Biomonitoring by phytoplankton diversity and biovolume depth profile of the Pasak Jolasid Reservoir, Lopburi Province, Thailand

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The study of the distribution of phytoplankton diversity and biovolume by depth profile was carried out by sampling water obtained from Pasak Jolasid Reservoir, Lopburi Province, Thailand. The samples were collected between November 2009 to October 2010 at 2 meters depth intervals from the surface towards the bottom area of the reservoir with maximum depth. From obtained results, 220 species from 89 genera of phytoplankton belonging to 7 phyla were observed, which were *Chlorophyta* (44.75%), *Euglenophyta* (15.98%), *Cyanophyta* (15.53%), *Bacillariophyta* (15.07%), *Chrysophyta* (4.11%), *Pyrrhophyta* (4.11%), and *Cryptophyta* (0.46%), respectively. Findings demonstrated uniform distribution of phytoplankton at the water surface but showed specific distributions at the thermocline layer. Highest biovolume was observed at the water surface, which decreased with increasing water depth. The highest phytoplankton biovolume was found to be 108,132,447 mm^3/m^3 at a water depth of 4 meters followed by 2, 0, and 6 meters, and then a steady decrease in biovolume from 8 to 20 meters with the lowest value was observed at 22 meters depth. Differences in distribution among depth profiles were observed in terms of phytoplankton diversity, density, and biovolume. The results of this study can be used as reference database in the assessment of water quality for further conservation and utilization of the reservoir.

Keywords: phytoplankton; distribution; diversity; Pasak Jolasid Reservoir; depth profile.

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Introduction

Phytoplankton is distributed mainly in surface water where there is availability of light. Its viability can be used to indicate water quality as different species of phytoplankton have a wide range of tolerance towards environmental stress. The advantages of using phytoplankton as bioindicator include its simplicity as well as the requirement for less expensive chemicals and equipment. Phytoplankton photosynthesis requires light energy. Its growth tends to concentrate near the water surface and declines in deeper water. Phytoplankton species are responsive to a number of factors affecting their growth such as light, nutrients, and temperature. Variance in these factors will result in physiological changes with regards to biochemical processes and the ability of phytoplankton photosynthesis [1]. The flow of the water also contributes to the growth of phytoplankton as higher levels of nutrients may accumulate more in certain areas. It can be the main effect between seasonal variability and can influence productivity at all trophic levels [2]. The effect of eutrophication also has a strong impact as excessively nutrient-rich waters induce rapid growth of certain phytoplankton referred to as an algal boom. The rapid growth of certain phytoplankton can be of major impact on the water environment. Phytoplankton is the main primary producer in many aquatic systems and is an important food source for other organisms along the food chain. Phytoplankton has long been effectively used as bio-indicators in aquatic environments to determine environmental conditions and the extent of water pollution. Some factors are very sensitive to environmental changes and can be useful indicators of water quality such as pH, light, chlorophyll, and temperature [3]. Species composition of the phytoplankton community is an efficient bio-indicator in quality assessment of fresh water [4].

Pasak Jolasid dam is a part of His Majesty's initiative towards the development of Pasak River, an important basin in the east of Chao Phraya River. The large reservoir is now located in Pattana Nikom district, Lopburi Province. The characteristic of the Pasak River is a feather, narrow, slender, rather flat, and filled with large fishery resources in the central part of Thailand [5-7]. Communities surrounding the river are directly affected by the changes of the reservoir including various activities aimed towards tackling the problem of water shortage in agriculture, providing water storage for consumption and industry, enabling the introduction of new technologies for water management in irrigation projects, as well as accommodating the breeding of commercial fish species, and large-scale fishing activities in the area [5]. The aims of this research are to study the distribution of phytoplankton diversity and biovolume according to depth profile at Pasak Jolasid Reservoir, Lopburi Province, Thailand; and then to investigate the influence of some environmental parameters on the division dynamics of phytoplankton community through the application of statistical tests. The outcome of this research has contributed to management of Pasak Jolasid and other reservoirs, and subsequent studies on phytoplankton.

Materials and Methods

Sampling sites

Samples were collected from Pasak Jolasid Reservoir, Lopburi Province (14°50'32" N and 101°15'00" E) in tropical climate. Study areas were selected to most effectively examine the presence of phytoplankton in the aquatic environment of maximum depth (Figure 1).

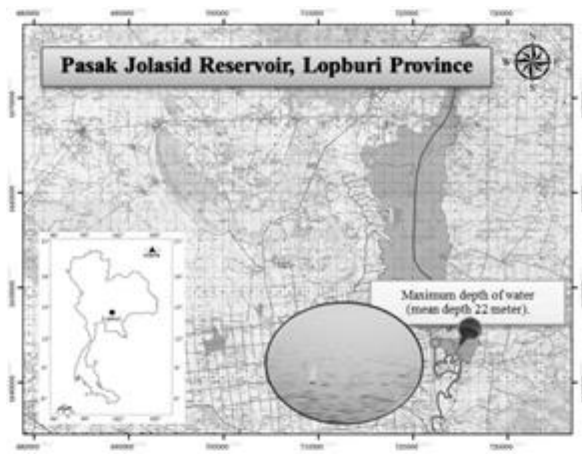


Figure 1. Map of Lopburi Province, Thailand and the sampling site locations in Pasak Jolasid Reservoir (referred from [7]).

Water sampling and analysis

Water samples were collected every 2 weeks from November 2009 to October 2010. Sampling was conducted along 2-meter intervals of increasing water depth followed by depth profiling from the surface towards the bottom of the reservoir. Water samples were collected using Ruttner water sampler [8-9]. Twenty (20) liters of water were filtered through a 10 mm-mesh size plankton net. The phytoplankton samples were preserved in dark glass bottles with 3-6 drops (about 2 ml) of 1% Lugol's solution per 100 ml of sample. The phytoplankton samples were observed under inverted microscope using the Utermöhl method [10], and then were identified according to the classifications described by Huber–Pestalozzi [11-14], Whitford and Schumache [15], Croasdale *et al*. [16], Komárek and Anagnostidis [17, 18], Lee [19], John *et al*. [20], Lewmanomont [21], Wongrat [22], and Peerapornpisal [23].

Biovolume was determined by the method of Utermöhl [10].

Certain physical-chemical properties of the water body, e.g. depth, water temperature, and conductivity, were determined by using a Multiparameter Display System (YSI 650 MDS) (YSI Incorporated, Yellow Springs, Ohio, USA). Dissolved oxygen (DO) and biochemical oxygen demand (BOD_5) values were determined by using iodometric method [24]. The measurement of nutrient values, such as nitrate-nitrogen, ammonium-nitrogen, and soluble reactive phosphorus (SRP) was done according to the Standard Method for Examination of Water and Wastewater of APHA method [25].

