Temporal Variation of Microzooplankton Community in Prasae Estuary, The Gulf of Thailand

Pailin Jitchum[1*] and Teerapong Duangdee[2]

ABSTRACT

The microzooplankton community was studied in February, June and November 2008 in Prasae Estuary, Rayong Province, located along the eastern coast of the Inner Gulf of Thailand. Microzooplankton was collected by horizontal hauling with a 125 µmmesh size plankton net. Twelve stations were used for sampling in three study areas of Prasae Estuary, namely the inner riverine, estuarine and marine sections. Several hydrographical parameters were measured. Thirty-two groups of microzooplankton were recorded. The holoplankton was more abundant than meroplankton. The most diverse sample was found in the marine section (32 groups), followed by the estuarine mouth (23 groups), and the inner riverine area (16 groups). The pooled data of all samples showed the highest average abundance in the estuarine area, followed by the inner riverine area, and the marine section (2,679 ± 1,563, 1,755 ± 1,043 and 1,097 ± 877 ind. m^{-3}, respectively). The dominant group was copepods, comprising between 70-87% of the total microzooplankton abundance. The microzooplankton community showed temporal variation in abundance in the annual cycle. The inner riverine and marine sections had the highest abundance in February while the estuarine mouth showed the highest abundance in June. In this regard, the monsoon season might be the main factor influencing the microzooplankton community in this study area.

Keywords: microzooplankton, distribution, species composition, Prasae Estuary, Gulf of Thailand

INTRODUCTION

The estuary is an extremely complicated ecosystem with numerous physical, chemical and biological processes influencing population dynamics. Dynamic processes include diel and seasonal variations of tide, current, salinity, temperature, dissolved oxygen and also nutrients which directly impact species diversity and ecosystem functions (Day *et al*., 1989; Dame and Allen, 1996). It is necessary to investigate the transitional waters of an estuary from various perspectives, and especially the structure of biological communities. An important factor in monitoring community structure is the linkage between primary and secondary production at all trophic levels. For example, the microbial (Danovaro and Pusceddu, 2007), phytoplankton (Froneman, 2006), zooplankton

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(Marques *et al*., 2008; Hwang *et al*., 2010) and fish (Jovanovic *et al*., 2007) communities all show changing features and functions over time. Hence, due to the spatiotemporal variations, complex communities must adjust to the stress and possess wide tolerances to variable conditions (Elliott and Quintino, 2007).

Zooplankton is important in showing the direct adaptative response and sensitivity to environmental changes in the transitional water (Beaugrand, 2004; Dame and Allen, 1996). Additionally, it is the primary consumer grazing on phytoplankton while also being the prey of fish larvae. Zooplankton abundance and species composition can shape the productivity of the pelagic food chain (Calbet, 2008). The structure and functioning of zooplankton communities in coastal and estuarine waters have received much consideration in recent works, covering wide geographical regions such as the Southern Chesapeake Bay (Park and Marshall, 2000), South Africa (Froneman, 2004), Southeastern Brazil (Sterza and Fernandes, 2006), Western Portugal (Marques *et al*., 2008) and Northern Taiwan (Hwang *et al*., 2010). Results of these studies indicate that zooplankton reflect the interactive effects of freshwater inflow, eutrophication, water temperature, and also mouth status. The most dominant group is copepods, in all stages. However, in order to manage the system, it is necessary to approach by identifying which parameters can describe the responsibility of zooplankton to their environmental changes.

Prasae Estuary is located along the eastern coast of the inner Gulf of Thailand. It is a complex estuarine ecosystem. The headwaters are located in the Khun –in Mountains and the river has a length of 120 km with many tributaries to the estuary in the lowlands. Land use in the lower areas of the river consists of agriculture, industry and domestic areas (Pokila, 2006). These are major sources of pollutant discharges, which are transported from riverine estuaries to the sea. Consequently, researchers have investigated the biological and hydrological conditions along the eastern coast of the inner Gulf (Blumenshine *et al*., 2007; Srinui, 2007; Tantichaiwanit *et al*., 2007); however, limited information is available on the response of the zooplankton to the impact in terms of community structure and function. The aim of this study was to determine the temporal variations of microzooplankton in their composition and abundance within three different habitats: riverine, estuarine and marine.

MATERIALS AND METHODS

Study sites

Prasae Estuary is located in eastern Thailand (12º 36′58′′N-12º 46′26′′N and 101º 39′36′′E-101º 47′41′′E), covering portions of Rayong, Chanthaburi and Chachoensao Provinces (Figure 1). The area includes the Prasae - Phangrad National Forest Reserve Area, covering 14.54 km^2 of the eastern area of the river mouth (Pokila, 2006). Three zones with twelve stations were selected to represent the low salinity riverine (st.1-3), estuarine (st.4-8) and marine habitats (st.9-12). The sampling stations are shown in Table 1.

