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Water quality factors related to phytoplankton population changes in the estuary ecosystem: a case study of Mae Klong estuary and Tha Chin estuary, upper Gulf of Thailand

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Abstract The water quality impacts on phytoplankton dynamics in the 3 seasons: winter (January), summer (April) and rainy (September). The total ammonia in the rainy season was significantly higher than in other seasons ($p < 0.05$) , the BOD value is significantly higher than other seasons ($p < 0.05$). All four groups of plankton were found, namely blue-green algae, green algae, diatoms, and dinoflagellate, with a total of 40 species. After analysis of the correlation coefficient between the average density of the blue-green algae and the water quality factors showed a high level of correlation ($r = 0.7 - 0.9$) with pH ($r = 0.899$) and BOD ($r = 0.818$), but high concentration of total ammonia ($r = -0.875$) had high level in opposite direction, the diatomic group showed a high level of correlation with the salinity of water ($r = 0.879$) and total hardness ($r = 0.944$), and the dinoflagellate had a high level of correlation with the total ammonia ($r = 0.761$) were statistical significance ($p < 0.05$). It can be concluded that the water quality factors varied in each season which are related to the changes in the quantity of prominent phytoplankton. It proved that in the winter season during the water had high salinity and hardness that found a lot of the diatomic group. While in the rainy season with low salinity but high concentration of total ammonia, found a lot of the dinoflagellate. The blue-green algae positively correlated with BOD value and had a negative relationship with high concentration of total ammonia. Therefore, in the summer which had high ammonia, a lot of blue-green algae are found, but in the rainy season with a high concentration of total ammonia, a small amount of blue-green algae were found.

Keywords: Phytoplankton, Water quality, Estuary, Brackish water

Introduction

The topography of Mae Klong estuary and Tha Chin estuary are connections between the land and the sea, which are influenced by tides, resulting in constant environmental changes. The salinity of water is

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particularly affected because the inflow of freshwater flowing into the saltwater brings organic sediments and nutrients contaminated by various human activities (Jackson *et al*., 2001). The estuary is also rich in minerals and is an area with potential for natural resources, especially the abundance of mangrove forests and aquatic resources. The estuary is important in agriculture, fishery, and water travel. Therefore, it is a destination that supports local utilization activities such as daily consumption, agricultural activities, aquaculture, and industry (Hopkinson *et al*., 2005). These activities affect water quality and the integrity of biological resources within the estuary ecosystem. These problems result in eutrophication in water sources, which has become a source of degradation of the estuary ecosystem (Nixon, 1995). At the same time, the estuary has high ecological production with potential for both primary producers and consumers. One of them is the phytoplankton, which is considered an essential component of the ecosystem of water resources and is natural food at the primary level of organisms that are important in the food chain (Battish, 1992; Saeiam *et al*., 2020). The types of phytoplankton will vary according to the water quality conditions of the water source (Wu *et al*., 2014). There are also biological indicators because each phytoplankton group is resistant to different environmental changes (Siddika, 2012). The diversity of species and quantities of phytoplankton found in different environments can be an indicator of the abundance of water resources and water quality (Chowdhury *et al*., 2008). Therefore, if talking about changes in phytoplankton groups, they are always related to the water quality of the water source (Masmoudi *et al*., 2015).

From these problems, it shows the impact on the coastal resources of the estuary. The researcher aims to study the change in species composition and the amount of phytoplankton in the area of Mae Klong estuary and Tha Chin estuary, along with studying the classification and distribution of phytoplankton to water quality factors that influence populations of phytoplankton in the ecosystem to evaluate primary productivity. Moreover, the study aimed to apply as basic information in natural resource management planning for assessing impacts that may be linked to the productivity status of water resources of nearby coastal ecosystems and resulting in the maximum benefit to local people.

Materials and methods

Study area and culture conditions

The samples of water collected from Tha Chin Estuary in Mueang District Samut Sakhon province and Mae Klong estuary in Muang district

Samut Songkhram Province (Figure 1), Samples were collected in 3 seasons: January 2018 (winter representative), April 2018 (summer representative) and September 2018 (rainy season representative).

ST.1 Tha Chin estuary, Bang Ya Phraek Subdistrict, Mueang Samut Sakhon District, Samut Sakhon Province.

ST.2 The coastal area, Ban Bo Subdistrict, Mueang Samut Sakhon District, Samut Sakhon Province.

ST.3 The coastal area, Bang Kaew Subdistrict, Mueang Samut Songkhram District, Samut Songkhram Province.

