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Relationships Between Seasonal Variation and Phytoplankton Dynamics in Kaeng Krachan Reservoir, Phetchaburi Province, Thailand

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ABSTRACT.– Kaeng Krachan Reservoir is located in the Phetchaburi watershed, western Thailand. It was constructed as a multipurpose dam for irrigation, electricity generation, fisheries and recreation. Various human activities outside and in the reservoir are major causes of ecological change. A limnological study on the relationships between seasonal variation and phytoplankton dynamics in Kaeng Krachan Reservoir was carried out and bimonthly samples were collected from December 2001 to October 2002, representing the dry (December-April) and wet (June-October) seasons. The results indicate that the highest phytoplankton diversity were represented by 39 genera in the wet season. Apparently, the dominant species were *Microcystis aeruginosa* Kützing, *Peridinium* sp., *Cylindrospermopsis raciborskii* (Wolosz.) Seenayya et Subba Raju, *Botryococcus braunii* Kützing, *Oscillatoria* sp. and *Staurastrum limneticum* Schmidle var. *burmense* West and West. The annual average phytoplankton biovolume was $6.87x10^3 \pm 6.66x10^3$ mm^3/m^3. The phytoplankton biovolume in the wet season ($9.65x10^3 \pm 5.78x10^3$ mm^3/m^3) was higher than in the dry season ($4.09x10^3 \pm 6.34x10^3$ mm^3/m^3) (at $p \leq 0.05$). *Peridinium* sp. had the highest biovolume (42.73%) in the dry season while the toxic cyanobacterium, *M. aeruginosa* had the highest biovolume (78.01%) in the wet season. Annual average chlorophyll *a* concentration was 15.71±8.50 mg/m^3. Chlorophyll *a* concentration was positively correlated with nitrate–nitrogen concentration (at $p \leq 0.01$). In conclusion, we found that the phytoplankton biovolume and chlorophyll *a* concentrations were significantly different between seasons (at $p \leq 0.01$) which clearly relates to nutrient availability in water, particularly ammonium-nitrogen and phosphate-phosphorus. Evidently, both biological factors in the wet season were higher than in the dry season. Moreover, the reservoir can be classified as a mesotrophic lake in the dry season and a eutrophic lake in the wet season.

KEY WORDS: phytoplankton, ecological factors, reservoir, Kaeng Krachan, Thailand

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INTRODUCTION

Amid the high population growth in Asia, the rate and extent of environmental changes in the region are having impacts on aquatic biota that are probably greater than anywhere else on the planet (Dudgeon, 2000). Consequently, freshwater ecosystems in Thailand are under growing threat due to rapid human population growth and increasing consumer demands; thus causing natural environmental degradation throughout the country. This is particularly evident in the western Phetchaburi watershed in southwest Thailand, where the Kaeng Krachan, a man-made reservoir is a lentic freshwater ecosystem. This reservoir supplies water for electricity generation, irrigation, transportation, tourism and fisheries. However, it also receives run-off and wastewater discharges from agriculture and domestic uses (Royal Forest Department, 1994). Forest area in this watershed decreased 3.40 % from 1991 to 1998 (National Statistical Office, 2002) while tourist numbers increased to the Kaeng Krachan National Park and reservoir from 3,900 to 160,000 visitors from 1982 to 2003 (Srikanha, 2004). Consequently, the ecological patterns and processes of aquatic ecosystems were considerably altered, leading to a decline in water quality.

In Thailand, limnological studies on seasonal variation and human activities causing changes in nutrient availability and creating unfavorable conditions for other aquatic life, especially phytoplankton are limited. Phytoplankton abundance and composition in aquatic ecosystems are regulated by abiotic factors such as, nutrients related to physico-chemical variability and biotic, trophic interactions (Sin et al., 1999; and Lewis, 2000). The growth of phytoplankton in tropical regions depends on ambient nutrient levels more than other environmental factors (Morris, 1980; and Al-Jassabi and Khalil, 2006). However, the relationships between phytoplankton dynamics and environmental change are still poorly understood in many regions of the world (Miretzky et al., 2002).

In this study, our aim was to examine phytoplankton dynamics in terms of species composition, biovolume and chlorophyll *a* content in relation to seasonal variation in Kaeng Krachan Reservoir.

Study area

Built in 1965, the Kaeng Krachan Reservoir is located at the upper part of the Phetchaburi watershed (Royal Forest Department, 1994) (Fig. 1). The dam is 56 m high and 1,320 m long. The reservoir capacity is up to 700 million m^3, while the surface area is 49.51 km^2 and the overflow passage can achieve 75 m^3/s. The watershed area consists of different land use types such as forest, agriculture, human settlement and water resources. After the end of logging concessions in upper Phetchaburi watershed in 1981, the workers still settled their homes in the logged areas in which were converted to agricultural area (TISTR, 2000). Recently, agricultural areas around the reservoir are increasing, contributing to higher fertilizer and pesticide run-off.