Table 1. The twelve sampling points for zooplankton collection in Prasae Estuary, 2008

Station	Locality	Point	
		Latitude	Longitude
PR 1	Riverine low salinity area	12º46' 25.70" N	101º39' 47.00" E
PR 2	Riverine low salinity area	12º46' 21.40" N	101º40' 35.70" E
PR 3	Riverine low salinity area	12º46' 2.60" N	101º40' 49.80" E
PR 4	Estuarine area, river mouth	12º44' 41.30" N	101º41' 36.00" E
PR 5	Estuarine area, river mouth	12º43' 29.60" N	101º41' 19.00" E
PR 6	Estuarine area, river mouth	12º43' 0.90" N	101º41' 48.10" E
PR 7	Estuarine area, river mouth	12º41' 54.00" N	101º42' 9.70" E
PR 8	Estuarine area, river mouth	12º41' 19.20" N	101º42' 13.30" E
PR 9	Marine coastal area	12º37' 6.10" N	101º39' 35.50" E
PR 10	Marine coastal area	12º37' 26.00" N	101º42' 37" E
PR 11	Marine coastal area	12º36' 58.60" N	101º44' 51.80" E
PR 12	Marine coastal area	12º37' 2.60" N	101º47' 40.50" E

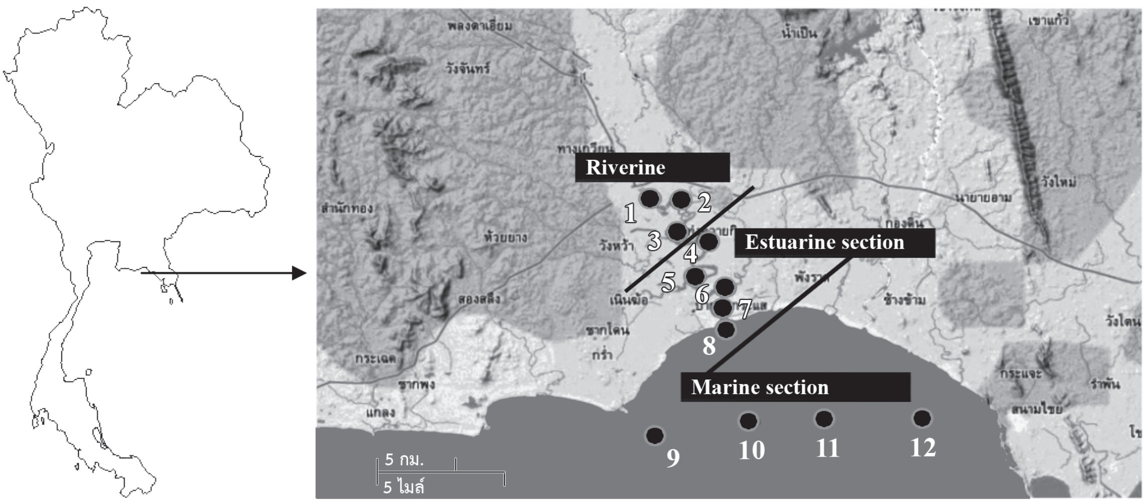


Figure 1. Geographic location of Prasae Estuary (12º 36´58´´N-12º 46´26´´N and 101º 39´36´´E-101º 47´41´´E), showing position of sampling stations in the inner riverine low salinity area, estuarine river mouth, and marine coastal area.

Sampling techniques

Microzooplankton samples were collected seasonally in February, June and November 2008. The months were chosen as representatives of the Northeast and Southwest monsoons, and the transitional period. A plankton net (125 µm mesh size), was fitted with a TSK flow meter in the center of the net mouth to determine the amount of water filtered during each tow. Hauls were towed horizontally for 5 min at speed of 1 m s^{-1} by fishing boat during the daytime. Samples were immediately preserved in 5% buffered formaldehyde solution. Zooplankton was sampled in three replicates. Specimens were identified to the lowest possible taxa and counted under stereomicroscope in the laboratory. Average abundance was expressed as number of individual m^{-3}.

At each station, hydrographic parameters were measured, including water temperature and dissolved oxygen using DO meter (YSI 550), salinity (refractometer, Asahi) and pH (pH meter, YSI 60). Monthly mean precipitable water data were obtained from the Thai Royal Irrigation Department (http://water.rid.go.th/hydro6/data-4/4-01_r/Z11.htm). Water samples for determination of chlorophyll *a* concentrations were collected at 50 cm depth from water surface and were analyzed in the laboratory as an index of phytoplankton biomass determined by spectrophotometric method (Strickland and Parsons, 1972).

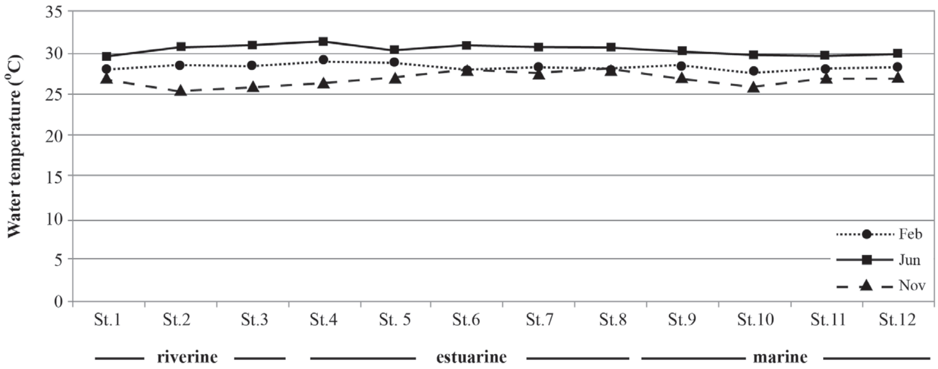
Data analysis

Pearson correlation analysis was used to determine the relationship between the hydrographical parameters and phytoplankton biomass (chlorophyll *a* concentration), and zooplankton abundance (Legendre and Legendre, 1983). Analysis of variance (ANOVA) was used to test the differences in phytoplankton biomass and zooplankton abundance between stations and months. Data were transformed prior to analysis of variance (ANOVA) in all cases (Zar, 1984).

