Influence of environmental factors on abundance and temporal variation of benthic fauna resources in the eutrophic Tha Chin estuary, Samut Sakhon province, Thailand

Nittaya Ritnim and Charumas Meksumpun

ABSTRACT

The influence of environmental factors on the abundance and temporal variation of benthic fauna resources was studied in the eutrophic Tha Chin estuary located in Samut Sakhon province. The objectives were to analyze the status of abundance and temporal variation of the benthic fauna and to clarify the impacts from environmental factors (water and sediment quality). Field surveys were conducted monthly from August 2007 to March 2008 at 11 sampling stations in the estuary. Based on freshwater runoff volumes, the high-, medium-, and low-loading periods were categorized to be from August to October 2007, November to December 2007, and January to March 2008, respectively. The benthic fauna resources were composed of 57 species in eight phyla. Annelids were the dominant species (with the maximum density being 19,885 individuals/m^2), followed by the mollusks. Both densities decreased during the low-loading period in 2008. Water quality deteriorated during the high-loading period. Land-based wastewater discharges decreased the levels of salinity and dissolved oxygen but dramatically increased various nutrients. Consequently, the sediment quality deteriorated during the medium-loading period. Bottom deposits during this time depicted high accumulation of acid volatile sulfides (more than 0.76 mg/g dry weight). Analyzing the environmental relationships, deposit feeders (for example, *Nereis* sp. and *Prionospio* sp.) and a clam (*Arcuatula* sp.) showed potential as bio-indicators for environmental monitoring. The overall results revealed the importance of changes in the water and sediment qualities that had an influence on related benthic resources. The increase in the level of NH_4^+-N had a negative impact on the economic clam species, while the sedimentary TOM showed positive correlation ($P < 0.05$) with this increase. The succession of groups based on feeding behavior seemed to correspond with stress in eutrophication along the salinity gradient and in different estuarine parts. In addition, the economic clam population decreased noticeably during the medium-loading period, as a consequence of deteriorated sediment conditions. Thus, the land-based runoff should be controlled for the protection of resources. Further effective sustainable management will be enhanced by giving serious consideration to an eco-based zoning scheme for conservation and restoration of the Tha Chin estuary.

Key words | abundance, benthic fauna, environmental responses, species composition, Tha Chin estuary, water and sediment quality

Nittaya Ritnim
Charumas Meksumpun (corresponding author)
Department of Fishery Biology,
Faculty of Fisheries,
Kasetsart University,
Chatuchak,
Bangkok 10900,
Thailand
E-mail: *ffiscmc@ku.ac.th*

Charumas Meksumpun
Center of Advanced Studies in Tropical Natural Resources,
KU Institute for Advanced Studies,
Kasetsart University,
Bangkok 10900,
Thailand

INTRODUCTION

Tha Chin River is a tributary of the Chao Phraya River located in the central part of Thailand. The Tha Chin River passes through the provinces of Chai Nat, Suphan Buri, and Nakhon Pathom and enters the Gulf of Thailand in Samut Sakhon province. The river water has been used for water supply, agriculture, aquaculture, transportation, and industry (Mahujchariyawong & Ikeda 2001; REO5 2005). In addition, the estuarine areas have provided

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many benefits for fisheries (for example, a commercial fishing port and small-scale capture and culture fisheries). Unfortunately, wastewater from anthropogenic activities has affected water quality, especially in the lower river basin and estuary. The lower river and estuarine zones have been reported to be in a hypertrophic condition (Meksumpun & Meksumpun 2008). Although distinguishable deterioration of the water quality occurred, some evidence suggested the eco-potential of self-remediation (Thaipichitburapa *et al*. 2010).

Benthic animals live in the bottom sediment and burrow in or crawl on the surface sediment. They move very slowly so they could be directly affected by environmental deterioration. Since the benthic animals can be recognized easily, they have been widely used for assessment of environmental status. Changes of water and sediment quality were reported to affect their species composition, diversity and density (Suzuki & Moritaka 1997). Thus, environmental deterioration in the Tha Chin estuary should have an influence on the distribution and temporal variation of the benthic species in the impacted areas. Such deterioration could also impact on clam populations which are an economically important fishery resource in this area. The present study aimed to clarify the abundance and temporal variation of the benthic fauna and clarify their relationships with various estuarine environmental factors. The results could provide information on patterns of benthic invertebrate responses and environmental factors significantly impacting the benthic resources. The knowledge gained could be further applied for the development of environmental mitigation and/or remediation schemes for the estuarine ecosystem.