The statistical analysis was performed by using R software (version 3.4.2) supported by The Comprehensive R Archive Network (CRAN) (https://cran.r-project.org/). A non-metric multidimensional scaling technique (NMDS) with Bray–Curtis distance measure was used to evaluate microalgal biovolume of each division and the water quality of each depth. The physical-chemical factors were correlated to the NMDS axes by using the Fits an Environmental Vector (envfit) of the library (vegan). The fit (R^2) of each variable to the ordination was assessed by using the envfit function with Monte-Carlo analysis of 999 permutations. The NMDS result was plotted using ggplot function of the ggplot2 as described elsewhere [25].

Results and discussion

The means and ranges of environmental parameters at 12 depths were summarized in Table 1. The stratification events did not appear in this reservoir. The water temperature was very constant with less variation over the year. It was because of this reservoir located in tropical area and the depth of the reservoir was shallow. Thus, the whole water column should be well mixed. The dissolved oxygen (DO) concentrations decreased with depth and gradually reduce after 6 meters-depth. This may be caused by the limit of light penetration in this area. The BOD_5 trends were also similar with DO. The highest BOD_5 was observed in the water column close to the surface and gradually decrease. However, conductivity and the nutrient concentrations (ammonium-nitrogen, nitrate-nitrogen, and orthophosphate) were fluctuated with depth, but showing slightly increase consistent to the depth. It may be because of organic sedimentation at the bottom of the reservoir. During the study period, the chlorophyll-α concentrations decreased steadily from the surface to the bottom. However, the significant lower of chlorophyll-α than those on the surface-depths was only shown at 22 meters depth, which indicated the entire water column circulation.

From November 2009 to October 2010, 7 phyla, 89 genera, and 220 species of phytoplankton were found in Pasak Jolasid Reservoir, Lopburi Province, following Rott's system of classification [26] (Table 2). *Phylum Chlorophyta* demonstrated the greatest phytoplankton abundance of 99 species, or approximately 44.75% of the total phytoplankton population followed by the *Euglenophyta* division with 35 species (15.98%). There were 34 (15.53%), 33 (15.07%), 9 (4.11%), 9 (4.11%), and 1 (0.46%) species from the *Cyanophyta*, *Bacillariophyta*, *Chrysophyta*, *Pyrrhophyta*, and *Cryptophyta phyla*, respectively. Similar findings were shown in the studies of Manoj Kumar *et al*. [27] at Yamuna River, Kalpi; Kadam *et al*. [28] at reservoirs of Parbhani District, Maharashtra; and Bamane *et al*. [29] at Upvan-lake, Thane, Maharashtra, India. These studies suggested higher population density of phytoplankton species belonging to the *Chlorophyceae* division.

Distribution of phytoplankton abundance varied in different depth levels of the reservoir. Table 2 showed the distribution of phytoplankton according to depth profile of the Pasak Jolasid Reservoir between November 2009 to October 2010. The maximum abundance appeared at a depth of 2 meters followed by 0, 6, 8, 10, 12, 14, 16, 20, and 18 meters, respectively, while

Table 1. Environmental variables recorded in the Pasak Jolasid Reservoir from November 2009 to October 2010.

Depth (m)	Water temperature (°C)					Dissolved oxygen (mg/L)				
	Mean±sd	Min	Median	Max	C.V.	Mean±sd	Min	Median	Max	C.V.
0	29.05±1.4a	26.05	29.21	30.82	0.05	5.96±1.31a	3.74	5.96	8.40	0.22
2	28.93±1.37ab	25.99	28.99	30.73	0.05	5.9±1.25a	3.85	5.98	7.57	0.21
4	28.75±1.45ab	25.91	28.89	30.54	0.05	5.65±1.4a	1.52	5.92	7.35	0.25
6	28.65±1.48ab	25.82	28.88	30.53	0.05	5.13±1.51a	0.72	5.17	8.04	0.29
8	28.24±1.62ab	25.59	28.67	30.45	0.06	3.79±2.04ab	0.22	4.15	7.06	0.54
10	27.39±1.36ab	25.64	27.19	29.47	0.05	2.16±1.74b	0.14	2.64	5.37	0.81
12	27.17±1.41ab	25.55	26.76	29.35	0.05	1.85±1.75b	0.08	0.97	5.32	0.95
14	26.8±1.53b	23.73	26.20	28.92	0.06	1.65±1.75b	0.10	0.56	4.86	1.06
16	27.31±1.58ab	25.47	26.92	29.69	0.06	1.72±1.69b	0.10	0.93	4.67	0.98
18	27.75±1.76ab	24.02	28.09	29.69	0.06	2.41±1.82b	0.11	2.90	5.26	0.75
20	27.92±1.11ab	25.94	28.21	29.13	0.04	2.54±1.68b	0.11	3.49	4.38	0.66
22	27.96±0.35ab	27.61	27.96	28.30	0.01	3.74±0.11ab	3.63	3.74	3.84	0.03
	df: 11 F: 4.697 p-value: 0.000					df: 11 F: 20.636 p-value: 0.000				

Depth (m)	Conductivity (μs/cm)					BOD_5 (mg/L)				
	Mean±sd	Min	Median	Max	C.V.	Mean±sd	Min	Median	Max	C.V.
0	338.54±31.92	292.00	341.00	397.00	0.09	2.35±1.25a	0.50	2.25	4.60	0.53
2	337.73±31.74	289.00	336.50	396.00	0.09	2.27±1.35a	0.09	2.55	4.50	0.59
4	332.31±43.43	186.00	338.50	396.00	0.13	2.06±1.34ab	0.10	2.37	4.40	0.65
6	335.88±37.52	227.00	339.00	397.00	0.11	2.04±1.29ab	0.20	1.79	3.80	0.63
8	335.79±28.63	291.00	335.00	396.00	0.09	1.36±1.26a	0.10	0.77	3.50	0.92
10	326.67±41.79	184.00	329.00	393.00	0.13	0.47±0.5b	0.08	0.25	1.80	1.06
12	337.72±31.19	292.00	332.00	402.00	0.09	0.39±0.43b	0.09	0.20	1.50	1.10
14	338.14±32.84	295.00	335.00	402.00	0.10	0.48±0.53b	0.09	0.15	1.63	1.11
16	330.17±24.27	294.00	332.50	374.00	0.07	0.41±0.49b	0.10	0.15	1.60	1.18
18	330±27.35	301.00	322.00	392.00	0.08	0.65±0.38b	0.10	0.70	1.16	0.59
20	321.8±18.1	300.00	314.00	353.00	0.06	1.03±0.63ab	0.10	1.36	1.68	0.61
22	344.5±41.5	303.00	344.50	386.00	0.12	1.5±0ab	1.50	1.50	1.50	0.00
	df: 11 F: 0.332 p-value: 0.978					df: 11 F: 9.405 p-value: 0.000				

