Integration of aquatic ecology and biological oceanographic knowledge for development of area-based eutrophication assessment criteria leading to water resource remediation and utilization management: a case study in Tha Chin, the most eutrophic river of Thailand
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ABSTRACT

This research was carried out in Tha Chin Watershed in the central part of Thailand with attempts to apply multidisciplinary knowledge for understanding ecosystem structure and response to anthropogenic pollution and natural impacts leading to a proposal for an appropriate zonation management approach for sustainable utilization of the area. Water quality status of the Tha Chin River and Estuary had been determined by analyzing ecological, hydrological, and coastal oceanographic information from recent field surveys (during March 2006 to November 2007) together with secondary data on irrigation, land utilization, and socio-economic status. Results indicated that the Tha Chin River and Estuary was eutrophic all year round. Almost 100% of the brackish to marine areas reflected strongly hypertrophic water condition during both dry and high-loading periods. High NH4\(^+\) and PO4\(^{3-}\) loads from surrounding agricultural land use, agro-industry, and community continuously flew into the aquatic environment. Deteriorated ecosystem was clearly observed by dramatically low DO levels (ca 1 mg/l) in riverine to coastal areas and Noctiluca and Ceratium red tide outbreaks occurred around tidal front closed to the estuary. Accordingly, fishery resources were significantly decreased. Some riverine benthic habitats became dominated by deposit-feeding worms e.g. Lumbricus, Branchiura, and Tubifex, while estuarine benthic habitats reflected succession of polychaetes and small bivalves. Results on analysis on integrated ecosystem responses indicated that changing functions were significantly influenced by particulates and nutrients dynamics in the system. Based on the overall results, the Tha Chin River and Estuary should be divided into 4 zones (I: Upper freshwater zone; II: Middle freshwater zone; III Lower freshwater zone; and IV: Lowest brackish to marine zone) for further management schemes on water remediation. In this study, the importance of habitat morphology and water flow regimes was recognized. Moreover, nearshore extensive shrimp culture ponds, irrigation canals, and surrounding mangrove habitats belonging to local households seemed to act as effective natural water treatment system that can yet provide food resources in turns. These remediation-production integrated functions should be deserved depth considerations for water quality development of the Tha Chin areas.

Key words | ecosystem response, eutrophication, Tha Chin River and Estuary, water quality criteria, zonation management

INTRODUCTION

The Tha Chin River is located in the central part of Thailand (13°50′N and 100°17′E) with a distance of ca 325 km. It is an important area for agriculture, agro-industry, and local community resident. The river passes through 4 provinces; Chai Nat, Suphan Buri, Nakhon Pathom, and Samut Sakhon, and then flows into the inner part of the Gulf of Thailand (Figure 1). According to Pollution Control Department (1997), water quality in the river through the estuary was below the standards for several water quality parameters. Major causes of deteriorating water quality have been reported to be untreated wastewater discharge from agriculture, animal husbandry, urban communities, and industrial activities and leading to the continuous flow of organic and inorganic contaminants, nutrients, and toxic wastes into the river. Nowadays, more than 15 governmental and private agency (including non-governmental organization sectors) have paid attention on the changes of the river and relating resources. Nevertheless, water quality is still uncertainty and seems to be worse day by day.

Despite of knowing deteriorated situation, the Tha Chin River future is still un-expected. Almost related sectors have non-sharing actions on river development. The resulting lack of robust water quality data together with precise land use and socioeconomic information introduced a greater level of uncertainty when developing of management strategy for water resources and planning infrastructure development. Reduction in yield from river and estuarine fisheries, in addition, really needs the answers from ecological point of views.

According to information on benthic organisms and heavy metal distribution, we realize the necessary of understanding how aquatic ecological remediation potentials have changed with time. The area topography, hydrology, and water utilization patterns were also deserved depth consideration. In this study, suitable water quality assessment criteria have been discussed. Aquatic functions both as physicochemical and biological phases were concentrated. This study, therefore, was carried out with attempts to apply multidisciplinary knowledge for understanding ecosystem structure and their response to anthropogenic pollution and natural impacts. The conceptual frame work of the research was depicted as Figure 2. According to 5-steps research, we aimed to illustrate recent water quality situation in aspects of pollution and production potentials, prioritize problems, and propose integrated water quality criteria. This knowledge can lead to develop a suitable community-based management approach for waste water remediation and resource enhancement of the area.