METHODS

Study area

The water and sediment was examined at 11 stations (Stns) of the Tha Chin estuary (Figure 1). The innermost station (Stn 1) received wastewater from both the upper Tha Chin river and from the Bangkok municipal area (through the Mahachai canal). This station was reported to have the most severely affected water quality with the average dissolved oxygen (DO) level < 1 mg/L (Thaipichitburapa *et al*. 2009). Stns 11.5, 15, and 25 were located along the channel area with a seaward salinity gradient at average depths of 5.0, 3.3, and 3.1 m, respectively. Stns 3, 9, 17, and 23 (in the western part) and Stns 5, 16, and 22 (in the eastern part) were located on a shallower, sandy-mud tidal flat at average depths for the western and the eastern parts of 2.9 and 2.1 m, respectively.

Field surveys were carried out every month from August 2007 to March 2008. During this time, three different periods were categorized according to the amount of inflows (see Table 2) as high-loading (August to October 2007), medium-loading (November to December 2007), and low-loading (January to March 2008) periods. Such inflows were a response to the SW and NE monsoon seasons of Thailand (TMD 2010).

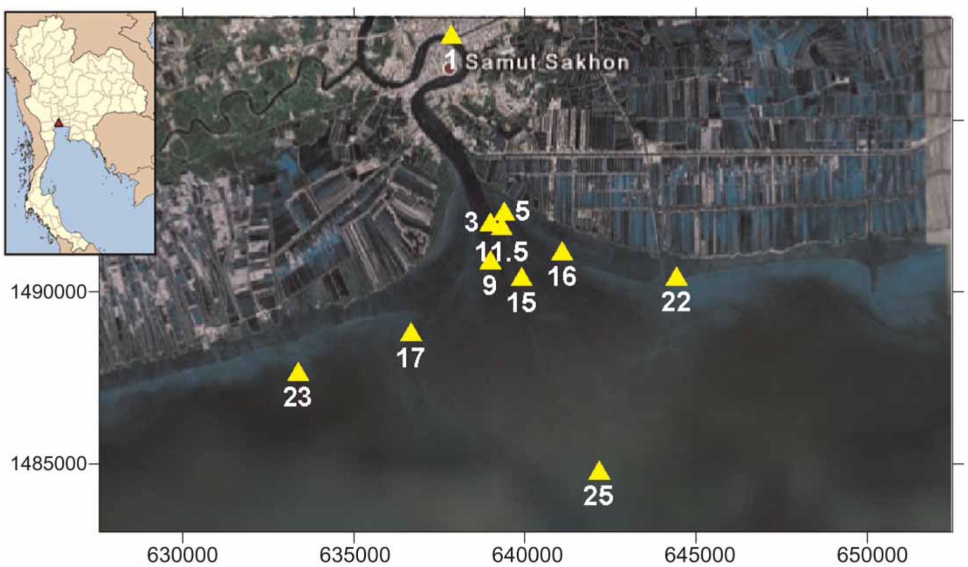

Figure 1 | Map of sampling stations located in the Tha Chin estuary, Samut Sakhon province.

Study on benthic fauna

Benthic fauna were collected by an Ekman grab sampler (25×25 cm). The samples were sieved through 250 μm mesh and fixed in 10% formaldehyde for further analysis. Taxonomic classification was performed according to Carpenter & Niem (1998) and Day (1967). The Shannon–Wiener diversity index was determined by the method of Ludwig & Reynolds (1988).

Study on water and sediment quality

Water sampling at each sampling event was carried out only during the low tide period in the day time (9–15 a.m.). For each sampling event, the whole procedure was completed within approximately 4 h. Water temperature, salinity, dissolved oxygen, and pH were measured by a multi-parameter probe (YSI Model 6600). The surface water was sampled and analyzed for chlorophyll *a* and total suspended solids by a spectrophotometric method and freeze drying technique, respectively. Ammonium-nitrogen, nitrite, nitrate-nitrogen, orthophosphate-phosphorus, and silicate-silicon were analyzed by an auto-nutrients analyzer (SKALAR). Sediments were collected by a gravity corer. The samples were sectioned into depth layers of 1 cm, the apparent characteristics were recorded and then the samples were kept in a freezer before analysis. Sedimentary organic matter was analyzed by the ignition loss method. Acid volatile sulfides (AVS) were examined by H_2S absorbent columns (Gastec Model 201H).