Depth (m)	Nitrate-nitrogen (mg/L)					Ammonium-nitrogen (mg/L)				
	Mean±sd	Min	Median	Max	C.V.	Mean±sd	Min	Median	Max	C.V.
0	0.24±0.18	0.01	0.22	0.66	0.75	0.02±0.03	0.002	0.012	0.121	1.37
2	0.17±0.16	0.01	0.11	0.61	0.94	0.02±0.02	0.003	0.013	0.122	1.16
4	0.17±0.19	0.01	0.08	0.76	1.12	0.02±0.02	0.004	0.014	0.127	1.25
6	0.16±0.16	0.01	0.06	0.50	0.99	0.02±0.02	0.003	0.015	0.128	1.22
8	0.18±0.16	0.01	0.12	0.54	0.90	0.02±0.03	0.003	0.014	0.125	1.21
10	0.19±0.19	0.03	0.10	0.69	1.03	0.02±0.02	0.007	0.016	0.085	0.82
12	0.2±0.16	0.03	0.14	0.60	0.81	0.03±0.02	0.006	0.021	0.056	0.61
14	0.21±0.15	0.03	0.18	0.53	0.71	0.04±0.06	0.007	0.019	0.255	1.38
16	0.31±0.18	0.05	0.27	0.74	0.60	0.04±0.03	0.010	0.019	0.099	0.81
18	0.34±0.13	0.15	0.29	0.53	0.39	0.02±0.02	0.009	0.017	0.066	0.77
20	0.31±0.11	0.18	0.26	0.49	0.35	0.02±0.01	0.010	0.014	0.026	0.38
22	0.23±0.03	0.20	0.23	0.27	0.13	0.02±0	0.020	0.020	0.020	0.01
	df: 11 F: 1.615 p-value: 0.097					df: 11 F: 1.199 p-value: 0.290				

Depth (m)	Soluble reactive phosphorus (mg/L)					Chlorophyll a (μg/L)				
	Mean±sd	Min	Median	Max	C.V.	Mean±sd	Min	Median	Max	C.V.
0	0.01±0.01a	0.003	0.006	0.015	0.73	9.54±5.57a	0.90	9.82	26.64	0.58
2	0.01±0.01a	0.003	0.006	0.012	0.71	10.03±5.15a	1.11	9.77	24.19	0.51
4	0.02±0.01a	0.003	0.006	0.010	0.81	9.89±5.72a	0.52	9.25	27.76	0.58
6	0.01±0.01a	0.001	0.006	0.012	0.75	9.59±5.37ab	0.92	9.36	25.25	0.56
8	0.01±0.01a	0.003	0.006	0.011	0.84	8.46±5.46ab	0.97	8.27	25.24	0.65
10	0.01±0.01a	0.004	0.006	0.009	0.76	7.13±4.89ab	0.84	6.82	19.94	0.69
12	0.02±0.01ab	0.004	0.006	0.010	0.74	5.36±4.65ab	0.08	4.28	18.68	0.87
14	0.02±0.01ab	0.005	0.006	0.008	0.60	5.91±4.22ab	0.44	5.37	14.76	0.71
16	0.02±0.01ab	0.005	0.006	0.008	0.41	5.33±4.08ab	0.41	5.12	12.23	0.77
18	0.03±0.02bc	0.004	0.006	0.011	0.55	7.84±4.57ab	0.26	10.40	12.24	0.58
20	0.04±0.01cd	0.006	0.008	0.011	0.34	5.29±3.13ab	0.30	4.76	9.34	0.59
22	0.05±0d	0.009	0.009	0.009	0.01	1.64±1.45b	0.20	1.64	3.09	0.88
	df: 11 F: 6.315 p-value: 0.000					df: 11 F: 2.405 p-value: 0.008				

Note: df: degrees of freedom; F: F-statistic; *p*-value: probability value; C.V.: coefficient of variation; The letters refer to significant differences ($p<0.05$) of ANOVA with post-hoc Tukey's b.

minimum abundance was recorded at water depth of 22 meters. It showed that *Aulacoseira muzzanensis (Meister) Krammer* demonstrated the highest abundance along the depth range of 0 to 18 meters followed by *Cylindrospermopsis raciborskii (Wolosz.) Seenayya & Subba* in depth

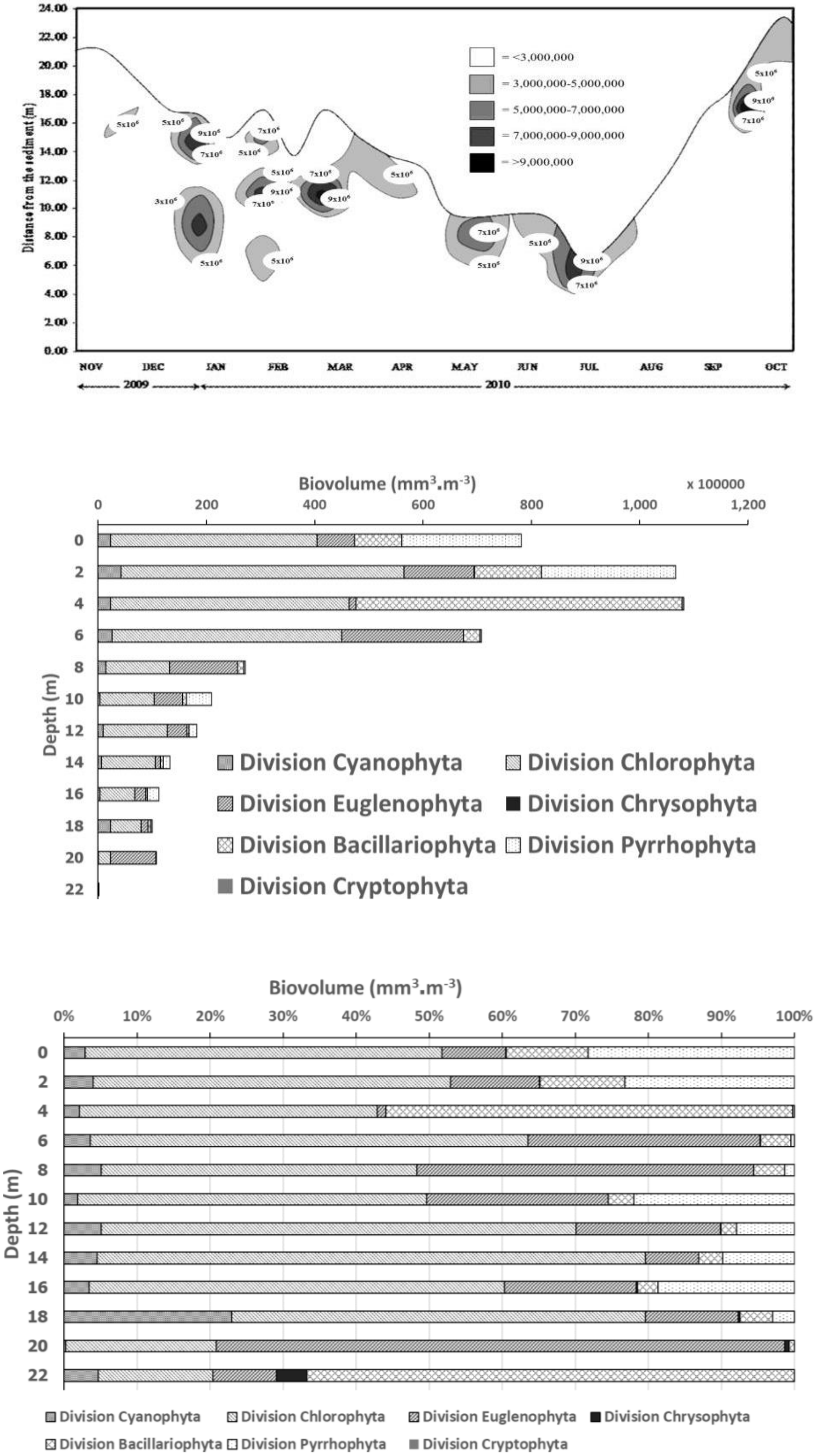
Table 2. List of phytoplankton species distribution in depth profiles of Pasak Jolasid Reservoir from November 2009 to October 2010. (Occurrence: ++++: frequent, +++: occasional, ++: rare, +: very rare)

