

WATER QUALITY AND DIVERSITY OF PHYTOPLANKTON IN A HARD-WATER LAKE, THAILAND

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Abstract

A study of water quality and the diversity of phytoplankton in the Rama IX lake, a man-made lake, in Pathumthani province, Thailand. This study was conducted from February 2000 to January 2001. The lake was divided into two parts, identified by the Irrigation North Rungsit as the first and the second sections. The water quality of both sections, as classified by the National Environmental Boards standards of surface water quality, was found to be in the second category and relatively clean for household consumption when properly treated. However, the main problem was the assessment of water quality of the first section which was found to be mesotrophic to eutrophic while the second section was oligotrophic to mesotrophic. Phytoplankton found in the first section showed a total number of 86 different taxa which were divided into 9 taxonomic groups. The taxonomic groups most rich in species were Chlorophyceae with 30, Euglenophyceae with 21, Cyanophyceae with 17, Diatomophyceae with 9, Dinophyceae and Cryptophyceae with 4, Zygnemaphyceae with 3 and Chrysophyceae and Xanthophyceae with 1 taxa. In the second section, phytoplankton were of 59 different taxa, and divided into 8 taxonomic groups. The Chlorophyceae was the most common with 21 species, Cyanophyceae with 12, Euglenophyceae with 11, Diatomophyceae with 9, Cryptophyceae and Dinophyceae with 4, Zygnemaphyceae with 2 and Chrysophyceae with 1. *Cylindrospermopsis raciborskii* was found to be the dominant species and was the highest phytoplankton biovolume throughout the investigation in the both sections.

Keywords: Water quality, phytoplankton diversity, a hard-water lake, Thailand, tropical area

Introduction

This investigation is based on a study of water quality and the biodiversity of phytoplankton in the Rama IX lake, a man-made lake located in Pathumthani province, Thailand. It is one of

His Majesty's Royal Projects, providing a water supply for the public in Pathumthani province. It supplies water for growing rice and vegetables during the dry season. It also serves as storage

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for excess water during heavy rains thereby reducing the damage caused by floods. During the dry seasons, the water from this lake is irrigated into different canals in Bangkok's suburbs in order to decrease water contamination in those canals (Irrigation North Rangsit, 1998). Therefore, continuous monitoring of the physical, chemical and biological factors of the water to meet the required standards and the maintenance of good water quality are extremely important.

Phytoplankton can serve as a good water quality indicator in standing water. These organisms are high potential living organisms and they respond to chemical and physical changes in the habitat. Different environments or ecosystems determine the species of phytoplankton that can be found, for example, some species grow in high nutrient water, others flourish in low nutrient water. The presence of a particular species of phytoplankton indicates the quality of the water. Furthermore, this study will benefit other investigations in biodiversity by increasing the data base on phytoplankton in Thailand. The government offices concerned with the environment can also use the species of phytoplankton as water quality indicators.

At present, the status of phytoplankton diversity in Thailand deserves much greater attention. The comparison between the number of phytoplankton species known in the world and in Thailand implies that there are many more species waiting for discovery. There are 1,700 species of blue green algae known worldwide while in Thailand only 700 species have been identified and it has been estimated that 1,000 species have still not been categorized. Another example is green algae of which over 7,000 species are well-known in the world while whereas in Thailand only 1,500 species have been identified and over 1,000 are still undiscovered (Thailand Study on Biodiversity, 1992).

Study Area

The Rama IX lake is located at 14° 02' N latitude and 100° 44' longitude in Amphur Khlongluang

and Amphur Thanyaburi, Pathumthani province, Thailand. The entrance of the lake can be approached from 2 direction, firstly from Rangsit-Nakornnayok road on the highway, and secondly along North Klong 6 about 2.3 km from the highway. The Rama IX lake is a big lake and it consists of 2 sections (Figure 1).

The first section receives water from Khlong 6, covering an area of about 1,264 km².

The second section receives water from Khlong 5, covering an area of approximately 2,864 km², (Irrigation North Rangsit, 1998). The climate of the area of Rama IX lake consists of 3 seasons over the year. The rainy season (May-middle of October) is influenced by southwest monsoons. The cold season (the end of October-February) is influenced by northeast monsoons and summer season is from March to May.

Materials and Methods

Collection of Water

Water samples were collected biweekly from February 2000 to January 2001 from the 2 deepest points of the 2 sections. Samples were collected from the water surface and every meter for the first 3 m depth and then for every 5 m to the bottom of the lake. The water of both sections was collected only from the annual rainfall and neither section had true inflows or outflows.

Lake's Morphometry

The study of the lake's morphometry was done by making contour lines of both sections for finding the deepest points, the surface areas and the capacity of both sections.

Physical and Chemical Properties of the Lake

Transparency was determined using the analysis by a Secchi disk; pH and temperature were measured in the field using a pH meter. Conductivity of water was measured in the field by a conductivity meter (Hach Company). Dissolved oxygen and biochemical oxygen demand readings were obtained by the azide modification method. Alkalinity was conducted by the application of the phenolphthalein

methyl-orange indicator method. Water hardness was assessed by the use of the EDTA titration method. Water samples for a nutrient analysis were preserved independent and were analyzed according to APHA *et al.* (1992). Nitrate-nitrogen was measured by applying the cadmium reduction method, ammonia-nitrogen by the phenate method, total phosphorus by the application of the persulfate digestion method and soluble reactive phosphorus by the ascorbic acid method. For colorimetric detections the spectrophotometer, "UV-160A" was used.

Ionic Composition

Samples for cations (calcium, magnesium, iron, manganese, zinc and copper) were analyzed by atomic absorbance spectrophotometry, while potassium and sodium were measured by flame photometry. Samples for anions (carbonate and bicarbonate) were conducted by the indicator titration method, sulfate by the turbidmetric method and chloride by the argentometric method. Water samples were collected every two months from May 2000 to March 2001. Samples

were collected at a depth of 1 m below the surface of the water.

Biological Properties of the Lakes

Chlorophyll a Analysis

As a second measure of phytoplankton biomass, the chlorophyll a content was determined after double filtration of water samples of 3 l in the first section and 5 l in the second section on Whatman GFC filter paper. For the extraction and evaluation of the chlorophyll a, the ethanol method (ISO 10260, 1992) was used.

Coliform Bacteria

To study the number of coliform bacteria in the laboratory the MPN method was used APHA *et al.* (1992), samples were collected from 30 cm below the surface at the deepest point of both sections using medical flats.