METHODOLOGY

Water quality of Tha Chin River and Estuary had been examined in ca 37 stations located from sea to upstream
areas. The survey times in 2 years were set during dry (March 2006, May 2007) and high-loading (November 2006, November 2007) periods. Water parameters measured at the field stations were as follows: dissolved oxygen, temperature, pH, salinity, depth, flow speed/direction, and transparency. To determine total suspended solids (TSS), chlorophyll $a$, and dissolved inorganic nutrients ($\text{NH}_4^+$, $\text{NO}_2^+$, $\text{NO}_3^-$, $\text{Si(OH)}_4$, and $\text{PO}_4^{3-}$), surface water samples were collected. In addition, levels of the nutrients along estuarine area (in where dilution by tidal effect can change loaded concentrations) were calibrated according (Soontornprasit & Meksumpun 2008).

A comparative study site located beneath to the river tributary was set at a large scale extensive shrimp culture pond systems located in the eastern part of the Tha Chin Estuary (in Phanthai Norasing District). Along this site, eight sampling points were selected as representatives of different seawater-exchangeable and ecological-balance potentials of in-pond and canal systems. Here, species composition of phytoplankton, zooplankton, and benthic animals were simultaneously investigated.

In addition, database on precipitation, irrigation, inflow, land-use, tidal phenomena, and socio-economic information have been gathered from the local governments and relating authorities. Some necessary information were also collected from direct interview of local people in the field areas.

**RESULT AND DISCUSSIONS**

**Physicochemical characteristics**

Results indicated that the Tha Chin River and Estuary was in eutrophic condition all year round. High $\text{NH}_4^+$ and $\text{PO}_4^{3-}$ loads from surrounding agricultural land use, agro-industry, and community continuously flew into the aquatic environment. Ranged of $\text{NH}_4^+$ and $\text{PO}_4^{3-}$ were $0.8$–$152.0 \text{ M}$ and $0.3$–$17.0 \text{ M}$, respectively (Figure 3). The $\text{NH}_4^+$ of more than $570 \text{ M}$ was observed in tidal front area off the river mouth.

The results have revealed apparently accumulation of $\text{NH}_4^+$ and $\text{PO}_4^{3-}$ nutrients in the lower part of the river while the upper part reflected lower nutrients. When the levels of inorganic and organic forms of particulate phosphorus of water surveyed during high-loading period (November 2006) were comparatively analyzed, we found that changes in each composition varied upon stations and zones (Figure 4a). Generally, higher total particulate phosphorus can be found in the lower part. This phenomenon could response the magnitude of anthropogenic runoff. Moreover, ratios of inorganic/organic forms of PP could imply the rate of aerobic decomposition mechanism in the water column. Oppositely, organic PP ratios in some locations e.g. stn2, stn8-9, and stn12-20 indicated comparative higher levels that implied higher organic accumulation process in the water column. Consideration on stations with PP levels
> 3 \mu M, comparative higher-mechanism were belonging to the nearshore stations (stn1-3; Figure 4b). In this study, the levels of PO_4^{3-} (DIP) had related to PP with the power function of DIP = 0.067 e^{0.671 PP} in which r^2 = 0.60.

**Biological and ecological response**

High nutrient loads resulted in apparent increment of primary producer (phytoplankton) in the water column. Generally, chlorophyll a concentrations which represented productive phytoplankton cells can be found >20 \mu g/l (Figure 5). Almost 100% of the stations in brackish to marine zones reflected strongly hypertrophic (The Organisation for Economic Co-operation and Development 1982) water conditions during both dry and high-loading periods (chlorophyll a >50 \mu g/l). The levels in stations near the river mouth were higher than 100 \mu g/l and reached 535 \mu g/l during Noctiluca (Figure 6a) red tide outbreak.
During red tide (*Noctiluca* and *Ceratium*) outbreaks in late high-loading period in a year, deteriorated water quality was clearly observed by dramatically low DO levels (<1–2 mg/l). The area around tidal font closed to the estuary was most impacted. Here, recognition of dead shells in the sediment surface was generally noticed.

