ORIGINAL ARTICLE

# Phytoplankton diversity and its relationships to the physico-chemical environment in the Banglang Reservoir, Yala Province

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## Abstract

**Ariyadej, C., Tansakul, R., Tansakul, P. and Angsupanich, S.**
**Phytoplankton diversity and its relationships to the physico-chemical environment in the Banglang Reservoir, Yala Province**
**Songklanakarin J. Sci. Technol., 2004, 26(5) : 595-607**

**The diversity of phytoplankton and its relationships to the physico-chemical environment were studied in Banglang Reservoir, located on the Pattani River in Southern Thailand. Samples were collected monthly from May 2000 to April 2001 at three stations and three different depths: water surface, 10, and 30 meters. Physico-chemical parameters: temperature, pH, dissolved oxygen, alkalinity, conductivity, water transparency, and nutrients were measured simultaneously. One-hundred and thirty-five species in seven divisions of phytoplankton were found. The greatest number of species were in Division Chlorophyta (50%), followed by Cyanophyta (21%), Bacillariophyta (13%), Pyrrophyta (6%), Cryptophyta (4%), Chrysophyta (3%) and Euglenophyta (3%). The most diverse genus was *Staurastrum* (15 species). Phytoplankton density ranged from zero to $2.1 \times 10^9$ cells.$m^{-3}$. *Microcystis aeruginosa* Kützing in January at 30 m at the lacustrine zone had the highest phytoplankton density. By applying a PCA(principal components analysis) using the MVSP statistical analysis program on the abundance of species, it was found that *Cyclotella meneghiniana***


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**Received, 29 March 2004 Accepted, 9 June 2004**

**Kützing and *Melosira varians* Agardh were the most abundant in each station. Diversity index (Simpson's diversity index) was maximum at 10 m at the transition zone and lowest at the outflow zone. The factors affecting the phytoplankton species by Canonical correspondence analysis ordination (PC-ORD program) were alkalinity, water temperature, water transparency, nutrients and conductivity. When the water quality parameters were classified by the trophic level, Banglang Reservoir belonged to oligo-mesotrophic status. Furthermore, *Cyclotella meneghiniana* Kützing and *Melosira varians* Agardh could be used as the phytoplankton indicator of oligo-mesotrophic reservoir.**

**Key words :** phytoplankton, Banglang reservoir, water quality, diversity

## บทคัดย่อ

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**ความหลากหลายของแพลงก์ตอนพืชและความสัมพันธ์กับปัจจัยสิ่งแวดล้อมในอ่างเก็บน้ำบางลาง จังหวัดยะลา**

**ว. สงขลานครินทร์ วทท. 2547 26(5) : 595-607**

**ศึกษาความหลากหลายของแพลงก์ตอนพืชและความสัมพันธ์กับปัจจัยทางกายภาพและทางเคมีบางประการที่เกี่ยวข้อง เช่น อุณหภูมิ ความเป็นกรด-เบส ออกซิเจนที่ละลายน้ำ ความเป็นด่าง ค่าการนำไฟฟ้า ความลึกที่แสงส่องถึง และสารอาหาร ในอ่างเก็บน้ำบางลาง จังหวัดยะลา ซึ่งตั้งอยู่บนแม่น้ำปัตตานี ทางภาคใต้ของประเทศไทย เก็บตัวอย่างเดือนละครั้ง ตั้งแต่เดือนพฤษภาคม 2543 ถึงเดือนเมษายน 2544 จำนวน 3 สถานี ที่ระดับผิวน้ำ 10 และ 30 เมตร พบแพลงก์ตอนพืช 135 ชนิด ใน 7 หมวด (division) โดยพบหมวด Chlorophyta มีความหลากชนิดมากที่สุด (50%) รองลงมาคือหมวด Cyanophyta (21%), Bacillariophyta (13%), Pyrrophyta (6%), Cryptophyta (4%), Chrysophyta (3%) และ Euglenophyta (3%) ตามลำดับ โดย *Staurastrum* มีความหลากหลายของชนิด (species) มากที่สุด (15 ชนิด) ความหนาแน่นของแพลงก์ตอนพืชมีค่าตั้งแต่ 0 ถึง $2.1 \times 10^{9}$ เซลล์/ลบ.เมตร โดย *Microcystis aeruginosa* Kützing เป็นชนิดที่มีความหนาแน่นมากที่สุด พบที่ระดับ 30 เมตรหน้าเขื่อน ในเดือนมกราคม ความชุกชุมแสดงผลด้วย PCA โดยใช้โปรแกรม MVSP พบว่า *Cyclotella meneghiniana* Kützing และ *Melosira varians* Agardh เป็นชนิดที่มีค่ามากในทุกจุด ค่าดัชนีความหลากหลาย ใช้วิธีของ Simpson พบสูงสุดที่ระดับ 10 เมตร กลางเขื่อน และต่ำสุดพบที่ทางระบายน้ำ ปัจจัยที่มีผลต่อการเปลี่ยนแปลงแพลงก์ตอนพืช ซึ่งหาโดยวิธี CCA ใช้โปรแกรม PC-ORD มีดังนี้ ความเป็นด่าง อุณหภูมิน้ำ ความลึกที่แสงส่องถึง สารอาหาร และค่าการนำไฟฟ้า สามารถจัดคุณภาพน้ำตามความอุดมสมบูรณ์อยู่ในระดับปานกลางค่อนข้างดี (oligo-mesotrophic) นอกจากนี้ *Cyclotella meneghniana* Kützing และ *Melosira varians* Agardh สามารถใช้เป็นดัชนีชี้คุณภาพน้ำในระดับปานกลางค่อนข้างดีของอ่างเก็บน้ำได้**

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The study of phytoplankton diversity in relation to water quality in Thailand started at the end of the 20[th] century. Although phytoplankton have been collected all over Thailand, most works has been mainly from the north and northeast (Wongrat, 1999). There are only a few reports from inland water especially in Southern, Thailand.

Algae belong to a highly diverse group of photoautotrophic organisms with chlorophyll a and unicellular reproductive structures, which are important for aquatic habitats. Based on the taxonomic schemes of the numbers of algal divisions, they ranged from 4 to 13 with as many as 24 classes and about 26,000 species (Bold and Wynne, 1985). The checklist of algae in Thailand, compiled from 53 publications, lists 161 genera, 1,001 species, 287 varieties and 63 forms (Wongrat, 1999).