Phytoplankton was collected using two techniques to serve two purposes. Firstly, phytoplankton was collected for identification

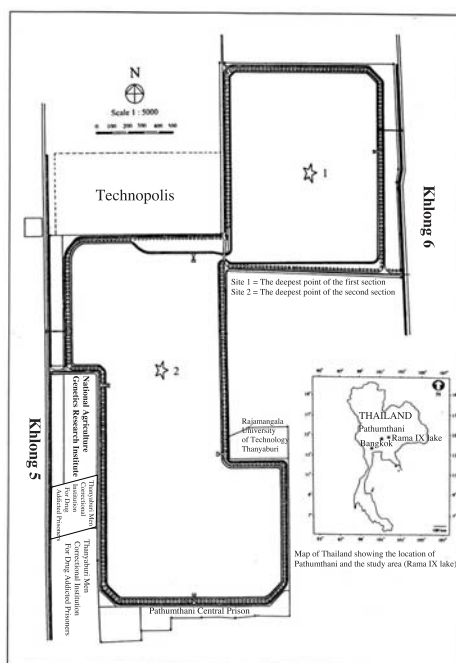


Figure 1. The Rama IX lake showing sampling sites

by using a plankton net (mesh size 10 μm) which was pulled up vertically to the surface. The water sample from the plankton net was placed into an approximately 100 ml bottle; this process required 2 - 3 samples to fill the bottle. The water sample was then poured into a dark glass bottle and the phytoplankton was preserved with 2 ml of Lugol's solution per 100 ml of sample. Secondly, phytoplankton was collected to assess the number of phytoplankton by using the water sampler. The water samples at the deepest point of both sections were collected from the surface water and every meter for the first three meters depth and every 5 m from there on to the bottom of the lake. The water sample was poured into dark glass bottles and was preserved with 2 ml of Lugol's solution per 100 ml of sample. For counting and biovolume estimation, the samples were sedimented and studied with an inverted microscope using the Utermöhl method (Utermöhl, 1958). Calculation of the individual number (per liter) was based on the cell counts from the subsample. The biovolume of total phytoplankton was calculated from the abundance and volume approximations for each species (Rott, 1981).

Identification of phytoplankton from the net samples was based on relevant texts (i.e. the floras of Huber-Pestalozzi (1955, 1961, 1968, 1982 and 1983) and Prescott (1970). For detailed identification of the genera and species, several special publications from tropical environments (Yamagishi and Hirano, 1973; Hirano, 1975; Peerapornpisal, 1996) were mostly used.

Data Analysis

The computer statistical package Microsoft and SPSS for Window Version 13 were used to perform the following statistical analysis. The mean and standard deviation were used to analyse the water quality in terms of physical, chemical and biological parameters.

Two-tailed significance of the simple correlation analysis was used to determine the interrelationship between the differences of the physical, chemical and biological parameters on the surface of the water of both sections. For the

analysis of water quality in terms of physical, chemical and biological parameters at each depth for each section, the F-test was used. To compare the differences of the means of each depth of each section, Duncan's new multiple range was selected.

The F-test was used to analyse the water quality in terms of physical, chemical and biological parameters on the surface of the water in each section.

Results

Lake's Morphometry

A study of the contours lines of both sections produced a bathymetric map of the point which showed the deepest points of both sections. It was found that in the first section, the widest part was 1,110 m and the longest part was 1,195 m; the surface area of this section was 1,264 km^2 and the capacity of this section was 7,820,000 cubic m. The mean depth was 6.19 m and the deepest point was 19.63 m. For the second section, the widest part was 1,150 m, the longest was 2,215 m, the surface area was 2,864 km^2 and the capacity was 17,400,000 cubic m. The mean depth was 6.08 m. and the deepest point was 21.63 m.

Physical and Chemical Variables

The conductivity at the water surface in the first section was between 620 - 870 $\mu\text{s.cm}^{-1}$. The conductivity was high in the cold season and was slightly lower in the summer and the rainy seasons. Vertical profiles of conductivity were low at the water surface and varied little with depth. This value was high at the bottom of the section (Figure 2(a)). For the second section, the conductivity fluctuated between 1,080 - 1,360 $\mu\text{s.cm}^{-1}$. This value altered only slightly throughout the investigation. The conductivity changed little with depth. The value at the water surface was lower than that at the lower levels in some months but sometimes the values at the water surface was nearly the same as at the lower levels (Figure 2(b)).

For the second section, the conductivity fluctuated between 1,080 - 1,360 $\mu\text{s.cm}^{-1}$. This

value altered only slightly throughout the investigation. The conductivity changed little with depth. The value at the water surface was lower than that at the lower levels in some months but sometimes the values at the water surface was nearly the same as at the lower levels (Figure 2(b)).

The pH of the water in the first section was between 7.68 - 8.87 and showed little variation between the cold and summer seasons, although it was slightly lower in the rainy season. In the second section, the pH value was between 7.25 - 7.92 and remained nearly the same throughout the year. In both sections, the pH of the water varied with depth and the stratification was clearly visible. The pH value at the water surface was

higher than that of the lower levels (Figure 3(a)) but sometimes in the second section, little change was seen from the surface to lower level depths (Figure 3(b)). The alkalinity of the water in the first section varied from 53.30 - 99.50 mg.l^{-1} . This value was at its highest in February 2000, decreased slightly in the summer, and the rainy season, it decreased further in the cold season. It was low at the surface and varied little with depth. However, it was high at the lake's bed (Figure 4(a)). For the second section, this value was between 22.40 - 38.00 mg.l^{-1} . This value was high in February and fluctuated throughout the investigation. In some months it was low at the water surface while in other months it varied little with depth (Figure 4(b)).