RESULTS AND DISCUSSIONS

Benthic fauna resources

Dominant species and community structure analysis

The benthic fauna were composed of 8 phyla; Annelida (22 species), Arthropoda (18 species), Mollusca (13 species), Nematoda (1 species), Chordata (1 species), Sipuncula (1 species), Chaetognatha (1 species), and Cnidaria (1 species). An *Ancistrosyllis* annelid was the dominant species with the maximum density of 6,224 individuals/m^2 (Table 1). At almost all stations, annelids comprised more than 50% of the total benthos; almost of them were deposit feeders. Only two species of polychaetes (*Nereis* sp. and *Pectinaria* sp.) had predatory behavior. The oligochaete (*Ophidonais* sp.) had distributed over the innermost sites (Stns 1, 3, 5) with comparatively low salinity.

The broadly distributed mollusk species were *Arcuatula* sp., *Pitar* sp. and *Tellina* sp. with maximum densities of 14,128, 1,904, and 1,472 individual/m^2, respectively. The proportion of the mollusks decreased slightly during the medium-loading period (Figure 2(b)). Such decreases were considered to be due to low salinity (approximately 9 psu) and started from the high-loading period that existed over a comparatively long period covering the benthic boundary layers. *Pholas* sp. and *Paphia* sp., the famous economically important clams of the area, recorded the highest densities of 1,200 and 2,288 individuals/m^2 during August 2007 and January 2008, respectively. The populations of *Paphia* sp. usually preferred the outer estuary (more than 5 km distant from the shoreline), while those of *Pholas* sp. preferred the inner part. According to Gireesh & Gopinathan (2004), populations of *Paphia* sp. can decrease along a freshwater gradient. In addition, sea anemones were often found adhered to the living and non-living shells in the muddy sand habitat at Stn 22. Nematodes and Sipunculid worms were found in stations close to the river mouth, while species of the phyla Chaetognatha and Chordata were found more in the outer part.

Benthos distribution analysis

Benthos densities at the stations located along the channel were comparatively lower (Figure 2). Along the channel, the proportion of mollusks at Stns 11.5 and 25 decreased over time, while the annelid proportion increased. During the last sampling period, the annelid densities increased approximately 10 times. The diversity index (H') at Stn 11.5 reached a high level of approximately 1.70. Such increases may imply a trend of organic material accumulation in the mid-estuarine zone. In the present study, H' values varied among stations and sampling periods. Since the index was composed of the complex responses of the benthic community, the application of such information to evaluate eutrophication stress or land-based impacts may still be questioned. This observation was supported by Karydis (2009), who considered that H' was not a suitable parameter for quantifying the extent of environmental changes in such locations. In the eastern part of the estuary, the dominant groups were the annelids and mollusks (Figure 2). Their abundance levels tended to decrease during the medium-loading period (for example, at Stn 22). The arthropods

Table 1 | Occurrence of benthic fauna surveyed monthly from August 2007 to March 2008