MATERIALS AND METHODS

Data collection

The samples were collected bimonthly from December 2001 to October 2002. The climatic condition was divided into the dry

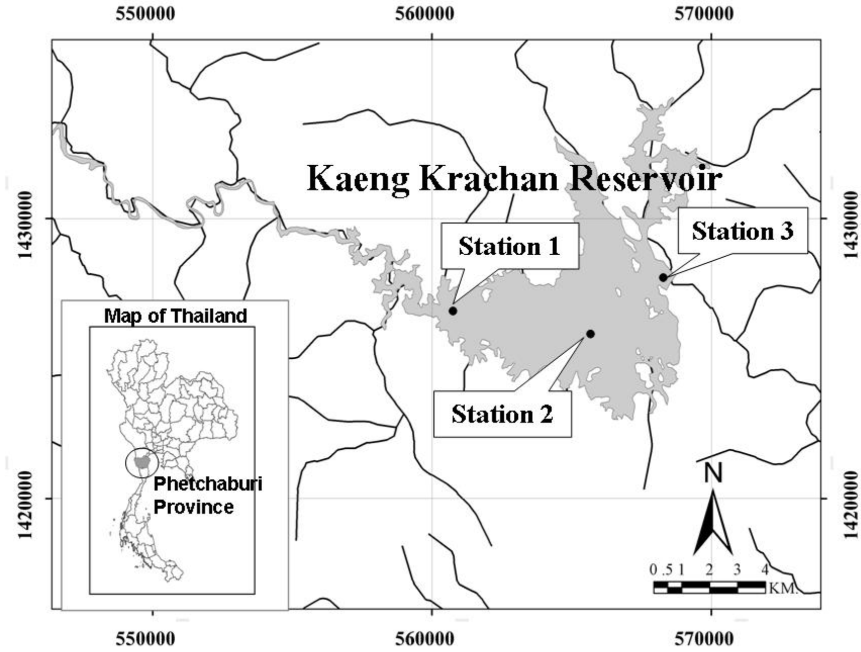

FIGURE 1. Sampling stations in Kaeng Krachan Reservoir, Phetchaburi Province.

season (December 2001 to April 2002) and the wet season (June 2002 to October 2002). Sampling sites was designated into 3 stations: 1) a shallow area close to the principal inlet, 2) an area near the middle of the reservoir, and 3) an area close to the dam (the deepest part of the reservoir) (Fig. 1). Six samples were taken at each station.

Ecological factors: The measured parameters included water depth by directly measuring transparency depth using a Secchi disc, pH by a pH-meter, and dissolved oxygen (DO) and water temperature with a DO meter YSI model (reference). Six 3.5 liters water samples were collected by a 1 liter Van Dorn sampler at each station. Nutrients such as nitrate–nitrogen, ammonium–nitrogen, phosphate–phosphorus and silica concentrations were analyzed according to Wetzel and Likens (2000) and suspended solid on standard APHA, AWWA & WEF (1998) methods. The monthly rainfall data of Kaeng Krachan Reservoir were collected from the Meteorological Department.

Biological factors: Phytoplankton: At each station, six 5 liter Van Dorn water samples were collected and 40 liters of water filtered through a plankton net (mesh size 20 microns). These phytoplankton samples were collected and preserved with Lugol's solution for identification. Chlorophyll *a* analysis was performed according to Wetzel and Likens (2000). Phytoplankton composition, biovolume and chlorophyll *a* concentration were analyzed in the laboratory at Department of Biology, Chulalongkorn University, Bangkok.

Data Analysis

Phytoplankton Identification and Density Assessment: Identification was based on taxonomic references including, Cox (1996); Croasdale et al. (1994); Prescott (1978); and Rott (1981).

TABLE 1. A comparison of ecological parameters between the wet and the dry seasons in Kaeng Krachan Reservoir (* means the significant difference at $p \leq 0.05$)

Parameter	Dry season	Wet season	Mean±SD	Sig.
Water depth (m)	17.13±5.15	20.81±9.41	18.97±7.71	0.157
Transparency depth (m)	1.84±0.52	1.25±0.14	1.55±0.48*	0.000
Temperature (°C)	27.53±2.64	28.54±0.88	28.04±2.02*	0.009
pH of water	7.66±0.35	8.07±0.25	7.87±0.37*	0.000
Suspended solid (mg/l)	4.70±4.73	4.08±1.63	4.39±3.52	0.522
Dissolved Oxygen (mg/l)	7.01±1.02	6.99±0.78	7.05±0.91	0.908
NO3-N (ug/l)	4.19±7.70	5.63±6.57	0.91±7.18	0.072
NH3-N (ug/l)	4.32±4.97	7.09±11.59	5.71±9.01*	0.006
PO4-P (ug/l)	1.23±1.87	3.16±3.36	2.20±2.89*	0.000
Silica (mg/l)	6.00±3.70	11.37±0.51	8.70±3.78*	0.000
Chlorophyll *a* (mg/m^3)	10.75±1.71	20.66±9.62	15.71±8.50*	0.000
Phytoplankton biovolume (mm^3/m^3)	$4.09x10^3 \pm 6.34x10^3$	$9.65x10^3 \pm 5.78x10^3$	$6.87x10^3 \pm 6.66x10^{3*}$	0.000