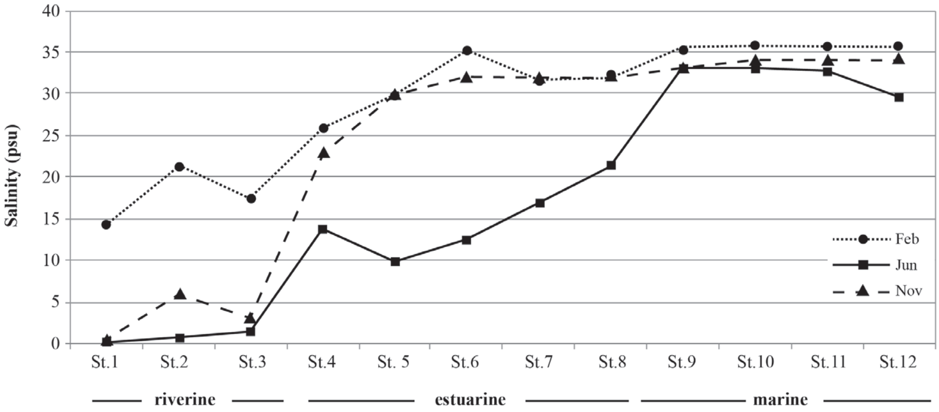
RESULTS

Environmental parameters

Environmental parameters and chlorophyll *a* concentrations were pooled within three areas: riverine, estuarine and marine sections and among the sampling periods. Figure 2 (a-f) shows the trends of salinity, water temperature, pH, dissolved oxygen, precipitable water and chlorophyll *a* concentration by station, area and month. Salinity values were 7 ± 9, 25 ± 9 and 34 ± 2 ppt for riverine, estuarine and marine sections, respectively. Water temperature was similar throughout the estuary, ranging from 28.3-28.9 ºC. Dissolved oxygen and pH of the inner riverine area were lower than in the estuarine and marine sections. Average pH values recorded in the riverine, estuarine and marine areas were 7±0.5, 7.8 ±0.4 and 8.3±0.2, respectively. Dissolved oxygen was 4.4±1.2, 5.2±0.7 and 4.7±2.1 mgL^{-1} from land to seaward. Chlorophyll *a* concentration in the marine area was significantly lower than in the other areas. Average values of 4.8±2.3, 4.9±3.3 and 1.0 ±0.2 mg m^{-3} were recorded from riverine, estuarine and marine areas, respectively. Chlorophyll *a* concentration was not analyzed



(a)



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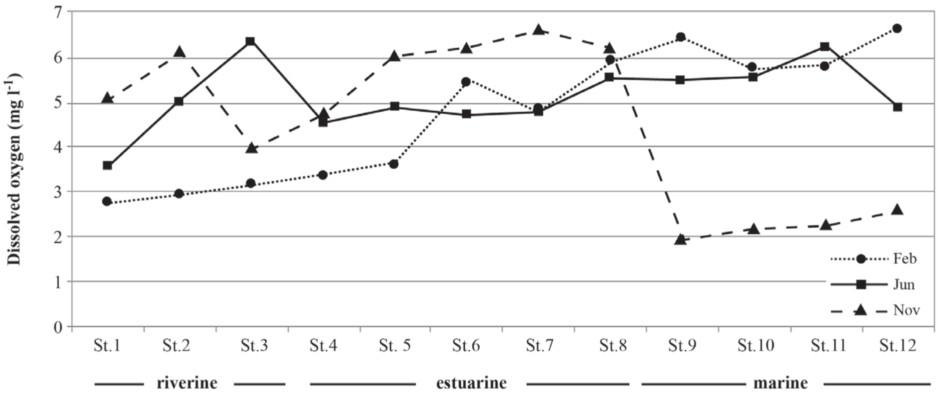
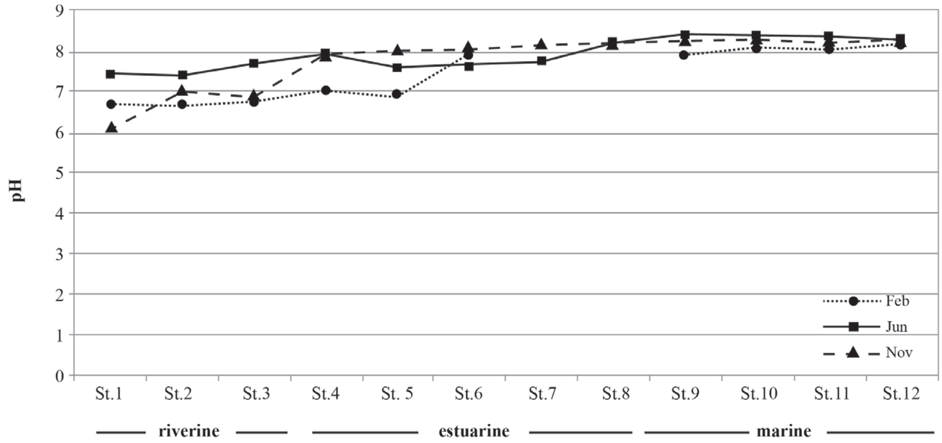


(c)

Figure 2. Average environmental parameters and chlorophyll *a* concentration in the Prasae Estuary; water temperature (a), salinity (b), dissolved oxygen (c), pH (d), precipitable water (e), and chlorophyll *a* concentration (f)