Benthic organisms in the survey stations were generally dominated by infaunal oligochaetes (*Figure 6b and c*) and some deposit-feeding polychates. The total densities had reached ca 20,000 individuals/m² in the lower zone of the Tha Chin River.

In benthic zones, 16 species of Annelids, 2 species of bivalves, and 10 species of Arthropods were recorded. From the results, riverine benthic habitats became dominated by deposit-feeding oligochaetes such as *Lumbriculus*, *Branchiura*, and *Tubifex*, while estuarine benthic habitats reflected the success of small polychaetes and bivalves instead of economic shells. Although there were fluctuations in benthos total densities (*Figure 7*), comparative higher densities were found in the lower river part, including brackish waters and nearshore areas.

According to information e.g. salinity intrusion, nutrients loads and biological distributions, we roughly divided the Tha Chin River into 4 categories; I: Upper zone of freshwater habitat (stn22-32), II: Middle zone of freshwater habitat (stn11-21.5), III Lower zone of freshwater habitat (stn5-10), and IV: Lowest zone of brackish to estuarine habitat (stn1-4). During 4 sampling times, ranges of benthos total densities of zones I-IV were 181–2,728, 496–1,048, 56–224, and 30–600 individuals/m², respectively. Stability of the density can be apparently observed in Zone II, while Zone IV of the estuarine waters reflected greater temporal variations.

Population density, therefore, could imply possible trend of organic accumulation at the bottom surface around the lower zones (in stn 1–10).

In addition, species compositions of the benthos (mainly oligochaetes) found in the representative stations of each zone (*Figure 8*) showed biological response of bottom community to environmental stress. Higher diversity was usually found during high-loading period of a year. Among several worms, the genus of *Lumbriculus*, *Branchiura*, and *Tubifex* were dominants. *Table 1* showed densities of *Lumbriculus*, *Branchiura*, and *Tubifex* and the calculated Diversity Index (*H*) of the Ta Chin River and Estuary during high-loading period (November) in 2007. Each maximum densities of 336, 512, and 889 individuals/m² were noticed in the Zones of I, II, and IV, respectively. Since their densities can reflect differences in environmental condition or location, they were further focused as target species to be monitored for water quality assessment.

**Development of water quality criteria**

Results on correlation analysis of ecosystem responses indicated that changing functions relating pollution response and production potential of the aquatic system were significantly influenced by *particulates* and *nutrients* dynamics. In this study, DIP provided more significant enhancement of phytoplankton production than those of dissolved inorganic nitrogen sources. The total levels of inorganic phosphorus (TIP), both in forms of particulates (PIP) and dissolved
orthophosphates (DIP), had revealed apparent proportion to those of ammonium nitrogen (Figure 9a).

Accordingly, the N:P ratio were rather constant in the levels of $ca\ 14:1$ which closed to the Redfield ratio of coastal phytoplankton (16:1) (Parsons et al. 1984). Comparatively low levels were considered to be due to impacts of anthropogenic phosphorus source in the study area. In addition, particular high $NH_4^+$ levels of more than 60 $\mu$M (e.g. in stn4) can cause high N:P ratio. Such phenomenon implied excess amount of N loaded into this hypereutrophic coastal area.