Species of phytoplankton	Total biovolume (mm^3)	Occur-rence	Depth profile (m)
Division Cyanophyta			
Anabaenopsis sp.	389643.52	+	0,2,4,6,8,10,12,14,16
Aphanizomenon tropicalis M.Horecká & J.Komárek	321365.88	+	0,2,4,6,8,10,16
Aphanocapsa holsatica (Lemmermann) G. Cronderg & J. Komárek	5376913.33	+	0,2,6,8
Chroococcus cf. *minutus* (Kützing) Nägeli	586267.69	++	0,2,4,6,8,10,12,14,16,18
Chroococcus sp.	273851.87	++	0,2,4,6,8,10,12,14,16
Coelomoron pusillum (Van Goor) Komárek	5840553.99	+	0,2,8
Coelomoron sp.	456881.06	+	0,2,8
Cylindrospermopsis cuspis Komárek *et* Kling, Algolog. Stud	2840290.09	++	0,2,4,6,8,10,12,22
Cylindrospermopsis raciborskii (Wolosz.) Seenayya & Subba	2834868.68	++++	0,2,4,6,8,12,14,16
Cylindrospermopsis sp.	3179147.21	++	0,2,4,6,8,12,14,16
Dolichospermum affine (Lemmermann) P.Wacklin, L.Hoffmann & J.Komárek	1774709.03	+	0,2,6,8,10,12,14
Dolichospermum sp.1	12778242.21	+++	0,2,6,8,10,14,16
Dolichospermum sp.2	8717117.64	++	0,2,6,8,10,14,16
Dolichospermum sp.3	2250881.09	+	0,2,6,8,10,14,16
Dolichospermum sp.4	495909.71	+	0,2,6,8,10,12,14,16
Lyngbya aestuarii Liebman ex Gomont	2464387.03	+	0,2,4,6,8,10,12,14,16
Merismopedia elegans A.Braun ex Kützing	18567.78	+	0,2,6,8,10,12
Merismopedia punctata Meyen	237603.82	+	0,2,6,8,10,12,14,16
Merismopedia tenuissima Lemmermann	6330.32	+	0,2,6,8,10,12
Microcystis aeruginosa Kützing	9953612.41	+++	0,2,4,6,8,10
Microcystis wesenbergii Komárek	32747431.52	+	0,2,4,6,8,10,12,14
Oscillatoria amoena (Kutzing) ex Gomont	20732008.19	+++	0,2,4,6,8,10,12,14,16,18,20
Oscillatoria cortiana (Meneghini) ex Gomont	20433211.96	+	0,2,4,6,8,10,12,14,16,18
Oscillatoria tenuis var. *salina* Starmach *et* An	5708507.59	+	0,2,4,6,8,12,14,16
Oscillatoria vizagapatensis Bhashyakarka Rao	5136902.44	+	0,2,4,6,8,12,14
Oscillatoria sp.	3586782.66	+	0,2,4,6,8,10,12,14,16
Planktothrix rubescens (de Candolle ex Gomont) Anagnostidis *et* Komárek	1165736.02	+	0,2,6,8,10,12,14
Pseudanabaena catenata Lauterborn	216982.73	+++	0,2,4,6,8,10,12,14,16
Pseudanabaena minima (G.S.AN) Anagnostidis	240827.55	+	2,6,8,10,12,14,16
Pseudanabaena sp.1	87967.75	+	2,6,8,10,12,14
Pseudanabaena sp.2	75726.26	+	2,8,10,12
Raphidiopsis curvata Fritsch *et* Rich (after Holsinger)	118293.37	+	2,4,12,20
Spirulina sp.1	120808.58	+	2,6,8
Spirulina sp.2	58656.53	+	2,8,10
Division Chlorophyta			
Actinastrum gracillimum G.M. Smith	10297.47	+	0,2,4
Actinastrum hantzschii Lagerheim	3973.14	+	0,2,4,8
Acutodesmus acuminatus (Lagerheim) Tsarenko	545950.98	+	0,2,4,6,8
Acutodesmus pectinatus (Chodat) Tasrenko	11029.11	+	0,2,4,8
Acutodesmus pectinatus var. *bernardii* (G.M.Smith) Tsarenko	121086.22	+	0,2,4
Ankyra ancora (G.M.Smith) Fott	751998.60	+	0,2,6,8
Botryococcus braunii Kützing	250062.29	+++	0,2,4,6,8,10,12,14,18,20,22
Botryococcus calcareus West	345921.75	+	0,2,4,6,8,10,12,14,20,22
Chlorella sp.	27454.34	+	0,2,4,6,8,10,12,14,16
Closteriopsis longissima Lemmermann	828093.55	+	0,2,4,6,8,10,12,14
Closteriopsis longissima var. *tropical* Lemmermann	1094032.63	+	0,2,4,6,10,12,14
Closteriopsis sp.1	6344988.19	+	0,2,4,6,8,10,12,16
Closteriopsis sp.2	2878099.18	+	0,2,4,6,10,12,14,16
Closterium acutum var. *variabile* (Lemmermann) Krieg	1220041.17	++	0,2,4,6,8,10,12,14,16
Closterium littorale F.Gay	1000158.14	+	0,2,6,10,12,14,16