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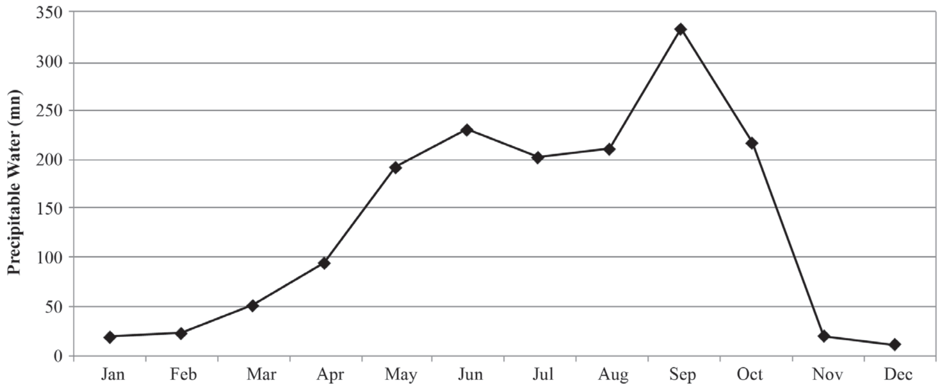

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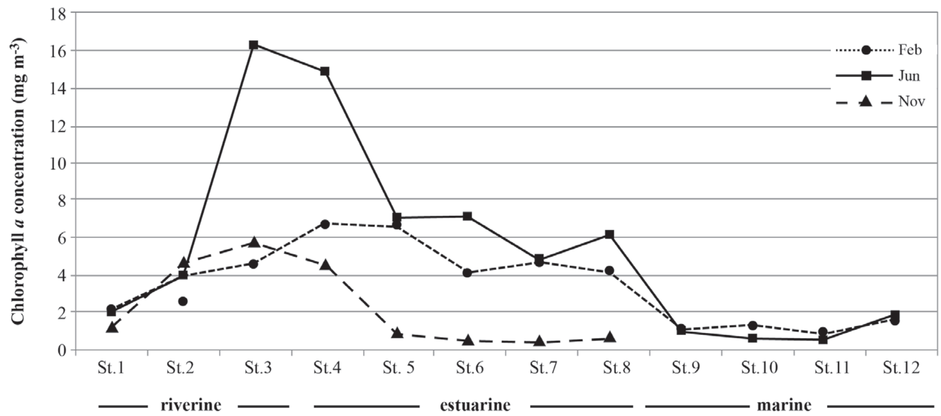

(f)

Figure 2. continued. Average environmental parameters and chlorophyll *a* concentration in the Prasae Estuary; water temperature (a), salinity (b), dissolved oxygen (c), pH (d), precipitable water (e), and chlorophyll *a* concentration (f)

in the marine stations (St. 9-12) in November 2008. Average monthly precipitable water data from the previous nineteen years established the minimum of 11.7 mm for December to the maximum of 332.1 mm for September.

Microzooplankton community

A total of 32 microzooplankton groups were collected in the Prasae Estuary. The highest diversity of microzooplankton was found in the marine section (32 groups), followed by the estuarine (23 groups) and the riverine sites (16 groups). Average abundances of microzooplankton were 1,775±1,043, 2,679±1,563 and 1,097±877 ind. m^{-3} from land to seaward areas during the sampling period (Figure 3). The average values significantly differed among the riverine, estuarine and marine sections. The riverine section showed the highest average abundance of 2,930±695 ind. m^{-3} in February 2008, followed by 1,600±185 ind. m^{-3} in June and 734 ±406 ind. m^{-3} in November. The highest value of 4,408±1,273 ind. m^{-3} was recorded during June in the estuarine section followed by 2,060±681 ind. m^{-3} in November and 1,570±844 ind. m^{-3} in February. Meanwhile, the marine section had its highest abundance of microzooplankton in February (1,903±1,066 ind. m^{-3}), followed by November (916±408 ind. m^{-3}) and June (471±292 ind. m^{-3}).

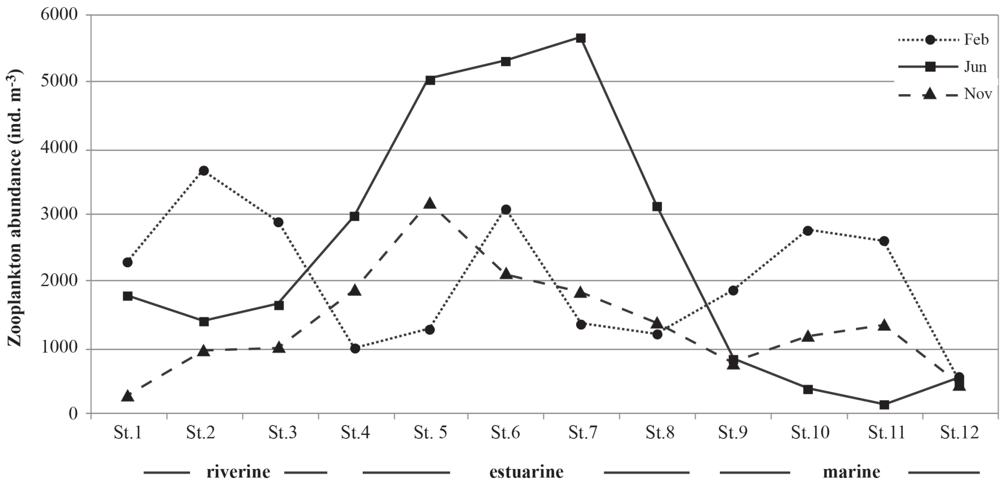

Figure 3. Average abundance of microzooplankton (ind. m^{-3}) in the Prasae Estuary in 2008

Copepods showed the highest contribution (70 - 87%) to the total microzooplankton abundance, followed by meroplankton (11-24%), then holoplankton (1 - 10%). Figure 4 shows the trends of microzooplankton composition among sampling areas and seasons. Meroplankton made the higher contribution to the total abundance during the Northeast monsoon and the transition period (Figures 4a and c). In contrast, the holoplankton was in higher proportion during the Southwest monsoon (Figures 4b).