Consideration on impacts of nutrients, the TIP could also play important roles on chlorophyll $a$ productions in

\begin{table}[h]
\centering
\caption{Densities of \textit{Lumbriculus} (Lumb), \textit{Branchiura} (Bran), and \textit{Tubifex} (Tub) (individuals/m$^2$) and the calculated Diversity Index ($H$) of the Tha Chin River and Estuary during high-loading period in 2007.}
\begin{tabular}{cccccc}
Stn & Total density (ind/m$^2$) & $H$ & Lumb (ind/m$^2$) & Bran (ind/m$^2$) & Tub (ind/m$^2$) \\
\hline
1 & 1968 & 0.74 & 0 & 0 & 0 \\
2 & 0 & 0 & 0 & 0 & 0 \\
3 & 272 & 0.75 & 192 & 0 & 0 \\
4 & 2240 & 1.85 & 336 & 320 & 272 \\
5 & 464 & 1.05 & 0 & 272 & 64 \\
6 & 144 & 0.53 & 0 & 32 & 0 \\
7 & 1360 & 0.86 & 0 & 240 & 0 \\
8 & 592 & 1.33 & 64 & 80 & 64 \\
9 & 1472 & 1.54 & 48 & 512 & 96 \\
10 & 0 & 0 & 0 & 0 & 0 \\
11 & 16 & 0.00 & 0 & 0 & 0 \\
12 & 0 & 0 & 0 & 0 & 0 \\
13 & 128 & 0.66 & 0 & 0 & 0 \\
14 & 0 & 0 & 0 & 0 & 0 \\
15 & 0 & 0 & 0 & 0 & 0 \\
16 & 64 & 0.56 & 0 & 0 & 0 \\
17 & 304 & 1.00 & 0 & 96 & 48 \\
18 & 0 & 0 & 0 & 0 & 0 \\
19 & 112 & 0.60 & 0 & 0 & 0 \\
20 & 0 & 0 & 0 & 0 & 0 \\
21 & 0 & 0 & 0 & 0 & 0 \\
21.5 & 64 & 1.04 & 0 & 0 & 0 \\
23 & 144 & 1.10 & 0 & 0 & 0 \\
24 & 96 & 0.87 & 0 & 16 & 16 \\
25 & 16 & 0.00 & 0 & 0 & 0 \\
25.2 & 48 & 0.64 & 0 & 0 & 16 \\
25.5 & 355 & 1.21 & 0 & 44 & 178 \\
26 & 177 & 0.56 & 0 & 0 & 44 \\
26.5 & 44 & 0.00 & 0 & 0 & 44 \\
27 & 400 & 0.64 & 0 & 0 & 267 \\
27.5 & 400 & 0.69 & 0 & 0 & 222 \\
28 & 133 & 0.63 & 0 & 44 & 0 \\
29 & 355 & 0.73 & 0 & 44 & 267 \\
30 & 532 & 0.56 & 0 & 44 & 444 \\
31 & 933 & 0.19 & 0 & 44 & 889 \\
32 & 177 & 1.04 & 89 & 0 & 44 \\
\end{tabular}
\end{table}

Figure 8 | Species composition of benthic animals (%) in representative stations of the Ta Chin River and Estuary surveyed during May and November 2007.

$\text{\textit{Dero sp. Ophidonais sp. Nais sp. Branchiura sp. Tubifex sp. Aeolosoma sp. Haplotaxis sp. Lumbriculus sp.}}$
the water. In this study, polynomial function was applied to illustrate such impacts (Figure 9b). Chlorophyll $a$ depicted 2 loops of succession curves. During the low TIP of less than $2 \, \mu M$, TIP had revealed to effectively increase the phytoplankton population growth (as dashed line in Figure 9b). This finding related to a former study on nutrient requirement of red tide dinoflagellates in the Seto Inland Sea, Japan (Meksumpun et al. 1998) in which $2 \, \mu M$ DIP was enough for the growth. In this aspect, some dinoflagellate population may thus enhance by such nutrients and, consequently, the red tides can occur frequently (Lirdwitayaprasit et al. 2006). In the case of high TIP of more than $2 \, \mu M$, fluctuations on chlorophyll $a$ were noted. Such quantitative distribution of phytoplankton population, therefore, should be impacted by other species succession and/or flow and tidal action instead.

