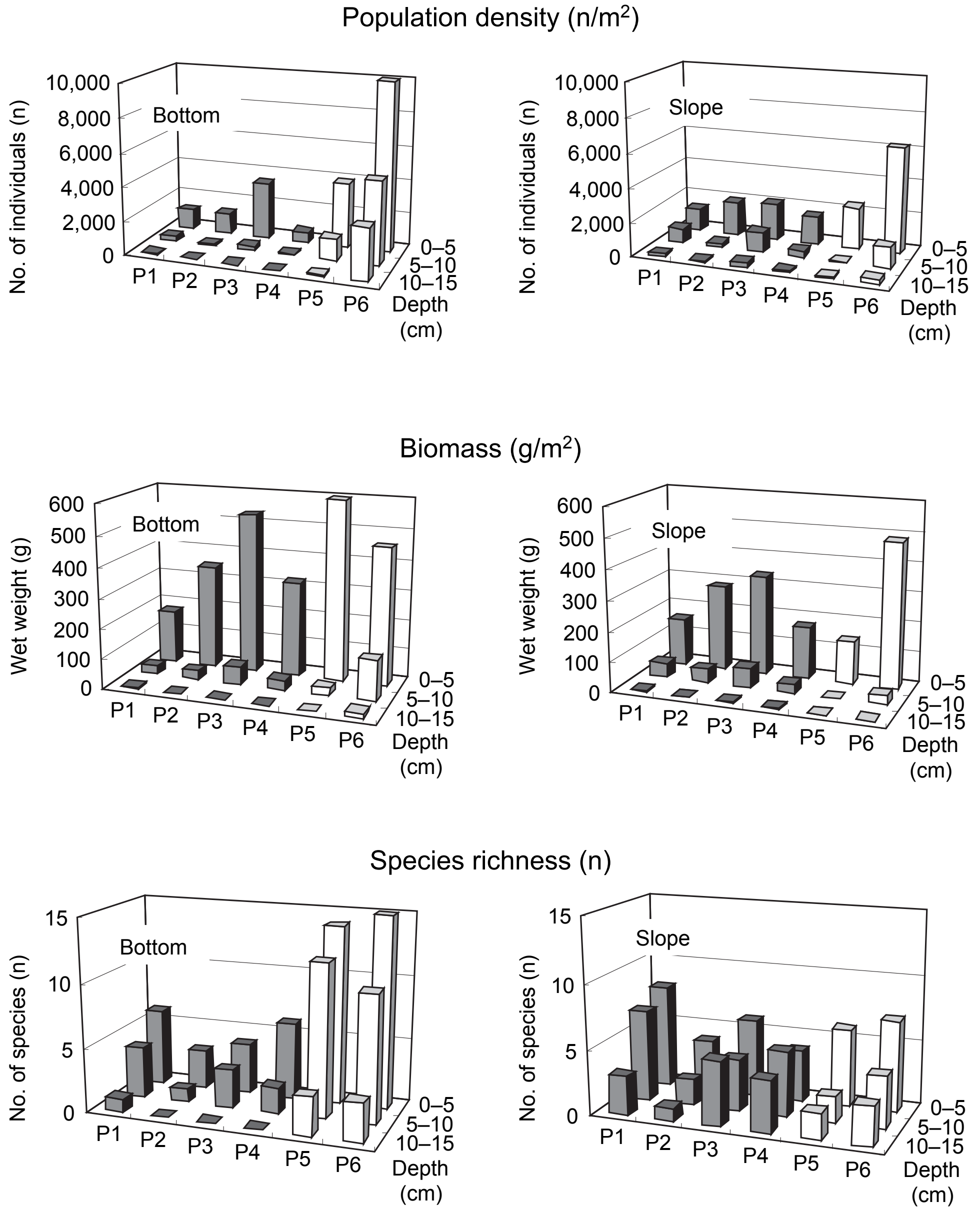

Fig. 2. Population density (upper), biomass (middle) and species richness (lower) of the macrobenthic organisms in the Samut Songkhram experimental ponds

Data of the bottom (left) and slope (right) are separately shown. Ponds 1–4 were the shrimp culture ponds, and Ponds 5–6 were the mangrove planted ponds.

which live on the surface or in the shallow layer of substratum (Mollusca), and (3) barnacles, *Balanus* sp., and some small arthropods such as ostracods, copepods, harpacticoids, amphipods, and dipterans (Arthropoda).

