Research article

Predictive Model for Biochemical Component of Phytoplankton in the River and Estuarine Systems of the Mae Klong River, Thailand

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Received 16 December 2012 Accepted 30 January 2013 (*Corresponding Author)

Abstract As one of the four major rivers of Thailand, the Mae Klong River flows in the west of the Kingdom and exits into the Gulf of Thailand. This research study was conducted during February 2006 through May 2008 and found the increased levels of NH_4^+, NO_2^-+NO_3^-, and PO_4^{3-} in the lower river and estuary areas of the Mae Klong River, which led to the phytoplankton blooming phenomenon in such areas. Three phyta and 63 genera of phytoplanktons were discovered in the river. The dominant groups were diatoms (*Plurosigma* or *Gyrosigma*), cyanobacteria (*Trichodesmium*), and dinoflagellates (*Peridinium* and *Gonyaulax*). In this study, generalized linear modeling (GLM) was applied to examine the factors influencing phytoplankton abundance in the river systems. The results showed that phytoplankton abundance varied according to the dissolved inorganic nutrient (DIN), zone, and season. Thus, the predictive model should be established to facilitate determination of phytoplankton abundance, assessment of water quality, and thereby more efficient management of water resources for sustainable use.

Keywords dissolved inorganic nitrogen, phytoplankton, GLM analysis, Mae Klong River

INTRODUCTION

The Mae Klong River is the most important river in the west of Thailand, with an approximate length of 140 km and a catchment covering 22,075 km^2. The river runs from Kanchanaburi province and flows toward the lower plain through Ratchaburi province before discharging into the Gulf of Thailand in Samut Songkhram province (Thongdonphum et al., 2010). It has long been known that changes of river flow could impact biochemical composition, including nutrient loading, in the river and thereby phytoplankton abundance. Nutrient loading restriction is the cornerstone of aquatic eutrophication control (Smith et al., 1999) and is readily available monitoring data of red tide/harmful algal bloom (Zhou et al., 2008). Regional Environmental Office 8 (REO8, 2004) reported that utilization of land along the Mae Klong River for agriculture was estimated at 83%, 58%, and 32% in Samut Songkhram, Ratchaburi, and Kanchanaburi provinces, respectively. According to REO8 (2007), the deterioration of water quality induced mainly by sewage, domestic discharges, and agriculture use has contributed to phytoplankton blooming phenomena in the estuarine and coastal zones.

OBJECTIVE

This study aims to assess the impacts of aquatic environmental factors on the variation or abundance of phytoplankton. The findings could subsequently be used to establish a biochemical predictive model that enables better management of water resources and thereby sustainable utilization of the river and estuarine systems as well as the ecosystem.

METHODOLOGY

Sampling sites and survey plan

The surveys were conducted at 27 sampling stations (stn.) along the Mae Klong River, the stations of which were grouped into 3 zones: the estuarine zone in Samut Songkhram province (stn.1-stn.8), the middle zone in Ratchaburi province (stn.9-stn.18), and the upper zone in Kanchanaburi province (stn.19-stn.27), spanning from February 2006 to May 2008 (Fig. 1). According to the rainfall patterns, Thailand is under the influence of monsoon winds (TMD, 2012). The seasons can thus be divided into rainy season (May- September), winter season (October-February), and dry season (March-April). In addition, large amounts of water typically flow into the lower river basin between September and February. Water samples from the 27 stations were collected during the three seasonal periods for the 2-year interval such that all possible loading periods were taken into consideration, hence giving rise to a total 6 sampling times: May 2006 and May 2008 (early-loading period), November 2006 and September 2007 (mid-loading period), and February 2006 and December 2007 (late-loading period).

Sample collection and analysis

The general water quality factors, namely temperature, dissolved oxygen (DO), salinity and pH, were measured with a multi-parameter probe (YSI-6600 Sonde instrument) at the sampling sites. Samples of surface water (30 cm deep) were pre-filtered through GF/F (Whatman) and then stored at 4°C before transporting to the laboratory for analysis of nutrients, including ammonium (NH_4^+), nitrite and nitrate (NO_2^-+NO_3^-), silicate ($Si(OH)_4$), and ortho-phosphate (PO_4^{3-}), with a SKALAR segmented flow analyzer. The samples for chlorophyll *a* (Chl *a*) and total suspended solids (TSS) measurement were analyzed by the spectrophotometric method and the freeze-dried technique, respectively. Phytoplankton samples were collected and preserved in formaldehyde buffered solution before being classified and enumerated with a Sedgewick-Rafter counting chamber under a light microscope.

