JFHB Journal of Food Health and Bioenvironmental Science

Journal of Food Health and Bioenvironmental Science

Journal homepage : http://jfhb.dusit.ac.th/

Phytoplankton Composition and Water Quality of Kwan Phayao Reservoir, Thailand, during Rainy and Cold Dry Seasons

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Article info

Article history:
Received 18 July 2018
Revised 26 August 2018
Accepted 31 August 2018

Keywords:
Kwan Phayao Reservoir, Biodiversity, Species Composition, Tropical Shallow Lake

Abstract

This research investigates the phytoplankton composition and water quality of Kwan Phayao Reservoir, Thailand, during rainy and cold dry seasons. From the results, 6 Divisions with 90 species of phytoplankton were observed for both seasons. Among them, Chlorophyta is the most dominant group, followed by Bacillariophyta and Cyanophyta. *Microcystis aeruginosa* is the dominant phytoplankton species in both seasons accounting for the total amount of 82.14 and 78.86% for the rainy and cold dry seasons, respectively. Shannon's diversity index (*H'*) and evenness (*J*) were 0.9 and 0.22 in the rainy season, and 1.14 and 0.30 in the cold dry season. Based on the physicochemical and biological parameters, nitrate nitrogen, phosphate, DO and BOD tended to decrease in the cold dry season. While, the conductivity and total coliform bacteria were higher in the cold dry than the rainy season. The canonical correspondence analysis (CCA) results indicate that the distribution and abundance of *Lyngbya* sp., *Spondylosium* sp., *Ankistrodesmus* sp., *Merismopedia* sp., *Crucigeniella* sp., *Cylindrocystis* sp., *Micractinium* sp., *Spirulina* sp., *Monoraphidium* sp., *Gonatozygon* sp. and *Volvox* sp. are related to the Secchi depth, water depth, pH, chlorophyll-a, air and water temperatures, DO, BOD, phosphate and nitrate in the rainy season. While, during the cold dry season, the distribution of *Strombomonas* sp., *Cyanobacterium* sp. and *Didymocystis* sp. are related to the conductivity, turbidity, ammonia nitrogen and total coliform bacteria. This research results indicate that the relationship between phytoplankton community and water quality of Kwan Phayao Reservoir are affected by climatic and seasonal changes.

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Introduction

Kwan Phayao Reservoir is a semi-natural wetland covering an area of approximately 1,980 hectares, reputed to be the 4th biggest reservoir of the country. The area of Kwan Phayao Reservoir is surrounded by agricultural land in the west and the residential and commercial sectors in the east, while its inlet and outlet are situated in the north and south direction, covering both urban and rural areas. The lake empties into the Nam Mae lng River to the east, which further empties into the Mekong River in Chiang Rai Province. It supplies water for drinking, fisheries, irrigation, tourism and the maintenance of ecological balance (Pithakpol, 2007).

Phytoplankton are the main contributors to the total primary production in aquatic ecosystem and a good indicator for nutrient-related impacts (Sathicq et al., 2017). The variation in the phytoplankton groups reflects the seasonal dynamics and the impact of water quality, and various physicochemical parameters directly play an important role as the limiting factors to phytoplankton diversity (El Gammal et al., 2017; Touliabah et al., 2010). Algal blooms are caused by a combination of factors including nutrient availability, light and temperature, all of which promote algal reproduction and density (Kudela et al., 2010). The most notable harmful algae (toxin-producing) in freshwater are cyanobacteria consisting of the genera *Microsystis, Lyngbya, Anabaena, Nodularia* and *Oscillatoria* (Paerl et al., 2001). The eutrophication in freshwater habitats can adversely affect other organisms in the food web dynamics. Eutrophication leads to dissolved oxygen depletion (hypoxia) resulting in increased incidences of fish kills especially the fish that require high levels of dissolved oxygen (Tammi et al., 1999). It also decreases the water transparency, which can inhibit the growth of submerged aquatic plants and affect other species relying on them (Balls et al., 1989).

In 2016, Kwan Phayao Reservoir experienced one of the worst droughts observed in the last 30 years, which might cause negative ecological impacts (Pinnaduang, 2016). As a result, many aquatic taxa populations could have declined and, in some reservoirs, are threatened with extinction (Bond et al., 2008). The water components such as suspended solids and some nutrients are more concentrated, causing the microbes including zooplankton and phytoplankton to be more densely populated. The composition of phytoplankton is an excellent indication of the trophic state of the water body (Reynolds, 1998). Many groups of algae, phytoplankton diatom and desmids serve as an efficient biological indicator for the water quality and environmental value. (Peerapornpisal et al., 2009; Leelahakriengkrai & Peerapornpisal, 2011; Ngearnpat & Peerapornpisal, 2007). The comparative studies on distribution of phytoplankton and water quality according to seasonal variation were investigated throughout Thailand. In Kaeng Krachan Reservoir, Phetchaburi Province, the phytoplankton biovolume in the wet season was higher than the dry season (Meesukko et al., 2007). While, in Doi Tao lake, Chiang Mai Province, the number of species and density of phytoplankton showed high seasonal variation with higher species number and density of phytoplankton in winter and summer than the rainy season (Khuantrairong & Traichaiyaporn, 2008). However, the data are very limited in Kwan Phayao Reservoir. Thus, this study investigates the phytoplankton composition and water quality of Kwan Phayao Reservoir during the rainy and cold dry seasons of 2015 before the severe drought of 2016.