Population density (number of individuals), biomass (wet weight), and species richness (number of species/taxa) of macrobenthic organisms are compared in Fig. 2, in which the data for the bottom (left figure) and the slope (right figure) of ponds are shown separately. Population density and species richness exhibited a significant difference for the bottom between the shrimp culture ponds and the mangrove planted ponds (t-test: $t = 2.446$ $p < 0.05$ and $t = 11.314$ $p < 0.01$, respectively). On the slope of the ponds, however, population density, biomass and species richness were not significantly different between the shrimp culture ponds and the mangrove planted ponds (t-test: $t = 1.538$ $p > 0.05$, $t = 0.320$ $p > 0.05$ and $t = 0.00$ $p > 0.05$, respectively).

The population density and the biomass were very high for the bottom of the mangrove planted ponds in which the maximum density and biomass exceeded 10,000 individuals/m^2 and 600 g/m^2, respectively, including a lot of juveniles. They were highest in the surface layer of 0–5 cm and decreased largely as the depth increased from 5–10 cm to 10–15 cm. There were only a small number of macrobenthic organisms in the deepest layer (10–15 cm).

Taxonomic composition based on population density (number of individuals) and biomass (wet weight) of the three major categories of macrobenthos, Annelida, Mollusca and Arthropoda, found in experimental ponds are compared in Fig. 3. In the layer near the surface, 0–5 cm deep, mollusks were the most dominant of all taxa and comprised 28.6–84.1% of the total number of individuals and 81.7–98.9% of the wet weight of all macrobenthic organisms. The composition of taxa was sometimes changed due to the great abundance of a few dominant species such as barnacles, *Balanus* sp., in Pond 2, and gastropod, *Stenothyra* spp., in Pond 6. Arthropods including barnacles, crustaceans and insects ranked second, comprising 13.2–71.0% of the total number of individuals but only 0.98–18.2% of the wet weight of all macrobenthic organisms. Annelids (polychaete worms) ranked third comprising about 0.36–11.7% of the total number of individuals and only 0.04–0.52% of the wet weight of all macrobenthic organisms. Nematodes occurred in small numbers and biomass. When compared by wet weight, some gastropods and barnacles resulted in higher rates than by the number of individuals because of their heavy calcareous shells. On the other hand, comparison by wet weight for annelids resulted in lower rates though they dominated numerically because they are small and light.