Data analysis

Comparisons of water quality in terms of temperature, salinity, DO, pH, Chl *a*, and TSS among the sampling periods and zones were performed using average levels and distribution characteristics. Least Significant Differences (LSD) or Tamhane's T2 of Post Hoc test of the one-way analysis of variance (ANOVA) was used for the environmental variation comparison, and the level of confidence greater than 95% ($p < 0.05$) was considered to indicate a statistically significant impact. The Mann-Whitney test was used where a normal distribution was not observed. Based on the work of Zuur et al. (2007), GLM analysis was applied to the proposed predictive model for phytoplankton assessment, with attention given to the goodness of fit of the model.

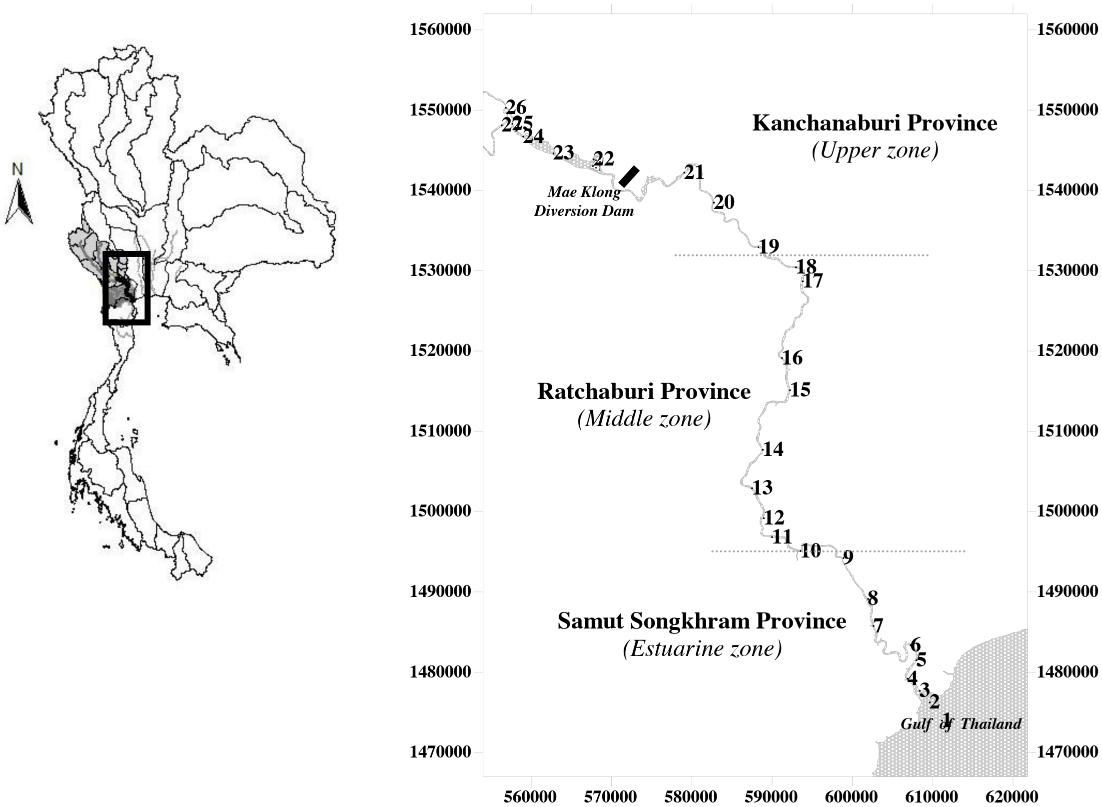

Fig. 1 Sampling stations (Stn. 1–27) from the estuarine to the upper zone of the Mae Klong River