Closterium praelongum Brébisson	8347184.46	+	0,2,6,10,12,16
Coelastrum astroideum De Notaris	117001022.85	+++	0,2,4,6,8,10,12,14
Coelastrum microsporum Nageli	404010368.52	+	0,2,6,8,10,12
Coelastrum sphaericum Nägeli	228993353.51	+	0,2,6,8,10,12
Coelastrum verrucosum (Reinsch) Reinsch	118557538.65	+	0,2,4,6,8,10,12
Cosmarium contractum Kirchn	7732941.51	++	0,2,4,6,8,10,12,16
Cosmarium contractum var. *rotundatum* Borge	27064983.27	+	0,2,4,6,8,10,12,14,16
Cosmarium cymatopleurum Nordstedt	144080750.96	+	0,2,4,6,8,10,12,16
Cosmarium denboeri Meesters & Coesel	474120.79	+	0,2,4,6,8,10,12,16
Cosmarium limnophilum Schmidle	230681.56	++	0,2,4,6,8,10,12,16
Cosmarium rectangular Grunow	1861555.05	+++	0,2,4,6,8,10,12,14,16
Cosmarium tumidum Lund	104242.81	+	2,4,6,8,10,12,16
Crucigenia tetrapedia (Kirchner) W. West et G.S.	427383.68	+	0,2,4,6,8,10,12
Crucigeniella irregularis Wille	164840.01	+	0,2,4,6,8,14
Desmodesmus armatus var. *bicaudatus* (Guglielmetti) E.Hegewald	790226.23	+	0,2,4,6,10,14
Desmodesmus brasiliensis (Bohlin) E.Hegewald	41172.16	+	0,2,4,6,10
Desmodesmus communis (E.Hegewald) E.Hegewald	1572172.14	+	0,2,4,6,8,10,12
Desmodesmus denticulatus (Lagerheim) An, Friedl et E.Hegewald	748527.67	+	0,2,4,6,10
Desmodesmus insignis (West & G.S.West) E.Hegewald	360959.33	+	0,2,6,8,10
Desmodesmus perforatus Lemmermann	1466397.27	+	0,2,6,10
Desmodesmus tropicus Crow	243312.86	+	0,2,4,8,12
Desmodesmus velitaris Komárek	134758.15	+	0,2,6,10
Dictyosphaerium ehrenbergianum var. *minutum* W.R.Taylor	287545.34	+	0,2,6,8,10
Dictyosphaerium pulchellum Wood	379539.08	+	0,2,4,6
Dictyosphaerium tetrachotomum Wood	779538.91	+	0,2,4,6,8,12
Dictyosphaerium sp.	1230352.85	+	2,4,6,8,12,16
Elakatothrix gelatinosa Wille F.minus F.NOV.	413599.23	+	0,2,4,12,16
Elakatothrix spirochroma (Reverdin) Hindák	30863.56	+	0,2,4,12
Euastrum denticulatum F.Gay	257371.92	+	0,2,6,8
Euastrum diverrucosum var. *alatum* Wolle	538852.50	+	0,2,8
Eudorina sp.	87621748.87	++	0,2,8,10,12,14,16,20
Golenkinia radiata var.*longispina* G.M.Smith	630286.51	+	0,2,4,6,8,12
Golenkiniopsis sp.	103831.69	+	0,2,4,6,12
Kirchneriella obesa (W.West) Schmidle	13197.58	+	0,2,6
Kirchneriella lunaris (Kirchner) K.Mobius	4117.43	+	0,2,4,6
Lagerheimia ciliata (Lagerheim) Chodat	2476180.99	+	0,2,4,6,8,18
Lagerheimia citriformis (J.Snow) Collins	16124.46	+	0,2,6,8
Micractinium pusillum Fresenius	128341.09	+	0,2,4,6,16
Micractinium quadrisetum (Lemmermann) G.M.	87733.17	+	6,16
Monoraphidium arcuatum (Korshikov) Hindák	38625.91	+	0,2,6,12
Monoraphidium contortum (Thuret) Komàrková-Legnerová	38234.74	+	0,2,6,10,12,14,16
Mougeotia sp.	926684.20	+	2,6,8,10,12,14,16
Nephrocytium agardhianum Nägeli	2284292.74	+	0,2,6,12,14,16
Oocystis borgei J. Snow	4873933.08	+++	0,2,4,6,8,10,12,14,16
Oocystis lacustris Chodat	4528504.12	+	0,2,4,6,8,10,12,14,16
Oocystis marsonii Lemmermann	3656217.19	++	0,2,4,6,8,10,12,14,16
Oocystis natans (Lemmermann) Lemmermann	653433.62	+	0,2,4,6,8,10,12,14,16
Oocystis sp.	1975951.24	+	0,2,4,6,8,10,12,14,16
Pandorina morum (O.F.Müller) Bory de Saint-Vincent	21763309.48	+++	0,2,6,8,10,12,14,16,18,20
Pandorina sp.	257882090.70	++	0,2,4,6,8,10,12,14,16,18,20
Pediastrum asymmetricum Hegewald	495377.08	+	0,2,4,6,8,10,14
Pediastrum biradiatum var. *Longicornutum* Gutwinski	285663.67	+	0,2,4,6,10,14
Pediastrum biwae Negoro	5891703.47	+	0,2,4,6,8,10,12,14,16
Pediastrum duplex var. *duplex* Meyen	912098.98	+	0,2,4,6,8,10,12,14
Pediastrum duplex var. *gracillimum* West *et* G.S.West	1754471.81	+	0,2,4,6,8,10,12,14
Pediastrum duplex var. *reticulatum* Lagerheim	2627804.03	+	0,2,4,6,10,14
Pediastrum simplex var. *clathratum* Schröter	6517954.25	++	0,2,4,6,8,10,12,14,16
Pediastrum simplex var. *echinulatum* Wittrock	4293755.50	++	0,2,4,6,8,10,12,14,20,22