Phytoplankton density was measured with a Sedgewick-Rafter counting chamber. Phytoplankton size i.e. thickness, cell diameter, length and process of each phytoplankton cell or colony were examined under a compound microscope and the biovolume was calculated using the Rott method (Rott, 1981).

Statistical analysis: All data were analyzed statistically in terms of correlation and ANOVA by SPSS software version 10.5.

RESULTS

Ecological factors.

The results of ecological physico-chemical factors are shown in relation to seasonal variation and locality as follows:

Rainfall: The monthly rainfall averages varied from 0.0 to 168.4 mm. However, the highest rainfall was in March 2002, it was influenced from the changing season from the northeast monsoon to the southwest monsoon (Fig. 2A).

Water depth: The water depth averages varied from 13.17±4.48 to 20.17±8.24 m (Fig. 2B). With the deepest occurring at the beginning of the wet season (June 2002) due to the high rainfall and the high surface water inflow from upstream and surrounding area (199.93 m^3/s) (Asriningtyas et al., 2005). It is clear that the water depth variations correlate with season variations.

Transparency depth: The transparency depth averages varied from 0.81±0.32 to 1.50±0.32 m (Fig. 2C) and was significantly different between seasons at $p \leq 0.05$ (Table 1). The high surface water inflow increased water turbidity and reduced transparency depth in the wet season from June to August correlating with suspended solids.

Water temperature: The water temperature averages ranged from 24.33±0.29 °C to 31.00±1.00 °C (Fig. 2D) and varied significantly between seasons at $p \leq 0.05$ (Table 1).

pH: The water pH ranged from 7.13 to 7.60 (Fig. 2E) and varied significantly between seasons at $p \leq 0.05$ (Table 1). The pH also varied in depth corresponding to dissolved oxygen influenced by the rate of