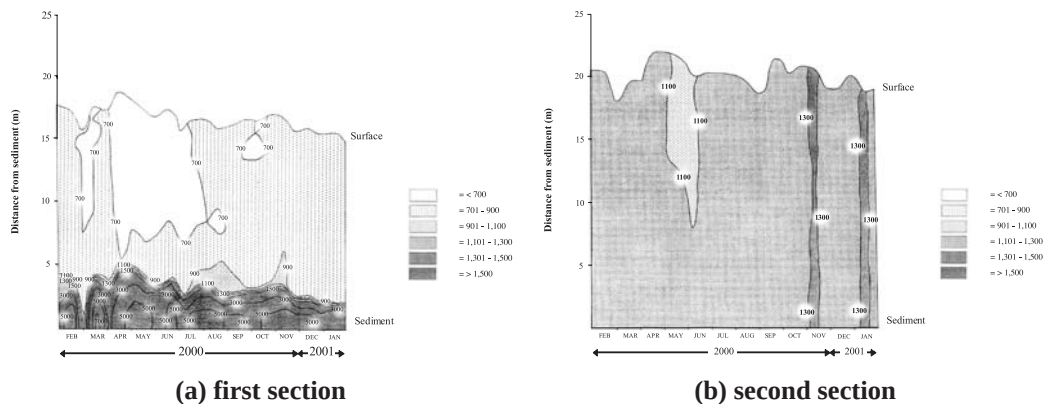


Figure 2. The variation of conductivity ($\mu\text{s.cm}^{-1}$) of Rama IX (February 2000 - January 2001)

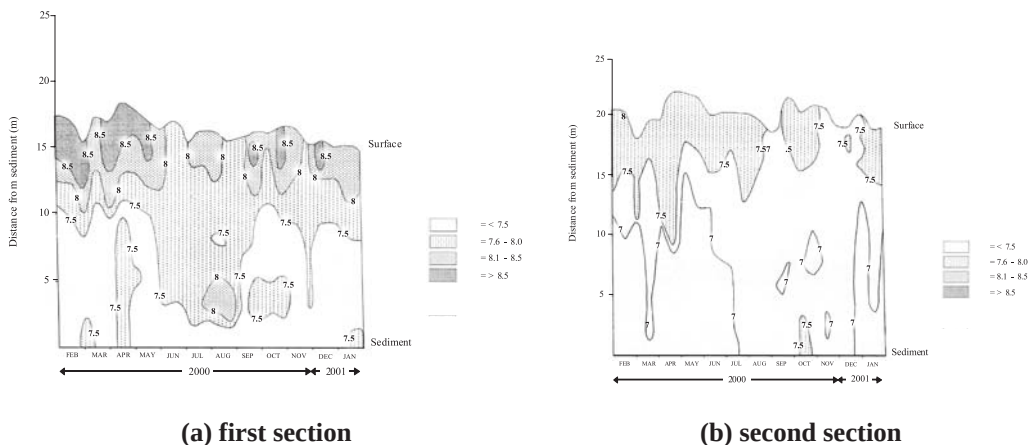


Figure 3. The variation of pH of Rama IX lake (February 2000 - January 2001)

The volumes of nitrate-nitrogen of both sections at the water surface were low throughout the investigation and these values did not exceed 5 mg.l⁻¹, and 0.5 mg.l⁻¹ respectively, the maximum figures set as the standard for surface water quality in Thailand by the National Environmental Board, 1994 Figures 5(a-b). The amount of total phosphorus stratification in the first section was low at the water surface, but it was high on the lake's bed (Figure 6(a)). In the second section, the amount of total phosphorus varied little with depth (Figure 6(b)).

The cations (Mn²⁺ and Zn²⁺) were always below 1 mg.l⁻¹, while Cu²⁺ showed low value not exceeding 0.1 mg.l⁻¹ throughout the investigation. These values did not exceed the standard for

surface water quality of Thailand set by the National Environmental Board in 1994 (Table 1). In addition, these cations in both sections were not significantly different. Irons concentrations in both sections were low in every season and the differences were not marked (Table 1). The quantity of the other four cations of both sections were present in a similar order, namely Na⁺ > Ca²⁺ > Mg²⁺ > K⁺. Furthermore, these cations in the second section were noticeably higher than they were in the first section (Table 1). Analysis of the samples for anions (Cl⁻, HCO₃⁻ and SO₄²⁻) showed fluctuation throughout the investigation in both sections (Table 1). The amount of anions (SO₄²⁻ and Cl⁻) in the second section was significantly higher

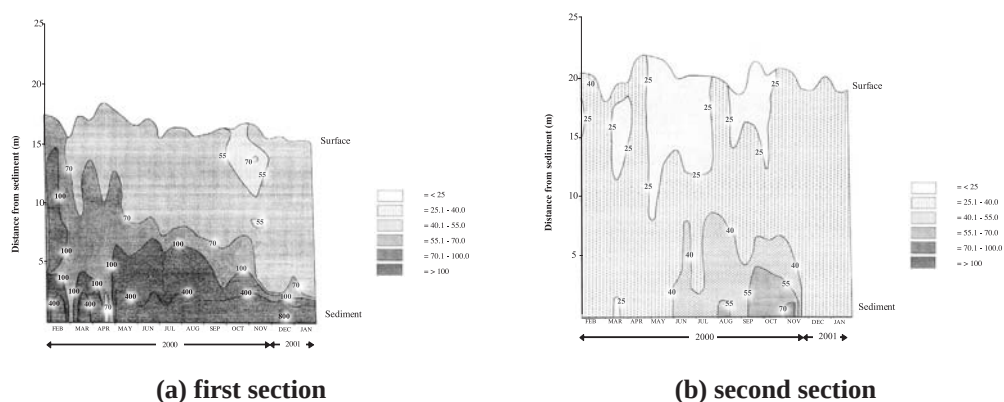


Figure 4. The variation of alkalinity (mg.l⁻¹) of Rama IX lake (February 2000 - January 2001)

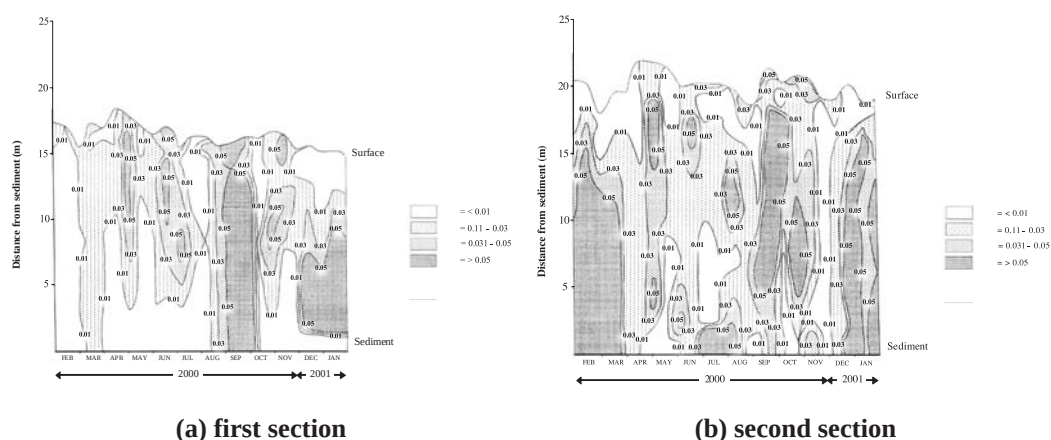


Figure 5. The variation of nitrate-nitrogen (mg.l⁻¹) of Rama IX lake (February 2000 - January 2001)

than in the first section, but HCO_3^- and CO_3^{2-} in the first section were considerably higher than in the second section (Table 1).