Pediastrum simplex var. *simplex* Meyen	16473468.37	+++	0,2,4,6,8,10,12,14,16,20
Pediastrum simplex var. *sturmii* (Reinsch) Wolle	2263180.50	+	0,2,4,6,8,10,12,14
Planktonema lauterbornii Schmidle	285934.93	+	0,2,4,6,8,10,12,18,20
Scenedesmus arcuatus (Lemmermann) Lemmermann	220092.91	+	0,2,4,6,8,12
Schroederia indica Philipose	176249.67	+	0,2,4,6,8,10,12
Spondylosium sp.	201484.81	+	0,2,4,6,8,10,16,22
Staurastrum boreale var. *robustum* E.Messikommer	410070.30	+	0,2,4,6,8,10,12,20
Staurastrum dybowskii Woloszynska	2448416.44	+	0,2,4,6,8,10,12,14,16,20
Staurastrum paradoxum var. *diacanthum* (A.Lemaire) Homfeld	2360410.37	+++	0,2,4,6,8,10,12,14,16,20
Staurastrum tetracerum var. *cameloides* M.Florin	949183.49	++	0,2,4,6,8,10,12,14,16,18,20
Tetradesmus wisconsinensis F.Sihirica (Printz) Fott & Kom	14118.89	+	2,4,6,10,12
Tetraedron caudatum (Corda) Hansgirg	3981.52	+	0,2,4,12,14
Tetraedron minimum (A. Braun) Hansgirg	51370.61	+	0,2,4,12,14
Tetraedron trigonum (Nägeli) Hansgirg	7543.94	+	2,4,6,12,16
Tetrastrum heterocanthum (Nordstedt) Chodat	536.46	+	4,10
Treubaria schmidlei (Schroder) Fott et Kovacik	14099.97	+	14
Ulothrix tenuissima Kützing	85965973.33	+	6
Volvox aureus Ehrenberg	5314583.34	+	6,8,10
Volvox tertius A. Meyen	110858095.97	+	4,6
Volvox sp.1	3360418.54	+	6,20
Volvox sp.2	1311610.33	+	8
Westella botryoides (W.West) De Wildeman	949183.49	+	0,2,4,8,10
Division Euglenophyta			
Euglena allorgei Deflandre	9987481.41	+	0,2,6
Euglena ehrenbergii Klebs	646979.84	+	0,2,6,8,12
Euglena geniculata F.Schmitz	454541.16	+	0,2,4,6,8
Euglena sanguinea Ehrenberg	29271545.51	+	0,2,6
Euglenaria anabaena (Mainx) Karnkowska & E.W.Linton	552718.97	+	0,2,4,6,10,12
Lepocinclis acus (O.F.Müller) Marin & Melkonian	7756325.27	+	0,2,4,6,8,10
Lepocinclis acus var. *longissima* (Deflandre) D.A.Kapustin	1080856.69	+	0,2,4,6,8
Lepocinclis fusiformis (H.J.Carter) Lemmermann	5138657.42	+	0,2,4,6,8,10
Lepocinclis oxyuris (Schmarda) Marin *et* Melkonian	37573067.64	+	0,2,6,8,10,16
Monomorphina pyrum (Ehrenberg) Mereschkowsky emend Kosmala *et* Zakrys	1218943.51	+	4,6,14
Phacus circulates Pochmann	747280.73	+	6,8
Phacus helikoides Pochmann	124700027.14	+	2,6,8,10
Phacus longicauda (Ehrenberg) Dujardin	66043885.24	+	0,2,6,8,10
Phacus longicauda var. *tortus* Lemmermann	2694260.58	+	2,6
Phacus morii Skvortzov	29371394.04	+	6,8,10
Phacus orbicularis f. *communis* Popova	2786624.81	+	8
Phacus ranula Pochmann	84496172.19	+++	0,2,4,6,8,10,12,16
Phacus salina Fritsch	7365408.78	+	2,4,8
Strombomonas acuminata var. *amphora* (Playfair) Deflandre	5544335.28	+	0,2,4,8,20
Strombomomas australica (Playfair) Deflandre	49267719.47	+	2,4,8,10,14,20
Strombomonas fluviatilis var. *levis* (Lemmermann) Skvortzkov	18382187.71	+	2,8,10,20
Strombomomas gibberosa (Playfair) Deflandre	51135904.80	+	2,6,8,12,14,20
Strombomonas rotunda f. hortobagyi Huber-Pestalozzi	1949180.37	+	2,6,8,12,14,20
Trachelomonas acanthostoma A.Stokes	15859650.47	+++	0,2,6,8,10,12,14,16,20
Trachelomonas armata var. *longispina* Playfair	58056641.92	+	0,2,4,6,8,10,20
Trachelomonas armata var. *steinii* Lemmermann	44601938.21	+	0,2,6,8,10,20
Trachelomonas euchlora (Ehrenberg) Lemmermann	20165522.37	+	0,2,6,8,10,20
Trachelomonas hispida var. *coronata* Lemmermann	1586508.81	+	0,2,6,8,10,14,20
Trachelomonas lacustris var. *lacustris* Drezepolski emend. Balech	1011220.06	+	0,2,4,6,8,10,16,20
Trachelomonas rostafinskii Drezepolski	25735063.93	+	0,2,4,6,8,10,20
Trachelomonas superba Svirenko emend. Deflandre	49733415.24	+	0,2,6,8,10,20
Trachelomonas verrucosa var. *macrotuberculata* Grandori	669748.75	+	0,2,6,8,10,16,20
Trachelomonas volvocina Ehrenberg var. *derephora* Conrad	3996190.29	+	0,2,4,6,8,10,20
Trachelomonas volvocina var. *volvocina* Ehrenberg	770199.84	+	0,2,4,8,10,20