Materials and methods

1. Sampling site

The sampling site is located between latitude 19°09'35.2" to 19°12'12.1" N of the Equator and longitude 99°54'52.5" to 99°52'02.5 E of Greenwich. Sampling was carried out during the rainy season starting from August to November 2015 and in the cold dry season starting from December 2015 to March 2016. Samples were collected from 5 sites of Kwan Phayao Reservoir: the inlet (Khun Dej bridge) station 1 (S1), San Wieng Mai village station 2 (S2), the middle of the reservoir station 3 (S3), Phayao water supply pumping station site 4 (S4) and the outlet (fishery research station) station 5 (S5) (Fig 1).

2. Phytoplankton samplings

Surface water samples were monthly collected from all five sampling sites at Kwan Phayao Reservoir. Phytoplankton samples were collected by filtering 20 L of water sample with a 10 µm mesh size net. The samples were fixed with Lugol's iodine solution to preserve the collected phytoplankton. Phytoplankton numeration were carried out under light microscope (objective x40) by whole count method in which 0.02 mL of sample were investigated in triplicates. Taxonomic identification was conducted with the help of standard books and monographs based on specialized taxonomic literatures. (Hirano, 1975; John et al., 2003; Peerapornpisal, 2015)

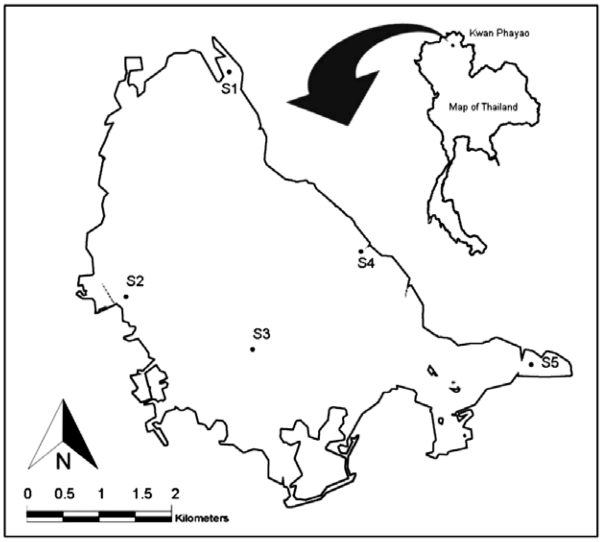

Fig. 1 Location of Kwan Phayao Reservoir and the sampling sites (S1 – S5).

3. Physicochemical analyses

Water temperature, conductivity and pH were measured in the field using portable Multi-Parameter CyberScan PCD650 (Thermo scientific, Singapore). Ammonium nitrogen (NH_3-N), nitrate nitrogen (NO_3-N) and orthophosphate-phosphorus (PO_4-P) were determined using HACH Spectrophotometer Model 890 (HACH, USA). Dissolved oxygen (DO) and biochemical oxygen demand (BOD) were analyzed in the laboratory using the standard methods (Greenberg et al., 2005).

4. Biological parameters

Total coliform bacteria were determined as the Most Probable Number (MPN) counts using the multiple tubes fermentation technique (Greenberg et al., 2005). For chlorophyll-a determination, water samples were filtered through the Whatman GF/C glass fiber filters. The chlorophyll-a was extracted with 10 mL of 90% methanol then inoculated at 70 ºC for 20 min. The extract was centrifuged at 3000 rpm for 10 min. The absorbance was measured at 630, 645, 665 and 750 nm using GENESYS 10S UV-Vis spectrophotometer (Thermo Scientific, USA) (Saijo, 1975; Wintermans & De Mots, 1965). The concentration of chlorophyll-a was calculated using the following equation:

5. Data analysis

The physicochemical and biological data were statistically analyzed using one-way analysis of variance (ANOVA). Difference between means was considered using Duncan's New Multiple Range Test (DMRT) at the significant level of 0.05. The diversity index (*H'*) and evenness (*J*) were calculated using Shannon's diversity index (Shannon & Wiener, 1949). The canonical correspondence analysis (CCA) was computed using the multivariate statistical package (MVSP) for Windows.