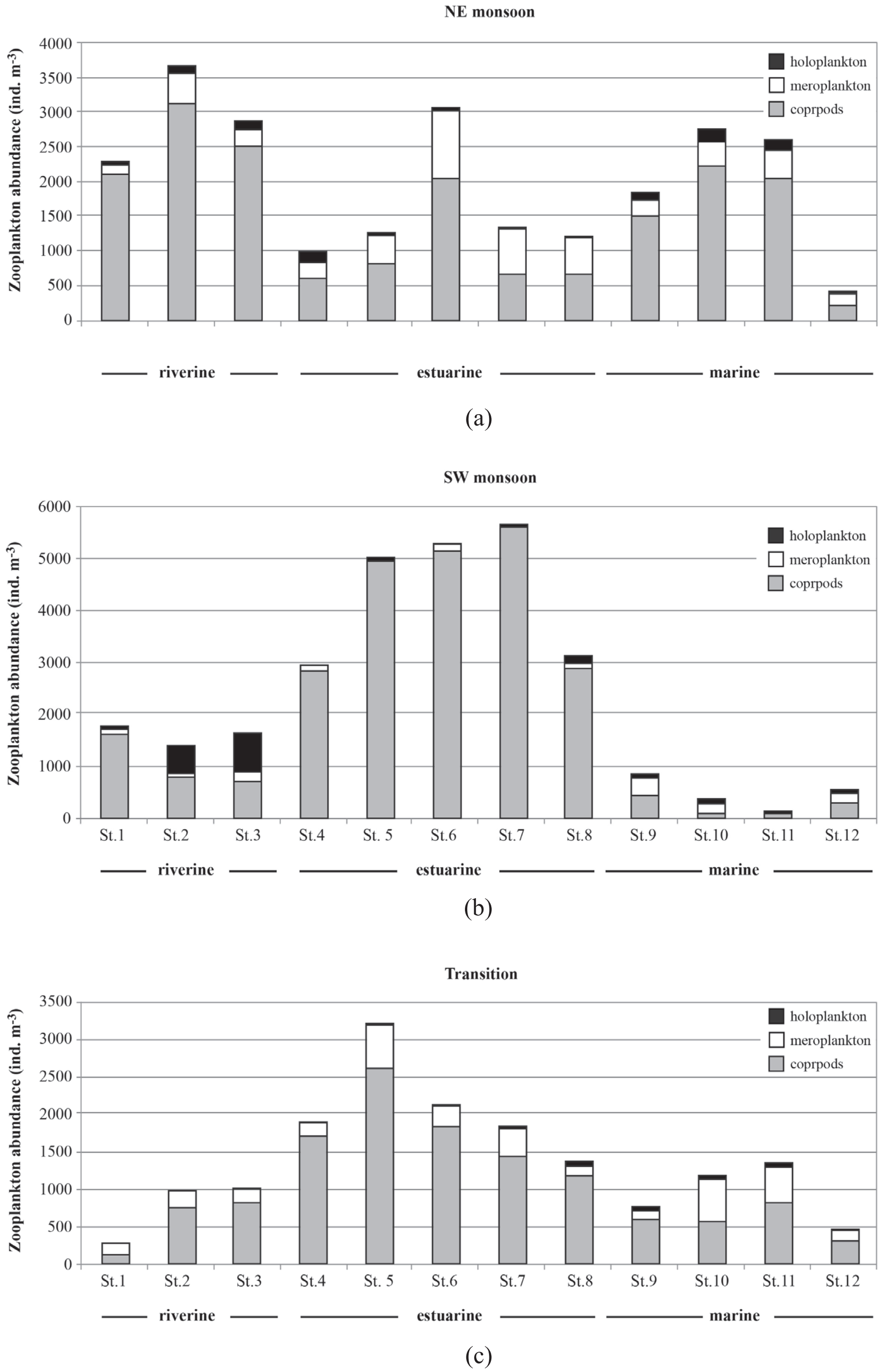

Figure 4. Seasonal contribution abundance of microzooplankton: Northeast monsoon (a), Southwest monsoon (b), and transitional period (c), in three different areas of Prasae Estuary in 2008