Trachelomonas volvocinopsis var. *spiralis* E.G.Pringsheim	3231503.51	+	0,2,4,8,10,12,20
Division Chrysophyta			
Centritractus africanus F.E.Fritsch & M.F.Rich	282369.49	+	0,2,12,16,18,20
Centritractus belanophorus Lemmermann	113191.12	+	0,2,10,12,16,18,20
Dinobryon divergens O.E.Imhof	121656.45	+	2,4,12,14,22
Goniochloris contorta (Bourrelly) Ettl	53885.25	+	2,6,12
Goniochloris smithii (Bourrelly) Fott	62666.55	+	12
Isthmochloron gracile (Reinsch) Skuja	349236.29	+	0,2,8,10,12,16
Mallomonas sp.	877331.70	+	4,18,20
Pseudogoniochloris tripus (Pascher) L.Krienitz, E.Hegewald O.L.Reymond & T.Peschke	11180.01	+	12
Synura favus Bradley	205144.74	+	0,2,6,10,12
Acanthoceras zachariasii (Bron.) Simonsen	986119.81	+++	0,2,6,8,10,20
Amphora elliptica (Agardh) Kützing	80910.02	+	2,4,6,8,10,12
Amphora libyca Ehrenberg	16014392.55	++	2,6,8,10,12
Amphora sp.	930818.76	+	0,2,6,8,12,14
Aulacoseira granulata (Ehrenberg) Simonsen	5596321.41	+++	0,2,6,8,10,12,14,16,18
Aulacoseira italic (Ehrenberg) Simonsen	4764404.12	++	0,2,4,6,8,10,12
Aulacoseira muzzanensis (Meister) Krammer	222993904.85	++++	0,2,4,6,8,10,12,14,16,18
Aulacoseira sp.	1495848.79	+	0,2,4,6,8,10,12,14,16
Cyclotella meneghiniana Kützing	4119774.20	+	0,2,4,6,10,12
Cyclotella stelligera Cleve & Grunow	2166639.53	+	0,2,6,12
Cymbella affinis Kützing	22007.06	+	2,4,6,8,12
Cymbella tumida (Brébisson) van Heurck	98699.82	+	0,2,8,10,12,16
Fragilaria crotonensis Kitton	203147.39	+	0,2,6,8,12,14,20,22
Fragilaria ulna var. *acus* (Kützing) Lange-Bertalot	2514645.00	+++	0,2,4,6,8,14,20,22
Geissleria decussis (Østrup) Lange-Bertalot & Metzeltin	67776.95	+	0,2,8,14
Gomphonema parvulum (Kützing) Kützing	152555.13	+	0,2,8,16
Gomphonema sp.1	458399.03	+	0,2,4,8,12
Gomphonema sp.2	209553.75	+	0,2,14
Gyrosigma scalproides (Rabenhorst)	199117.97	+	0,2,8,12
Gyrosigma spencerii (Smith) Cleve	490106.31	+	0,2,4,6,8,12
Hantzschia amphioxys (Ehrenberg)	603129.82	+	4,6,8,12,14
Melosira sp.	3623831.12	+	0,2,6,8,12,14,22
Navicula amphirhynchus Ehrenberg	1996069.32	+++	0,2,4,6,8,14,16
Navicula transitans Cleve	468202.95	+	0,2,6,8
Navicula sp.	1996747.88	+	0,2,6,8,10,12,14,16
Nitzschia sigmoidea (Nitzsch) W.Smith	305553.32	+	0,2,4,6,8,12
Nitzchia sp.	970732.80	+	0,2,4,8,10,12,14,16
Pinnularia sp.	627538.64	+	0,2,6,8,10,16
Pleurosigma sp.	407372.49	+	0,2,4,6,8
Rhizosolenia setigera Brightwell	316126.80	+	0,2,6,8
Surirella biseriata Brebisson	685914.33	+	0,2,6,8,10,14,18
Synedra ulna (Nitzsch) Ehrenberg	2349243.63	+	0,2,4,8,10,12,16
Synedra sp.	150399.72	+	0,2,4,6,8,10,12,14,16,20
Division Pyrrhophyta			
Ceratium brachyceros Daday	141529520.51	++	0,2,6,8,10,12,14,16
Ceratium hirundinella (O.F.Müller) Dujardin	418025297.94	+++	0,2,4,6,8,10,12,14,16
Gymnodinium cinctum Ehrenberg	1508809.99	+	0,2,4,6,8,14
Gymnodinium colymbeticum T.M.Harris	1689059.58	+	0,2,4,8,10
Peridiniopsis borgei Lemmermann	380176.88	+	0,2,4,8,10
Peridiniopsis elpatiewskyi (Ostenfeld) Bourrelly	595332.23	+	0,2,4,8
Peridiniopsis sp.	5614923.04	+	0,2,6,8
Peridinium lomnickii var. *wierzejskii* Woloszynska	2079125.73	+	0,2,8,16
Peridinium palatinum R.Lauterborn	1191165.78	+	0,2,6,8,12
Division Cryptophyta			
Cryptomonas sp.	440.82	+	0,2,12,14, 18



(A)

(B)

(C)

Figure 2. The biovolume of phytoplankton of Pasak Jolasid Reservoir per every two-meter depth interval from the surface towards the bottom of the reservoir during November 2009 to October 2010. **(A):** the isoline graph of biovolume, **(B):** the mean biovolume of phytoplankton per every two-meter depth interval from the surface to the bottom of the reservoir, **(C):** percentage of biovolume in each phytoplankton Division.

range of 0 to 16 meters. *Oscillatoria amoena (Kutzing) ex Gomont*, *Botryococcus braunii Kützing*, *Pandorina morum (O.F.Müller) Bory de Saint-Vincent*, *Pandorina sp.*, *Pediastrum simplex var. echinulatum Wittrock*, *Pediastrum simplex var. simplex Meyen*, *Staurastrum dybowskii Woloszynska*, *Staurastrum paradoxum var. diacanthum (A.Lemaire) Homfeld*, *Staurastrum tetracerum var. cameloides M.Florin*, *Trachelomonas acanthostoma A.Stokes*, and *Synedra sp*. were found distributed in all depth profiles. Changes in nutrient composition had strongly influenced the phytoplankton community structure at various depth profiles. The surface area had a high amount of nutrients and light that was important to the growth of plankton, which decreased by increasing the depth of the water. Increasing of nutrient concentration and other factors, such as light, currency, temperature, pH, *etc*., stimulate the growth of phytoplankton via enhanced photosynthesis ability. Phytoplankton may abundantly be found in surface layers, deep layers, or in both depth characteristics of water. The greatest light supply was available at the surface of mixed depth layers. The phytoplankton was hypothesized to be capable of exhibiting high levels of growth with adequate nutrient supply. The vertical distribution of phytoplankton affects primary production as well as energy transfer to higher trophic levels [30].

The biovolume of phytoplankton was calculated following the method proposed by Rott [26]. The total biovolume of phytoplankton categorized by depth profile was highest at the water surface, and steadily decreased with increased depth. The highest measurement was 108,132,447 mm^3/m^3 at a depth of 4 meters followed by 106,667,930 mm^3/m^3 at a depth of 2 meters, 78,188,706 mm^3/m^3 at 0 meter, 70,807,760 mm^3/m^3 at 6 meters, and a steady decrease in biovolume from 8 to 20 meters with the lowest biovolume of 37,028 mm^3/m^3 at 22 meters depth (Figure 2A). Greater biovolumes of phytoplankton were found at the water surface than that at the lower depths with the greatest measurement taken at a depth of 4 meters (Figure 2B). The phytoplankton biovolume in the wet season was higher than it in the dry season. Differences in phytoplankton biovolume and composition have been found between different water depths, climate, seasons, and trophic status. As a result, different distribution patterns of phytoplankton were observed (Figure 2C). Similar results have been reported by Meesukko *et al*. [31] in the Kaeng Krachan Reservoir, Phetchaburi Province, Thailand. The phytoplankton biovolume has the highest value at wet season than it at dry and cold season. Environmental changes frequently promote high densities of phytoplankton, known as algal blooms, which can deteriorate water quality and pose serious consequences to the health of humans and animals [32]. In addition, the amount of carbon dioxide and light intensity at each depth level affects the rate of cell death and biomass of the phytoplankton [2].