ST.4 Mae Klong estuary, Bang Ja Kreng Subdistrict, Mueang Samut Songkhram District, Samut Songkhram Province.

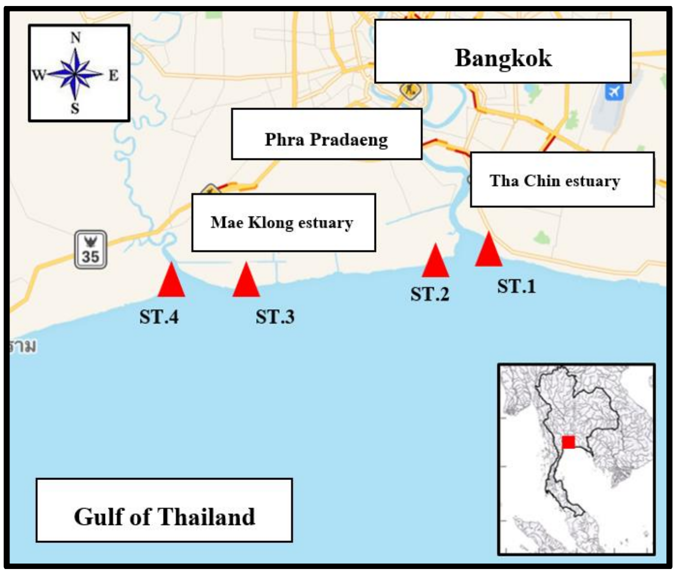

Figure 1. Sampling areas in the Tha Chin estuary and Mae Klong estuary

Water-quality sampling and analysis

The study of 9 indexes water quality effects on phytoplankton species and density of phytoplankton in the estuary ecosystem (Table 1). Water samples were taken at 30 centimeters below the water surface and collected in a 1000 milliliter container, kept in a freezer at 10 degrees Celsius and taken to the laboratory for analysis of water quality. The water samples are collected in 3 seasons for analysis of changes to environmental conditions all year round. All water-quality measurements were conducted according to American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF) standard methods for examination of water and wastewater. Five indexes of the water-quality factors were analyzed in the field, including water transparency was measured with a Secchi disk. Salinity was measured using a Salinity meter. Dissolved oxygen (DO), pH and temperature at the water surface using a YSI oxygen meter (Multi-Probe PRO20, YSI Inc.) Water samples were analyzed in laboratory including total hardness using the EDTA titrimetric method modified form Saeiam *et al*. (2020) total ammonia-nitrogen and orthophosphate following standard methods (APHA *et al*., 1995) and BOD measures the oxygen consumed by bacteria from the decomposition of organic matter (Sawyer and McCarty, 1978).

Total phytoplankton estimation

Phytoplankton samples were collected by filtering 20 liters of water through a 20 micrometers plankton net. The samples were fixed with 4% formalin for analysis in laboratory. The samples were collected in the same location as the water quality samples and then the plankton samples were observed under the microscope and identified with relevant phytoplankton taxonomy documents using the method of Hoppenrath *et al.* (2009). Moreover, the taxonomic group was classified and the phytoplankton density in cells per liter was analyzed.

Statistical analysis

Water-quality data were analyzed using descriptive statistics. Furthermore, if the data were normal distribution (parametric data), one-way ANOVA analysis was used to compare the differences between various factors such as water quality, phytoplankton density, and the ecological index. However, if the data were not normal distribution (nonparametric data), nonparametric statistics were used.

Ecological structure data of phytoplankton including density, diversity index, evenness index, and dominant index were based on Krebs (2001). Correlation analysis of phytoplankton populations and the water-quality factors were tested under parametric statistical conditions beforehand. If the data were normally distributed, Pearson correlations were not used in the analysis of the relationship. However, if the data were not normally distributed, the Spearman correlation statistics were performed in the analysis of the relationship, at a 95-percent-confidence level. Linear regression was analyzed for essential factors that had a high correlation coefficient (r = 0.7-0.9).

Results

Water-quality factors in study areas

Water quality data in the 3 seasons of the study areas were analyzed (Table 1). It found that most of the average water quality data were in the appropriate criteria for the growth of fish. The exception to this is for the total ammonia, which is higher than the appropriate criteria during the rainy season with an average value of 1.91±0.57 mg/L nitrogen. It indicated high levels of accumulated waste in the form of organic matter during that period, which may affect the growth of estuarine fish.