RESULTS AND DISCUSSION

Environmental factors

The results indicated that the Mae Klong River was influenced by freshwater runoffs, which in turn contributed to varying water quality by loading periods. Water temperatures slightly decreased with seasons ($p < 0.05$), and low level of salinity was detected during the early-loading period for which large quantity of water flows into the river. The pH level was found to be relatively constant for the entire study area, while DO varied and markedly decreased to unsuitable levels (<4 mg/l) in the estuarine zone during the early-loading period. The levels of TSS were between 2.40 and 187.50 mg/L with higher TSS levels found in the lower and estuarine zones. The Chl *a* concentration ranged between 1.34 - 14.69 µg/l with high concentration levels mostly found in the estuarine zone. Chl *a* of approximately 10 µg/l has been regarded as the initial level for eutrophication in the estuarine zone. In addition, this study has found that the level of Chl *a* in the upper zone was 4.24 µg/L, which far exceeded the natural base-line level of Chl *a* of approximately 3.3 µg/L (Thongdonphum et al., 2011).

The levels of NH_4^+ and NO_2^-+NO_3^- varied significantly ($p < 0.05$) with seasons. The concentrations of NH_4^+ and NO_2^-+NO_3^- varied from 0.63 to 74.47 µM and 0.40 to 24.75 µM, respectively. Higher concentration levels were found in the lower and estuarine zones with land utilization for agriculture, of which rice fields and aquaculture areas accounted for 108.2 and 29.1 square kilometer, respectively (NSO, 2010). The highest population density was reported at 496 people per square kilometer in Samut Songkhram province (REO8, 2008). $Si(OH)_4$ concentrations ranged from 30.13 to 148.35 µM with the concentration level apparently decreasing around the estuarine stations near the river mouth. The results show that the nutrients induced by rainfalls during the early-loading period in the three zones under the study were significantly different ($p <$

0.05). PO_4^{3-} levels ranged from undetectable to 8.07 µM with noticeably high levels in the estuarine zone where population density and land use were high. Of concern is that PO_4^{3-} concentration in the Mae Klong estuary was much higher than the recommended level of 0.48 µM for the ASEAN marine water quality (Chongprasith et al., 1999).

Table 1 The quality of water (mean±SD) along the Mae Klong River during the study period

Para meters	Early-loading period			Mid-loading period			Late-loading period		
	Upper	Middle	Estuarine	Upper	Middle	Estuarine	Upper	Middle	Estuarine
Temp (°C)	29.3±0.7	30.3±0.3	30.5±0.5	28.4±0.7	29.4±0.7	29.5±1.2	27.1±1.1	27.8±1.3	27.6±0.9
Salinity (psu)	0.1±0.0	0.1±0.0	2.5±4.7	0.1±0.0	0.1±0.0	9.1±10.5	0.1±0.0	0.1±0.0	10.5±9.6
DO (mg/L)	6.0±1.6	6.2±1.4	4.8±0.8	7.7±1.3	6.5±1.0	5.7±1.8	6.8±2.0	7.4±1.3	6.2±1.0
pH	7.7±0.7	8.6±0.2	8.0±0.7	8.5±1.0	8.7±0.2	8.2±0.6	8.5±0.6	7.8±0.5	8.1±0.4
Chl *a* (µg/L)	3.7±1.5	3.8±1.1	4.5±2.0	4.8±1.9	3.1±1.2	5.4±3.0	4.1±1.5	3.4±0.9	6.8±3.9
TSS (mg/L)	17.5±7.9	25.6±17.9	32.8±23.0	21.1±15.8	20.9±10.0	30.7±19.1	11.7±5.1	16.5±6.0	27.2±43.9
NH_4^+ (µM)	3.4±2.0	9.6±4.3	12.8±5.3	2.9±2.1	7.8±3.3	19.4±9.4	2.1±1.1	11.4±9.2	22.4±17.9
NO_2^- $+NO_3^-$ (µM)	4.9±2.28	8.7±4.4	13.4±4.9	6.4±2.8	9.0±2.0	10.8±6.3	6.0±1.4	9.2±2.8	11.0±5.2
$Si(OH)_4$ (µM)	98.9±49.2	99.6±48.7	95.8±44.8	73.6±5.7	73.66±5.8	69.1±8.1	64.6±7.3	66.5±4.8	54.5±13.6
PO_4^{3-} (µM)	0.2±0.1	0.7±0.4	2.2±0.8	0.2±0.1	0.8±0.4	4.4±2.4	0.2±0.1	0.5±0.3	1.8±1.1