The NMDS ordination revealed differences in phytoplankton diversity in different depths (Figure 3). The data stress from NMDS analysis was 0.08, which indicated an acceptable ordination summarizing the observed distances among the samples. Subsequent to the environmental variables, based on R^2 values, only SRP and chlorophyll-α had a strong relationship with biovolume diversity in each division (Table 3). The division in the NMDS ordination diagram indicated that the increase of SRP showed a positive correlation to the biovolume of division *Chrysophyta*, while Ammonium-nitrogen showed a positive correlation to the biovolume of division *Crptophyta* and conductivity showed a positive correlation to the biovolume of division *Pyrrophyta*. This statistical result may be an advantage for support the control of some phytoplankton division in the reservoir.

Conclusions

The study of the biological diversity of phytoplankton by depth profile in Pasak Jolasid

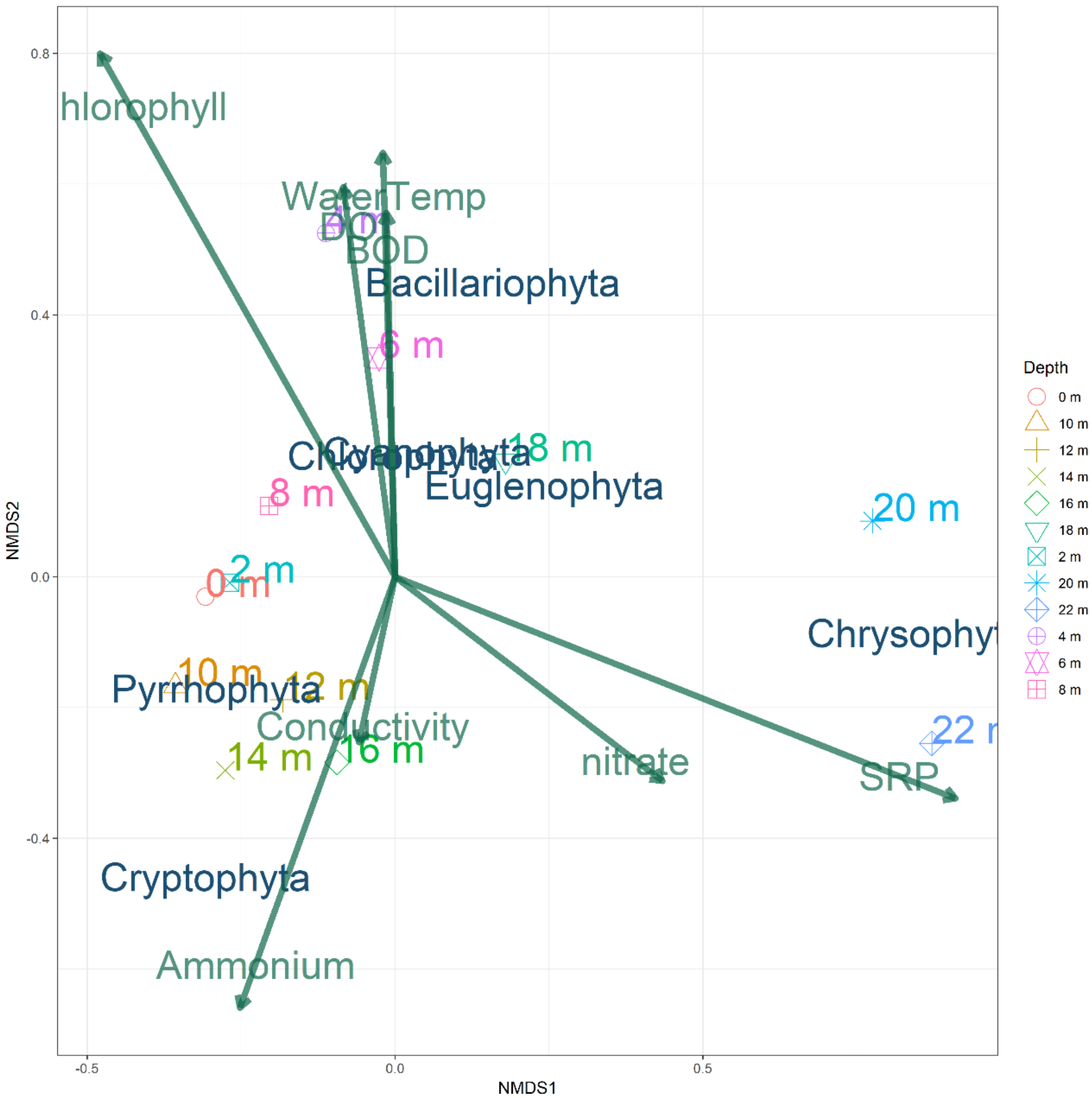


Figure 3. Non-metric multidimensional scaling (NMDS) ordination diagram of the biovolume based on division composition.

Table 3. Relationships between the species ordination scores (NMDS) and the influenced environmental factors.

	NMDS1	NMDS2	r2	*P*
Water temp. (°C)	-0.03038	0.99954	0.4201	0.090
DO (mg/L)	-0.13959	0.99021	0.3613	0.128
Conductivity (μs/cm)	-0.22485	-0.97439	0.0674	0.728
BOD$_5$ (mg/L)	-0.02455	0.99970	0.3094	0.182
Nitrate-N (mg/L)	0.81161	-0.58420	0.2859	0.202
Ammonium-N (mg/L)	-0.35704	-0.93409	0.4975	0.036*
SRP (mg/L)	0.93712	-0.34899	0.9433	0.001 ***
Chlorophyll *a* (μg/L)	-0.51375	0.85794	0.8686	0.001 ***

Note: Significant codes: (***): p < 0.001, (**): p < 0.01, (*): p < 0.05. Permutation: free, number of permutations – 999.

Reservoir, Lopburi Province, Thailand was conducted over a period of 12 months (from November 2009 to October 2010). The samples were collected every two weeks within the area of the reservoir with maximum depth, at depth level intervals of every 2 meters from the water surface to the bottom of the reservoir. This study examined amount and type of phytoplankton found in each division including the number of species of phytoplankton found in each phylum, common types of phytoplankton, and dominant species of phytoplankton. The biodiversity of phytoplankton in the reservoir area of maximum depth was classified into 7 phyla, 89 genera, and 220 species. *Phylum Chlorophyta* contained the greatest species abundance followed by *Euglenophyta*, *Bacillariophyta*, *Chrysophyta*, *Pyrrhophyta*, and *Cryptophyta*, respectively. The biovolume of phytoplankton was the highest at water depth of 4 meters, while the lowest value was observed at a depth of 22 meters. There was a total of 10 dominant species of phytoplankton. The most dominant species was *Aulacoseira muzzanensis (Meister) Krammer*, which was vastly found at high levels within the reservoir. However, the reservoir needs to be appropriately managed and utilized sustainably in order to protect the ecosystem and minimize or prevent the occurrence of adverse algal blooms.

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