Biological Variables

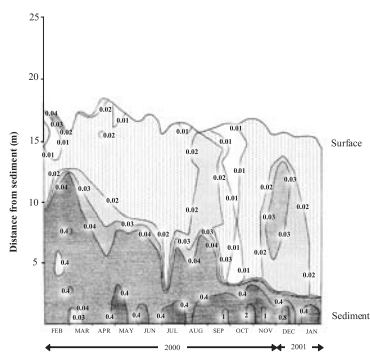
Chlorophyll a

In the first section, variations of the amount of chlorophyll a with depth were distinct, while the volume of chlorophyll a at the water surface was higher than at the lower levels. In some months, the amount of chlorophyll a at the lower levels was higher than at the water surface (Figure 7(a)). In the second section, the chlorophyll a content was high at the water surface and it was low at lower

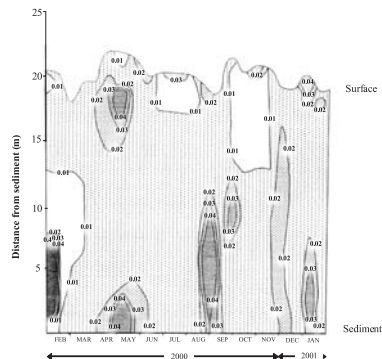
depths and at the hypolimnion. In some months, the amount of chlorophyll a at the lower levels was higher than at the water surface, but sometimes the volume of chlorophyll a varied little with depth (Figure 7(b)). The amount of chlorophyll a in both sections was very high at the water surface in the rainy season, but was very low in the cold season.

Coliform Bacteria

It was clear that the numbers of investigated bacterias were too low to affect the water quality in this lake. They did not exceed 5,000 MPN.100/ml⁻¹, and could be placed in the second category set by the National Environment Board (1994).

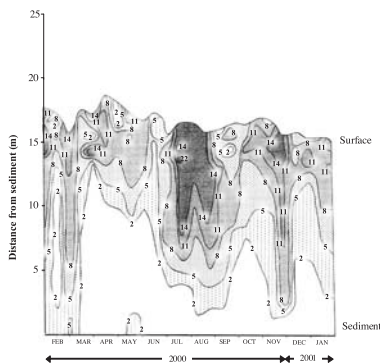


(a) first section

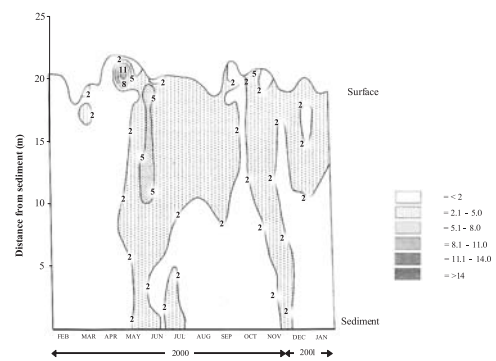


(b) second section

Figure 6. The variation of total phosphorus (mg.l⁻¹) of Rama IX lake (February 2000 - January 2001)



(a) first section



(b) second section

Figure 7. The variation of chlorophyll a content (mg.l⁻¹) of Rama IX lake (February 2000 - January 2001)

Species Composition

A total of 86 species (9 classes) were identified from the first section and 59 species (8 classes), from the second section.

Following Rott (1981) classification, we found that the total phytoplankton consisted of 9 classes in the first section. The Chlorophyceae was the most abundant class with 30 species representing 34% of the total species number. There were 17 species of Cyanophyceae, (19%), 21 species of Euglenophyceae 24%; a species of Diatomophyceae (10%). Four species of Dinophyceae and Cryptophyceae were present, calculated as 4% of the total species number. Zygnemaphyceae had 3 species calculated as 3% of the total species number and Chrysophyceae and Xanthophyceae had 1 species each calculated as 1% of the total species number (Figure 8(a)). In the second section, the total species number could be divided into 8 classes. The Chlorophyceae was the most rich in species with 21 species found, calculated at 33% of the total. Euglenophyceae had 11 species present estimated at 17%. Twelve species of Cyanophyceae were found constituting around 19% of the total. Nine species of Diatomophyceae, added up to around 14% of the total species number. Cryptophyceae and Dinophyceae had 4 species each, calculated at 6% of the total.

Zygnemaphyceae had 2 species present calculated at 13% of the total, and Chrysophyceae had 1 species calculated at 2% of the total (Figure 8(b)). In the first section, phytoplankton comprised 86 species. The abundance in decreasing order was Cyanophyceae, Euglenophyceae and Dinophyceae respectively. The dominant species were *Cylindrospermopsis raciborskii*, *Peridiniopsis cunningtonii* and *Trachelomonas volvocina* respectively. In the second section, phytoplankton comprised 59 species. The abundance in decreasing number was Cyanophyceae, Euglenophyceae and Dinophyceae respectively. The dominant species were *Cylindrospermopsis raciborskii*, *Trachelomonas volvocina*, *Peridinium* sp.1 respectively.