There was a clear tendency that mollusks and arthro-

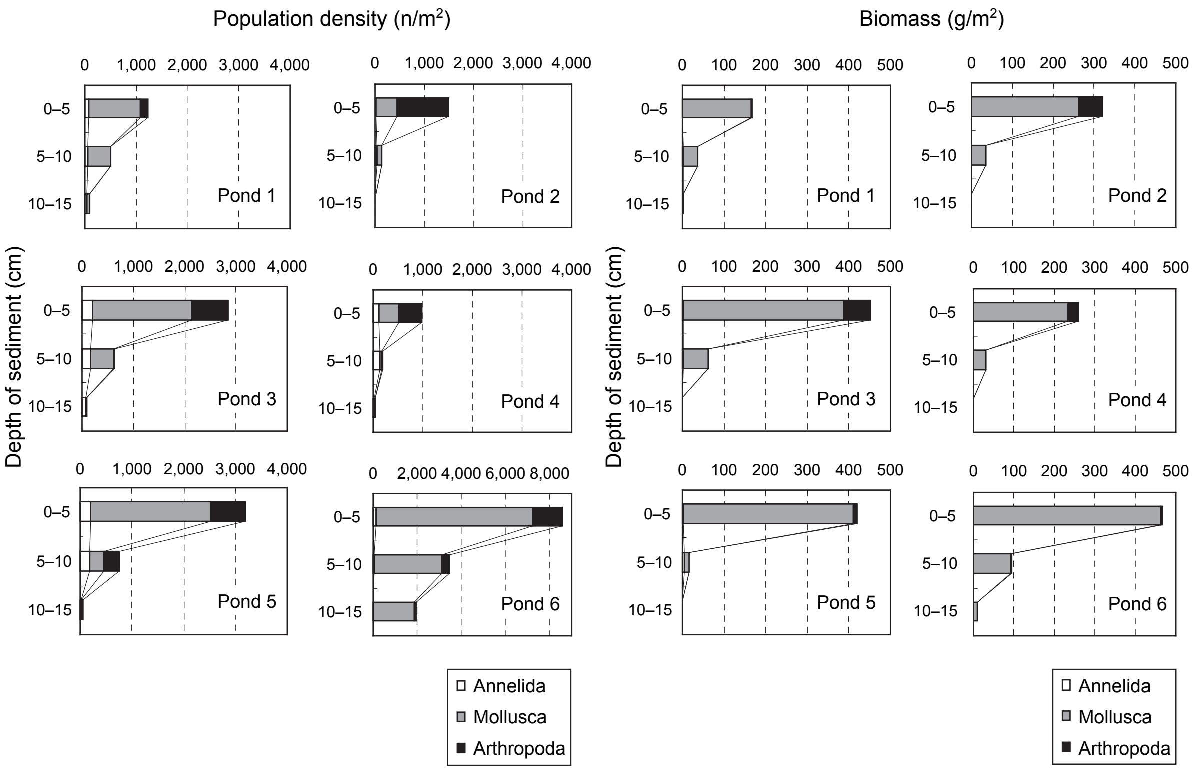

Fig. 3. Population density (left) and biomass (right) of three major taxonomic categories of macrobenthos, Annelida, Mollusca and Arthropoda, found in the Samut Songkhram experimental ponds

pods decreased as the depth increased from the surface layer (0–5 cm) to deeper layers (5–10 cm and 10–15 cm). On the other hand, annelids were found not only in the surface layer (0–5 cm) but also in the moderately deeper layer (5–10 cm).

Species diversity indices based on population density (H'n) and biomass (H'w) of macrobenthic organisms in the experimental ponds are compared in Fig. 4. Species diversity indices of the surface layer ranged from 0.83–1.80 and 0.13–1.03 in the bottom and 0.68–2.29 and 0.28–1.52 in the slope of the ponds, respectively. Species diversity indices of the bottom of the ponds of the mangrove planted ponds (Ponds 5–6) were significantly higher than those of the shrimp culture ponds (Ponds 1–4) (t-test: H'n $t = 2.991$ $p < 0.01$, H'w $t = 2.508$ $p < 0.05$). The difference was clearer in the deepest layer (10–15 cm) because there were few organisms in this layer of the shrimp culture ponds. Species diversity in the bottom decreased as the depth increased from the surface layer (0–5 cm) to the deepest layer (10–15 cm). Whereas, species diversity of the slopes was not different between the mangrove planted ponds and the shrimp culture ponds.

Population densities of eight dominant species found in experimental ponds are separately shown in Fig. 5. *Cerithidea cingulata* was the most dominant and representative species of all macrobenthic organisms, and reached more than 2,000 individuals/m^2, in which a considerable number of small juvenile snails just after settlement were included. Although the population densities of *Cerithium coralium* and *Thiara riqueti* were not numerically large, they were frequently found in four out of the six ponds. *Stenothyra ovalis* exhibited a highly aggregated distribution pattern, and the mean population density reached more than 10,000 individuals/m^2 in Pond 6. *Polydora* sp. inhabited all ponds, and the population density was about 100–300 individuals/m^2 in Ponds 3–6. *Perinereis* sp. was also found frequently in four out of the six ponds, especially in the mangrove planted ponds. Because the barnacle *Balanus* sp. attached to hard substratum, they were found in the various environments such as on marking poles, water hoses and pipes, paddle wheels, mangrove roots, and on the surface of shells.