Results and discussion

1. Phytoplankton community

The frequency of appearance, abundance, and seasonality of phytoplankton observed in Kwan Phayao Reservoir are summarized in Table 1. Total 90 taxa of 6 algal divisions were identified, which are Bacillariophyta, Chlorophyta, Cyanophyta, Chrysophyta, Euglenophyta and Pyrrophyta. Considering the species composition, the main genera were Chlorophyta (45.6%) followed by Bacillariophyta (21.1%) and Cyanophyta (17.8%) for the total period of the study. Nevertheless, Chlorophyta was strongly and negatively affected by seasonal changes. The percentage of Chlorophyta decreased from 48.2 to 23.3 while the increase in percentage was found in the others, especially for the Euglenophyta (Fig 2). Green algae (Chlorophyta) always account for a larger species richness in reservoir because they can grow under a wide range of environmental factors. Peerapornpisal et al. (2008) demonstrated that Chlorophyta was the most dominant species collected from 30 reservoirs in the northern Thailand and the distribution of these species was mainly affected by the water quality.

The averages of Shannon's diversity index (*H'*) and evenness (*J*) were 0.90 and 0.22, respectively in the rainy season. Whereas, the higher diversity index and evenness appeared in the cold dry season with the values of 1.14 and 0.30, respectively. The highest diversity index was observed at D-S1 station and the lowest biodiversity was found at D-S4 station. Overall, the cold dry season influenced higher phytoplankton diversity index. However, according to the species richness (total number of species), it markedly demonstrated that the rainy season

$$\text{Chl-a } (\mu g/mL) = \frac{11.6(A_{665}-A_{750})-1.31(A_{645}-A_{750})-0.014\,(A_{630}-A_{750})\ (\text{The volume of methanol} \times \text{mL})}{\text{The volume of filtered water} \times \left(\dfrac{1}{\text{cuvette width}}\right)}$$

where A630, A645, A665 and A750 are the absorbance at 630, 645, 665 and 750 nm, respectively.

Table 1 Frequency of appearance, abundance of phytoplankton encountered in the different seasonality between August 2015 to March 2016. (C : common, R : rare, F : frequent, − : absent, + : present, ++ : abundant, +++ : highly abundant)