Phytoplankton Biovolume

The dominant species of phytoplankton in both sections was *Cylindrospermopsis raciborskii* which had the highest phytoplankton biovolume. In the first section, this species was followed by *Peridiniopsis cunningtonii*, *Trachelomonas volvocina*, *Peridinium* sp.1, *Ceratium furcoides*, *Peridinium* sp.2, *T. mucosa*, *Fragilaria ulna* etc. respectively (Figure 9(a)). This group of phytoplankton represents about 10% of the total species of

Table 1. The cations and anions (mg.l⁻¹) dynamic in Rama IX Lake (May 2001 - March 2002)

	May 2001		July 2001		September 2001		November 2001		January 2002		March 2002		Mean	
Section	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Parameters	(mg.l ⁻¹)													
Cations														
Mn ²⁺	0.01	0.02	0.05	0.11	0.02	0.12	0.00	0.01	0.00	0.04	0.10	0.03	0.03	0.06
Zn ²⁺	0.00	0.02	0.01	0.00	0.00	0.01	0.03	0.06	0.03	0.01	0.00	0.01	0.01	0.02
Cu ²⁺	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Fe ²⁺	0.01	0.02	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.00	0.08	0.07	0.02	0.02
Na ⁺	69.69	126.96	69.23	121.44	72.45	127.42	80.50	131.10	80.50	126.04	83.03	126.96	75.90	126.65
Ca ²⁺	23.40	49.60	35.20	49.80	31.40	47.20	32.40	47.20	33.40	47.80	38.60	51.60	32.40	48.87
Mg ²⁺	21.48	38.40	21.72	37.56	23.28	38.40	24.12	37.44	24.12	39.36	24.12	37.92	23.14	38.18
K ⁺	8.97	12.09	8.97	11.70	8.97	11.31	9.36	11.70	10.14	12.09	9.75	11.7	9.36	11.77
Anions	(mg.l ⁻¹)													
SO ₄ ²⁻	117.12	193.92	162.72	309.60	165.60	301.92	201.60	318.24	171.36	337.44	211.68	279.36	171.68	290.08
Cl ⁻	75.62	156.56	76.68	155.49	78.81	157.62	80.94	155.49	87.33	159.75	91.59	164.01	81.83	158.15
CO ₃ ⁻	6.00	0.00	6.00	0.00	6.00	6.00	6.00	0.00	6.00	6.00	6.00	6.00	6.00	4.00
HCO ₃ ⁻	73.20	30.50	54.90	18.30	78.80	12.20	36.60	24.40	42.70	14.64	42.70	12.20	54.82	18.71

phytoplankton. In the second section, *T. volvocina* was the second most dominant species followed by *Peridinium* sp.1, *Peridiniopsis cunningtonii*, *Ceratium furcoides*, *Anomoeoneis vitrea*, *T. mucosa*, *Staurostrum perndulatum* etc. respectively. This group of phytoplankton represents about 10 percent of the total species of phytoplankton (Figure 9(b)). When *C. raciborskii* and *T. volvocina* increased *Peridinium* sp.1, *Peridiniopsis cunningtonii*, *Ceratium furcoides*, *Anomoeoneis vitrea* tended to decrease, although no correlation was found. These species of phytoplankton can indicate water quality.

Consideration of the water quality of both sections was classified using the surface water quality standards of Thailand set by the National Environmental Board (1994). Some parameters used in decision making were color, odor, taste, water temperature, pH, dissolved oxygen, BOD, nitrate-nitrogen, ammonia-nitrogen and total coliform bacteria. The water in both sections could be placed in the second category, but the water from both sections was clean enough for household consumption after being properly treated. According to the investigation, consideration of the trophic level of both sections especially phosphorus and nitrogen followed the classification of Reynolds (1980) cited in Lampert and Sommer (1993); Lorriane and Vollenweider (1981) and Wetzel (1983). The water in both sections was low and the trophic levels did not exceed the standard set by the National Environmental Board. The water quality of the first sections was found to be mesotrophic at the water surface using the trophic status, color, turbidity and primary production as parameters. However, when the amounts of chlorophyll a and phytoplankton biovolume were the parameters, the first sections were considered mesotrophic to eutrophic. In the second section, consideration of the water quality at the water surface using the parameters of trophic status, color, turbidity, primary production, chlorophyll a and phytoplankton biovolume revealed the lake was oligotrophic to mesotrophic, and in some months the water could be classified as mesotrophic.

Discussion

According to Tables 2 - 3, the water quality in 2000 - 2001 in both sections was better than in 1995 - 1998 because the conductivity, total hardness and ionic composition decreased while alkalinity and pH increased. However, the total hardness and the conductivity at the water surface was high in both sections throughout the investigation, especially in the second section. In addition, the natural water from both sections of the lake was classified as hard-water (exceed $180 \text{ mg.l}^{-1} \text{ CaCO}_3$), following the classification of Mays (1996). In both sections, water hardness exceeded the water quality standard of water supply which standardizes water hardness as, between $50 - 80 \text{ mg.l}^{-1}$ (Health Department, 1996). High conductivity values were resulted from the concentrations of ionic composition such as SO_4^{2-} , HCO_3^- , Ca^{2+} , Mg^{2+} etc. in both sections.

The pH values of both sections at the water surface was higher than at the lower levels because the photosynthesis of phytoplankton took place more at the water surface than at the lower levels. As a result, the phytoplankton used high levels of carbon dioxide which caused an increase in the pH value in the water. Furthermore, the condition of soil in this area was acidic which caused low pH at the hypolimnion, and acidity in the water too (Duangsawasdi and Somsiri, 1985). The alkalinity of both sections was high in February 2000 for the first time due to polluted water, drained from Khlong 6 to Khlong 5, passing through Rama IX lake into Khlong Rangsit to decrease water contamination two months earlier. This caused a decrease in acidity in the lake and increased the alkalinity of the water.

In the first section, as increase of total alkalinity was already observed in metalimnion but was more apparent in hypolimnion. This could be attributed to the degradation of organic matter and to other processes such as nitrification of ammonia and sulphide oxidation (Otsuki and Wetzel, 1974). In this investigation the presence of hydrogen sulphide (H_2S) was found in the hypolimnion. Although not measured analytically, there should have been

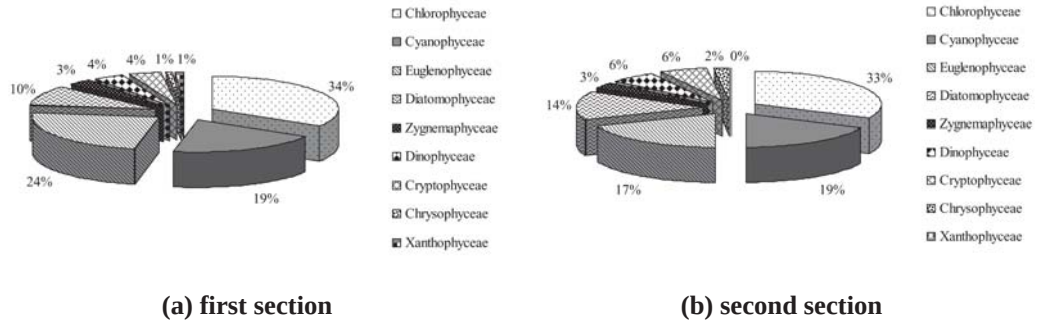


Figure 8. The percentage of each class of species number of Rama IX lake (February 2000 - January 2001)