### Integrated water quality assessment

From the overall views of ecosystem functional analysis, to keep levels of dissolved oxygen concentrations in the study area in suitable condition for living resources, the distribution pattern of chlorophyll $a$ that was influenced by nutrients should be deserved depth consideration. Moreover, their changing pattern relating to coastal flow regimes should also be clarified so as to determine magnitude and direction of algal blooming and impacts to related aquatic environment.

According to typical land topography and water flow structure from upstream through the coastal zone, some locations in the river were found to be particular area of particle settlement with autotrophic mechanism in resource production, while some locations reflected heterotrophic and deteriorated aquatic habitats. The water quality of estuarine zone also showed large variation due to tidal action.

Nevertheless, in order to develop the water resource, effective zonation management should be proposed based on general response pattern of their local ecosystems. In this study, the river was, therefore, categorized into 4 zones; I: Upper freshwater habitat (stn22-32), II: Middle freshwater habitat (stn11-21.5), III Lower freshwater habitat (stn5-10), and IV: Lowest brackish-estuarine habitat (stn1-4). Thereafter, important water quality assessment criteria or major key parameters of each zone were proposed (Figure 10). These criteria were critical important for monitoring and management approach.

From the Japanese experience on water pollution control (Okada & Peterson 2000), the water quality Tokyo Bay has improved considerably by a result of effluent controls and guidance based on the laws and the ordinances. In addition, citizens, administration, and industries have made a large contribution. However, significant improvement in water quality for the Bay has not been noted. Red tides occurred every summer at the head of the bay, and oxygen depletion of bottom layers damaged the aquatic ecosystem.

This experience leaded us to pay concentrate on the roles of nutrients. We agreed that advanced treatment processes for nutrient removal from sewage should be needed together with further reduction of pollution loads and the expansion of sewage systems. Accordingly, all the water bodies here require the control of nutrients. More
attention should also be paid on identification of potential for eutrophication. Waters currently in hypertrophic condition or that might be soon should have high priority.

**Natural water treatment system in coastal zone**

Results on comparative study site in a large scale extensive shrimp culture pond system located in the eastern part of the Tha Chin Estuary indicated ca 10 times lower N and P nutrients and chlorophyll a concentrations (Figure 11). These nearshore pond systems consisting with water management pattern for extensive shrimp culture and other seafood production should act as natural treatment or sedimentation pond. Such the ponds in these areas, thus, might play an important role on controlling material flux and water purification. Consideration on long-term water quality development, such styles of coastal structure could help our future water environment with less investment cost.

**CONCLUSIONS AND RECOMMENDATION**

Knowledge on ecological response, natural habitat topography, and water flow regimes should be applied for future water resource development. For effective management schemes for water remediation, the Tha Chin River and Estuary water system should be divided into 4 zones (I: Upper freshwater; II: Middle freshwater; III Lower freshwater; and IV: Lower brackish water) for management approach. The lower ones (zones III, IV) were in severe water condition that should receive prior attention and improvement.

In this study, nearshore extensive shrimp culture ponds, their irrigation canals, and surrounding mangrove habitats
seemed to act as large-scale natural treatment system that can still provide food resources in turns. Such a natural system should be considered as possible management strategies. The overall findings from this research have revealed the importance of river natural habitats. Thus, precise understanding of local ecosystem process was necessary for development of effective management strategy of any area. Nevertheless, results on land utilization and socio-economic condition of local community reflected somewhat trend of gradual deterioration of water quality. In this aspect, lacks of impact information, education, and social awareness were critical problems. Unless understanding and cooperation for water quality conservation and development from industrial and local community, the water quality in the Tha Chin River and Estuary could not be improved.

ACKNOWLEDGEMENTS

The research was supported by National Research Council of Thailand. We gratefully acknowledge Assoc.Prof.Sangtien Ajimangkul for her suggestion. Special thank is due to Marut Suksumjot for kind providing particulate phosphorus data. Thanks are also due to Patrawut Thaipichitburapa, Suchitta Champa, Pattira Kasemsiri and all members of Sediment and Aquatic Environment Laboratory (Department of Fishery Biology) and Marine Environment Laboratory (Department of Marine Sciences) for their kind cooperation in both field surveys and laboratory analyses.

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