The phytoplankton in a reservoir is an important biological indicator of the water quality. While phytoplankton are important primary producers and the basis of the food chain in open water, some species on the other hand can be harmful to human and other vertebrates by releasing toxic substances (hepatotoxins or neurotoxins etc.) into the water. Proliferation of harmful organisms, particularly species should be monitored. Phytoplankton studies and monitoring are useful for control of the physico-chemical and biological conditions of the water in any irrigation project. Therefore certain groups of phytoplankton, especially blue green algae, can degraded recreational value of surface water, particularly thick surface scum, which reduces the use of amenities for contact sports, or large concentrations, which cause deoxygenation of the water leading to fish death (Whitton and Patts, 2000). Over the last few decades, there has been much interest in the processes influencing the development of phytoplankton communities, primarily in relation to physico-chemical factors (Akbay *et al.*, 1999; Peerapornpisal *et al.*, 1999; Elliott *et al.*, 2002).

The algae co-occur even though each species has a specific niche based on its physiological requirements and the constraints of the environment. These are many detailed descriptions of phytoplankton succession being correlated with changes in environmental parameters particularly temperature, light, nutrients availability and mortality factors such as grazing and parasitism. Because the variation of phytoplankton succession is strongly linked to meteorological and water stratification mixing processes, patterns in temperate ecosystems differ considerably from those of tropical waters (Wetzel, 2001). The dynamics of phytoplankton are a function of many of the some environmental processes that affect species diversity. For example, the onset of the spring bloom in dimitic lakes is controlled by the relief of light limitation at a time when nutrient concentrations are high and growth abundance is low (Roelke and Buyukates, 2002). The abundance of algae of different kinds is rather closely associated with restricted seasonal periodicity, differing of course in widely separated geographical locations (Smith, 1951). Within reservoirs, the irregular dynamics of inflow and variable flushing rates markedly alter environmental conditions for biotic communities. A reservoir can be viewed as a very dynamic lake in which a significant portion of its volume possesses characteristics of, and functions biologically as,a river (Wetzel, 2001).

The study area was the Banglang Reservoir (BR), a man-made reservoir located at 6º 09' 12.83"N and 101º 16' 32.91"E, in the Ban-Nangstar District, Yala Province, Southern Thailand (Figure 1). It was constructed in 1981 to irrigate agricultural land in Yala and Pattani Provinces, with a storage volume of 1,404 million-$m^3$ and a rockfill dam height of 85 m. In addition, the reservoir is used for fishery and recreational activities. Since the reservoir is situated in the Indochina peninsula belt with northwest monsoon, so there is a long rainy season (8 months) between May to February and short summer phase (4 months) between February to May (Climatology Division, 1989).

The main objectives of the research were to determine phytoplankton diversity and water quality in the Banglang Reservoir (BR), and to study the effects of physico-chemical parameters on phytoplankton density.

## Materials and Methods

Samples were collected monthly from May, 2000 to April, 2001 at three stations in the BR; station 1 in the transition zone (TZ), station 2 in the lacustrine zone (LZ), and station 3 in the outflow zone (OZ) at the depths 0 m (referred to as the surface water sample), 10 and 30 m. The transition zone located between riverine and lacustrine zone, receives water from the riverine zone and has a low water velocities; turbidity in general is low with a high sedimentation. The lacustrine zone is the region above the dam with characteristics similar to natural lakes with regard

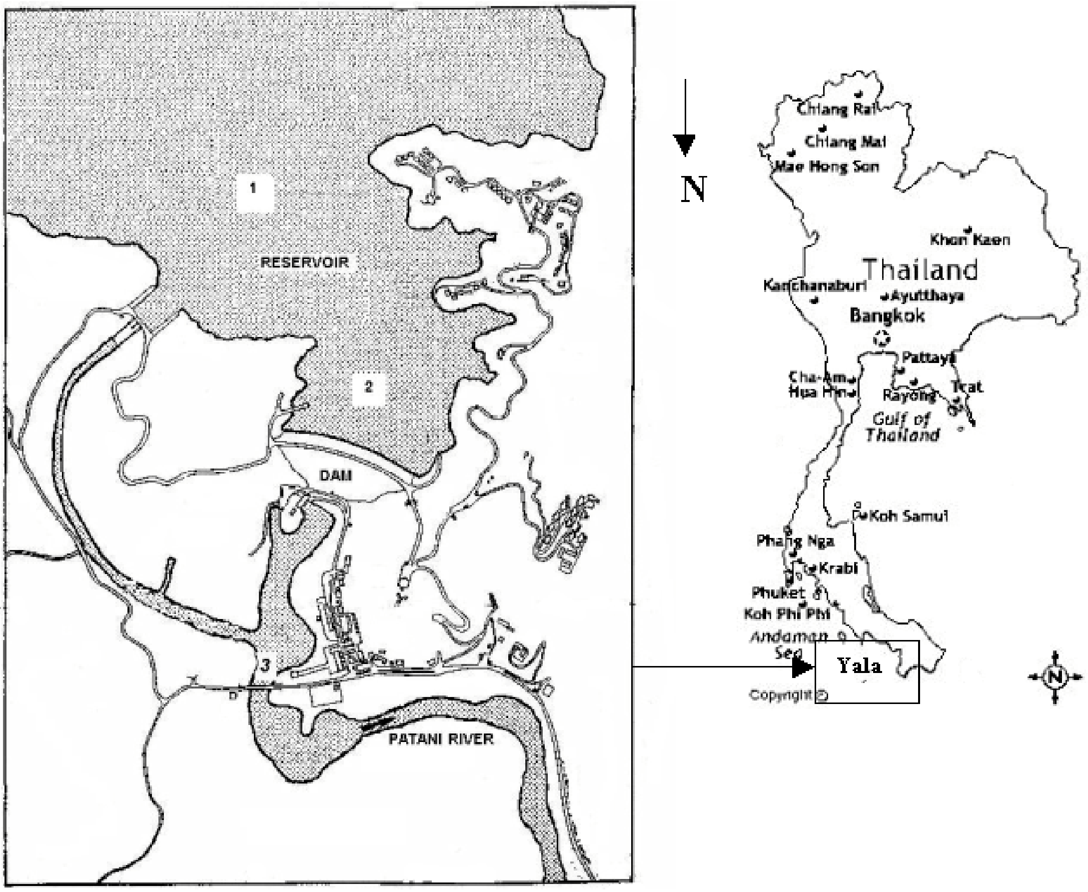


**Figure 1. Location of the Banglang reservoir and sampling stations**
**1. transition zone 2. lacustrine zone 3. outflow zone**

to planktonic production, limitations by nutrients, sedimentation of organic matter, and decomposition in the hypolimnion. At the outflow zone, samples were collected only at the surface, because the depth was less than 10 m throughout the year.