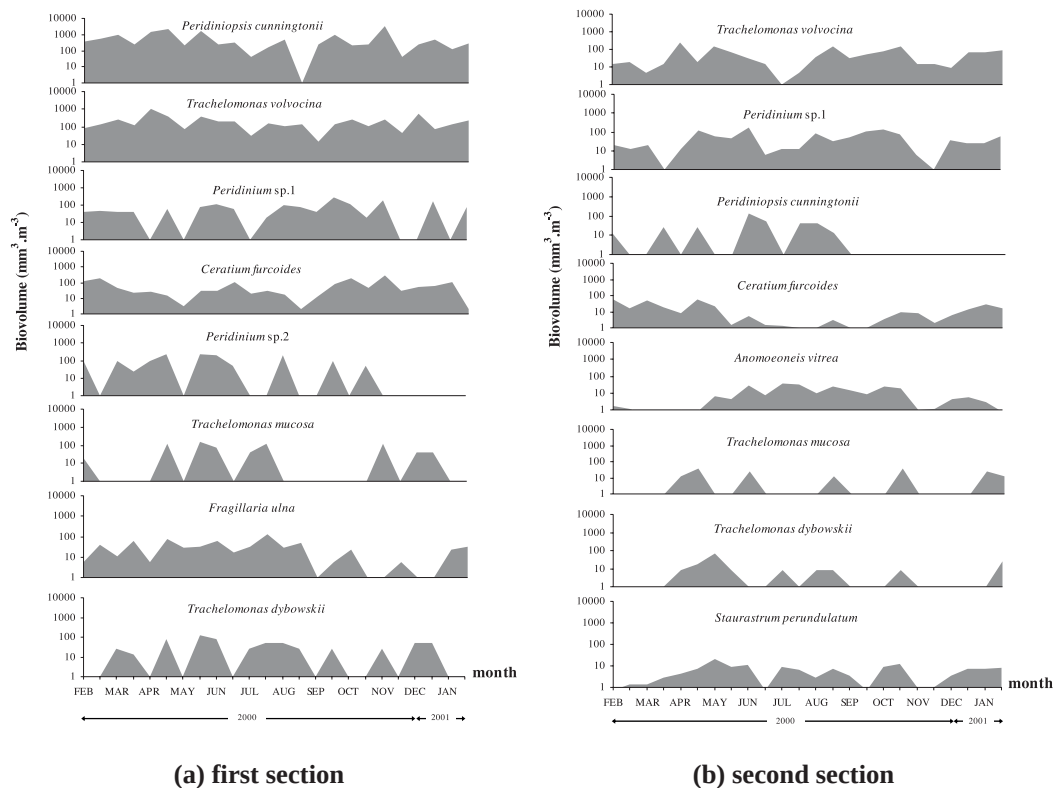


Figure 9. Comparison of the biovolume (mm³.m⁻³) of the dominant species using 10% of the total species of phytoplankton of Rama IX lake (February 2000 - January 2001)

Table 2. Comparison of some physical and chemical parameters in the first section of Rama IX lake from 1995 to 2001.

Parameters	Jumroonwap and Kwankaew (1995 - 1997)			Ninkhuha and Kittanong (1997-1998)	The present researcher (2000-2001)
	1995	1996	1997		
Conductivity ($\mu\text{S.cm}^{-1}$)	843 - 205,000	385 - 1,123	1,135 - 1,620	1,500	620 - 870
PH	3.1 - 7.2	6.6 - 7.7	6 - 7.8	6.6 - 7.2	7.68 - 8.87
Alkalinity (mg.l^{-1})	0 - 76.6	19.5 - 68.1	5 - 43	9 - 10	53.30 - 99.50
Total hardness (mg.l^{-1})	138.1 - 4,850	122.1 - 337.8	317.3 - 411.0	368 - 385	174 - 190
Mn^{2+} (mg.l^{-1})	0.18 - 120.20	0.06 - 4.53	0.35 - 3.33	-	0.00 - 0.10
Fe^{2+} (mg.l^{-1})	ND - 3.65	ND - 0.08	ND - 0.23	-	0.00 - 0.08
Na^+ (mg.l^{-1})	28.7 - 2,300	21.8 - 184.0	107.40 - 160.50	-	83.03 - 69.23
Ca^{2+} (mg.l^{-1})	36.3 - 599.20	33.5 - 78.20	50.9 - 69.3	-	23.40 - 38.60
Mg^{2+} (mg.l^{-1})	11.50 - 814.80	09.40 - 44.40	43.30 - 63.7	-	21.48 - 24.12
K^+ (mg.l^{-1})	4.3 - 123.6	6.6 - 12.9	10.9 - 15.2	-	8.97 - 10.14
Zn^{2+}	-	-	-	0.02 - 0.48	0.00 - 0.03
Cu^{2+}	-	-	-	0.02 - 0.08	0.00 - 0.01
SO_4^{2-} (mg.l^{-1})	93.70 - 5,528.00	85.0 - 374.60	341.50 - 464.90	-	117.12 - 211.68
Cl^- (mg.l^{-1})	22.0 - 3,009.00	11.30 - 212.80	120.60 - 264.40	775 - 1,275	75.62 - 91.59
HCO_3^- (mg.l^{-1})	0 - 93.30	23.8 - 83.0	6.1 - 52.50	-	36.60 - 78.80

ND = non detectable

Table 3. Comparison of some physical and chemical parameters in the second section of the Rama IX lakes from 1995 to 2001