For comparing the community structure of macrobenthic organisms in the experimental ponds, a cluster

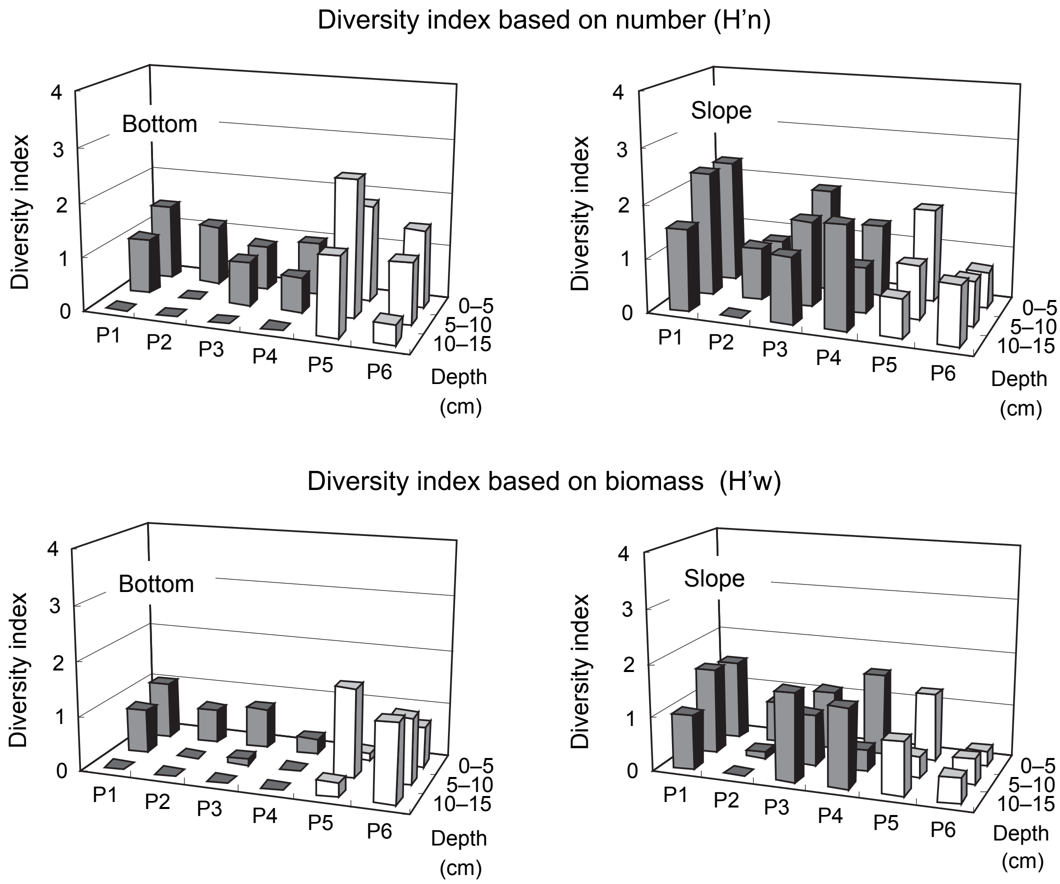

Fig. 4. Species diversity indices (Shannon-Weaver diversity index) of macrobenthic fauna in the Samut Songkhram experimental ponds

Indices were calculated based on the population density (upper) and biomass (lower).

analysis based on similarity of species composition was conducted (Fig. 6). The dendrogram showed three major groups. The data of surface (0–5 cm) and middle (5–10 cm) layers of the shrimp culture ponds (Ponds 1–4) constructed one group which was concentrated to the uppermost side of the dendrogram. Whereas, the data of surface (0–5 cm) and middle (5–10 cm) layers of the mangrove planted ponds (Ponds 5–6) constructed another group which was concentrated to the lower half side of the dendrogram. Thus the species composition was clearly separated between the shrimp culture ponds and the mangrove planted ponds with a few exceptions (*ex.* P5_S_0, P1_S_0 and P1_S_5 in Fig. 6). Furthermore, the data of the deepest layers (10–15 cm) were distinguished into the middle and the lowermost side of the dendrogram. In the deepest layers, however, the data could not be clearly separated between the shrimp culture ponds and the mangrove planted ponds.