At each station, pH was measured with a Denver model 15, water temperature (wt.t) by a mercury-in-glass thermometer (INDEX model ID1090), and water transparency by a Secchi disc. Water samples were then collected using a 1-liter Ruttner water sampler for chemical and phytoplankton analysis. As to the laboratory analysis, the conductivity was measured with a model LF 3000, turbidity with a HACH model 2100AN, alkalinity (Akal) by titration with sulfuric acid using methyl orange as an indicator. Dissolved oxygen (DO) was measured using the Azide modification method by titration. For nutrient analysis; the nitrite nitrogen ($NO_2$) was measured by a calorimetric method using sulfanilamide, nitrate nitrogen ($NO_3$) by the cadmium reduction method, ammonium nitrogen ($NH_3$) by the phenate method, soluble reactive phosphorus ($PO_4$) and total phosphorus (TP) by the ascorbic acid method (APHA and WAAS, 1992).

Samples for phytoplankton counting and identification were immediately fixed with Lugol's solution and stored in dark glass bottles. Phytoplankton was condensed by settling 100 ml of water sample in an Utermöhl chamber and enumerated (3 replications) using the inverted microscope technique (Utermöhl, 1958). The text books of Desikachary (1959), Prescott (1973), John *et al*. (2002), Smith (1951), Withford and Schumacher (1969) were used to identified phytoplankton species.

The diversity of phytoplankton in BR was expressed both as the number of species and the number of individuals (cells.$m^{-3}$). The abundance of species was estimated by number of individuals and was calculated using Simpson's index (Margalef, 1978).

**Statistical analysis**

The computer statistical package was used to calculate the correlation coefficient between phytoplankton density and physico-chemical factors. Principal Components Analysis (PCA) in the Multivariate Statistical Package (MVSP) was used to identify the dominant species in each area. The large axis (the axis with the greatest variance) is the first PCA axis, the second longest axis perpendicular to the first is the second PCA axis, and so forth. Thus these first few PCA axes represent the greatest amount of variation in the data set and contain significant patterns. The PC-ORD program by MJM Software Design was used for performing multivariate analysis of ecological data by Canonical Correspondence Analysis (CCA) was conducted to detect patterns of species distribution related to physical and chemical parameters. The results contain the environmental variables plotted as arrows emanating from the center of the graph along with points for the samples and taxa. The arrows representing the environmental variables indicate the direction of maximum change of that variable across the diagram. The position of the species points indicates the environmental preference of the species.

## Results

**Variation of phytoplankton diversity**

One hundred and thirty five species in the seven divisions of phytoplankton were identified from the samples at three stations and three different depths (Table 1). The relative number of species in decreasing number were Chlorophyta (50%), Cyanophyta (21%), Bacillariophyta (13%), Pyrrophyta (6%), Cryptophyta (4%), Chrysophyta (3%) and Euglenophyta (3%). Phytoplankton diversity was mostly high near the surface. The highest number of species (52) occurred in July at 10 m at LZ. The most diverse genus was *Staurastrum* (15 species). The phytoplankton density ranged from zero to $2.1 \times 10^9$ cells.$m^{-3}$ during the study period. The density at OZ was lower than as TZ and LZ. Phytoplankton density mostly exhibited high abundance at the surface (Figure 2). However, the maximum phytoplankton density appeared at 30 m in January (2001) at LZ with *Microcystis aeruginosa* as a dominant species with high concentration of nutrients ($NO_3$ and TP). At the surface of TZ, it was found that *Melosira varians* was the predominant species in May (2000) coinciding with high DO and low turbidity. At OZ, *Botryococcus braunii* was recorded in March (2001) with the high concentration of nutrient (TP, $NO_3$ and $NH_3$), high conductivity and alkalinity. Phytoplankton diversity and species indexes are shown in Table 2. The highest number of species was observed at the surface at LZ and lowest at OZ. The phytoplankton species index was highest at 10 m at TZ and lowest at 30 m at LZ.

The abundance of phytoplankton was described with PCA axes. PCA axes 1 and 2 explained 67% of the variance in the species cell count biplot in the surface of TZ, 67% at LZ, and 54% at OZ. It was found that *Cyclotella meneghiniana* and *Melosira varians* were the most abundant species (Figure 3).

**Physico-chemical factors**

The physico-chemical factors and their values that affect the succession of phytoplankton in the study area are presented in Table 2. DO and water temperature were highest at the surface and decreased with greater depth. Conductivity and alkalinity values slightly differed among stations and depths all year round. Average pH value was between 6.7 to 7.2. The highest turbidity value was found at 30 m (61.50 NTU) at LZ and lowest at the surface (3.91 NTU) at LZ.