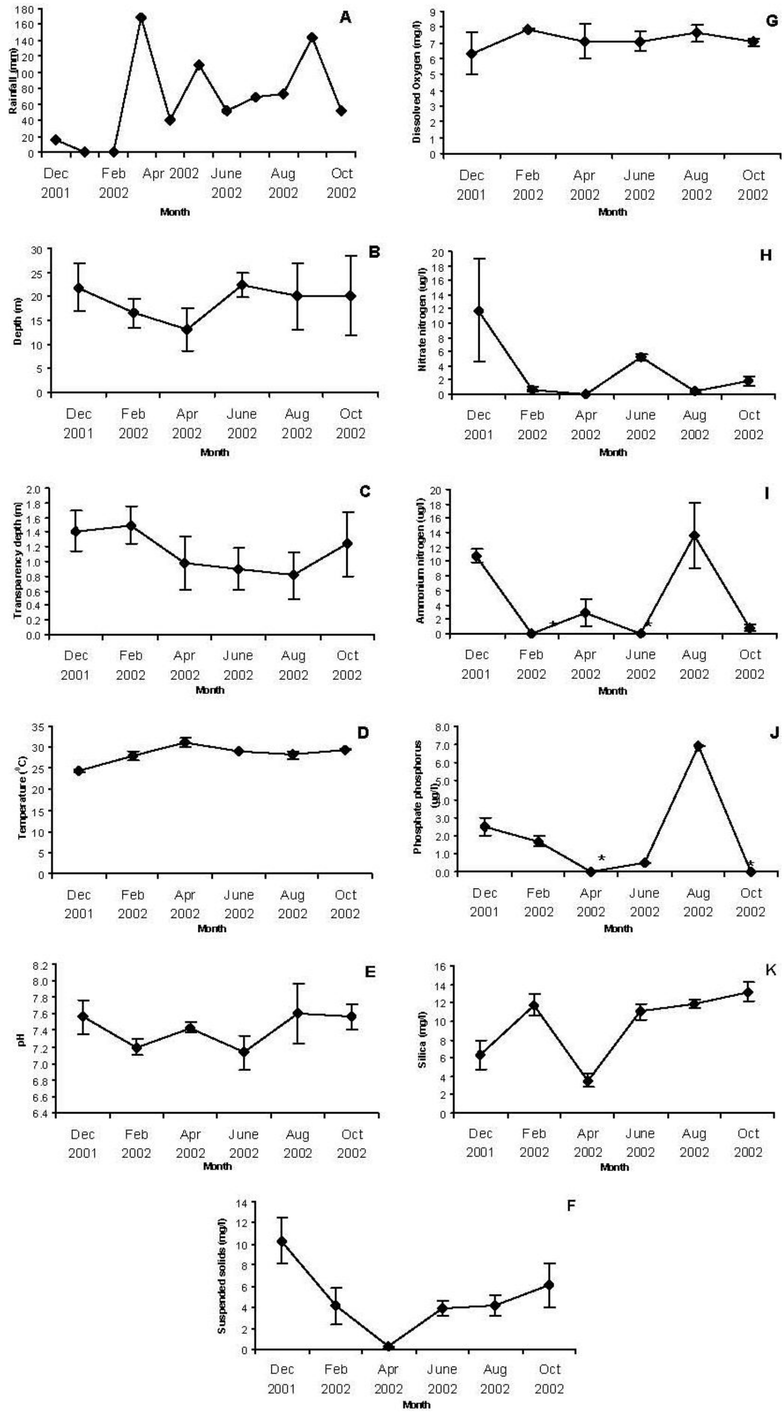

FIGURE 2. Average of rain fall (**A**), water depth (**B**), transparency depth (**C**), water temperature (**D**), Dissolved Oxygen (**E**), pH (**F**), suspended solids (**G**), nitrate-nitrogen (**H**), ammonium-nitrogen (**I**), phosphate-phosphorus (**J**) and silica (**K**) in Kaeng Krachan Reservoir, Phetchaburi Province, Thailand. (* = value below detection limit)

photosynthesis and respiration of aquatic organisms.

Suspended solids (SS): The suspended solids averages varied from 0.23±0.06 to 10.30±2.14 mg/l. (Fig. 2F) with the highest average recorded at the beginning of the dry season with rainfall of 15.6 mm in December 2001 due to the collective effect of flooding in October (297.3 mm) and November (10.7 mm) in 2001 (Meteorological Department, 2005). Suspended solids varied in relation to seasonal change, which decreased at the end of the dry season and increased again in the following wet season due to the rainfall data in Figure 2A. It also affected to the turbidity of water in reservoir more than natural lake (Wetzel, 2001).

Dissolved oxygen (DO): The dissolved oxygen averages varied from 6.33±1.34 to 7.87±0.06 mg/l with the lowest average being 6.33±1.34 mg/l in the early dry season (December 2001) (Fig. 2G). It was affected by flooding and consequent suspended solids increment caused by the high rainfall in the preceding wet season.

Nitrate-nitrogen: The averages of nitrate-nitrogen concentration varied from 0.005±0.003 to 11.760±7.120 ug/l (Fig. 2H). In the wet season, the surface water inflow carried high amounts of nutrients into the reservoir due to high rainfall flushing from the surrounding agricultural areas. This caused a higher nitrate–nitrogen concentration in the dry season December 2001 than other periods. However, the nitrate–nitrogen concentration in Kaeng Krachan Reservoir during the study indicated the acceptable water quality as it did not exceed 5 mg/l, the maximum standard level of surface water quality in Thailand (PCD, 1997).

Ammonium-nitrogen: The ammonium-nitrogen concentration varied from ND (value below detection limit) to 13.65±4.48 ug/l (Fig. 2I) with the concentration varying significantly between seasons at $p \leq 0.05$ (Table 1). The highest concentrations occurred in the end of wet season (August 2002) due to the effects of high soil erosion loading from the surrounding agricultural areas. The ammonium–nitrogen concentration was also lower than the surface water quality standard in Thailand (<500 ug/l) (PCD, 1997).

Phosphate-phosphorus: The phosphate-phosphorus concentration averages ranged from ND to 7.46±0.00 ug/l (Fig. 2J), with no detectable values at the end of the dry and wet seasons (April and October 2002). Phosphate–phosphorus concentration was significantly different between seasons at $p \leq 0.05$ (Table 1) with an increase in the middle of the wet season (August 2001). This could be partly due to nutrient run-off from surrounding areas.

Silica: The silica concentration averages ranged from 3.55±0.66 to 13.18±1.02 mg/l (Fig. 2K) and was significantly different between seasons at $p \leq 0.05$ (Table 1) as in the wet season, the high rate of rock and soil weathering could increase silica concentration in the water body. The natural silica concentration of freshwater most commonly ranges from 1–30 mg/l (Wetzel, 2001).