Phytoplankton distribution

The phytoplankton community during the study period consisted of 63 genera, namely 7 Cyanophyceae, 19 Chlorophyceae, 26 Bacillariophyceae (diatoms), 10 Dinophyceae (dinoflagellates), and 1 Chrysophyceae. The amount of phytoplankton varied from 125 to 1.86×10^5 unit cells/L with the highest density found around the stations in the estuarine zone. The results showed that diatoms were the most dominant group with highest phytoplankton abundance (1.86×10^5 cells/L). Other species, such as *Trichodesmium* sp., *Gymnodinium* sp., *Noctiluca* sp., *Ceratium* sp., *Gonyaulax* sp., *Peridinium* sp. and *Protoperidinium* sp., were also found in the estuarine zone and markedly increased in the late-loading period.

Predictive model for phytoplankton

The results of GLM analysis in Table 2 show that M2 is the optimal model (Adj.R^2 = 0.400). The model indicates that phytoplankton abundance depends on the dissolved inorganic nitrogen (DIN; $NH_4^+ + NO_2^- + NO_3^-$), zone, and loading period (Load). Moreover, an interaction effect exists between Load and DIN.

Table 2 Predictive model of phytoplankton density for the Mae Klong River

Model	Adj.R^2	MSE	Goodness of Fit
M1: Total_Phyto1 = Zone1 + Zone2 + DIN	0.254	239183423	p = 0.913
M2: Total_Phyto2 = Zone1 + Zone2 + DIN + Load + Load*DIN	0.400	192354102	p = 0.963
M3: Total_Phyto3 = Zone1 +Zone2 +DIN + Load + Load*Zone	0.283	229810498	p = 0.925

A numerical example of phytoplankton abundance estimation in the estuarine zone is shown below:

$$
\begin{aligned}
\text{Total\_Phyto2} &= \text{Intercept} + \text{zone} + \text{DIN} + \text{Load} + \text{Load*DIN} \\
&= 4{,}843.427 - 5{,}475.341(\text{Zone1}) - 7{,}211.332(\text{Zone2}) + 226.213(\text{DIN}) - \\
&\quad 16{,}936.047(\text{Load1}) + 194.040(\text{Load2}) + 1{,}060.511(\text{Load1})(\text{DIN}) - \\
&\quad 115.320(\text{Load2})(\text{DIN}) \\
&= 4{,}843.427 - 5{,}475.341(1) - 7{,}211.332(0) + 226.213\text{DIN} - 16{,}936.047(1) \\
&\quad + 194.040(0) + 1{,}060.511(1)(\text{DIN}) - 115.320(0)(\text{DIN}) \qquad (1)
\end{aligned}
$$

From Eq. (1) and as shown in Table 3, the estimated values of phytoplankton or phytoplankton density is dependent upon the levels of DIN.

Table 3 Predicted phytoplankton density in the estuarine zone during the study periods

Study period	Predicted phytoplankton density	Phytoplankton density (unit cells/l)		
		Median	Min	Max
Early-loading period (DIN* = 23.30)	4,739	1,600	325	63,750
Mid-loading period (DIN* = 27.06)	2,663	2,150	550	7,900
Late-loading period (DIN* = 26.77)	16,977	3,350	200	186,400

* *median values*

CONCLUSION

This study has revealed the ability of the proposed predictive model to identify dissolved inorganic nitrogen (DIN) as the crucial influencing factor of phytoplankton growth. DIN has greatly influenced the phytoplankton density of the Mae Klong River and the estuary. The predictive model could be employed to monitor and manage eutrophication sites. In addition, the levels of chlorophyll *a* well in excess of the natural base-line level (3.3 μg/L) point to the fact that the nutrient loading is impacted by the anthropogenic and natural activities in the area. The study results could be applied to estimate the level of phytoplankton density for more efficient management of water resources and thereby sustainable utilization.

AKNOWLEDGEMENTS

The authors would like to express deep gratitude to Dr. Urairat Netharn, to Dr. Sansanee Wangvoralak, and to all the staff members of the Marine Environmental Laboratory (Department of Marine Sciences) and the Sediment and Aquatic Environment Research Laboratory (Department of Fishery Biology), Faculty of Fisheries, Kasetsart University, for their invaluable advice and assistance.

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