Nitrite, nitrate and ammonia gradually

**Table 1. List of phytoplankton species in the Banglang Reservoir from May 2000 to April 2001.**

| Division | Taxa | Taxon code | Division | Taxa | Taxon codl |
|---|---|---|---|---|---|
| Cyanophyta | *Anabaena catenula* | Aca | Chlorophyta | *Ankistrodesmus braunii* | Abr |
| | *Anacystis rupestris* | Aru | | *Ankistrodesmus convolutus* | Aco |
| | *Aphanocapsa delicatissima* | Ade | | *Ankistrodesmus falcatus* | Afa |
| | *Aphanocapsa elachista* | Ael | | *Ankistrodesmus spiralis* | Asi |
| | *Aphanocapsa pulchra* | Apu | | *Arthodesmus convergens* | Acn |
| | *Chroococcus dispersus* | Cdi | | *Asteriococcus superbus* | Asu |
| | *Chroococcus minutus* | Cmi | | *Botryococcus braunii* | Bbr |
| | *Chroococcus turgidus* | Ctu | | *Chlorangium stentornum* | Cst |
| | *Chroococcus varius* | Cva | | *Chlorella vulgaris* | Cvu |
| | *Dactylococopsis acicularis* | Dac | | *Chlorococcum infusionum* | Cin |
| | *Glaucocystis nostochinearum* | Gno | | *Closteriopsis longisima* | Clo |
| | *Gloeocapsa aeruginosa* | Gae | | *Closterium acutum* | Cau |
| | *Gloeocapsa conglomerata* | Gco | | *Closterium parvulum* | Cpr |
| | *Gloeocapsa punctata* | Gpu | | *Cosmarium moniliforme* | Cmo |
| | *Gloethece concluens* | Gcn | | *Cosmarium contractum* | Ceo |
| | *Gloethece rupestris* | Gru | | *Cosmarium notabile* | Cno |
| | *Gomphosphaeria aponina* | Gap | | *Cosmocladium constrictum* | Ccn |
| | *Gomphosphaeria lacustris* | Gla | | *Crucigenia irrigularis* | Cir |
| | *Lyngbya nana* | Lna | | *Cruciginia quadrata* | Cqu |
| | *Merimopedia glauca* | Mgl | | *Dictyosphaerium granulatum* | Dgr |
| | *Merimopedia glaucaforma* | Mga | | *Euastrum eIegans* | Eel |
| | *Microcystis aeruginosa* | Mae | | *Eudrorina elegans* | Eee |
| | *Microcystis firma* | Mfi | | *Elakatothrix gelatinosa* | Ege |
| | *Oscillatoria minnesotensis* | Omi | | *GoIenkinia radiata* | Gra |
| | *Phormidium angustissmum* | Pan | | *Golenkiniopsis solitaria* | Gso |
| | *Schizothrix lardacea* | Sla | | *Kirchneriella danubiana* | Kda |
| | *Thiothrix nivea* | Tni | | *Kirchneriella obesa* | Kob |
| | *Trichodesmium laucustre* | Tla | | *Kirchneriella subcapitata* | Ksu |
| Cryptophyta | *Chilomonas paramacium* | Cpa | | *Kirchneriella subsolitaria* | KIu |
| | *Chroomonas acuta* | Cac | | *Monoraphidium dybowskii* | Mdy |
| | *Chrysocapsa paludosa* | Cpa | | *Monoraphidium falcatus* | Mfa |
| | *Cryptomonas spendiada* | Csp | | *Monoraphidium lunalatum* | MIu |
| | *Rhodomonas costata* | Rco | | *Monoraphidium nanum* | Mna |
| | *Rhodomonas lacustris* | Rla | | *Nephrocytium lunatum* | Nlu |
| Pyrrophyta | *Ceratium hirundinella* | Chi | | *Oocystis borgei* | Obo |
| | *Cystodinium Cornifax* | Ccr | | *Oocystis marssonii* | Oma |
| | *Cystodinium iners* | Cie | | *Oocystis parva* | Opa |
| | *Peridinium aciculiferum* | Pac | | *Oocystis rupestris* | Oru |
| | *Peridinium inconspicuum* | Pin | | *Pandorina morum* | Pmo |
| | *Peridinium limbatum* | Pli | | *Planktosphaeria gelatinosa* | Pge |
| | *Peridinium pusiIum* | Ppu | | *Pseudoquadrigula* sp. | Psp |
| | *Peridinium wiscosinense* | Pwi | | *Scenedesmus acunae* | Sac |
| Chrysophyta | *Dinobryon cylindricum* | Dcy | | *Scenedesmus acutus* | Sau |
| | *Dinobryon sertularia* | Dse | | *Scenedesmus bijuga* | Sbi |
| | *Harpochytrium tenuissimum* | Hte | | *Scenedesmus incrassatulus* | Sin |
| | *Mallomonas splenens* | Msp | | *Siderocystopsis fusca* | Sfu |
| Bacillariophyta | *Achnanthes* sp. | Asp | | *Spondylosium panduriforme* | Spa |
| | *Cyclotella meneghniana* | Cme | | *Staurastrum bibrachiatum* | Sbb |
| | *Cymbella affinis* | Caf | | *Staurastrum cerastes* | Sce |
| | *Fragilaria capucina* | Fca | | *Staurastrum cingulum* | Sci |
| | *Gomphonema truncatum* | Gtr | | *Staurastrum connatus* | Sco |
| | *Melosira varians* | Mva | | *Staurastrum dilatatum* | Sdi |
| | *Navicula incertata* | Nia | | *Staurastrum freemanii* | Sfr |
| | *Navicula lanceolata* | Nla | | *Staurastrum gracile* | Sgr |
| | *Navicula* sp. | Nsp | | *Staurastrum javanicum* | Sja |
| | *Nitzschia diselpata* | Ndi | | *Staurastrum manfeldtii* | Sma |
| | *Nitzschia frustulum* | Nfr | | *Staurastrum muticum* | Smu |
| | *Pinnularia* sp. | Pse | | *Staurastrum pentacerum* | Spe |
| | *Pinnularia subcapitata* | Psu | | *Staurastrum punctulatum* | Spu |
| | *Rhizozolenia setigera* | Rse | | *Staurastrum sexagulare* | Sse |
| | *Rhopalodia* sp. | Rsp | | *Staurastrum smihii* | Ssm |
| | *Synedra famelica* | Sfa | | *Staurastrum tetracerum* | Ste |
| | *Tabellaria flocculosa* | Tfl | | *Staurodesmus megacanthus* | Sme |
| Euglenophyta | *Euglena sanguinea* | Esa | | *Stigeoclonium flagelliferum* | Sfl |
| | *Phacus longicauda* | Plo | | *Tetradesmus crocini* | Ter |
| | *Trachelomonas volvocina* | Tvo | | *Tetraedron caudatum* | Tca |
| | *Trachelomonas volvocinopsis* | Tvl | | *Tetraedron gracile* | Tgr |
| | | | | *Xanthidium antilopaeum* | Xan |
| | | | Total | 135 species | |