Name of species	Rainy season		Cold dry season	
	Frequency	Abundance	Frequency	Abundance
Division Bacillariophyta				
1 ***Acanthoceras*** **sp.**	C	+	R	+
2 ***Achnanthidium*** **sp.**	R	+	-	-
3 ***Amphora*** **sp.**	C	+	R	+
4 ***Aulacoseira granulata***	F	+++	F	+
5 ***Aulacoseira*** **sp.**	F	+++	F	++
6 ***Brachysira*** **sp.**	C	+	C	+
7 ***Caloneis*** **sp.**	R	+	-	-
8 ***Cyclotella*** **sp.**	C	+	C	+
9 ***Eunotia*** **sp.**	R	+	-	-
10 ***Fragilaria*** **sp.**	C	+	-	-
11 ***Frustulia*** **sp.**	R	+	R	+
12 ***Gyrosigma*** **sp.**	F	+	F	+
13 ***Neidium*** **sp.**	C	+	-	-
14 ***Pinnularia*** **sp.**	R	+	-	-
15 ***Pleuroseira*** **sp.**	C	+	-	-
16 ***Rhizosolenia*** **sp.**	R	+	-	-
17 ***Rhopalodia*** **sp.**	R	+	R	+
18 ***Surirella*** **sp.**	F	+	F	+
19 ***Synedra*** **sp.**	R	+	-	-
Division Chlorophyta				
20 ***Actinastrum*** **sp.**	R	+	R	+
21 ***Ankistrodesmus*** **sp.**	C	+	R	+
22 ***Botryococcus*** **sp.**	F	++	F	+
23 ***Carteria*** **sp.**	-	-	R	+
24 ***Chlamydomonas*** **sp.**	F	+	F	+
25 ***Chlorella*** **sp.**	F	++	F	++
26 ***Closteriopsis*** **sp.**	F	+	F	+
27 ***Closterium*** **sp.**	R	+	R	+
28 ***Coelastrum*** **sp.**	F	++	F	+
29 ***Cosmarium*** **sp.**	F	++	F	+
30 ***Crucigeniella*** **sp.**	C	+	R	+
31 ***Cylindrocystis*** **sp.**	C	+	R	+
32 ***Dictyosphaerium*** **sp.**	C	+	C	+
33 ***Didymocystis*** **sp.**	R	+	C	+
34 ***Dimorphococcus*** **sp.**	R	+	R	+
35 ***Elakatotrix*** **sp.**	C	+	C	+
36 ***Eudorina*** **sp.**	R	+	R	+
37 ***Golenkinia*** **sp.**	C	+	F	+
38 ***Gonatozygon*** **sp.**	C	+	R	+
39 ***Gonium*** **sp.**	F	++	F	+
40 ***Kirchneriella*** **sp.**	C	+	C	+
41 ***Micractinium*** **sp.**	C	+	R	+
42 ***Monoraphidium*** **sp.**	F	+	R	+
43 ***Nephrocytium*** **sp.**	C	+	C	+
44 ***Oocystis*** **sp.**	F	+	F	+
45 ***Pediastrum*** **sp.**	F	++	F	+
46 ***Rhizoclonium*** **sp.**	-	-	R	+
47 ***Scenedesmus*** **sp.**	F	+	C	+
48 ***Sirogonium*** **sp.**	R	+	-	-
49 ***Sphaerozosma*** **sp.**	R	+	-	-
50 ***Spirogyra*** **sp.**	-	-	R	+
51 ***Spondylosium*** **sp.**	C	+	R	+
52 ***Staurastrum*** **sp.**	F	++	F	+
53 ***Staurodesmus*** **sp.**	C	+	C	+
54 ***Teilingia*** **sp.**	C	+	-	-
55 ***Tetmemorus*** **sp.**	C	+	-	-
56 ***Tetraedron*** **sp.**	F	++	F	+
57 ***Tetraspora*** **sp.**	F	++	F	+
58 ***Ulothrix*** **sp.**	C	+	-	-
59 ***Volvox*** **sp.**	F	+	-	-
60 ***Zygnema*** **sp.**	R	+	-	-
Division Cyanophyta				
61 ***Anabeana*** **sp.**	F	+	F	+
62 ***Aphanocapsa*** **sp.**	C	+	-	-
63 ***Aphanothece*** **sp.**	C	+	-	-
64 ***Chroococcus*** **sp.**	F	+	C	+
65 ***Coelomoron*** **sp.**	C	+	F	+
66 ***Cyanobacterrium*** **sp.**		-	-	+
67 ***Cyanosarcina*** **sp.**	R	+	-	-
68 ***Gloeocapsa*** **sp.**	R	+	-	-
69 ***Lyngbya*** **sp.**	C	+	R	+
70 ***Merismopedia*** **sp.**	C	+	R	+
71 ***Microcystis aeruginosa***	F	+++	F	+++
72 ***Oscillatoria*** **sp.**	F	+	C	+
73 ***Phormidium*** **sp.**	R	+	R	+
74 ***Planktolyngbya*** **sp.**	F	+	C	+
75 ***Pseudanabaena*** **sp.**	C	+	C	+
76 ***Spirulina*** **sp.**	C	+	-	-
Division Chrysophyta				
77 ***Centritractus*** **sp.**	C	+	R	+
78 ***Dinobryon*** **sp.**	-	-	R	+
79 ***Isthmochloron*** **sp.**	F	+	F	+
80 ***Synura*** **sp.**	C	+	-	-
Division Euglenophyta				
81 ***Euglena*** **sp.**	F	+	F	+
82 ***Lepocinclis acus***	F	+	C	+
83 ***Lepocinclis salina***	F	+	F	+
84 ***Phacus*** **sp.**	F	+	F	+
85 ***Strombomonas*** **sp.**	R	+	F	+
86 ***Trachelomonas*** **sp.**	F	+	F	+
Division Pyrrophyta				
87 ***Ceratium*** **sp.**	F	+	F	+
88 ***Gymnodinium*** **sp.**	R	+	-	-
89 ***Peridiniopsis*** **sp.**	C	+	C	+
90 ***Peridinium*** **sp.**	F	+	F	+

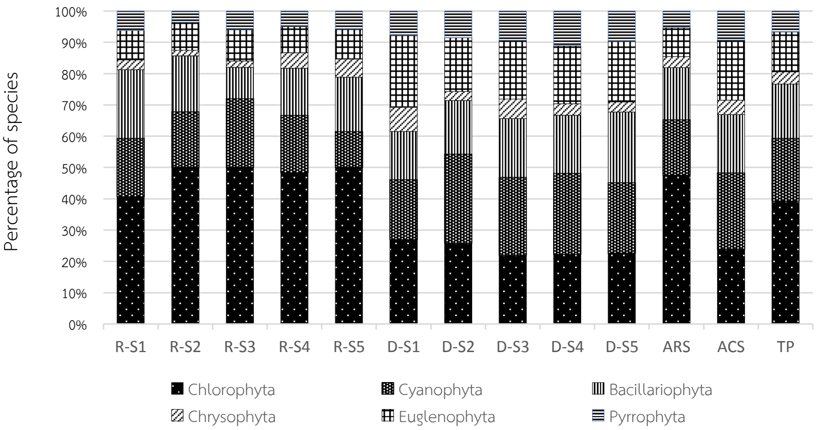

Fig. 2 Percentage of phytoplankton species of Kwan Phayao Reservoir during the rainy and cold dry seasons (R- : Rainy season, D- : Cold dry season, ARS: Average in rainy season, ACS: Average in cold dry season, TP: Average Total period of study)

Table 2 Shannon's diversity index, evenness and abundance of phytoplankton in the rainy and cold dry seasons of Kwan Phayao Reservoir.