Temporal variation of microzooplankton abundance showed similar patterns for the riverine and marine sections during the monsoon season, whereas the estuarine area showed an opposite pattern (Figure 4). The five highest relative contributions to microzooplankton in the riverine area were copepods (996±811 ind. m^{-3}, 56.8%), copepod nauplii (395±283 ind. m^{-3}, 22.6%), cladocerans (175±266 ind. m^{-3}, 10%), gastropod larvae (60±66 ind. m^{-3}, 3.4%) and foraminiferans (22±37 ind. m^{-3}, 1.2%). The most common five groups of microzooplankton in the estuarine section were copepods (1,631±1,023 ind. m^{-3}, 60.9%), followed by copepod nauplii (699±870 ind. m-$^{-3}$, 26%), cirripede nauplii (94±183 ind. m^{-3}, 7.2%), gastropod larvae (62±64 ind. m^{-3}, 2.3%) and cladocerans (19±36 ind. m^{-3}, 0.7%). The marine microzooplankton community was comprised mostly of the following: copepods (734±727 ind. m^{-3}, 66.9%), bivalve larvae (152±152 ind. m^{-3}, 13.9%), gastropod larvae (40±40 ind. m^{-3}, 3.6%), chaetognaths (34± 20 ind. m^{-3}, 3.1%) and larvaceans (28±27 ind. m^{-3}, 2.5%).

Microzooplankton composition and average abundance within three different zones during the sampling period are shown in Table 2. The results revealed that the marine indicator groups were siphonophorans, *Creseis* sp., *Pseudevadne tergestina*, *Lucifer* sp., *Sagitta* spp., larvaceans, thaliaceans, echinoderm larvae, cyphonautes larvae, tornaria larvae, and fish eggs. They did not migrate into low salinity areas of the riverine region. Conversely, the riverine species were rotifers and cladocerans, transported from the riverine area seaward.

Correlation between environmental parameters and microzooplankton

Pearson correlation analyses between environmental parameters, phytoplankton biomass (Chlorophyll *a* concentration) and microzooplankton abundance are shown in Table 3. The pooled data of all samples within each of the three zones were used. The results indicated that chlorophyll *a* concentrations were positively correlated to water temperature and rainfall, but showed a negative correlation to salinity in both riverine and estuarine sections. Other hydrographical conditions (pH and dissolved oxygen) were positively correlated to chlorophyll *a* concentration within the riverine stations, but dissolved oxygen was negatively correlated to those parameters within the estuarine area. Regarding the marine area, chlorophyll *a* concentration was only sampled in two of the months, and so it was not included in correlation tests.

Microzooplankton abundance was positively correlated to chlorophyll *a* concentration ($r=0.99$, $P<0.05$) only in the estuarine section. Correlations of other environmental parameters with microzooplankton abundance are shown in Table 3. The results showed similar trends of correlation with microzooplankton abundance between the riverine and marine sections but mostly opposite correlations from the estuarine data. For example, salinity was negatively correlated ($r=-0.99$, $P<0.05$) with microzooplankton abundance in estuarine sites but positively correlated in the riverine ($r=0.86$, $P<0.05$) and marine ($r=0.98$, $P<0.05$) sections. Pearson correlation tests

Table 2. Average abundance and standard deviation (ind. m^{-3}) of microzooplankton and relative percentage contribution to total microzooplankton (in parentheses) in three areas of Prasae Estuary in 2008

Taxonomic groups	Riverine	Estuarine	Marine
Phylum Sarcomastigophora			
Foraminiferans	22 ± 37 (1.2)	16 ± 39 (0.6)	11 ± 3 (0.1)
Phylum Cnidaria			
Hydromedusae	< 1	< 1	2 ± 3 (0.2)
Siphonophores	0	0	2 ± 3 (0.2)
Phylum Rotifera			
Rotifers	6 ± 8 (0.3)	1 ± 3 (0)	< 1
Phylum Annelida			
Polychaete larvae	2 ± 3 (0.1)	17 ± 26 (0.6)	17 ± 13 (1.6)
Phylum Mollusca			
Creseis sp.	0	0	11 ± 21 (1.0)
Gastropod veliger larvae	60 ± 66 (3.4)	62 ± 64 (2.3)	40 ± 40 (3.6)
Bivalve veliger larvae	3 ± 6 (0.2)	10 ± 11 (0.4)	152 ± 152 (13.9)
Phylum Arthropoda			
Cladocerans	175 ± 266 (10)	19 ± 36 (0.7)	< 1
Psuedevadne tergestina Claus	0	< 1	< 1
Cirripede nauplii	85 ± 141 (4.8)	194 ± 183 (7.2)	2 ± 2 (0.2)
Copepod + copepodid larvae	996 ± 811 (56.8)	1631 ± 1023 (60.9)	734 ± 727 (66.9)
Copepod nauplii	395 ± 283 (22.5)	699 ± 870 (26.1)	35 ± 27 (3.2)
Mysids	< 1	1 ± 3 (0)	5 ± 5 (0.5)
Lucifer sp.	0	2 ± 9 (0.1)	11 ± 10 (1.0)
Brachyuran zoea	2 ± 3 (0.1)	7 ± 12 (0.3)	4 ± 5 (0.4)
Shrimp larvae	2 ± 2 (0.1)	6 ± 14 (0.2)	3 ± 3 (0.2)
Aquatic insects	6 ± 9 (0.4)	2 ± 5 (0.1)	< 1
Phylum Ectoprocta			
Cyphonautes larvae	0	< 1	1 ± 1 (0)
Phylum Chaetognatha			
Sagitta spp.	0	5 ± 13 (0.2)	34 ± 20 (3.1)
Phylum Echinodermata			
Brachiolaria larvae	0	0	2 ± 3 (0.2)
Ophiopluteus larvae	0	0	3 ± 3 (0.3)
Echioplutues larvae	0	0	3 ± 3 (0.2)
Juvenile	0	0	< 1
Phylum Hemicaudata			
Tornaria larvae	0	< 1	< 1
Phylum Chordata			
Larvaceans	0	2 ± 5 (0.1)	28 ± 27 (2.5)
Oikopleura sp.	0	0	2 ± 3 (0.2)
Doliolids	0	0	1 ±1 (0.1)
Salps	0	< 1	< 1
Fish larvae	1 ± 2 (0.1)	1 ± 1 (0)	1 ± 1 (0.1)
Fish egg	0	4 ± 13 (0.2)	2 ± 2 (0.2)
Amphioxus	0	0	2 ± 4 (0.1)
Total	**1,755 ± 1,043**	**2,679 ±1,563**	**1,097 ± 877**