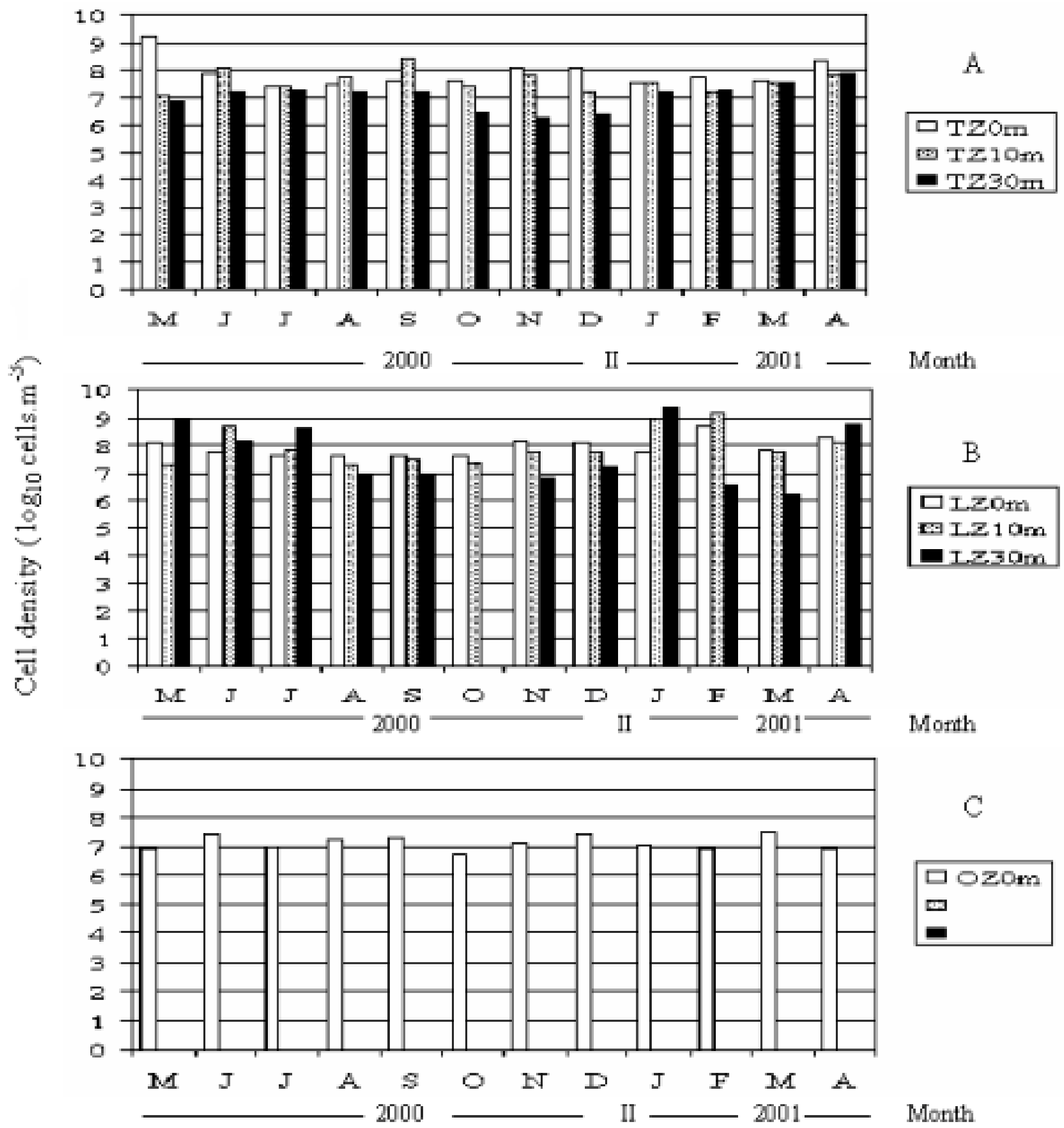


**Figure 2. Vertical profile of phytoplankton density in the Banglang Reservoir from May 2000 to April 2001. A: transition zone, TZ; B: lacustrine zone, LZ; C: outflow zone, OZ.**

increased with depth. Maximum nitrite was found at 30 m at TZ and was below threshold at the surface at TZ and at LZ. The highest values of nitrate and ammonia were recorded at OZ and lowest at the surface at TZ.

Water transparency values ranged from 0.90 to 3.5 m with the highest depth at LZ and lowest at OZ (Table 2). According to average water transparency and average total phosphorus concentrations, BR can be classified as an oligo-mesotrophic reservoir (Lorraine and Vollenweider, 1981).

To view the environmental factors as water profiles, four important factors, DO, water temperature, nitrate and soluble reactive phosphorus were selected (Figure 4). DO and water temperature decreased from the surface to the 30 m depth,

**Table 2. Average physico-chemical data and Simpson's diversity index at the Banglang Reservoir.**

| Variables | Stations | | | | | | |
|---|---|---|---|---|---|---|---|
| | Transition zone | | | Lacustrine zone | | | Outflow zone |
| | 0 m | 10 m | 30 m | 0 m | 10 m | 30 m | 0 m |
| Dissolved Oxygen ($mg.l^{-1}$) | 7.1±0.9 | 2.9±1.7 | 1.8±0.9 | 6.9±1.0 | 2.9±1.9 | 1.6±0.8 | 2.5±1.3 |
| Conductivity ($uhos.cm^{-1}$) | 45.83+8.16 | 51.17+9.56 | 45.92+7.14 | 47.83+8.80 | 51+10.57 | 43.75+9.23 | 50.5+9.61 |
| pH | 7.2±0.3 | 7.0±0.2 | 6.7±0.2 | 7.2±0.3 | 7.1±0.2 | 6.8±0.2 | 6.7±0.3 |
| Alkalinity ($mg.l^{-1}$) | 27±4.2 | 30±6.7 | 26±6.1 | 29±6.5 | 30±6.1 | 25±6.2 | 28±5.8 |
| Water transparency (m) | | 3.4±0.7 | | | 3.5±0.8 | | 0.9±0.4 |
| Turbidity (NTU) | 4.18±6.2 | 8.45±13.41 | 61.50±100.65 | 3.91±5.40 | 26.45±70.47 | 65.24±89.08 | 60±90.92 |
| Water Temperature (ºC) | 30.18+0.96 | 28.63+0.90 | 26.98+0.88 | 29.88+0.92 | 28.64+0.94 | 26.15+2.96 | 27.58+2.08 |
| Nitrite ($mgl^{-1}$) | un-detect | 0.002±0.005 | 0.016±0.018 | un-detect | 0.000±0.003 | 0.015±0.018 | 0.013±0.013 |
| Nitrate ($mgl^{-1}$) | 0.03±0.05 | 0.09±0.08 | 0.14±0.20 | 0.02±0.02 | 0.05±.06 | 0.17±0.21 | 0.20±0.43 |
| Ammonia($mgl^{-1}$) | 0.028±0.045 | 0.030±0.047 | 0.082±0.080 | 0.041±0.059 | 0.0483±0.060 | 0.048±0.060 | 0.089±0.096 |
| Soluble reactive-P ($mgl^{-1}$) | 0.012±0.013 | 0.011±0.010 | 0.023±0.015 | 0.078±0.231 | 0.011±0.011 | 0.020±0.013 | 0.017±0.013 |
| Total phosphorus ($mgl^{-1}$) | 0.477±1.303 | 0.488±1.238 | 1.079±2.379 | 0.640±1.098 | 0.537±1.036 | 0.880±1.603 | 1.068±2.446 |
| Number of species | 37±5 | 28±8 | 13±10 | 38±11 | 36±10 | 12±9 | 8±4 |
| Phytoplankton density (cells.$m^{-3}$) | 210x$10^6$ | 58x$10^6$ | 17x$10^6$ | 116x$10^6$ | 261x$10^6$ | 347x$10^6$ | 14x$10^6$ |
| Simpson's index | 0.71±0.26 | 0.73±0.20 | 0.56±0.18 | 0.72±0.25 | 0.56±0.33 | 0.35±0.32 | 0.47±0.26 |