Taxa	Species	Stations found	Maximum density (individual/m^2)	Occurrence[a] (months found) 2007	2008
Phylum Annelida					
Hirudinea	Unidentified sp.	**5**,11.5,15,16,25	720	10,**11**,12	1,2,3
Capitellidae	*Notomastus* sp.	1,3,5,**11.5**,15,16,25	256	8,10,**11**,12	1,2,3
Scalibregmatidae	*Parasclerocheilus* sp.	25	80	–	1
Pilargidae	*Ancistrosyllis* sp.	1,3,5,9,11.5,15,16,17,22,23,**25**	6,224	8,9,10,11,12	**1**,2,3
Onuphidae	*Diopatra* sp.	1,3,5,9,11.5,15,**16**,22,25	576	8,9,**10**,11,12	1,2,3
Goniadidae	*Glycinde* sp.	**15**,16	384	**10**,11	1
Hesionidae	*Hesione* sp.	11.5,15, **16**,17,25	208	11,**12**	1,2,3
Lumbrineridae	*Lumbrinereis* sp.	16	32	–	2
Nephtyidae	*Nephtys* sp.	11.5,16,17,**22,25**	64	**11**,12	1,2,3
Nereididae	*Nereis* sp.	1,3,5,**9**,11.5,15,16,17,22,25	2,752	8,9,10,11,12	**1**,2,3
Spionidae	*Aonides* sp.	3,9,11.5,15,16,**17**,22,23,25	10,048	8,10,11,**12**	1,2,3
	Polydora sp.	1,3,5,9,**11.5**,15,16,17,23	1,952	8,10,11,12	1,**2**,3
	Prionospio sp.	3,9,11.5,15,16,**17**,22,23,25	8,576	8,10,11,**12**	1,2,3
	Paraprionspio sp.	5,22,**25**	1,616	10,11,12	**1**,3
Sabellidae	*Chone* sp.	1,3,5,9,15,**22**	2,976	**8**,9,10,11	1
	Sabella sp.	3,5,9,11.5,15,**16**,22,25	9,424	8,9,**10**,11,12	1,2,3
	Sabellonga sp.	5	224	9	–
Cirratulidae	*Cirriformia* sp.	1,3,5,9,11.5,15,16,**17**	1,136	10,12	**1**,2,3
Magelonidae	*Magelona* sp.	**9**,17	32	12	**1**
Oweniidae	*Owenia* sp.	**22**	32	–	**1**
Pectinariidae	*Pectinaria* sp.	5,17,22,**25**	224	12	**1**,3
Naididae	*Ophidonais* sp.	**1**,3,5	464	10,**11**	–
Phylum Mollusca					
Gastropod	Unidentified sp.	**5,3**	32	**11**	**1**
Bivalve	Unidentified sp.	**5**,25	1,008	9,**11**	1,2,3
Arcidae	*Anadara* sp.	**5**,16,22	48	8,**9**,111	1
Mytilidae	*Arcuatula* sp.	3,5,**9**,11.5,15,16,17,22,25	14,128	8,9,**10**,11	1,2,3
	Perna sp.	17	16	11	–
Mactridae	*Mactra* sp.	9	176	9	–
Veneridae	*Pitar* sp.	3,5,9,15,16,17,**22**,23,25	1,904	8,9,**10**,11,12	1,2,3
	Meretrix sp.	11.5,**22**	32	**8**,11	–
	Paphia sp.	5,17,22,23,**25**	2,288	8,10,11,12	**1**,2,3
Tellinidae	*Tellina* sp.1	5,9,15,16,17,22,23,**25**	1,472	**8**,9,10,11,12	1,2,3
	Tellina sp.2	3,**5**,9,15,16,17,23,25	1,328	8,**9**,10,11	1,2
	Tellina sp.3	3,**5**,15,17,22	736	8,**9**,10,11	–
Pholadidae	*Pholas* sp.	1,5,9,11.5,15,22,**25**	1,200	**8**,10	1,2,3
Phylum Arthropoda	Calanoid copepod	**3**,5,11.5,15,16,17,22,23	576	8,10,11,12	1,2,**3**
	Cycloploid copepod	1,3,5,9,**11.5**,15,16	320	9,11	1,2,**3**
Mysidae	*Mysis* sp.	5	16	–	3

(*continued*)