Parameters	Jumroonwap and Kwankaew (1995-1997)			Ninkhuha and Kittanong (1997-1998)	The present researcher (2000-2001)
	1995	1996	1997		
Conductivity ($\mu\text{S.cm}^{-1}$)	433 - 14,090	1,156 - 1,563	1,345 - 1,914	1,600	1,110 - 1,360
pH	3.3 - 7.5	6 - 8.1	6.6 - 7.6	7.1 - 7.3	7.25 - 7.92
Alkalinity (mg.l^{-1})	0.76.6	10 - 33.5	6 - 24.5	20 - 21	22.40 - 38.00
Total hardness (mg.l^{-1})	140.6 - 2,208	210 - 7,436.9	325.3 - 432.4	356 - 369	275 - 290
Mn^{2+} (mg.l^{-1})	0.19 - 120.6	0.05 - 1.38	0.53 - 2.07	-	0.01 - 0.12
Fe^{2+} (mg.l^{-1})	ND - 3.57	ND - 0.10	ND - 0.06	-	0.00 - 0.07
Na^+ (mg.l^{-1})	28.7 - 1,472.0	103.5 - 184.0	109.9 - 190.9	-	121.44 - 127.42
Ca^{2+} (mg.l^{-1})	35.9 - 487.00	47.7 - 85.40	52.90 - 67.30	-	47.20 - 51.60
Mg^{2+} (mg.l^{-1})	12.40 - 648.10	22.20 - 54.30	47.40 - 64.20	-	37.44 - 39.36
K^+ (mg.l^{-1})	04.3 - 80.1	08.2 - 12.50	11.3 - 15.60	-	11.31 - 12.09
Zn^{2+}	-	-	-	0.20 - 1.20	0.00 - 0.06
Cu^{2+}	-	-	-	0.02 - 0.60	0.00 - 0.01
SO_4^{2-} (mg.l^{-1})	93.7 - 4,928.00	297.80 - 540.80	374.60 - 473.10	-	193.92 - 337.44
Cl^- (mg.l^{-1})	23.0 - 2,188.0	97.50 - 211.70	126.60 - 255.30	1,075 - 1,275	155.49 - 164.01
HCO_3^- (mg.l^{-1})	0.93.30	12.20 - 38.40	7.30 - 29.90	-	12.20 - 30.50

ND = non detectable

considerable amounts, judging by its characteristic smell in the hypolimnetic samples (Overbeck and Anagnostidis, 1982). Under the reducing conditions prevailing in the anoxic hypolimnion during stratification, a considerable contribution of HCO_3^- , as well as a relative conductivity increase, were expected due to the dissolution of CaCO_3 (Golterman, 1975; Wetzel, 1983). Consequently, the alkalinity at the bottom

of the first section increased. For the second section, the alkalinity showed little change throughout the investigation because this lake had an oligotrophic status which meant there was little change in the nutrients in the water (Wetzel, 1983). There was little change in the content of nutrients, (total phosphorus and nitrate-nitrogen), throughout the investigation. Low nutrients values resulted from the closure

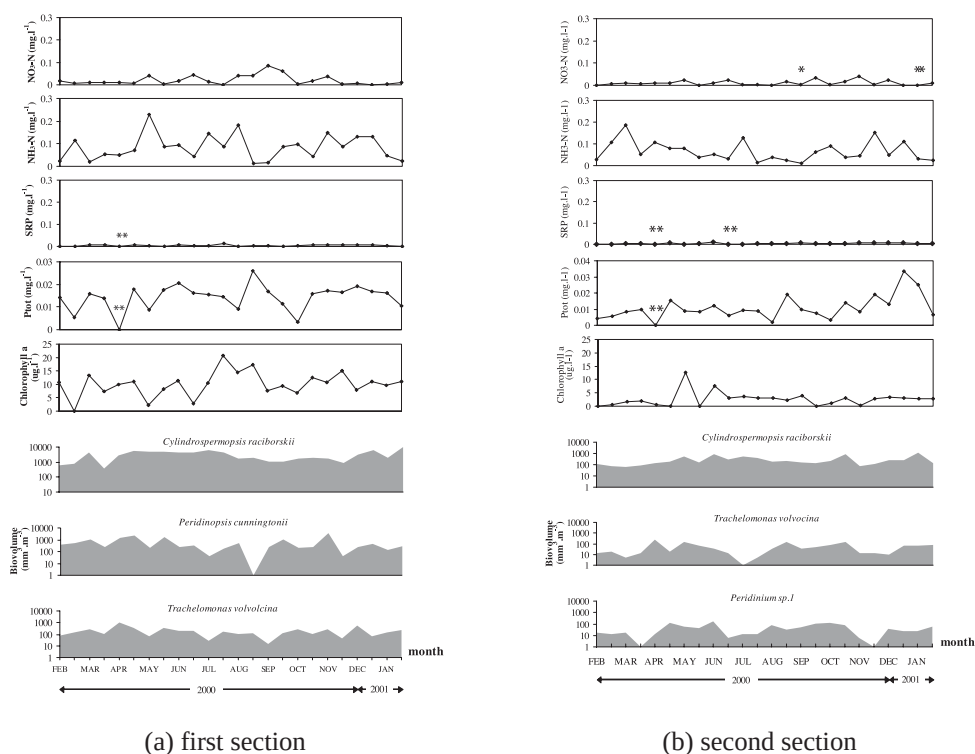


Figure 10. The correlation between dissolved nutrient (mg.l⁻¹), total phosphorus (mg.l⁻¹) chlorophyll a (mg.l⁻¹), related to the dominant species of Rama IX lake (February 2000 - January 2001) ** = not analysed

of the inflow - outflow drains of Khlong 5 and Khlong 6 throughout the investigation, which meant there was little contamination from the outside lake. In addition, there was little contamination caused by some of people as they went swimming and fishing in the lake even on holidays and even when there was a small activity.

Cylindrospermopsis raciborskii was found to be the dominant species and was the highest phytoplankton biovolume throughout the investigation. This phytoplankton is one type of filamentous blue green algae, cosmopolitan in tropical zones and in the summer in temperate zones (Rott, 1987). Peerapornpisal (1996) reported that the genus *Cylindrospermopsis* is known to be commonly distributed throughout all the tropical countries. The very common *C. raciborskii* has a pantropical distribution, but

occasionally occurs in the summer season in warmer temperate areas. The less common *C. philippinensis* is known from several localities in very distant tropical regions (Komárek and Kling, 1991). This investigation of both sections found that nutrients such as nitrogen and phosphorus were low throughout the investigation. The assessment of the water quality indicated that both sections were oligotrophic, but the water was very hard.

Nevertheless, in the first section, the total amount of phosphorus was 0.02 mg.l⁻¹ in June and August, 2000. While in the second section, the total amount of phosphorus was 0.03 mg.l⁻¹ in December 2000 and 0.02 mg.l⁻¹ in January 2001. The assessment of the water quality indicated that it was mesotrophic according to the classifications of Lampert and Sommer (1993).