Table 3. Correlation coefficients (r) in relationships between environmental parameters, chlorophyll *a* concentration and microzooplankton abundance in the three sections of Prasae Estuary (* P<0.05)

Parameters	Chlorophyll *a* concentration		Zooplankton abundance		
	riverine	estuarine	riverine	estuarine	marine
Salinity (psu)	-0.74*	-0.78*	0.86*	-0.99*	0.98*
Water temperature (ºC)	0.75*	0.94*	0.40	0.90*	-0.40
pH	0.98*	-0.38	-0.78*	0.99*	-0.82*
Dissolved oxygen (mg l^{-1})	0.61*	-0.81*	-0.94*	-0.16	0.35
Rainfall (mm)	0.98*	0.82*	-0.11	0.98*	-0.73*
Chl *a* con.	-	-	-0.30	0.99*	-

Remark: - no data.

revealed that the environmental parameters affected the abundance of microzooplankton groups in relation to their various habitats.

DISCUSSION

Environmental parameters

Prasae Estuary was divided into three areas based on the effects of tidal currents and seawater. The riverine area showed lower salinity and pH characteristics while these parameters were higher in the marine area. The estuarine area is the zone of mixing, influenced by the coastal water during the Northeast monsoon season and the input of freshwater during the Southwest monsoon season. The low dissolved oxygen observed in this study might have been caused by diminishing phytoplankton, contamination by pollutants, and/or increase in the biological oxygen demand in the water column.

Chlorophyll *a* concentration showed relatively low values (1.0±0.2 mg m^{-3}) in the marine section and it can be assumed that this area was low in primary production. It can be explained by the dispersion of nutrients along the complex mangrove canals, and diminishing organic and inorganic matter by sedimentation. Additionally, the shallowness and narrowness of the branched canals reduce the flow velocity of the freshwater runoff. Particles and nutrients are also trapped in the riverine and estuarine sections by the natural morphology of the estuary and this helps explain the higher chlorophyll *a* concentrations compared to the marine section (Grange and Allanson, 1995). Particularly, the buffer area of the Prasae-Phangrad National Forest Reserve Area, which is located in the eastern area of the river mouth, protects and traps the particles and nutrients from the adjacent discharge areas (Pokila, 2006). Moreover the important organism, phytoplankton, might have a reduced biomass during these conditions (estuarine ecosystem).

Microzooplankton community

The microzooplankton community was characterized by the salinity gradient in this study area. siphonophorans, *Creseis* sp., *Pseudevadne tergestina*, *Lucifer* sp., *Sagitta* spp., larvaceans, thaliaceans, echinoderm larvae, cyphonautes larvae, tornaria larvae and fish eggs were not found in the riverine section. Prasae Estuary was dominated by copepods. They comprised as much as 70-87% of the total microzooplankton abundance. Microzooplankton composition in this study area was similar to other coastal areas along the eastern inner Gulf of Thailand (Srinui, 2007; Tantichaiwanit *et al*., 2007). The highest abundance was found in the riverine and marine sections during the Northeast monsoon season. The estuarine community, in contrast, had its highest abundance of microzooplankton during the Southwest monsoon season. Additionally, holoplankton showed the highest proportion of the total microzooplankton abundance in the riverine section during the Southwest monsoon season. It can be related to the higher amount of precipitable water and freshwater runoff into the system. The indicator group for the riverine sites was cladocerans, which were found in large numbers (Marques *et al*., 2008). Meroplankton was higher in number during the Northeast monsoon and the transitional period than in the Southwest monsoon season. The high salinity water is suitable for the reproductive mechanisms of the marine species and so they may produce more of their larvae during the dry season (Park and Marshall, 2000). On the other hand, copepods formed the dominant proportion of the total microzooplankton in the estuarine area during the Southwest monsoon season. This could be explained by the low salinity condition, which might stimulate copepod reproduction (Hwang *et al*., 2010). These species might be considered as euryhaline species that are widely distributed along the estuarine area.

The small microzooplankton groups such as small copepods, rotifers and tintinnids were underestimated in our sampling, caused by limitations of equipment efficiency. The large mesh size of the net was not suitable for the small size zooplankton. Moreover, the estuary morphology (shallow, narrow channels) and large sediment volume during the dry season made sampling by tow nets more difficult. A large portion of the microzooplankton was copepods, which showed high abundance in the estuarine and coastal water. They act as the linkage of small size plankton to the larger components (Rakhesh *et al*., 2013).

This work serves as the baseline data for ecological investigations of the microzooplankton community in this study area. Further studies should focus on copepod diversity and community structure, including the small size microzooplanktons such as ciliated protozoans. The linkage of primary and secondary production is the key for determining the enrichment of the natural environment and maintenance of the proportion of the very important producers and consumers in the pelagic trophic pyramids. Finally, the information can be used to help conserve the native microplankton community in the face of increasing human impacts, pollutants and climate change.