whereas nitrate increase proportionally. The soluble reactive phosphorus ($PO_4$) concentration at TZ was low and changed only slightly within the profile but was fairly high at the surface in LZ.

### The relationships between phytoplankton and some physico-chemical parameters

Statistical relationships between the composition of phytoplankton and the physico-chemical environment variables in the surface water at the stations were explored (Figure5). The PC-ORD program designed to calculate multivariate analysis of ecological data by CCA used to detect patterns of species distribution in relation to physical and chemical parameters. Twenty dominant species computed from PCA were selected for analysis by CCA. The factors correlating with the composition of phytoplankton were DO, alkalinity, water temperature, water transparency, nutrients and conductivity.

For the surface of TZ, CCA axes 1 and 2 explained 72% of the variance in the species environment biplot (Figure 5A). $PO_4$ was the most important variable in the data set. Because axis 1 represented mainly the $PO_4$ gradient, taxa that commonly occur in high $PO_4$ waters (also high transparency and $NH_4$) were positioned on the left, whereas taxa found in low $PO_4$ water also dominated by water transparency and nutriens ($PO_4$ and $NH_3$), species that have large contributions to water transparency and nutrients ($PO_4$ and $NH_3$), values (e.g. *Lyngbya nana*) were positioned on the left, whereas those with lower contributions lay to the right (Figure 5A). Species from high oxygen environments (e.g. *Cosmarium moniliforme*) were on the lower right. The distribution of taxa along axis 2 reflected their occurrence at TP, alkalinity and $NO_3$. Consequency, species such as *Dactylococopsis acicularis* dominated at positions with high TP, low alkalinity and low $NO_3$).

For the surface of the LZ, CCA axes 1 and 2 explained 69.5% of the variance in the species environment biplot (Figure 5B). Water transparency was the most important variable in the surface of LZ. Because axis 1 was dominated by water transparency and $NH_3$, species that have large contributions to water transparency and $NH_3$ values (e.g. *Lyngbya nana*) were positioned on the left, whereas those with lower contributions lied to the right (Figure 5B). Species from high conductivity

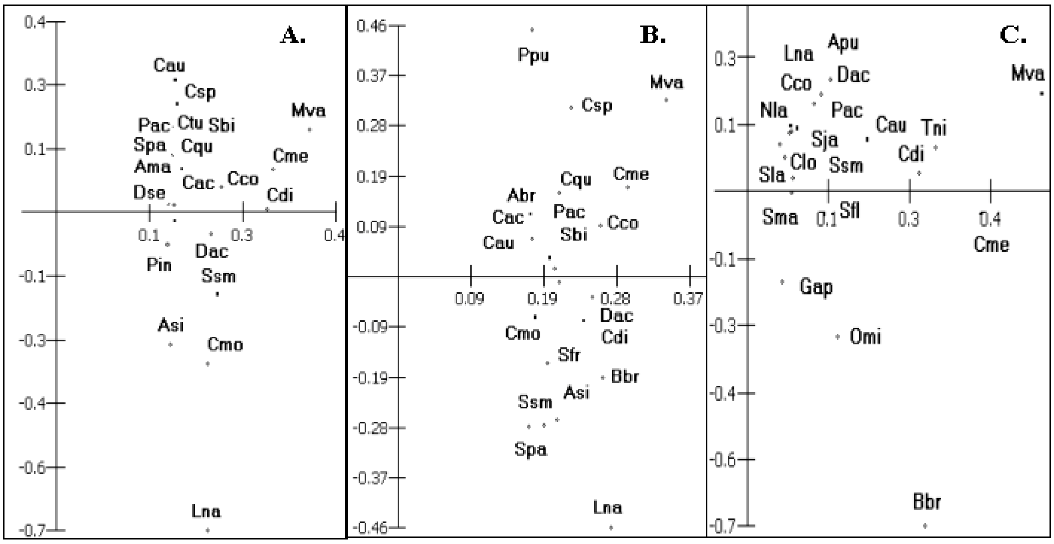


**Figure 3. PCA of phytoplankton species cell count in the Banglang Reservoir from May 2000 to April 2001. (The first 20 dominant species were counted) (A = transition zone, B = lacustrine zone, C = outflow zone)**