Discussion

Dominant macrobenthos found in the Samut Songkhram aquaculture ponds were classified into three taxonomic categories of annelids, mollusks and arthropods. They are predominant not only in the Samut Songkhram aquaculture ponds but also in many other

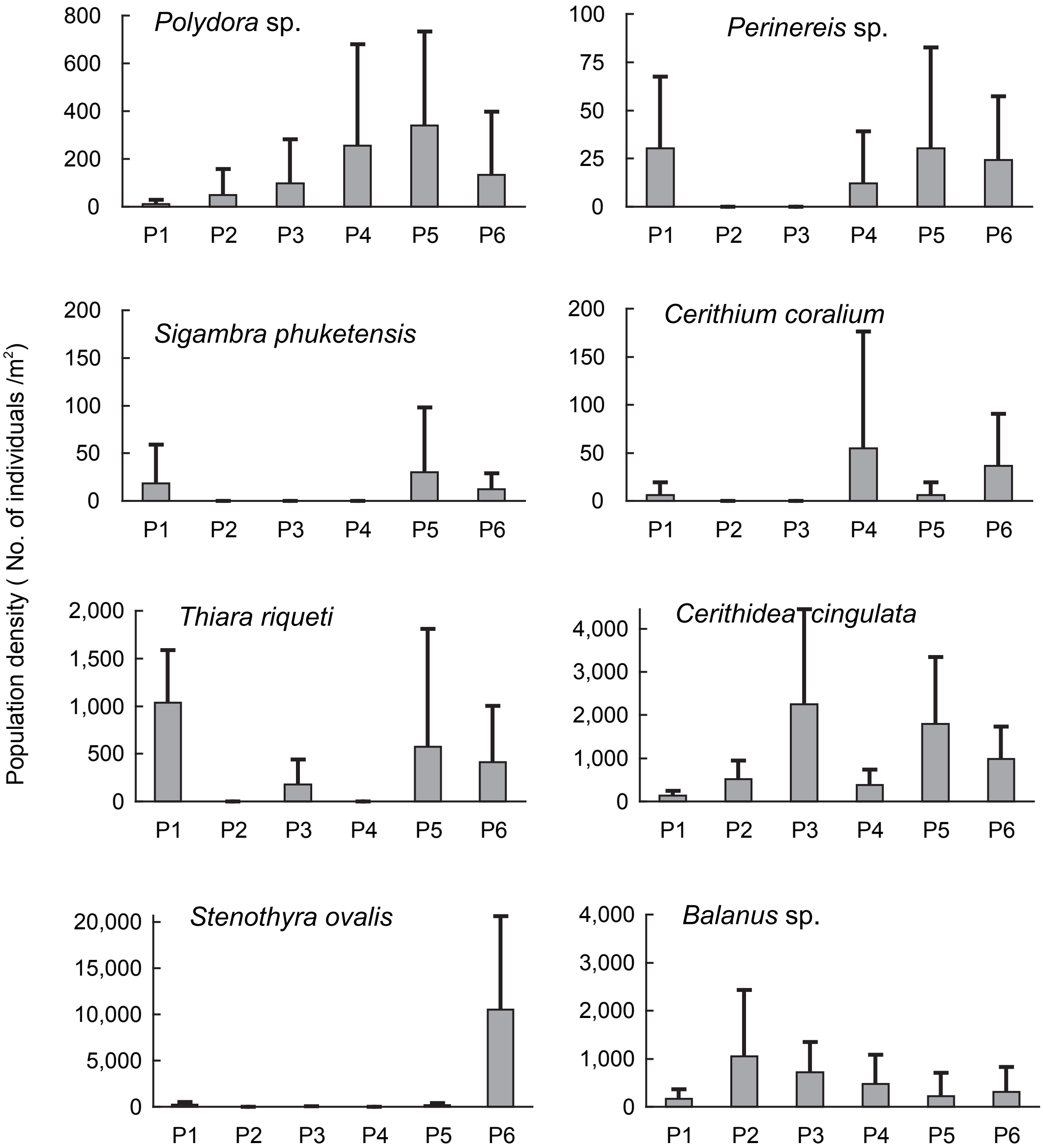

Fig. 5. Population density of the major eight macrobenthic organisms in the Samut Songkhram experimental ponds

Bars show the average of five replicates with standard deviation (SD).

coastal habitats such as mangrove swamps and the neighboring muddy flats[10,11]. The similarity of these three representative macrobenthic taxa (annelids, mollusks and arthropods) between the aquaculture ponds and the mangrove swamps is possibly related to the fact that the original mangrove forests had been reformed and converted to the shrimp ponds[11]. Thereby, the environments of the aquaculture ponds were partly maintained as those of the coastal mangrove swamps before the establishment of the shrimp culture ponds.