Season	Sampling site	Diversity Index (*H'*)	Evenness (*J*)	Total number of species	Average Amount (cell.L^{-1})
Rainy	R-S1	1.03	0.25	64	453,582
	R-S2	1.00	0.25	56	1,991,203
	R-S3	0.81	0.21	50	3,125,936
	R-S4	0.83	0.20	60	6,560,341
	R-S5	0.83	0.21	52	6,861,548
	Average	0.9	0.22	56	3,798,522
Cold dry	D-S1	2.05	0.57	36	93,131
	D-S2	1.04	0.26	52	604,334
	D-S3	0.91	0.24	44	485,271
	D-S4	0.68	0.19	40	367,292
	D-S5	1.04	0.28	42	286,156
	Average	1.14	0.30	30	367,236

Table 3 Dominant species and amount of phytoplankton.

Season	No.	Dominant species	Average amount (cell.L^{-1})	%Totalamount
Rainy	1	*Microcystis aeruginosa*	3,120,150	82.14
	2	*Aulacoseira granulata*	325,271	8.56
	3	*Chlorella* sp.	72,509	1.91
	4	*Tetraspora* sp.	55,703	1.47
Cold dry	1	*Microcystis aeruginosa*	313,768	78.86
	2	*Aulacoseira* sp.	14,771	3.71
	3	*Chlorella* sp.	11,124	2.80
	4	*Gonium* sp.	8,909	2.24

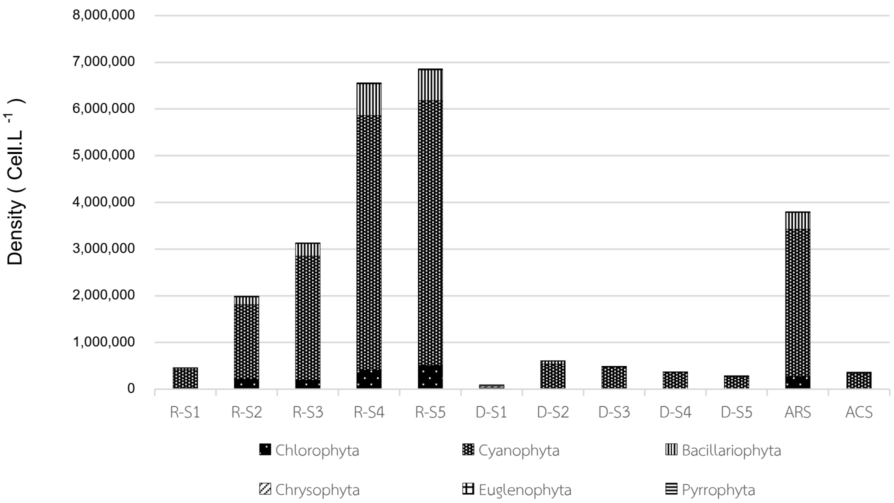

Fig. 3 Average abundance of phytoplankton in the rainy and cold dry seasons of Kwan Phayao Reservoir. (R- : Rainy season, D- : Cold dry season, ARS: Average in rainy season, ACS: Average in cold dry season)

influenced higher species richness of 56 species while only 30 species appeared in cold dry season. A similar trend was also found in the total amount of phytoplankton with the higher average number of 3,798,522 cell.L^{-1} in the rainy season. Whereas, the 10-time lower number of 367,236 cell.L^{-1} appeared in the cold dry season (Table 2, Fig 3).

In the studied rainy and cold dry seasons, the abundant phytoplankton are *Microcystis aeruginosa*, *Aulacoseira granulata, Chlorella* sp., *Tetraspora* sp. and *Gonium* sp. *M. aeruginosa* and are the principle dominant species in both seasons with the total amount of 82.14 and 78.86% for the rainy and cold dry seasons, respectively. Moreover, the amount of *M. aeruginosa* in the rainy season was 3.12 x 10^6 cell.L^{-1}, which was more than 10 times higher than that in the cold dry season. Previous reports also supported that the amount of cyanobacteria including *M. aeruginosa* was higher in the rainy season than the cold dry season (Kaewsri & Traichaiyaporn, 2012; Suwanpakdee et al., 2015). *M. aeruginosa* is widely distributed and is a common toxic cyanobacteria in tropical reservoirs. Macronutrients, such as phosphorus and nitrate nitrogen, are possibly the important controlling factors for bloom development (Harke et al., 2016). *Aulacoseira granulata, Chlorella* sp. and *Tetraspora* sp. are the 2^{nd}, 3^{rd} and 4^{th} dominant species in the rainy season with the total amount of 8.56, 1.91 and 1.47%, respectively. Similar trends were also found in the cold dry season where *Aulacoseira* sp. and *Chlorella* sp. still appeared as the 2^{nd} and the 3^{rd} dominant species (Table 3). Similarly, *A. granulata* has been reported to dominate in the highly turbid waters. During the Typhoon season in Lake Biwa, where the strong wind disturbed the bottom sediment with high concentration of nutrient, this species grew better than others (Nakano et al., 1996). In Thailand, *Aulacoseira granulata* and *Microcystis aeruginosa* were the most dominant species in several freshwater of 68 sampling sites including lakes, dams, reservoirs, ponds and ditches collected from 48 provinces (Prasertsin & Peerapornpisal, 2015). Moreover, *A. granulata* (Ehrenberg) was described as an indicative phytoplankton of the meso-eutrophic status while *M. aeruginosa* (Kützing) was dominant in the hypereutrophic status of water quality. Thus, according to our results, the presence of those species indicates that Kwan Phayao Reservoir had poor water quality during the two seasons of this study.