Table 1. Minimum - maximum, average, and standard deviation of water quality factors in each season (Average data of 4 sampling points)

Water quality factors	Season			p-value	Standard
	Winter	Summer	Rainy		
Water temperature (Degrees Celsius)	(27.10 – 29.10) 28.05±0.85 [a]	(31.20 – 32.70) 31.95±0.76 [b]	(29.10 – 30.30) 29.98±0.59 [c]	0.000*	25.00 – 32.00
Transparency (cm)	(25.00 – 45.00) 33.75±8.54 [a]	(25.00 – 35.00) 29.00±4.24 [a]	(25.00 – 35.00) 29.00±4.24 [a]	0.467	30.00 – 60.00
Salinity (ppt)	(15.40 – 22.00) 19.60±3.08 [a]	(18.30 – 25.00) 21.88±2.78 [a]	(4.20 – 15.40) 10.40±5.20 [b]	0.005*	8.00 – 25.00
Dissolved oxygen (mg/L)	(3.80 – 6.70) 5.10±1.23 [a]	(3.40 – 7.20) 5.45±1.59 [a]	(3.60 – 6.70) 5.49±1.45 [a]	0.916	≥ 4.00
pH	(7.70 – 7.80) 7.78±0.05 [a]	(7.60 – 8.30) 7.90±0.29 [a]	(7.30 – 7.60) 7.48±0.13 [b]	0.028*	6.50 – 8.50
Total hardness (mg/L $CaCO_3$)	(4,352 – 6,073) 5,167.0±706.0 [a]	(3,905 – 5,702) 5,069.5±797.0 [a]	(994 – 3,118) 2,268.5±915.8 [b]	0.001*	-
Total ammonia (mg/L nitrogen)	(0.67 – 1.41) 0.92±0.35 [a]	(0.26 – 0.40) 0.32±0.06 [a]	(1.12 – 2.41) 1.91±0.57 [b]	0.001*	< 1.00
Orthophosphate (mg/L phosphorus)	(0.08 – 0.22) 0.12±0.07 [a]	(0.12 – 0.33) 0.20±0.10 [a]	(0.10 – 0.22) 0.16±0.05 [a]	0.347	< 0.20
BOD (mg/L)	(1.61 – 2.82) 2.40±0.54 [a]	(4.46 – 5.00) 4.66±0.24 [b]	(1.10 – 2.64) 1.82±0.63 [a]	0.000*	> 20.0

Note: *different English alphabets in the horizontal landscape mean statistical differences at a 95% confidence level ** Standard value based on ACFS. (2016), Bhatnagar and Devi (2013)

By comparing the water quality during the seasons, it is found that the water quality of many parameters had a statistically significant difference ($p < 0.05$). The salinity in the rainy season is lower than other seasons ($p < 0.05$) and corresponded to the total hardness in the rainy season, which was lower than other seasons ($p < 0.05$). The total ammonia in the rainy season was significantly higher than in other seasons ($p < 0.05$), which indicated the nutrient leach from many sources into estuaries. In summer, the BOD value was significantly higher than in other seasons ($p < 0.05$). Details of water quality are shown in Table 1.

Species composition of phytoplankton in Tha Chin estuaries and Mae Klong estuaries

The results of the survey on species and quantity of phytoplankton in the estuary ecosystem were collected from 3 seasons. All four groups of plankton were found namely blue-green algae, green algae, diatoms, and found in 2 species, namely *Oscillatoria* sp. and *Arthrospira platensis*. Green algae (Chlorophyta) were found in 2 species, namely *Trachelomonas intermedia* and *Trachelomonas volvocina*. Diatoms (Baciliariophyceae) were found in 30 species and dinoflagellate were found in 6 species (Table 2).

This report Diatom, in large number and quantity of phytoplankton. The quantity of the diatom was 45.%7 of the total amount of phytoplankton, the dominant genera were *Chaetoceros* sp. and *Coscinodiscus* sp. It was inferior to blue-green algae groups with 30.8 percent of the total amount of phytoplankton. Diatoms were found to be the predominant phytoplankton group in the winter, while the blue-green algae was dominant in the summer. The dinoflagellate was dominant in the rainy season. The species number and quantity of Green algae were found only 2 species, namely *Trachelomonas intermedia* and *Trachelomonas volvocina*, which represented only 0.04% of the total amount of phytoplankton.