However, the detailed species composition and relative abundance of the macrobenthic organisms in the aquaculture ponds were considerably different from those of the nearby mangrove swamps which have been previously reported[11,16,17]. According to the ecological survey around the mangrove swamps near the present survey area, bivalves, sabellid polychaetes, sternaspid polychaetes, and ocypodid crabs were dominant in mudflats, whereas tanaid crustaceans and ocypodid crabs were abundant in the mangrove planted areas[16]. They[16] also demonstrated that gastropods (mainly ellobiid and assimineid snails) and polychaetes (*Notomastus* sp. and Nereidae spp.) were abundant in the mangrove forest. In another report[11], some gastropods such as *Cerithidea cingulata* and *Stenothyra* spp. were frequently observed in the Samut Songkhram coastal areas. In the present study, *Cerithidea cingulata*, *Cerithium coralium*, *Thiara riqueti*, *Stenothyra* spp. (gastropods), *Polydra* sp., and *Perinereis* sp. (polychaetes) were dominant in the aquaculture ponds. Therefore, there was only a few species which were predominantly distributed both in the mangrove swamps and in the aquaculture ponds.

As productivity of mangroves is very high, mangrove ecosystems can contain a considerable amount and variety of benthic organisms with a high diversity[1,8,16]. In the Samut Songkhram mangrove and mud flat, a total of 122 species/taxa of macrobenthic organisms were collected[16]. They suggested that mangrove plantations played important roles for maintaining biodiversity[16]. The results of the present study supported their consideration. In this study, it was evident that the diversity of the mangrove planted ponds was relatively higher than that of the shrimp culture ponds. In the mangrove planted ponds, a variety of habitats were provided by the plantation and a large amount of leaf litters from the mangrove stands was supplied to the bottom, suggesting that mangrove was important for maintaining and increasing the biodiversity as well as the productivity.