2. Physicochemical and biological parameters

The water temperature significantly decreased in the cold dry season, which ranged between 23.67-26.36 °C, compared with the range of 30.92-32.17 °C in the rainy season. The depth of water also strongly decreased at all 5 sampling stations. The highest water level was found at station 4 (Phayao water supply pumping station) in the rainy season with the depth of 277.88 cm and lowered to 221.33 cm in the cold dry season (Table 4). During the last month of our monitoring (March 2016), the water levels from major dams in Thailand including Kwan Phayao Reservoir were affected from the drought crisis caused by the severely dried water levels and the dry weather due to El Niño (Moottatarn, 2016)

Conductivity was directly impacted by the decrease of water level; higher conductivity values were found at all stations. A similar trend was observed between DO and BOD, which decreased in the cold dry season at all sampling stations. Mean concentrations of almost all nutrients showed no differences compared with the difference among the sampling stations and seasons, except that the concentration of ammonia nitrogen was significantly higher at station 5 (the outlet) in the cold dry season. The highest ammonia nitrogen ranged between 0.16-0.21 mg.L^{-1} at station 5 in both seasons. However, it was lower than the regulated value of Thailand's surface water quality standard (Pollution Control Department, 1994). It is interesting to note that the concentrations of both nitrate nitrogen and phosphate tend to be higher in the rainy season at all stations ($p>0.05$). These results are consistent with those obtained by Suwanpakdee et al. (2015) who found that the nutrients of phosphate, nitrate and ammonia were not significantly different among the seasons ($p>0.05$).

Considering the biological parameters, the chlorophyll-a contents were relatively lower in the cold dry season at all sampling stations. The decrease of chlorophyll-a was directly influenced by the decrease of total amount of phytoplankton. This indicates that even a small climate and seasonal change may destabilize phytoplankton dynamics in tropical lakes, thereby reducing water quality and food resources for planktivorous fish with the consequent negative impacts on human livelihoods. (Ndebele-Murisa et al., 2010). In contrast, the number of total coliform bacteria were consistently higher in the cold dry season, especially at station 5 with the significant highest number of 11,875 MPN/100 mL ($p<0.05$) (Table 4). Unfortunately, this number was above Thailand's surface water quality

Table 4 Variations in the rainy and cold dry seasons mean values of various physicochemical and biological parameters at 5 sampling stations from August 2015 to March 2016.