Table 1 | continued

Taxa	Species	Stations found	Maximum density (individual/m^2)	Occurrence[a] (months found) 2007	2008
Crab	Unidentified sp.	3,**5**,9,11.5,15,16	416	9,10	1,2,**3**
	Megalopa	5	16	–	2
Sergestidae	*Acetes* sp.	1,**3**,9,11.5,15,16,17,25	320	**12**	1,2,3
Portunidae	*Charybdis* sp.	15	16	–	1
Luciferidae	*Lucifer* sp.	1,3,5,11.5,15,16,22,**23**,25	128	**8**,12	1,2,3
Ocypodidae	*Ocypode* sp.	5	48	9	–
Penaeidae	*Penaeus* sp.	3,5,**9**	32	–	**2**,3
Thalassinidae	*Thalassina* sp.	5	16	11	–
Grapsidae	*Varuna* sp.	3	16	11	–
Amphipoda	Amphipod	17	16	12	–
	Gammarids	3,5,9,11.5,**16**,17,22,25	3,008	8,9,**10**,11	1,2,3
Squillidae	*Oratosquilla* sp.	1	16	–	2
Diastylidae	*Diastylis* sp.	**3**,22	240	10,11	**3**
Chthamalidae	*Balanus* sp.	5,9,**11.5**,	1,968	–	**1**,3
Chironomidae	*Chironomus* sp.	1	16	–	1
Phylum Nematoda	Nematode	1,5,9,**11.5**,16,17	240	8,9,11,12	**1**,2,**3**
Phylum Chordata	Fish larvae	**9,23**	16	**8**	**3**
Phylum Sipuncula	Sipunculan	**1**	80	–	**2**,3
Phylum Chaetognatha	*Sagitta* sp.	3,**15,23**	48	11,12	**1,3**
Phylum Cnidaria	Sea anemone	9,11.5,16,**22**	336	**8**,10,11,12	1,3

Note: [a]A number in bold-type indicates either a station or the time (months) with the highest benthos density.

were found in very high densities only at Stn 16. In the western part, the results indicated a different pattern of changes along the salinity gradient. Annelids at Stn 9 (close to the inner estuary) were the dominant group whose proportion increased over time. Nevertheless, the mollusk proportion here decreased by approximately 10 times during the medium-loading period. At Stn 23 (far from the river mouth), both annelids and mollusks decreased noticeably over time; the sediments there were composed of fine grains with high AVS levels that reached approximately 0.80 mg/g. This site may not be suitable for species from these benthos phyla.

The whole benthic invertebrate distribution and the temporal change patterns reflected the different responses of each benthic group and species. Since each species had a specific physiological response and tolerance to the environmental impacts, interpretation of the whole benthic structure should be very carefully considered. Potential species should be further clarified and monitored separately.

Environmental condition analysis

Water quality

The results of the water quality analysis showed that during high-loading periods the average silicate-silicon level was noticeably high (182.96 µM), while the salinity (9.58 psu) and pH (7.69) were comparatively low (Table 2). During this period, levels of dissolved inorganic nitrogen (DIN; $NH_4^+ + NO_2^- + NO_3^-$-N) and orthophosphate phosphorus also reached levels of approximately 78.27 and 9.09 µM, respectively. All nutrient levels were approximately 2–3 times those found in the medium- and low-loading periods. These characteristics reflected the influence of land-based runoff that provided large amounts of freshwater with high nutrient levels into the estuarine ecosystem.

In the study area, the temperatures changed less than the water quality over time (Table 2). Total suspended solids (TSS) were recorded at moderate-to-high levels. The TSS results showed no relation to inflow or other related