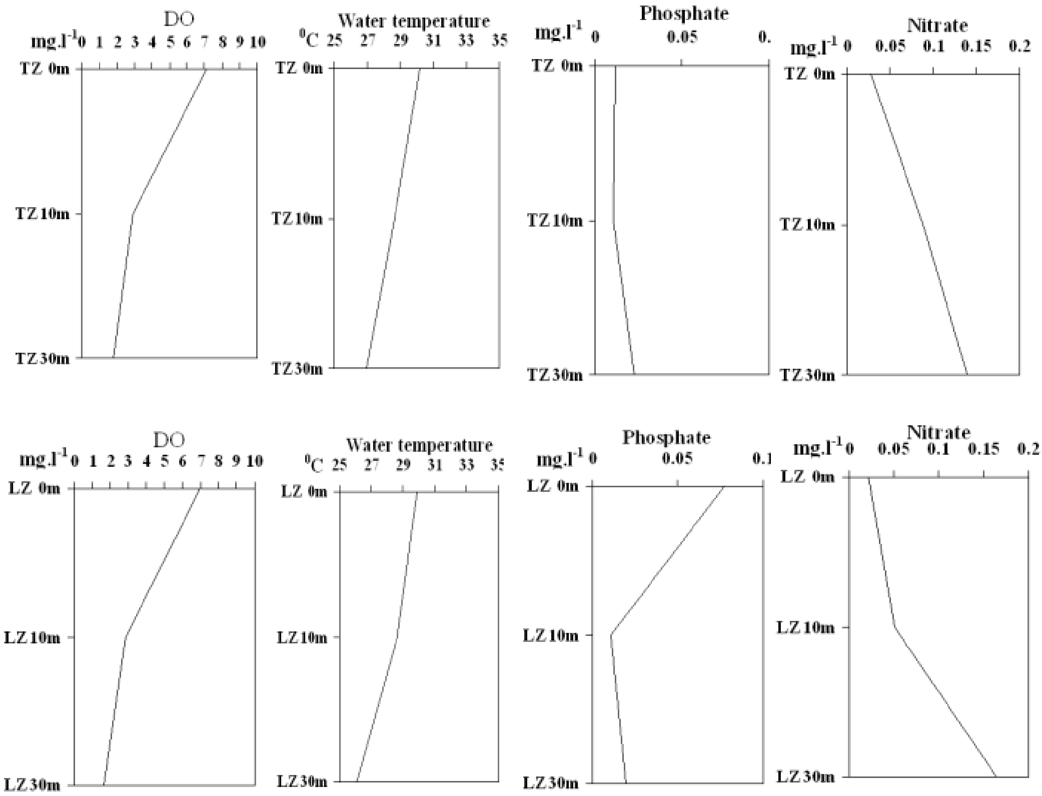


**Figure 4. Profiles of average physico-chemical factors at transition zone (top row) and lacustrine zone (bottom row) in Banglang Reservoir from May 2000 to April 2001.**

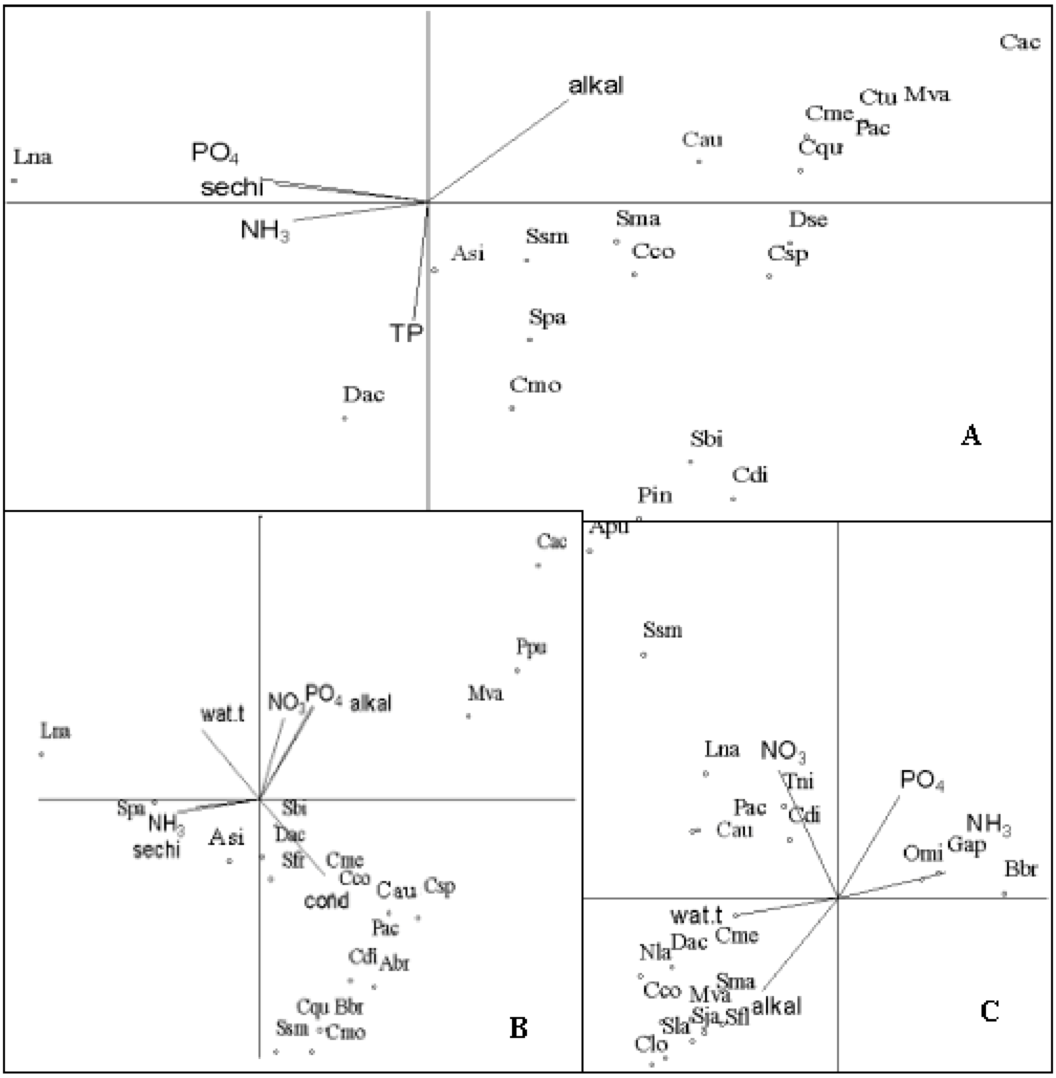


**Figure 5. CCA of phytoplankton species cell count and physico-chemical parameters in surface water at Banglang Reservoir from May 2000 to April 2001. (The first 20 dominant species in each station only selected) (A = transition zone, B = lacustrine zone, C = outflow zone)**

environments (e.g. *Closterium acutum, Crytomonas spendiada, Cyclotella meneghiniana*) were on the lower right. The distribution of taxa along axis 2 reflected their occurrence at $NO_3$, $PO_4$ and alkalinity. Consequently, species such as *Melosira varians* and *Peridinium pusilum* dominated at positions with high $NO_3$, $PO_4$ and alkalinity.