Parameters	Station 1		Station 2		Station 3		Station 4		Station 5	
	Season									
	Rainy	Cold dry	Rainy	Cold dry	Rainy	Cold dry	Rainy	Cold dry	Rainy	Cold dry
Physicochemical parameters										
Water temperature (°C)	**32.17 [a]**	**23.67 [c]**	**31.75 [ab]**	**25.25 [c]**	**30.92 [ab]**	**24.50 [c]**	**31.17 [ab]**	**25.25 [c]**	**31.17 [ab]**	**26.63 [bc]**
Secchi depth (cm)	**25.67 [a]**	**27.50 [a]**	**39.00 [a]**	**36.88 [a]**	**41.83 [a]**	**40.75 [a]**	**42.00 [a]**	**36.00 [a]**	**25.67 [a]**	**30.88 [a]**
Depth (cm)	**104.33 [abc]**	**87.83 [bc]**	**59.00 [bc]**	**38.60 [c]**	**180.33 [ab]**	**109.38 [abc]**	**221.33 [a]**	**124.13 [abc]**	**137.00 [abc]**	**75.75 [bc]**
Conductivity (μS.cm^{-1})	**166.33 [d]**	**200.60 [cd]**	**212.22 [c]**	**266.75 [ab]**	**230.67 [bc]**	**272.0 [a]**	**209.07 [c]**	**277.88 [a]**	**228.00 [bc]**	**278.30 [a]**
pH	**7.31 [bc]**	**6.95 [c]**	**8.51 [a]**	**8.12 [ab]**	**8.84 [a]**	**8.50 [a]**	**8.95 [a]**	**8.02 [ab]**	**8.58 [a]**	**8.06 [ab]**
Dissolved oxygen (mg.L^{-1})	**10.33 [a]**	**6.45 [a]**	**9.83 [a]**	**8.79 [a]**	**10.85 [a]**	**8.10 [a]**	**11.17 [a]**	**8.48 [a]**	**11.60 [a]**	**8.14 [a]**
BOD_5 (mg.L^{-1})	**7.92 [a]**	**3.87 [b]**	**7.13 [ab]**	**4.66 [b]**	**6.83 [ab]**	**3.89 [b]**	**9.18 [a]**	**4.68 [b]**	**8.27 [a]**	**4.56 [b]**
Turbidity (FAU)	**73.33 [a]**	**55.00 [a]**	**31.50 [a]**	**41.25 [a]**	**40.00 [a]**	**40.38 [a]**	**37.67 [a]**	**44.88 [a]**	**68.33 [a]**	**64.63 [a]**
NH_3-N (mg.L^{-1})	**0.11 [c]**	**0.10 [c]**	**0.11 [bc]**	**0.09 [c]**	**0.10 [c]**	**0.10 [c]**	**0.11 [bc]**	**0.10 [c]**	**0.16 [ab]**	**0.21 [a]**
NO_3-N (mg.L^{-1})	**0.18 [a]**	**0.10 [a]**	**0.15 [a]**	**0.14 [a]**	**0.15 [a]**	**0.10 [a]**	**0.18 [a]**	**0.16 [a]**	**0.32 [a]**	**0.19 [a]**
PO_4-P (mg.L^{-1})	**0.39 [a]**	**0.31 [a]**	**0.28 [a]**	**0.10 [a]**	**0.15 [a]**	**0.11 [a]**	**0.28 [a]**	**0.09 [a]**	**0.60 [a]**	**0.14 [a]**
Biological parameters										
Chlorophyll-a (μ.L^{-1})	**7.33 [a]**	**5.81 [a]**	**13.98 [a]**	**9.36 [a]**	**16.77 [a]**	**6.67 [a]**	**12.42 [a]**	**8.56 [a]**	**19.96 [a]**	**11.51 [a]**
Coliform bacteria (MPN/100 mL)	**191.00 [b]**	**933.33 [b]**	**125.33 [b]**	**1307.50 [b]**	**163.00 [b]**	**201.5 [b]**	**118.67 [b]**	**159.50 [b]**	**2733.33 [b]**	**11875.00 [a]**

Remark: Letter in each row with superscript following the values indicates statistical significance at p<0.05 (ANOVA and Duncan's multiple range test). Different letters indicate significant differences among sampling station

standard indicating a highly deteriorated water quality (Pollution Control Department, 1994).

3. Relationship of phytoplankton and environmental physicochemical parameters in the rainy and cold dry seasons

According to the Canonical Correspondence Analysis (CCA) results, axis 1 and axis 2 of CCA accounted for 36.03 and 19.03% of the total variance in the data set, respectively. The relationship between phytoplankton species richness and environmental factors was different in 3 scenarios, which was clearly separated by axis 1 of CCA. In Scenario 1, the right-hand side of axis 1, most of the sampling stations in the cold dry season (S1C, S3C, S4C and S5C) were closely correlated with the conductivity, turbidity, ammonia nitrogen and total coliform bacteria. Moreover, *Strombomonas* sp. *Cyanobacterium* sp. *Didymocystis* sp. were also related to those parameters (Fig 4).

The water level in the shallow lake in Brazil was reduced by half in cold dry season whereas the water turbidity, conductivity and nutrient contents increased (da Costa et al., 2016). This result is in contrast to this study, in which the water level in Kwan Phayao Reservoir decreased but low water turbidity and nutrient contents were found during the cold dry season. This higher turbidity and nutrient could result from rainfall, which brought sediment waters from the surface runoff during rainy season. Therefore, in tropical shallow lakes, phytoplankton biomass and cyanobacterial community may either increase or decrease by drought depending on the depth and nutrient concentration of water.

Whereas, the sampling stations in the rainy season were separately grouped into Scenario 2 and 3. In general, considering the left-hand side of axis 1, it can be concluded that most of the rainy season sampling stations were related to Secchi depth, water depth, pH, chlorophyll-a, air and water temperatures, DO, BOD and the phosphate and nitrate nutrients. The sampling stations of S2R and S5R in the rainy season strongly correlated with the phosphate and nitrate nutrients and water temperature. *Acanthoceras* sp., *Tetmemorus* sp., *Pleuroseira* sp. and *Teilingia* sp. were also grouped in Scenario 2. For Scenario 3, the sampling stations S3R and S4R in the rainy season was correlated with the Secchi depth and water depth. Besides, *Lyngbya* sp., *Spondylosium* sp., *Ankistrodesmus* sp., *Merismopedia* sp., *Crucigeniella* sp., *Cylindrocystis* sp., *Micractinium* sp., *Spirulina* sp., *Monoraphidium* sp., *Gonatozygon* sp. and *Volvox* sp. had a relationship with those stations and the parameters (Fig 4).