Table 2. Diversity and quantity of phytoplankton population in study area (Average 3 seasons)

Species composition	Average density of phytoplankton (cells/liter)				Total density	percent
	ST.1	ST.2	ST.3	St.4		
Blue-green algae (Cyanophyta)						
Family Oscillatoriaceae						
Oscillatoria sp.	1,455,250	81,817	1,103,800	10,350	662,804	30.78
Arthrospira platensis	2,400				600	0.03
Green algae (Chlorophyta)						
Family Euglenaceae						
Trachelomonas intermedia	1,600				400	0.02
Trachelomonas volvocina				1,333	333	0.02
Diatom (Baciliariophyceae)						
Family Coscinodiscaceae						
Coscinodiscus sp.	16,100	506,417	455,300	88,133	266,488	12.38
Family Thalassiosiraceae						
Planktoniella sol		8,400			2,100	0.10
Family Thalassiosiraceae						
Cyclotella sp.	24,600	25,100	148,033	6,850	51,146	2.38
Skeletonema costatum	4,300	5,600	21,400		7,825	0.36

Table 2. (Con.)

Species composition	Average density of phytoplankton (cells/liter)				Total density	percent
	ST.1	ST.2	ST.3	St.4		
Family Asterolampraceae						
Asteromphalus heptactis			1,767		442	0.02
Family Rhizosoleniaceae						
Guinardia flaccida			4,467		1,117	0.05
Rhizosolenia hyalina			8,933		2,233	0.10
Rhizosolenia calcar-avis		1,050			263	0.01
Family Chaetoceraceae						
Bacteriastrum sp.	4,000		73,700	27,400	26,275	1.22
Chaetoceros compressus	2,000				500	0.02
Chaetoceros lorenzianus		22,400	1,384,667	214,633	405,425	18.83
Chaetoceros pseudocurvisetus			35,733		8,933	0.41
Family Lithodesmaceae						
Ditylum brightwellii			2,233		558	0.03
Family Eupodiscaceae						
Odontella sinensis			3,533		883	0.04
Triceratium favus		1,950			488	0.02
Family Triceratiaceae						
Pleuroseira laevis		3,900			975	0.05
Family Diatomaceae						
Climacosphenia moniligera		1,950			488	0.02
Synedra ulna				9,333	2,333	0.11
Family Thalassionemataceae						
Thalassionema nitzschioides		3,733	12,467		4,050	0.19
Thalassiothrix frauenfeldii		48,700	104,967		38,417	1.78
Family Climacospheniaceae						
Climacosphenia moniligera			4,467		1,117	0.05
Family Achnanthaceae						
Cocconeis sp.	8,000		3,533	4,667	4,050	0.19
Family Naviculaceae						
Amphora sp.			8,933		2,233	0.10
Gyrosigma sp.	4,000	7,800	173,133	4,667	47,400	2.20
Navicula viridula				6,850	1,713	0.08
Pleurosigma sp.		33,933	314,233	16,133	91,075	4.23
Pleuronema sp.				1,333	333	0.02
Family Bacillariaceae						
Nitzschia sigma		3,733			933	0.04
Pseudo-nitzschia pungens	8,000	5,600	22,333	6,850	10,696	0.50
Family Surirellaceae						
Surirella robusta		5,600		10,400	4,000	0.19
Dinoflagellate (Dinophyceae)						
Family Prorocentraceae						
Prorocentrum micans	25,800	2,100			6,975	0.32
Family Noctilucaceae						
Noctiluca scintillans		44,800			11,200	0.52
Family Ceratiaceae						
Ceratium furca	49,333	45,267	1,802,717	25,133	480,613	22.32
Ceratium hirundinella		2,000			500	0.02
Ceratium tripos		1,867			467	0.02
Family Protoperidiniaceae						
Protoperidinium sp.		5,600	13,800		4,850	0.23

Changes in phytoplankton composition in each season

The amount of phytoplankton in the study area was compared (Table 3 and 4) and it is found that in the estuary, the density of phytoplankton tended to increase in the summer, with an average density of 3,152,262.5 cells/L. Also, the density of phytoplankton dropped to the lowest during the rainy season, with an average density of 1,453,375.0 cells/L. However, the density of phytoplankton in each season did not statistically significant difference ($p > 0.05$).

Table 3. Changes in phytoplankton composition in estuaries of each season

Phytoplankton group	Density of phytoplankton (cells/L)		
	Winter	Summer	Rainy
Blue-green algae	14,562.5 ±7,150.9 (0.79%)	1,973,850.0 ±2,180,297.9 (62.62%)	1,800.0 ±3,600.0 (0.12%)
Green algae	0.0 ±0.0 (0%)	0.0 ±0.0 (0%)	2,200.0 ±2,561.2 (0.15%)
Diatoms	1,767,738.5 ±2,549,970.9 (95.34%)	1,159,062.5 ±1,250,504.2 (36.77%)	26,662.5 ±24,133.4 (1.84%)
Dinoflagellate	71,750.0 ±79,025.9 (3.87%)	19,350.0 ±38,700.0 (0.61%)	1,422,712.5 ±2,631,307.5 (97.89%)
Total density	1,854,050.0	3,152,262.5	1,453,375.0