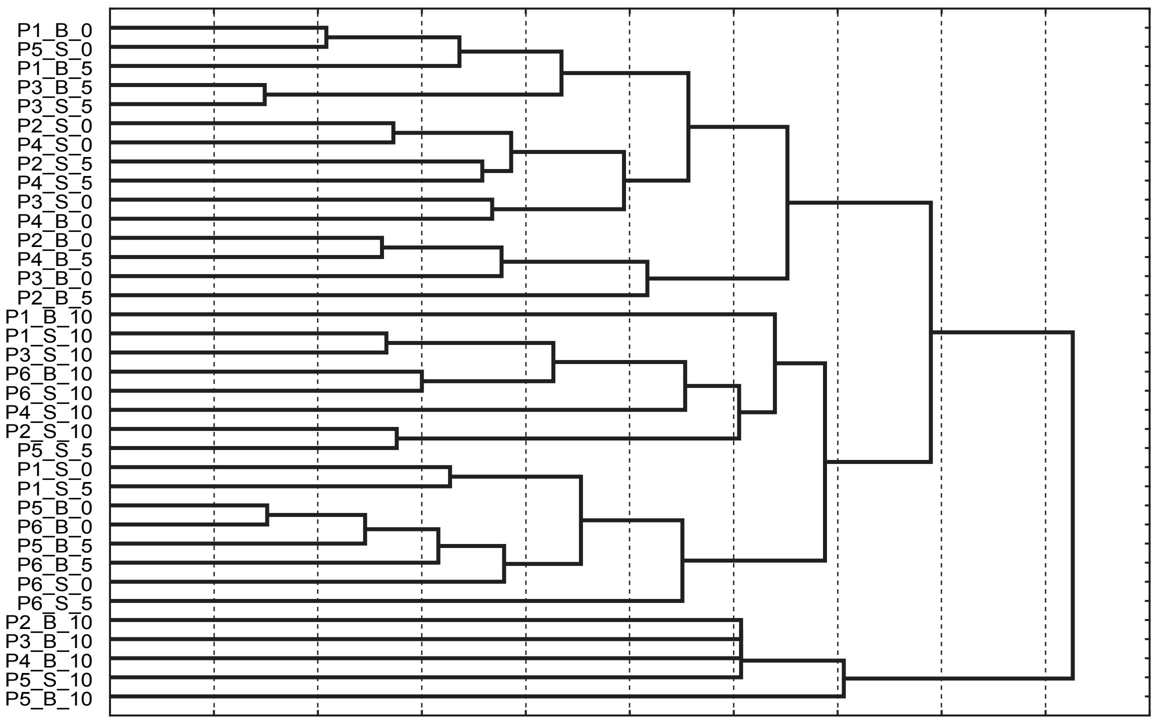

Fig. 6. Dendrogram showing the similarity of species composition based on the Jaccard index among all samples in Samut Songkhram experimental ponds

Horizontal axis indicates relative distance among samples.
P1–6: Ponds 1–6, B: Bottom, S: Slope, 0: Surface layer (0–5 cm),
5: Middle layer (5–10 cm), 10: Deeper layer (10-15 cm).

Whereas, the bottom of the shrimp culture ponds is usually flat and muddy. Irregular changes in salinity by rainfall, low oxygen content at night, high temperature at daytime, and the considerable amount of organic matter formed by shrimp production result in habitat degradation for macrobenthic organisms dwelling within. It is considered that such severe environments restrict the distribution of filter feeding bivalves and large crustaceans in the shrimp culture ponds, although they are common in the mangrove swamps[11,16,17]. Thereby, in the shrimp culture ponds, the diversity of habitats for inhabiting macrobenthic organisms is limited.

There was a clear tendency that mollusks and arthropods decreased evidently as the depth increased from the surface (0–5 cm) to the deeper layers (5–10 cm and 10–15 cm) because they were epibenthos which inhabited predominantly on the surface layer of the muddy substratum. The close similarity of macrobenthic fauna among the surface layer seems to be related to the dominance of these epibenthic organisms. On the other hand, annelids were found not only in the surface (0–5 cm) but also in the moderately deeper layer (5–10 cm) because they are endobenthos which inhabit in the muddy substratum where they bore holes with organic tubes. Thus, the vertical distribution of benthic organisms reflects clearly their respective life patterns.

Among dominant macrobenthic organisms, *Cerithidea cingulata*, *Cerithium coralium*, *Thiara riqueti*, and *Balanus* sp. were commonly observed both in the shrimp culture ponds and the mangrove planted ponds, as shown in Fig. 5. Whereas, the highest densities of *Polydra* sp., *Perinereis* sp., *Sigambra phuketensis*, and *Stenothyra ovalis* were predominantly observed in the mangrove planted ponds. Moreover, the total number of the latter four species was larger in the mangrove planted ponds than in the shrimp culture ponds, although the population densities differed largely among ponds. These species might be suitable as natural feed for the cultured shrimp, *Penaeus monodon*, because they were small organisms with soft bodies or fragile shells. In fact, *P. monodon* preferred some polychaetes and small mollusks under laboratory conditions (Fujioka, personal observation). As benthos plays an important role as the food for various species of prawns and other fishery products[2,9,13,19], there is a possibility that *P. monodon* fed on the latter four species in the aquaculture ponds. It is speculated that predation pressure by *P. monodon* resulted in a decrease in macrobenthic density and diversity of the shrimp culture ponds. If specific macrobenthic organisms become natural feed for cultured shrimp, the population dynamics during shrimp culture should be an important subject for a future study.

Acknowledgments

We are grateful to Dr. Yutaka Fukuda and Dr. Koji Nakamura, former director of the Japan International Research Center for Agricultural Sciences (JIRCAS) for supporting this project. We would like to express our sincere thanks to Taiji Kurozumi (mollusks), Chiba Central Museum, and Eijirou Nishi (polychaetes), Yokohama National University, for their assistance in identifying the macrobenthos.