Biological factors

Phytoplankton: The species composition, phytoplankton biovolume and chlorophyll *a* concentration are indicated as follows:

Species composition: A study of species composition of phytoplankton were classified into 5 divisions, 6 classes 13 orders, 24 families, 39 genera and 51 species (Table 2). In addition, the numbers of phytoplankton species were 44 in the dry season and 35 in the wet season.

Following Rott's classifications (1981), our investigation found that the total phytoplankton consisted of 7 groups. The major groups of phytoplankton were Cyanophyceae, Dinophyceae, Chlorophyceae and Zygnemaphyceae, respectively, while Chlorophyceae was the most abundant species throughout the year comprising 16 species. Moreover, the dominant species were *Microcystis aeruginosa* Kützing, *Peridinium* sp., *Cylindrospermopsis raciborskii* (Wolosz.) Seenayya et Subba Raju, *Botryococcus braunii*, *Oscillatoria* sp. and *Staurastrum limneticum* schmidle var. *burmense*. *Peridinium* sp. was dominant in the dry season while the toxic cyanobacterium, *M. aeruginosa* dominanted in the wet season.

Phytoplankton biovolume: The phytoplankton biovolume was calculated from the density and volume approximation of each species. The phytoplankton biovolume averages ranged from $2.76x10^3 \pm 1.03x10^2$ to $2.20x10^4 \pm 1.14x10^3$ mm^3/m^3 (Fig. 3A), with the highest value, $2.20x10^4 \pm 1.14x10^3$ mm^3/m^3 at the end of wet season (October 2002) and the lowest value, $2.76x10^3 \pm 1.03$ mm^3/m^3 in the early dry season (December 2001). The average annual of phytoplankton biovolume in Kaeng Krachan Reservoir was $6.87x10^3 \pm 6.66x10^3$ mm^3/m^3.

The phytoplankton biovolume was low in the dry season ($4.09x10^3 \pm 6.34x10^3$ mm^3/m^3) and increased rapidly in the wet season ($9.65x10^3 \pm 5.78x10^3$ mm^3/m^3) due to water flow (14.62 m^3/s in the dry season and 199.93 m^3/s in the wet season) (Asriningtyas et al., 2005). In the dry season, *Peridinium* sp. represented the highest biovolume at 42.73 % in February 2002 (Fig. 3B). Then, *Microcystis aeruginosa* rapidly grew in April and reached the highest biovolume at 78.01% in October 2002. Although *Botryococcus braunii* was noticeable as it floats on the water surface, its biovolume percentage was low. This is a clear indication that the dominant phytoplankton was Cyanophyceae in the wet season while there were co-dominants, Dinophyceae and Cyanophyceae in the dry season.

Chlorophyll *a* concentration: The averages of chlorophyll *a* concentration ranged from 10.38 ± 0.90 to 35.22 ± 5.60 mg/m^3 at the end of the wet season (February 2002) (Fig. 3C). Chlorophyll *a* concentration was significantly different between seasons at $p \leq 0.05$ (Table 1) at the beginning of the wet season there were phytoplankton blooms and both chlorophyll *a* concentration and phytoplankton biovolume increased rapidly until the end of the wet season in October 2002. The annual average chlorophyll *a* concentration was 15.71 ± 8.50 mg/m^3.

DISCUSSIONS

Species composition, phytoplankton biovolume and dominant species

This study found that phytoplankton composition was higher than a previous study in Kaeng Krachan Reservoir by the National Inland Fisheries Institute (1989) which only identified 22 species. The increase we observed could be due to increasing community and agricultural areas with the corresponding land use changes (National Statistical Office, 2002)

TABLE 2. List of species of phytoplankton in Kaeng Krachan Reservoir, Phetchaburi Province

Phytoplankton species	
Cyanophyceae	*Anabaena* sp.1
	Anabaena sp.2
	Anabaena sp.3
	Aphanocapsa sp.
	Coelomoron sp.
	Cylindrospermopsis raciborskii
	Lyngbya sp.
	Merismopedia sp.
	Microcystis aeruginosa
	Oscillatoria sp.
	Planktolyngbya sp.
	Pseudanabaena sp.
	Spirulina sp.
Cryptophyceae	*Chroomonas* sp.
	Cryptomonas sp.
	Rhodomonas sp.
Dinophyceae	*Ceratium* sp.
	Peridinium sp.
Bacillariophyceae	*Cyclotella* sp.
	Fragilaria sp.
	Gyrosigma sp.
	Meloseira sp.
	Navicula sp.1
	Navicula sp.2
	Nitzschia sp.1
	Nitzschia sp.2
	Surirella sp.
	Tabellaria sp.
Chrysophyceae	*Dinobryon* sp.
Chlorophyceae	*Ankistrodesmus* sp.
	Botryococcus braunii
	Coelastrum sp.
	Crucigenia sp.
	Dictyosphaerium sp.
	Eudorina sp.
	Pediastrum sp.1
	Pediastrum sp.2
	Planktonema sp.
	Scenedesmus sp.1
	Scenedesmus sp.2
	Scenedesmus sp.3
	Scenedesmus sp.4
	Spirogyra sp.
	Tetraedron sp.
	Ulothrix sp.
Zygnemaphyceae	*Cosmarium* sp.1
	Cosmarium sp.2
	Cosmarium sp.3
	Staurastrum limneticum
	Staurastrum sp.1
	Staurastrum sp.2

affecting the increase of nutrients surface runoff (Swank and Crossley, 1988).