Note: average data in all areas

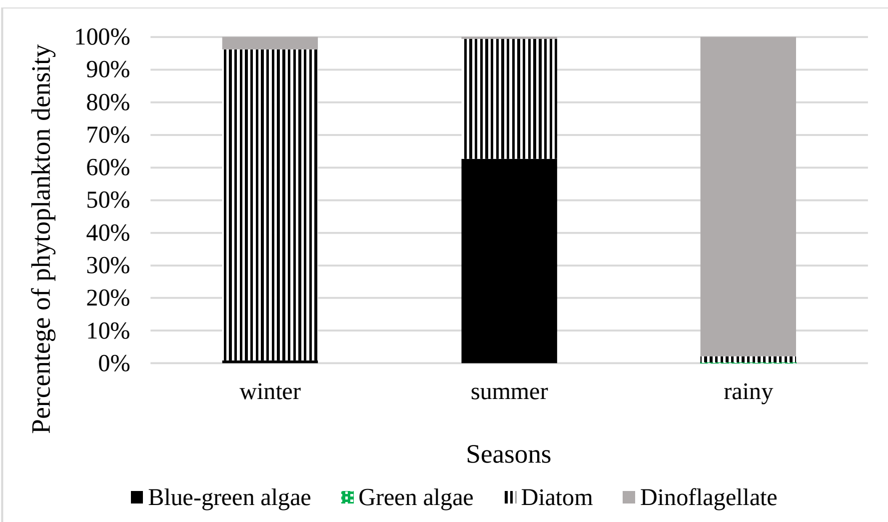

Figure 2. Changes in phytoplankton composition in estuaries

In the winter, the average diversity index of phytoplankton was 1.62, the average evenness index was 0.12, and the dominance index was 0.88. It can be explained that in the winter, some groups of phytoplankton were more prominent in quantity than other groups. In particular, the diatom group showed an average density of 1,767,738.5 cells/L (95.34% of all phytoplankton). During the summer, phytoplankton had the same ecological index as in the winter season, indicating that in the summer, some groups of phytoplankton were more prominent in quantity than other phytoplankton groups, in particular, the group of blue-green algae, with an average density of 3,152,262.5 cells/L (62.65% of all phytoplankton). Furthermore, dinoflagellate was the dominant group of phytoplankton in the rainy season. The ecological structure of phytoplankton and environmental factors on water quality can be assumed that different environmental factors in each season affected the change of dominant phytoplankton in the estuary (Figure 2).

Table 4. Changes in the ecological index of phytoplankton in each season

Parameter	Ecological index			p-value
	Winter	Summer	Rainy	
Dominant group	Diatoms	Blue-green algae	Dinoflagellate	-
Dominant genus	*Chaetoceros*	*Oscillatoria*	*Ceratium*	-
Average density (cells/L)	1,854,050.0 ± 2,561,412.5 [a]	3,152,262.5 ± 2,610,829.4 [a]	1,453,375.0 ± 2,630,575.4 [a]	0.642
Diversity index	1.62 ±0.48 [a]	0.92 ±0.55 [a,b]	0.52 ±0.33 [b]	0.024*
Evenness index	0.12 ±0.04 [a]	0.07 ±0.04 [a]	0.05 ±0.04 [a]	0.090
Dominance index	0.88 ±0.04 [a]	0.93 ±0.04 [a]	0.95 ±0.04 [a]	0.104

Note: *different English alphabets in the horizontal landscape mean statistical differences at a 95% confidence level (average data in all areas)

Relationship between water quality factors and phytoplankton population in estuary

Analysis of the correlation coefficient between the average density of the blue-green algae and the water quality factors showed a high level of correlation ($r = 0.7-0.9$) and statistical significance ($p < 0.05$), with pH ($r = 0.899$) and BOD high concentration of total ammonia ($r = -0.875$). The diatomic group showed a high level of correlation with statistical significance ($p < 0.05$) with the salinity of water ($r = 0.879$) and total hardness ($r = 0.944$). Yet, dinoflagellate had a high level of correlation ($p < 0.05$) with the total ammonia ($r = 0.761$) (Table 5).