References

1. Aksornkoae, S. (1993) Ecology and management of mangroves. IUCN, Bangkok, Thailand, pp.176. Available online at http://www.iucn.org/themes/marine/pdf/ecolmang.pdf.
2. Barbier, E. B. & Sathirathai, S. (eds.) (2004) Shrimp farming and mangrove loss in Thailand. Edward Elgar Publ. Ltd., Cheltenham, UK, pp.268.
3. Chantadisai, T. (1989) Environmental impact of aquaculture on mangrove ecosystem. *In* Symposium on mangrove management: its ecological and economic consideration, BIOTROP special publication no. 37, eds. Soerianegara, I. et al., SEAMEO-BIOTROP, Bogor, Indonesia, 215–223.
4. Chong, V. C., Low, C. B. & Ichikawa, T. (2001) Contribution of mangrove detritus to juvenile prawn nutrition: a dual stable isotope study in a Malaysian mangrove forest. *Mar. Biol.*, **138**, 77–86.
5. Chong, V. C. et al. (1990) The fish and prawn communities of a Malaysian coastal mangrove system, with comparisons to adjacent mud flats and inshore waters. *Estuar. Coast. Shelf Sci.*, **31**, 703–722.
6. Fujioka, Y. et al. (2006) Studies on the role of benthic organisms as food of shrimp aquaculture. *In* Studies on sustainable production systems of aquatic animals in brackish mangrove areas, JIRCAS working report no. 44, ed. Nakamura, K., JIRCAS, Tsukuba, Japan, 31–36.
7. Hayashi, I. & Nakao, S. (2005) Benthos in fisheries science. Kouseisha-kouseikaku, Tokyo, Japan, pp.159.
8. Hogarth, P. J. (1999) The biology of mangrove. Oxford University Press, pp.228.
9. Lee, S. Y. (1989) The importance of sesarminae crabs *Chiromanthes* spp. and inundation frequency on mangrove (*Kandelia candel* (L.) Druce) leaf litter turnover in a Hong Kong tidal shrimp pond. *J. Exp. Mar. Biol. Ecol.*, **131**, 23–43.
10. Nishihira, M. (ed.) (1997) Benthic communities and biodiversity in Thai mangrove swamps. Biological Institute, Tohoku University, pp.224.
11. Office of the Royal Development Project Board (ed.) (2000) Mangrove vol. 2 Samut Songkhram. Office of the Royal Development Project Board, Bangkok, Thailand, pp.99 [In Thai].
12. Robertson, A. I. & Alongi, D. M. (eds.) (1992) Tropical mangrove ecosystems, coastal and estuarine studies vol. 41. American Geophysical Union (AGU), Washington DC, USA, pp.336.

13. Sakiyama, K., Saito, H. & Suzuki, G. (2005) Role of benthic organisms as live food for broodstock management of kuruma prawn in earthen pond. *In* Benthos in fisheries science, eds. Hayashi, I. & Nakao, S., Kouseisha-kouseikaku, Tokyo, Japan, 22–31.
14. Sangtum, S. (1998) Culture of giant tiger prawn. Thankasettrakum Publ., pp.86 [In Thai].
15. Sontirat, S. (1989) Impact of the destructions on mangrove swamps or forests for shrimp-culture purpose in Thailand. *In* Symposium on mangrove management: its ecological and economic consideration, BIOTROP special publication no. 37, eds. Soerianegara, I. et al., SEAMEO-BIOTROP, Bogor, Indonesia, 235–243.
16. Suzuki, T. et al. (1997) Ecological distribution and community structure of benthic animals in Samut Songkhram mangrove swamp, Thailand. *In* Benthic communities and biodiversity in Thai mangrove swamps, ed. Nishihira M., Biological Institute, Tohoku University, 41–78.
17. Suzuki, T. et al. (1997) Population structure and distribution of *Ovassiminea brevicula* (Gastropoda) in Samut Songkhram mangrove swamp, Thailand. *In* Benthic communities and biodiversity in Thai mangrove swamps, ed. Nishihira M., Biological Institute, Tohoku University, 97–114.
18. Tongpurng, B. (2001) Sustainable aquaculture of giant tiger prawn. Thankasettrakum Publ., pp.127 [In Thai].
19. Yokoyama, H. et al. (2002) Evaluation of shrimp polyculture system in Thailand based on stable carbon and nitrogen isotope ratios. *Fish. Sci.*, **68**, 745–750.