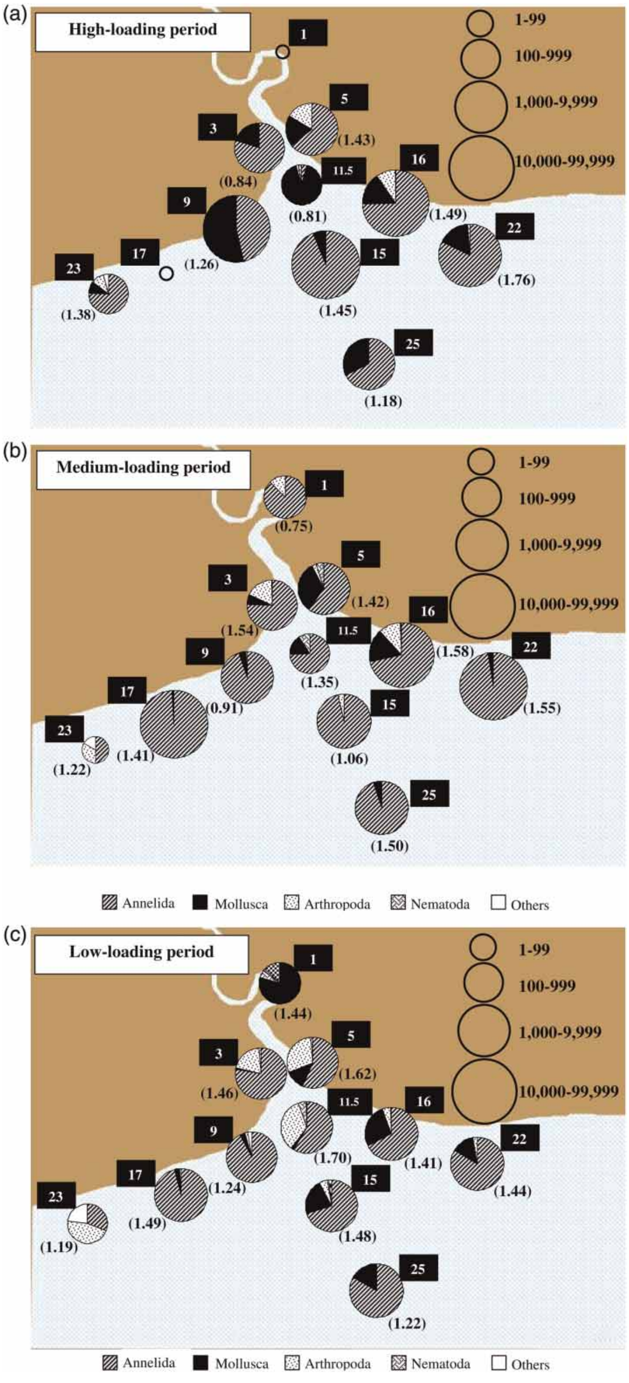

Figure 2 | Temporal changes in density (individual/m^2), composition (%), and diversity index (in parentheses) of benthic fauna found in the Tha Chin estuary during high- (a), medium- (b), and low- (c) loading periods. (Station identification codes are shown in rectangular boxes.)

factors (for example, silicates). The high TSS variation was considered to be due to tidal-induced resuspension and the patchiness of phytoplankton in some sites in the estuarine area. Nevertheless, the dissolved oxygen (DO) concentrations varied considerably and fell to less than 0.5 mg/L during the high loading-period. This level was harmful to several benthos including the spionids in the estuarine area (Llansó 1991). The inner part of the estuary usually faced hypoxia phenomena. During later periods, the DO levels were slightly improved and reached high levels exceeding 8 mg/L during the low loading-period. Very high DO levels were observed along the tidal front sites (outer part) where phytoplankton blooming occurred (Thaipichitburapa *et al.* 2009). In addition, average levels of chlorophyll *a* during the high-, medium-, and low-loading periods were 61.56, 93.48, and 58.04 μg/L, respectively. A peak chlorophyll *a* level of 1,431 μg/L was observed during December 2007 at Stn 25. Although the levels varied among stations within each study period, such high chlorophyll *a* levels revealed the hypertrophic conditions of the Tha Chin estuarine ecosystem.

Sediment quality

The average sedimentary water content (WC) of approximately 62% (Table 2) implied that the estuary had sandy mud deposits. The lowest and highest WC values were found at Stns 5 and 23, with the WC ranging between 38.93 and 46.94%, and 71.91and 83.82%, respectively. For these two stations, sedimentary organic matter (TOM) was 5.64 ± 1.62% and 14.57 ± 1.52%, respectively. Comparative low WC (with coarser grain size) and low TOM values were generally found in the inner or near-channel sites where the water flow rates were more rapid. The levels of TOM here were significantly related with WC ($P < 0.05$). Nevertheless, TOM did not vary significantly over time. In contrast, the levels of acid volatile sulfides (AVS) changed. The highest AVS (0.755 mg/g) found during the medium-loading period (approximately three months after large inflows) could imply deteriorated conditions of the bottom deposits due to high organic accumulation and an anaerobic decomposition process. According to the categorization of AVS impacting on benthic resources of the Tha Chin river basin by Meksumpun & Meksumpun (2008), the AVS levels during this period were harmful to the living invertebrate benthic resources.