The relationship between the ecological index and water quality factors showed that the diversity index had no statistically significant relationship ($p > 0.05$) with other water quality factors, except for the transparency related in the same direction ($r = 0.710$) with a statistically significant relationship ($p < 0.05$). Consistent with the evenness index, it had the same direction with the transparency ($r = 0.842$). The dominant index was in the opposite direction to transparency ($r = -0.848$). Overall, it can be indicated that most of the ecological index did not have any relation to water quality factors. Therefore, it can be concluded that water quality factors that varied in each season which related to the changes in the quantity of dominant phytoplankton groups.

Table 5. Correlation coefficient (r) between water quality factors and phytoplankton population

Water quality parameters	Correlation coefficient (r)						
	Density of phytoplankton (cells/L)				Ecological index		
	Blue-green algae	Diatoms	Dinoflagellate	Total density	Diversity	Evenness	Dominance
Water temperature	0.307 (p = 0.331)	-0.109 (p = 0.736)	0.031 (p = 0.924)	0.120 (p = 0.711)	-0.277 (p = 0.383)	-0.298 (p = 0.346)	0.296 (p=0.351)
Transparency	-0.360 (p =0.250)	0.047 (p = 0.885)	-0.126 (p = 0.697)	-0.501 (p = 0.097)	0.710* (p = 0.008)	0.842* (p = 0.001)	-0.848* (0.000)
Salinity	0.603* (p = 0.038)	0.879* (p = 0.000)	-0.115 (p = 0.722)	0.458 (p = 0.135)	0.476 (p = 0.117)	0.231 (p = 0.470)	-0.244 (p=0.444)
Dissolved oxygen	0.025 (p = 0.939)	-0.158 (p = 0.625)	0.305 (p = 0.335)	0.260 (p= 0.414)	0.049 (p = 0.880)	-0.049 (p = 0.880)	0.016 (p=0.961)
pH	0.899* (p = 0.000)	0.697* (p = 0.012)	-0.524 (p = 0.081)	0.313 (p = 0.323)	0.275 (p = 0.387)	0.068 (p = 0.834)	-0.038 (p=0.908)
Total hardness	0.627* (p = 0.029)	0.944* (p = 0.000)	-0.228 (p = 0.476)	0.379 (p = 0.224)	0.497 (p = 0.101)	0.252 (p = 0.430)	-0.260 (p=0.415)
Total ammonia	-0.875* (p = 0.000)	-0.553 (p = 0.062)	0.761* (p = 0.004)	-0.177 (p = 0.583)	-0.287 (p = 0.365)	-0.056 (p = 0.863)	0.044 (p=0.892)
Orthophosphate	0.293 (p = 0.356)	-0.284 (p = 0.372)	-0.207 (p = 0.519)	0.022 (p = 0.947)	-0.560 (p = 0.058)	-0.644* (p = 0.024)	0.641* (p=0.025)
BOD	0.818* (p = 0.001)	0.522 (p = 0.082)	-0.510 (p = 0.090)	0.465 (p = 0.128)	-0.112 (p = 0.729)	-0.284 (p = 0.372)	0.297 (p=0.348)

Discussion

The water quality in the study area was significantly different between seasons ($p < 0.05$). It was found that in the rainy season, the salinity and the total hardness of the estuary were significantly lower than other seasons ($p < 0.05$), because of the influence of freshwater in the upper river area. This is consistent with a report by Haddouta *et al*. (2015) that described that salinity in estuaries was generally between less than 0.5 – 35.0 ppt and that the influence of saltwater can be meet to the upper river far more than 35 kilometers. The 24-hour salinity in the estuary ecosystem was varied according to the tides. There were two main influences that affected the salinity in estuaries, namely the tides and the amount of freshwater flowing down from the upper river area. Therefore, in the rainy season, the estuary had a significantly lower salinity than other seasons ($p < 0.05$). At the same time, in the rainy season, there was a high rate of leaching the organic nitrogen into the estuary area, which affected the total ammonia in the rainy season significantly higher than other seasons ($p < 0.05$). The total ammonia detected during the rainy season had an average value of 1.91±0.57 mg/L nitrogen, which was higher than the appropriate criteria for aquatic animals. The total ammonia was higher than the appropriate criteria, indicating high levels of accumulated organic nitrogen, which can affect the production of aquatic animals in nature. The higher ammonia of the appropriate criteria would directly affect larvae or juvenile aquatic animals more than adults. Moreover, during the lower salinity levels, especially in the rainy season, the toxicity of ammonia would increase (Eddy, 2005). Ammonia in the estuary ecology is mostly accumulated in the form of sediment pore waters (Batley and Simpson, 2009). In the summer, the BOD was significantly higher than in other seasons ($p < 0.05$), with an average value of 4.66±0.24 mg/L. However, it is still within the appropriate criteria for aquatic animals.