According to the investigation, *C. raciborskii* tended to have a negative correlation with nitrate-nitrogen and ammonia - nitrogen. (Figure 10(a)). Although these nutrients decreased at the water surface, the phytoplankton biovolume did not decrease as this phytoplankton can adapt to low nitrogen water. *C. raciborskii* is able to fix nitrogen from the environment and convert it to ammonium and protein (Reynolds, 1984). Furthermore, this phytoplankton has the ability to store phosphorus in cells as polyphosphate bodies and can use it for growth (Horne and Goldman, 1994). Finally, this phytoplankton can move from the hypolimnion to the epilimnion to translocate phosphorus. So, it can adapt in the epilimnion which has low levels of phosphorus (Head *et al.*, 1999). The study of Peerapornpisal (1996) and Pooarlai (1999) who found that *C. raciborskii* showed a positive correlation with soluble reactive phosphorus and chlorophyll a. However, it showed a negative correlation with nitrate nitrogen and ammonium nitrogen and indicated mesotrophic to eutrophic status.

Furthermore, according to the investigation the second dominant phytoplankton were *Peridinopsis cunningtonii* and *Trachelomonas volvocina* etc. In the first section, *T. volvocina* had positive correlation with SRP ($P = 0.05$). This finding corresponds to the report of Presscott, 1962 were found that in the water resources containly high levels of phosphorus. Few species of phytoplankton were found that in the water resources. Some examples were *Microcystis*, *Oscillatoria*, *Anabaena* etc. and dinoflagellates. *Peridinium* and *Ceratium* were found in high quantities. According to Figure 10(a) as the increase in the growth of *Peridinopsis cunningtonii* occurred the total phosphorus increased, as in April, 2000. Based on the study of phytoplankton biovolume the dominant species of phytoplankton, chlorophyll a and total phosphorus in the first section resembled the trophic status study by Lorraine and Vollenweider (1981); Wetzel (1983) and Lampert and Sommer (1993). They also found that *C. raciborskii*, *Peridinopsis cunningtonii* and *Trachelomonas volvocina* were dominants and

indicated the water status as mesotrophic to eutrophic in the first section.

In the second section, *C. raciborskii* was the dominant species followed by *T. volvocina*, *Peridinium* sp.1, *Peridinopsis cunningtonii*, *Ceratium furcoides* etc. respectively. *Peridinopsis cunningtonii* had a positive correlation with SRP ($P = 0.01$) whereas *Peridinium* sp.1 had negative correlation with total dissolved solids ($P = 0.05$). The presence of *C. raciborskii*, *T. volvocina*, *Peridinopsis cunningtonii* tended to indicate mesotrophic status. When there was an increase in ion, nutrients etc., this caused a decrease in the quantities of *Peridinium* sp.1. Figure 10(b) shows a decrease of nitrate-nitrogen and total phosphorus, especially in June, 2000, which increased the quantities of *Peridinium* sp.1, tending to indicate oligotrophic status. The aforementioned species are of a particular kind, usually a flagellated form with considerable cellular volume, containly high levels of chlorophyll a and reproducing slowly as they have adapted to surroundings with low mineral nutrients. The slow rate of reproduction results in an expansion of specific diversity with a very high volume of pigment diversity, according to Moyá and Romá (1984).

In addition, the conductivity in the second section was found to be higher than that of the first. The high phytoplankton biovolume such as *Anoemoeoneis vitrea* in the second section could be used as an indicator of a high level of conductivity. The result corresponds to the report of Round *et al.* (1990). They found that *Anoemoeoneis vitrea* was found in waters with high conductivity.

In both sections, the water hardness was quite high. The most dominant phytoplankton was *C. raciborskii*, while the other dominant phytoplankton were Dinophyceae and Euglenophyceae. This finding corresponds to the work of Smith (1950) who studied the correlation between phytoplankton and total hardness and found that the quantities of Chrysophyta, Bacillariophyta and Pyrrophyta had a positive correlation with total hardness at the water surface. Both studies showed that the

quantities of the phytoplankton increase when the total hardness in the water increases.

Water hardness consists of two elements of divalent metallic cation such as calcium and magnesium elements as well as other metals such as Fe^{2+} , Mn^{2+} etc. However, calcium and magnesium are essential metals for the growth of algae (Smith, 1950). The minerals in the water are essential for the existence and growth of phytoplankton. Since magnesium is a constituent of chlorophyll, it is plainly an absolute requirement of pigmented algae of all groups and is also necessary for the formation of catalase. Magnesium is an essential cofactor or activator in many reactions, such as nitrate reduction, sulfate reduction and phosphate-transfers, involving adenosine triphosphate and diphosphate (ATP and ADP). Calcium ions undoubtedly play a part in the maintenance of cytoplasmic membranes and in wall structures (Horne and Goldman, 1994; Vymazal, 1995). Fogg (1975) found that some genus of Chrysophyta, such as *Dinobryon* and Diatom were found in high quantities in very hard water. Putthathorn (1986), who studied the abundance and distribution of algae as related to some water quantities of Ping-Wang River Basin, found that the quantities of diatoms had a positive correlation with calcium quantity whereas Pyrrophyta and *Euglena* could grow well in high calcium water resources. Boonyapiwat (1987) and Suravit (1996) studied the relationships between phytoplankton and water quality in Racha-Prabha reservoir in Surat Thani province and found that *Peridinium* sp. had a positive correlation with the water hardness, calcium and the conductivity. According to the investigation of both sections, apart from *C. raciborskii*, Euglenophyceae such as *Euglena* and *Trachelomonas* and others were the only dominant species; this could be attributed to the presence of high levels of ammonia-nitrogen at the hypolimnion. These aforementioned phytoplankton grow well in water with organic and decomposing matters. They move vertically up and down through the water column and this vertical movement allows access to the nutrient-rich hypolimnion during periods of

epilimnion. So these phytoplankton can adapt to both sections although there are low nutrients at the epilimnion.

Conclusion

Considering the natural water from both sections of Rama IX lake as classified by the National Environmental Boards standards of surface water quality was found to be in the second category, but the water hardness exceeded the water quality standards of water supply. So, the natural water from both sections are relatively clean for household consumption after proper treatment. *Cylindrospermopsis raciborskii* was found to be the dominant species and was the highest phytoplankton biovolume throughout the investigation in the both sections.

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