Benthic faunal and environmental relationships

Analysis of the relationships between the benthic fauna and environmental factors (Table 3) indicated that the diversity index (H') of benthos had a negative relationship ($P < 0.01$) with the sedimentary WC. Thus, bottom deposits

Table 2 | Levels of water and sediment factors of the Tha Chin estuary surveyed during high (August to October 2007), medium (November to December 2007) and low (January to March 2008) loading periods

Environmental parameter		High-loading period	Medium-loading period	Low-loading period
Water quality	Precipitation (mm)	4.85 ± 1.34	0.24 ± 0.34	0.50 ± 0.85
	Inflow volume ($\times 10^6$ m^3/d)	93.46	49.83	42.43
	Temperature (°C)	31.02 ± 0.58	28.71 ± 0.66	28.93 ± 1.50
	TSS (mg/L)	37.81 ± 24.61	18.43 ± 20.38	51.90 ± 59.14
	Salinity (psu)	9.58 ± 8.45	21.63 ± 7.48	22.97 ± 5.38
	pH	7.69 ± 0.66	8.01 ± 0.57	8.31 ± 0.53
	DO (mg/L)	3.15 ± 2.67	4.25 ± 2.12	6.00 ± 2.01
	NH_4^+-N (μM)	71.93 ± 26.80	53.48 ± 22.31	48.73 ± 22.98
	$NO_2^- + NO_3^-$-N (μM)	6.34 ± 7.65	2.79 ± 2.94	3.08 ± 3.01
	$Si(OH)_4$-Si (μM)	182.96 ± 57.49	52.95 ± 16.57	55.29 ± 20.12
	PO_4^{3-}-P (μM)	9.09 ± 5.07	5.16 ± 2.18	2.95 ± 2.06
	Chlorophyll *a* (μg/L)	61.56 ± 52.13	93.48 ± 300.23	58.04 ± 35.00
Sediment quality	WC (%)	62.31 ± 15.11	63.45 ± 12.82	61.08 ± 14.38
	TOM (%)	9.89 ± 4.40	10.33 ± 3.37	9.32 ± 2.88
	AVS (mg/g dry weight)	0.359 ± 0.340	0.755 ± 0.560	0.239 ± 0.370

with higher WC (that is, more fine grain) could be suitable only for some groups of benthic species. Accordingly, it was possible that decreases in either the number of species or the density occurred at high WC sites. In general, sediment composition was revealed to have a strong influence on the structure of the benthic fauna community. Moreover, H' has been suggested to be lower in muds than fine sands (Kennish 2000). Such a community response as

Table 3 | Relationships between the diversity index (H') and various species of benthic fauna and environmental factors of the Tha Chin estuary surveyed from August 2007 to March 2008

		Species of benthic fauna							
Environmental factor	***H'***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Precipitation (mm)	*ns*	*ns*	*ns*	-0.44^b	*ns*	*ns*	*ns*	*ns*	*ns*
Inflow volume ($\times 10^6$ m^3/d)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	0.34^b
Temperature (°C)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
TSS (mg/L)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
Salinity (psu)	*ns*	*ns*	0.29^a	0.43^b	*ns*	*ns*	*ns*	*ns*	-0.28^a
pH	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
DO (mg/L)	*ns*	*ns*	0.29^a	0.29^a	*ns*	*ns*	*ns*	*ns*	-0.40^b
NH_4^+-N (μM)	*ns*	-0.36^b	-0.25^a	*ns*	0.31^b	*ns*	*ns*	-0.77^a	0.34^b
$NO_2^- + NO_3^-$-N (μM)	*ns*	*ns*	*ns*	-0.37^b	*ns*	*ns*	*ns*	*ns*	*ns*
$Si(OH)_4$-Si (μM)	*ns*	-0.29^a	-0.28^a	-0.47^b	*ns*	*ns*	*ns*	*ns*	0.36^b
PO_4^{3-}-P (μM)	*ns*	*ns*	*ns*	*ns*	0.30^a	*ns*	*ns*	*ns*	0.35^b
Chlorophyll *a* (μg/L)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
WC (%)	-0.33^b	*ns*	*ns*	*ns*	*ns*	-0.31^b	*ns*	*ns*	-0.28^a
TOM (%)	*ns*	*ns*	*ns*	*ns*	*ns*	-0.29^a	0.62^a	*ns*	*ns*
AVS (mg/g DW)	*ns*	*ns*	*ns*	*ns*	*ns*	-0.25^a	*ns*	*ns*	*ns*

Note: Species: 1 = Nephtys; 2 = Aonides; 3 = Prionospio; 4 = Sabella; 5 = Nereis; 6 = Paphia; 7 = Pholas; 8 = Arcuatula.
ns = not significant.
[a]Correlation was significant ($P < 0.05$).
[b]Correlation was significant ($P < 0.01$).

shown by the H' value could thus imply a negative impact by the fine deposits enhanced by the eutrophication process in the estuary. Nevertheless, since H' showed no relation with any of the water parameters, such an index may not be applicable for reflecting changes in the water environment.