Currently, there are a few researches in relation to phytoplankton biovolume assessment in Thailand. Therefore, the results of this study ($2.76x10^3 \pm 1.03x10^2$ to $2.20x10^4 \pm 1.14x10^3$ mm^3/m^3) correspond to the study of Peerapornpisal (1996) which indicated the phytoplankton biovolume of three Thai reservoirs (1) Huai Hong Khrai Royal Development Study Centre, Northern Thailand, gave $2.96x10^3$, $7.90x10^3$ and $4.68x10^3$ mm^3/m^3, respectively. Pongswat (2002) also reported two reservoirs of Rama IX Lake, Central Thailand which the biovolumes were $4.45x10^3$ and $4.95x10^2$ mm^3/m^3, respectively.

We found that *Peridinium* sp. represented the highest biovolume in the dry season. Dinophyceae such as *Peridinium* and *Ceratium* spp. are usually present in medium nutrient-rich or mesotrophic lakes (Wetzel, 2001). While three species of Cyanophyceae, *Microcystis aeruginosa*, *Cylindrospermopsis raciborskii* and *Oscillatoria* sp. were dominant throughout the year, especially when *M. aeruginosa* bloomed and represented highest biovolume in the wet season. Therefore, the Kaeng Krachan Reservoir could be considered as “mesotrophic” during the dry season regarding the dominance of *Peridinium* and *Ceratium* spp. and “eutrophic” during the wet season regarding the dominance of Cyanophyceae e.g. *Microcystis* (Wetzel, 2001). These results correspond with Peerapornpisal et al. (1999) who reported that *M. aeruginosa* grew rapidly and bloomed in Mae Kuang Udomtara Reservoir, Chiang Mai throughout the year. In eutrophic lakes, Cyanophyceae could bloom and cell division occurs rapidly due to the enriched nutrients (Wetzel, 2001). Furthermore, lake and reservoir ecosystems are suitable conditions for *M. aeruginosa* growth (Wetzel, 2001; and Chen et al., 2003). We also found that, when *M. aeruginosa* and *B. braunii* rapidly increased their biovolume in the wet season, the number of cells per colony and the size of colonies also increased. Both species can occur worldwide in eutrophic lakes and drinking water reservoirs (Chen et al., 2003; and Al- Jassabi and Khalil, 2006). In Thailand, many reservoirs have undergone eutrophication due to industrial, agricultural and municipal wastewater causing *Microcystis* blooms, for example, in Mae Kuang Udomtara Reservoir, Chiang Mai Province, Thailand (Peerapornpisal et al., 1999 and 2002). The extensive cyanobacteria blooms can seriously affect water quality, causing deoxygenation and producing hydrogen sulphide usually accompanied by an unpleasant odour (Oberholster et al., 2004). Microcystins are toxins, which accumulate in the liver, viscera and muscle tissue of aquatic animals, especially fish (Megalhaes et al., 2001). Sengpracha et al. (2006) investigated microcystin LR in *M. aeruginosa* collected from Sri Sakhett (Northeastern Thailand) and the results showed a 0.059% yield of microcystin LR (2.93×10^{-4} g in 0.50 g of sample). However, the level of microcystins found in all reservoirs in Thailand was lower than that determined by the World Health Organization Standard for water supplies, the blooming is ignored by concerned agencies such as Fishery Department, Irrigation Department and Royal Forestry Department responsible for the Kaeng Krachan Reservoir.

In recent years the toxic phytoplankton bloom, *C. raciborskii*, has replaced *Microcystis* (Chapman and Schelske, 1997; and Mahakhant et al., 1998). We also found that *C. raciborskii* was the dominant species with a rapid biovolume increase in the wet season. In addition, several studies in northern Thailand reservoirs found *C. raciborskii* was the dominant species in three reservoirs in the Huai Hong Khrai Royal Development Study Centre, Chiang Mai Province (Peerapornpisal et al., 1999). Furthermore, Pongswat et al. (2004) reported that *C. raciborskii*, represented the highest biovolume in two reservoirs of Rama IX Lake, Pathumthani Province.