For the surface of the OZ, CCA axis 1 and 2 explained 47% of the variance in the species environment biplot (Figure 5C). $NO_3$ was the most important variable in the surface of OZ. Because axis 1 was dominated by water temperature and $NH_3$, species that thrive in water with a somewhat lower temperature and high $NH_3$ values as *Botryococcus braunii, Gomphosphaeria aponina* and *Oscillatoria minnesotensis* were positioned on the right, whereas those with lower contributions lay to the left (Figure 5C). Species that prefer high alkalinity environment (e.g. *Melosira varians*) were the lower left. The distribution of taxa along axis 2 reflects their relation to $NO_3$. Consequently, species such as *Lyngbya nana* dominated at positions with high $NO_3$ and low alkalinity.

## Discussion

The aim of the present investigation was to investigate species diversity and abundance of phytoplankton and its relationships to physico-chemical factors that affect the phytoplankton succession. In the case of the Banglang Reservoir (BR), nutrient levels in the reservoir were low to medium (oligo-mesotrophic status) and the species diversity high. A total of 135 species belonging to seven divisions was found. *Microcystis aeruginosa* reached the maximum density. *Staurastrum* was the most diverse genus, consisting of 15 species, similar to the findings in tropical Sri Lankan reservoirs, in which the same genus was recorded with 23 species (Rott and Lenzenweger, 1994). Phytoplankton in BR exhibited higher species diversity than that reported in 1985 (13 species) (Chookajorn, 1985). This might be due to the difference in sampling method. In Mae Kuang Udomtara reservoir, situated in northern Thailand; 122 species were recorded, with *Microcystis aeruginosa* as the predominant species (Peerapornpisal *et al*., 1999). One hundred and five species were found in Ratchaprapa reservoir in southern Thailand, where *Peridinium, Chroococcus* and *Trachelomonas* were the dominant species (Suravit, 1996). However, the dominant species differ between sites and depths. Generally, different planktonic species can tolerate different ranges of temperature as well as having light and nutrient limitations. These tolerance levels determine the dominance of species at different times and seasons (Fogg, 1975). In a multi-species algal community, the growth among different species is likely to be limited by the resources, including different nutrients (Wetzel, 2001).

The phytoplankton in BR were distributed thoughout the water column (from the surface down to 30 m depth), although the water transparency was less than 6 m. In fact, the Secchi depth is one third of the euphotic zone (Goldman and Horne, 1994) and some groups of phytoplankton can change their positions within their environment in a variety of ways. Some species of Cyanophyta can adapt by using intracellular structures known as gas vesicles or gas vacuoles, and some groups can move by using specific organelles such as flagella (Graham and Wilcox, 2000). *Microcystis aeruginosa* can used gas vacuoles to vertical moving. That was the results of the *Microcystis aeruginosa* occurred at 30 m.

Certain physico-chemical factors do affect the quality and the phytoplankton succession. In a period of high turbidity, especially in the outflow zone, the nutrient concentration increased, but the water transparency decreased. It was found that the phytoplankton density was then low ($14x10^6$ cells. $m^{-3}$). Thus, light is an important factor for phytoplankton growth through photosynthesis, in which light energy is used to transform inorganic molecules into organic matter (Graham and Wilcox, 2000). This investigation did not detect any problems from phytoplankton blooms, although the authors were looking for any sign of toxic algae such as *Microcystis aeruginosa*. This indicates that BR is a highly dynamic reservoir. Normally, the riverine portion of reservoirs operates analogously to large and turbid rivers, in which turbulence, sediment instability, high turbidity, reduced light availability, and other characteristics preclude extensive photosynthesis, despite high nutrient availability (Wetzel, 2001). In BR, the high concentration of total phosphorus, high turbidity and low water transparency was low, these results were not suitable conditions for phytoplankton growth. In this respect the situation was similar to that in Hartbeesport Dam in South Africa, in which a low phytoplankton density was occurred, while the nutrient level was high, and coincided with the high solar radiation, temperature and turbulence (Hambright and Zohary, 2000).

As to the water profile, physico-chemical factors at TZ were similar to those at LZ, except for phosphate at the surface at LZ. It was found that at TZ a high concentration of phosphate was recorded (0.81 mg.$l^{-1}$) in May. During that month, detergent (consisting of phosphate) was used for dried rubber sheets washing near the LZ station.

The BR is strongly influenced by North-East monsoon and the humid and the cool temperature from the nearby Bala-Hala forest, which brings heavy rain throughout the year. BR receives a large water volume of 862 to 1,364 million $m^3$ a year, thus rather more than the other reservoirs, which had a low level in the dry season. Therefore, the physico-chemical values were slightly different at the same levels. The abundance of phytoplankton in the reservoir was used as indicator of water quality. BR could be classified as oligo-mesotrophic. Moreover, it is noted that diatoms are good indicators of water quality (Odum, 1971). It was found that *Cyclotella meneghiniana* and *Melosira varians* might be used as bioindicators of the oligo-mesotrophic status in BR. The factors affecting the phytoplankton species resulting from the CCA ordination (PCORD program) were alkalinity, water temperature, water transparency, nutrients and conductivity. The effect of alkalinity on phytoplankton species succession was obvious clearly in May and January. Comparising with other reservoirs, the status of BR water is similar to the Keban Dam Reservoir in Turkey (Akbay *et al*., 1999) and Huay-Mae-Yen Reservoir in Thailand (Wannasai, 2000). The water quality of these reservoir differed from that of Mae Kung Udomtara in Northern Thailand, which was classified as meso-eutrophic, where *Microcystis aeruginosa* Kützing. was the dominant phytoplankton (Peerapornpisal *et al*., 1999; Bronco and Senna, 1994).

According to the standard of the National Environment Committee Announcement (Ministry of Science and Technology, 1994), the water quality in the reservoir could be placed into the second to third level, and thus the water can be consumed after being properly treated. The BR water quality showed that nutrient levels in the reservoir were low to medium. Thus the water quality of BR was classified as oligo-mesotrophic and *Cyclotella meneghiniana* and *Melosira varians* could be used as the phytoplankton indicator in the BR.

## Acknowledgements

The Graduate School, Prince of Songkla University and Surat Thani Rajabhat University, financially supported this research. We would like to thank the Banglang Dam Office, for position of a support boat during collection of the samples; Asst. Prof. Dr.Chutima Tantikitti, Department of Aquatic Science, Faculty of Natural Resources, and Prof. Ir. Sikke A. Hempenius, Dept. of Physics. Faculty of Science, for correcting the manuscript.

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