CONCLUSION

The microzooplankton community in Prasae estuary was dominated by copepods. The low species diversity but high abundance of microzooplankton was seen in the estuarine area throughout the year. Seasonal variations were established which showed the highest abundance in riverine and marine microzooplankton during the Northeast monsoon. Conversely, the estuarine community showed the highest abundance during the Southwest monsoon season. The salinity gradient was the most important environmental factor and was related to precipitation and freshwater flooding that have influence on the microzooplankton community.

ACKNOWLEDGEMENT

This work was supported by a grant from Kasetsart University Research and Development Institute. We owe our gratitude to Assist. Prof. Sunan Patrajinda and her team for sample collection. We wish to thank anonymous referees for their valuable comments on the manuscript.

LITERATURE CITED

Beaugrand, G. 2004. The North Sea regime shift: evidence, causes, mechanisms and consequences. **Progress in Oceanography.** 60, 245-262.

Blumenshine, S., Piumsomboon, A., Guunbua, V. and Paphavasit, N. 2007. Factors affecting spatial and temporal variations in water quality and plankton: Case study in the Bangpakong River. **Journal of Scientific Research (Section T).** 6, 11-27.

Calbet, R. 2008. The trophic roles of microzooplankton in marine systems. **ICES Journal of Marine Science.** 65, 325-331.

Dame, R.F. and Allen, D.M. 1996. Between estuaries and the sea. **Journal of Experimental Marine Biology and Ecology.** 200, 169-185.

Danovaro, R., Pusccedu, A. 2007. Biodiversity and ecosystem functioning in coastal lagoons: does microbial diversity play any role? **Estuarine, Coastal and Shelf Science.** 75, 4-12.

Day, J., Hall C.A.S., Kemp, W.M. and Yanez-Arancibia A. 1989. **Estuarine ecology.** Wiley, New York.

Elliott, M., Quintino, V.M. 2007. The estuarine quality paradox: Environmental homeostasis and the difficulty of detecting anthropogenic stress in naturally stresses area. **Marine Pollution Bulletin.** 54, 640-645.

Froneman, P.W. 2004. Zooplankton community structure and biomass in a southern African temporarily open/closed estuary. **Estuarine, Coastal and Shelf Science.** 60, 125-132.

Froneman, P.W. 2006. The importance of phytoplankton size in mediating trophic interations a southern African temporarily open/closed estuary. **Estuarine, Coastal and Shelf Science.** 70, 693-700.

Grange, N. and Allanson, B.R. 1995. The influence of freshwater inflow on the nature, amount and distribution of seston in estuaries of the Eastern Cape, South Africa. **Estuarine, Coastal and Shelf Science.** 40, 403-420.

Hwang, J.S., Kumar, R., Hsieh, C.W, Kuo, A.Y., Souissi, S., Hsu, M.H., Wo, J.T., Liu, W.C., Wang, C.F. and Chen, Q.C. 2010. Patterns of zooplankton distribution along the marine, estuarine and riverine portions of the Danshuei Ecosystem in Northern Taiwan. **Zoological Studies.** 49, 335-352.

Jovanovic, B., Longmore, C., O̓ Leary, A., Mariani, S. 2007. Fish community structure and distribution in a macro-tidal inshore habitat in the Irish Sea. **Estuarine, Coastal and Shelf Science.** 75, 135-142.

Legendre, L. and Legendre, P. 1983. **Numerical Ecology.** Elsevier, Amsterdam.

Marques, S.C., Azeiteiro, U.M., Leandro, S.M., Queiroga, H., Primo, A.L., Martinho, F., Viegas, I. and Pardal, A. 2008. Predicting zooplankton response to environmental changes in a temperate estuarine ecosystem. **Marine Biology.** 155, 531-541.

Park, G.S. and Marshall, H.G. 2000. Estuarine relationship between zooplankton community structure and trophic gradients. **Journal of Plankton Research.** 22, 121-135.

Pokila, B. 2006. **People Participation in the Conservation of Mangrove Forest Pa Prasae-Phang Rat National Forest Reserve, Amphoe Klaeng; Changwat Rayong.** Master of Science Thesis. Kasetsart University. (English Abstract).

Rakhesh, M., A. V. Raman, T. Ganesh, P. Chandramohan and F. Dehairs. 2013. Small copepods structuring mesozooplankton community dynamics in a tropical estuary-coastal system. **Estuarine, Coastal and Shelf Science** 126: 7 – 22.

Srinui, K. 2007. Distribution and abundance of zooplankton in estuary along the Eastern Coast of Thailand. **Journal of Scientific Research (Section T).** 6, 221-230. (English Abstract).

Sterza, J.M. and Fernandes, L.L. 2006. Zooplankton community of the Vitória Bay estuarine system (Southeastern Brazil). Characterization during a three-year study. Brazilain **Journal of Oceanography.** 54, 95 -105.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis. **Bulletin of Fisheries Research Canada.** 167, 1-310.

Tantichaiwanit, W., Gajaseni, N. and Piumsomboon, A. 2007. Zooplankton dynamics in Kung Krabaen Bay, Chanthaburi Province. **Journal of Scientific Research (Section T).** 6, 197-211. (English Abstract).

Zar, J.H. 1974. **Biostatistical Analysis.** Prentice-Hall, Englewood Cliffs.