In this study, it was found that the diatom was the dominant phytoplankton, both in number and density, which accounted for 45.70% of the total phytoplankton density, with dominance genera such as *Chaetoceros* and *Coscinodiscus*, which was inferior to blue-green algae groups (30.80%).

Both genera are considered an important natural food source for larvae in the estuary ecosystem. Analysis of the chemical composition of the phytoplankton in the genus *Chaetoceros* found that there were very high levels of unsaturated fat in the form of DHA and EPA. These characteristics were very suitable for the larvae and juveniles because fatty acids would become essential factors for the growth and development of aquatic animals (Zhuang and Wang, 2004; Tang *et al*., 2006).

Also, *Coscinodiscus* had a high carbohydrate composition which is a nutrient of many bivalve mollusks, especially clams (*Meretrix* spp.), needed for the growth and development of the reproductive system. From the analysis of the chemical composition of *Coscinodiscus*, it was found that carbohydrates accounted up to 29% in composition and a high amount of glucose when compared to other diatom genera (Meksumpun, 2002).

Changes in the phytoplankton population of the study area showed that the phytoplankton density increased in the summer and revealed the lowest in the rainy season. Nevertheless, when statistically tested, the density of phytoplankton in each season had no significant difference ($p > 0.05$). In the winter, the diatoms were the dominant phytoplankton, accounting for 95.34% of the total phytoplankton, but in the summer, the blue-green algae were the dominant group (62.62%), and during the rainy season, dinoflagellate was the dominant group (97.89%). Also, during the rainy season, the phytoplankton diversity index was significantly lower than in other seasons ($p < 0.05$), with an average of 0.52±0.33. It was indicated that in the rainy season, there was a higher accumulation of organic matter than other periods.

Trigueros and Orive (2001) described that phytoplankton in the group of diatoms, dinoflagellate, and blue-green algae are resistant to high salinity changes (polyhaline). Therefore, these 3 groups of phytoplankton are often found as a dominant group in the estuaries ecosystem. Changes in the nutrient concentration in water will directly affect the population structure of all three phytoplankton groups.

Blue-green algae were highly correlated (r = 0.818) in the positive direction with the BOD. Consistent with the report of Gupta *et al*. (2015), blue-green algae grow well in eutrophic water sources. During the blooms of blue-green algae, they can have several harmful effects on aquatic life, including a lack of dissolved oxygen in the water and off-flavor problem. This is because phytoplankton is essential to the creation of geosmin or MIB and both organic compounds are the main source of the off-flavor problem in fish products (Tucker, 2000).

In addition, blue-green algae can produce 3 types of toxins: 1) Hepatotoxins are toxic substances that are harmful to the liver and internal organs; 2) Neurotoxins are toxic substances that affect the nervous system, paralysis muscles, bones, and the respiratory system; 3) Endotoxins are toxins that affect the digestive tract and respiratory tract. The predominant plankton species that produce these toxins are *Anabaena*, *Oscillatoria*, *Microcystis*, and *Cylindrospermopsis*, etc (Gupta *et al*., 2015).

Diatoms were dominant phytoplankton in the winter and had a high level of correlation with salinity (r = 0.879) and hardness (r = 0.944). However, dinoflagellate had a high level of positive correlation with total ammonia (r = 0.761). Dinoflagellate is a major group of plankton that causes a red tide in estuaries and shores (Evens *et al*., 2001). The red tide in Thailand is caused by *Noctiluca* and *Ceratium*, which is consistent in this study. Red tide affected the organisms in the estuary and coastal ecosystem with the problem of a rapid reduction of dissolved oxygen in water, if many planktons drop down at the same time. It would create the issue of dead plankton remains floating on the water surface, resulting in less photosynthesis of other phytoplankton in the water source. Also, there are toxic problems caused by the dinoflagellate itself, especially neurotoxins groups including paralytic shellfish poisoning (PSP), neurotoxic shellfish poisoning (NSP), amnesic shellfish poisoning (ASP), diarrheic shellfish poisoning (DSP), ciguatera fish poisoning (CFP) and azaspiracid shellfish poisoning (ASP), etc (Wang, 2008).

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References

ACFS (2016). Guidance on the application of Thai agricultural standard, good aquaculture practices for freshwater animal farm. Ministry of Agriculture and Cooperatives, Bangkok.

APHA, AWWA and WEF (2012). Standard methods for examination of water and wastewater. (twenty-second edition), Washington, American Public Health Association.