Phytoplankton biovolume – chlorophyll a – nutrients relationships - seasons

The correlation analysis between physico-chemical-biological parameters and seasons (Table 3), showed that phytoplankton biovolume had a significant

TABLE 3. Matrix of correlation between physico-chemical-biological parameters and season in Kaeng Krachan Reservoir (* : p=0.05 , ** : p=0.01)

	Season	pH	DO	SS	NH3-N	NO3-N	PO4-P	Chl_ *a*	Biovolum
Season	1.0000	0.5520**	-0.0110	-0.0890	0.2530**	0.1000	0.3340**	0.5840**	0.4180**
pH of water		1.0000	-0.0267	-0.1919	0.3029**	-0.0718	0.2359*	0.2667**	0.3182*
Dissolved Oxygen			1.0000	-0.1087	-0.0867	-0.3277**	0.1530	-0.1251	-0.0129
Suspended Solid				1.0000	0.2298	0.4402**	0.1472	0.1275	-0.1237
NH_3-N					1.0000	-0.0313	0.7736**	-0.2664**	-0.2307**
NO_3-N						1.0000	-0.0099	0.2308**	0.0892
PO_4-P							1.0000	-0.2736**	-0.1793*
Chlorophyll *a*								1.0000	0.6571**
Phytoplankton Biovolume									1.0000

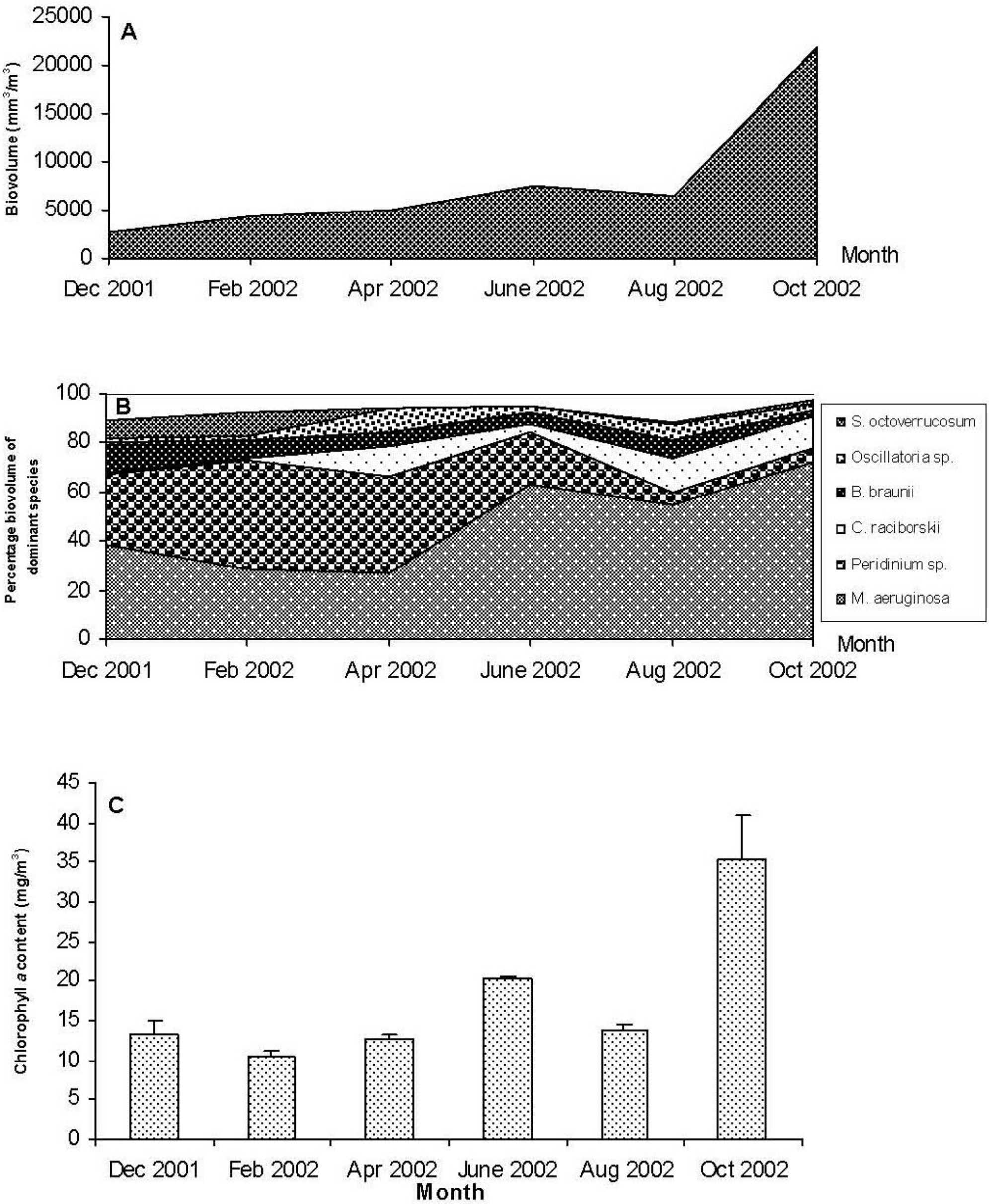

FIGURE 3. Total biovolume of phytoplankton (**A**), percentage of total biovolume of dominant species (**B**) and average chlorophyll *a* content (**C**) in Kaeng Krachan Reservoir, Phetchaburi Province, Thailand.