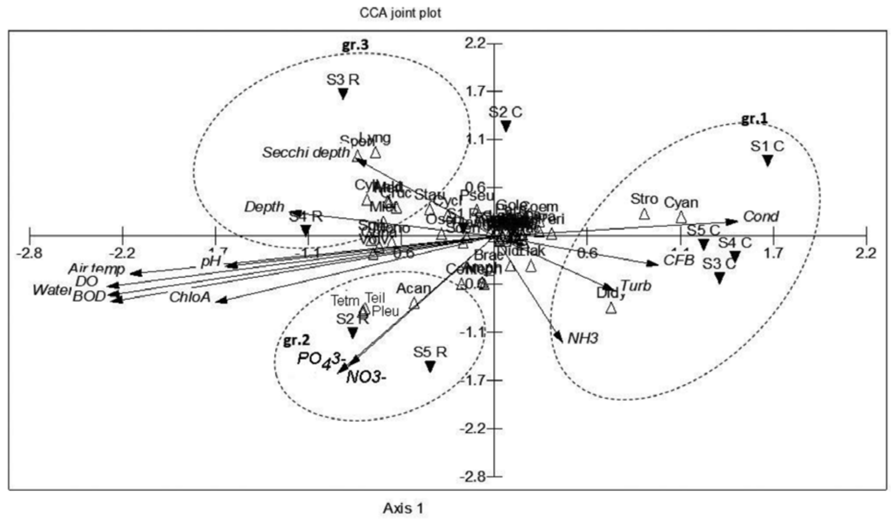

Fig. 4 Spatial ordination resulting from CCA of phytoplankton species with environmental physicochemical parameters.

According to Wehr & Sheath (2015), *Lyngbya* sp., *Spondylosium* sp., *Merismopedia* sp., *Cylindrocystis* sp., *Gonatozygon* sp. are classified as tychoplankton, which is normally classified as epiphyte. They grow in the planktonic form under the influence of water turbulence. Considering Kwan Phayao Reservoir where sunlight penetrates though to the bottom of the reservoir, these observed tychoplankton species are significantly related with S3R and S4R where the highest Secchi's depth values are recorded.

Conclusion

Ninety species of phytoplankton are classified into 6 Divisions. Chlorophyta is the most dominant group forming 45.6% of the total phytoplankton communities followed by Bacillariophyta (21.1%) and Cyanophyta (17.8%). Chlorophyta is directly affected by seasonal changes, resulting in the decreased percentage of species in the cold dry season. *Microcystis aeruginosa*, *Aulacoseira granulata* and *Chlorella* sp. are the top 3 dominant species in both seasons. *M. aeruginosa* is the principle dominant species in both seasons accounting for the total amount of 82.14 % with an average of 3,120,150 cell.L^{-1} in the rainy season and 78.86% with an average of 313,768 in cell.L^{-1} in the cold dry season, respectively. Based on Shannon's diversity index (*H'*), the highest phytoplankton diversity was found at station 1 (the inlet) in the cold dry season. In general, most of the sampling stations in the cold dry season demonstrated higher diversity than the rainy season.

Considering the physicochemical and biological parameters, the nitrate nitrogen, phosphate, DO and BOD tend to decrease in the cold dry season. While, the conductivity and total coliform bacteria are higher in the cold dry compared with the rainy season. The outlet of Kwan Phayao Reservoir (station 5) in the cold dry season reveals a very high total amount of coliform bacteria, which is related to the significantly highest content of ammonia nitrogen.

Based on the canonical correspondence analysis (CCA), it can be concluded that Secchi depth, water depth, pH, chlorophyll-a, air and water temperatures, DO, BOD, phosphate and nitrateare related to the distribution and abundance of *Lyngbya* sp., *Spondylosium* sp., *Ankistrodesmus* sp., *Merismopedia* sp., *Crucigeniella* sp., *Cylindrocystis* sp., *Micractinium* sp., *Spirulina* sp., *Monoraphidium* sp., *Gonatozygon* sp. and *Volvox* sp. in the rainy season. Whereas, the distribution of *Strombomonas* sp., *Cyanobacterium* sp. and *Didymocystis* sp. are related to conductivity, turbidity, ammonia nitrogen and total coliform bacteria in the cold dry season.

Acknowledgements

This research was financially supported by University of Phayao, Thailand. The authors would like to thank Phayao Inland Fisheries Research and Development Center for their help in water sampling.

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