Salinity and sediment stability should exert a strong control on the species composition and distribution of the estuarine benthos. The highest density of mud flat infauna existed in places where the salinity, sediment, and food supply were more favorable for biomass development. Similarly, Nichols & Thompson (1985) reported that spatial and temporal changes in some environmental factors (for example, freshwater inflow, salinity, and bottom current) can greatly influence periodicities of reproduction and recruitment that substantially contributed to the distribution patterns. Moreover, anthropogenic impacts may also significantly affect both the structure and dynamics of the benthic community.

In the present study, benthic species related to environmental factors in different ways. Subsurface deposit feeders such as *Nereis* sp. had a negative relationship with sedimentary WC, TOM, and AVS (Table 3). Thus, high organic matter and sulfides in the sediment should be harmful for their existence. Other deposit feeders such as *Nephtys* sp. and *Aonides* sp. showed no significant relationship with sediment quality. Such a response could be due to their wider ranges of tolerance to pollution stress. From the results, *Nereis* sp. could have more potential to reflect the organic pollution stress inherent in the bottom sediments. In addition, almost all deposit feeders were limited by decreasing trends of water salinity and/or DO. Accordingly, higher densities were recorded in the outer part of the estuary where the influence of freshwater was less. Among the deposit feeders there, *Prionospio* sp. (which related significantly to various water parameters) appeared to be the polychaete with the most potential to be used as a bio-indicator for further changes from land-based runoff.

Paphia sp., an economically important benthos, had a positive relationship ($P < 0.05$) with only sedimentary TOM (Table 3). Nevertheless, high sedimentary TOM occurred with very high AVS levels of more than approximately 1.5 mg/g that showed a negative impact on its population. The *Pholas* sp. clam had no significant correlation with TOM but possessed a negative relationship ($P < 0.05$) with NH_4^+-N, which implied that the *Pholas* sp. populations may prefer sites with greater circulation. In addition, the *Arcuatula* sp. clam related significantly with various environmental factors (for example, inflow, salinity, DO, nutrients, and sedimentary WC). Thus, its distribution pattern could be further analyzed to illustrate changes in estuarine environments. In the near future, this species could gradually increase as increasing problems of estuarine eutrophication occur.

CONCLUSIONS

The water quality of the Tha Chin estuary located in the innermost part of the Gulf of Thailand was revealed to be notably impacted by freshwater runoff with very high nutrient levels particularly during the high-loading period (August to October) in the year studied. During this period, the salinity and nutrient levels changed significantly. Consequently, the levels of chlorophyll *a* depicted the hypertrophic condition of the estuarine ecosystem. Related sediment qualities (for example, WC and AVS) were consequently affected and the toxicity from sulfide accumulation could cause deterioration in the benthic invertebrates. Analysis of the benthic fauna community structure showed that the dominant groups here were annelids and mollusks. The annelid proportion (almost all deposit feeders) made up more than half of the whole benthic invertebrates found. The succession of feeding behavior-based groups seemed to correspond with stress in eutrophication along the salinity gradient and different parts of the estuarine area.

The overall results from this study have revealed the importance of changes in the water and sediment qualities and their influence on related benthic resources. The proportion of clams species of economic value decreased during the medium-loading period, due to the deteriorated sediment conditions. Thus, the land-based runoff should be controlled to protect the clam resources in the area. The establishment of suitable sediment quality criteria for the estuarine area is also necessary. In addition, since some deposit feeders (for example, *Nereis* sp. and *Prionospio* sp.) and the clam species (*Arcuatula* sp.) of the Tha Chin estuary showed significant responses to changes in the environmental conditions, their application as potential bio-indicators for monitoring the area could be useful. For further effective sustainable management, an eco-based zoning scheme for conservation and restoration of the Tha Chin estuary should be given serious consideration by all stakeholders. The estuarine area could be categorized into suitable sub-ecological regions (the middle channel, the eastern, and the western parts), based on differences in the benthic community responses to the salinity gradient and eutrophication stress.

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