positive correlation with seasons and chlorophyll *a* concentration at $p \leq 0.01$, while it had a negative significant correlation with ammonium-nitrogen and phosphate-phosphorus at $p \leq 0.01$ and $p \leq 0.05$, respectively. In addition, the biovolume of *Microcystis aeruginosa* had a significant positive correlation with total biovolume and chlorophyll *a* concentration at $p \leq 0.01$. The total biovolume indicated high values due to the increasing cyanophyte biovolume. This corresponds to the study of Graham and Wilcox (2000) that Cyanophyceae is an important nitrogen-fixing planktonic bloom-former in tropical freshwaters around the world.

The chlorophyll *a* concentration also had a significant positive correlation with seasons, water pH, and nitrate-nitrogen at $p \leq 0.01$, while it had a negative correlation with ammonium-nitrate and phosphate-phosphorus at $p \leq 0.01$. Moreover, the average chlorophyll *a* concentration was 15.71±8.50 mg/m^3, being within the range of a meso-eutrophic lake (Wetzel, 2001). However, Peerapornpisal (1996) reported that chlorophyll *a* concentrations in three reservoirs in Northern Thailand were 18, 35 and 25 mg/m^3. We found both phytoplankton biovolume and chlorophyll *a* concentrations had a significant negative correlation with ammonium-nitrogen and phosphate–phosphorus concentrations (Table 3), on the contrary, both nutrients had a significant positive correlation with seasons due to the higher loading in the wet season than in the dry season. The negative correlation of both nutrients could be explained by the fact that phytoplankton bloomed throughout the wet season. Phosphorus is essential for all living organisms and is a common growth limiting factor for phytoplankton in lakes and reservoirs as it is often only available in low concentrations with a high turn-over rate (Graneli et al., 1999). While phytoplankton was blooming, the soluble phosphorus uptake was high, consequently the soluble phosphate form was undetectable during the bloom periods, especially in October (2002). As this phytoplankton can store excess phosphorus in polyphosphate granules when there is a high phosphate–phosphorus concentration, then the phytoplankton can divide several times while the external phosphate–phosphorus reserves are depleted (Goldman and Horne, 1994). Moreover, several Cyanobacteria exhibit vertical migrations from phosphorus-rich sediments at night to the surface water in early morning (Chapman and Schelske, 1997).

CONCLUSIONS

The Kaeng Krachan Reservoir study indicates the phytoplankton biovolume and chlorophyll *a* concentration increased in the wet season due to the water inflow and rainfall run off of organic matter and nutrients into the reservoir. Furthermore, several upstream forest areas passed commercial logging concessions and other areas were converted to agriculture particularly around the reservoir itself. Evidently, fertilizer was washed down into the reservoir during the wet season. It found that phytoplankton bloomed throughout the wet season and remained in bloom until February 2003 (notice after study period). Chlorophyll *a* concentration had a positive correlation with nitrate–nitrogen at $p \leq 0.01$, while it had a negative correlation with ammonium-nitrogen and phosphate-phosphorus concentrations at $p \leq 0.01$. Although phytoplankton biovolume had a negative correlation with phosphate-phosphorus concentration at $p \leq 0.05$ due to the high rate of phytoplankton phosphorus uptake at low concentrations throughout the study period.

Regarding the relationships between seasonal variation and phytoplankton dynamics, we found phytoplankton biovolume and chlorophyll *a* concentrations were significantly different between seasons (at $p \leq 0.05$), which were linked to water nutrient availability, particularly ammonium-nitrogen and phosphate-phosphorus. Dinophyceae was dominant in the dry season while Cyanophyceae; especially *Microcystis aeruginosa* was dominant throughout the year though increasing in the wet season. Therefore, the Kaeng Krachan Reservoir could be assessed as a "mesotrophic lake" during the dry season and a "eutrophic lake" during the wet season. This means the water quality is under threat from nutrient enrichment, even if the degree of blooming was still low when compared to blooming in temperate regions. Thus, it should be a matter for serious concern and increased awareness of the impacts of land use in reservoir and watershed areas. All land use activities around the reservoir need to be managed appropriately and sustainably in order to protect the ecosystem health from adverse algal blooms.

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