Batley, G. E. and Simpson, S. L. (2009). Development of guidelines for ammonia in estuarine and marine water systems. Marine Pollution Bulletin, 58:1472-1476.

Battish, S. K. (1992). Freshwater zooplanktons of India. Oxford and IBH publishing co. Ltd., New Delhi.

Bhatnagar, A. and Devi, P. (2013). Water quality guidelines for the management of pond fish culture. International Journal of Environmental Sciences, 3:1980-2009.

Chowdhury, M. M. R., Shahjahan, M., Rahman, M. S. and Sadiqul, I. M. (2008). Duckweed (*Lemna minor*) as supplementary feed in monoculture of Nile tilapia, *Oreochromis niloticus*. Journal of Fisheries and Aquatic Sciences, 3:54-59.

Eddy, F. B. (2005). Ammonia in estuaries and effects on fish. Journal of Fish Biology, 67:1495-1513.

Evens, T. J., Kirkpatrick, G. J., Millie, D. F., Chapman, D. J. and Schofield, O. M. E. (2001). Photophysiological responses of the toxic red-tide dinoflagellate *Gymnodinium breve* (Dinophyceae) under natural sunlight. Journal of Plankton Research, 23:1177-1193.

Gupta, C., Prakash, D. and Gupta, S. (2015). Role of blue green algae in environment management. Environmental Microbiology, pp.22-44.

Haddouta, S. S., Maslouhia, A., Magraneb, B. and Igouzala, M. (2015). Study of salinity variation in the Sebou River Estuary (Morocco). Desalination and Water Treatment. Balaban Desalination Publications, Morocco, pp.1-12.

Hopkinson, C. J., Smith, E. M., del Giorgio, P. A. and Williams, P. J. le B. (2005). Estuarine respiration: an overview of benthic, pelagic and whole system respiration, In: del Giorgio, P. A. and Williams, P. J. le B. ed. Respiration in Aquatic Ecosystems, Oxford University Press, New York.

Jackson, J. B. C., Kirby, M. X. and Berger, W. H. (2001). Historical overfishing and recent collapse of coastal ecosystems. Science, 293:629-638.

Krebs, C. J. (2001). Ecology: The experimental analysis of distribution and abundance. (fifth edition), Benjamin Cummings, San Francisco.

Masmoudi, S., Tastard, E., Guermazi, W., Caruso, A., Manceau, M. A. and Ayadi, H. (2015) . Salinity gradient and nutrients as major structuring factors of the phytoplankton communities in salt marshes. Aquatic Ecology, 49:1-19.

Meksumpun, S. (2002). Physiology of Marine Phytoplankton, Department of Marine Science, Faculty of Fisheries, Kasetsart University, Bangkok, Thailand.

Nixon, S. W. (1995). Coastal marine eutrophication: a definition, social causes, and future concerns. Ophelia, 41:199-219.

Siddika, F. (2012). Abundance of plankton population densities in relation to bottom soil textural types in aquaculture ponds. International Journal of Agricultural Research, Innovation and Technology, 2:56-61.

Tang, B., Liu, B., Wang, G., Zhang, T. and Xiang, J. (2006). Effects of various algal diets and starvation on larval growth and survival of *Meretrix meretrix*. Aquaculture, 254:256-533.

Trigueros, J. M. and Orive, E. (2001). Seasonal variations of diatoms and dinoflagellates in a shallow, temperate estuary, with emphasis on neritic assemblages. Hydrobiologia, 444: 119-133.

Tucker, C. S. (2000). Off-flavor problems in aquaculture. Reviews in Fisheries Science, 8:45-88.

Wang, D. Z. (2008). Neurotoxins from marine dinoflagellates: A brief review. Marine Drugs, 6:349-371.

Wu, M. L., Wang, Y. S., Yu-Tu, W., Sun, F. L., Sun, C. C., Jiang, Z. Y. and Cheng, H. (2014) . Influence of environmental changes on phytoplankton pattern in Daya Bay, South China Sea. Revista de Biología Marina y Oceanografía, 49:323-337.

Saeiam, Y., Pichitkul, P., Nedtharnn, U. and Wudtisin, I. (2020) Phytoplankton community dynamics and its impacts on the quality of water and sediments in the recirculated-water earthen pond system for hybrid red tilapia (*Oreochromis niloticus* x *mossambicus*) farming. International Journal of Agricultural Technology, 16:695-710.

Zhuang, S. H. and Wang, Z. Q. (2004). Influence of size, habitat and food concentration on the feeding ecology of the Bivalve, Meretrix meretrix Linnaeus. Aquaculture, 241:689-69.

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