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Variations in phytoplankton community structure: A case of Baharini reservoir, Eldoret, Kenya

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Abstract
Phytoplankton species composition and abundance within water bodies exhibit seasonal variation. The aim of this study was to obtain an overview of the variation of phytoplankton community structure during the rainy and dry seasons, and their implications regarding water quality. Samples were taken from three sampling sites, at two depths during the rainy dry seasons. All physicochemical parameters did not differ significantly (p>0.05) among sampling stations. However, there were significant (p<0.05) seasonal variations. The phytoplankton comprised of 30 species, mainly Chlorophyceae (12 of total species identified), Cyanophyceae (7), Bacillariophyceae (4), Dinophyceae (3) and Euglenophyceae (4). Phytoplankton density values were higher during the dry season than the rainy season (mean value 1 592 cells/L and 2 958 cells/L respectively). Abundance was dominated by *Melosira granulate* and *Microcystis sp.* during the rainy and the dry seasons respectively. The species diversity and evenness of phytoplankton varied significantly between seasons. The Shannon-Wiener diversity index ranged from 2.21 to 3.12 and evenness from 0.72 to 0.95. Seasonal variations in the occurrence, abundance and diversity of the phytoplankton community in the reservoir are influenced by the nature of physical and chemical environment.

Keywords: Baharini reservoir, physicochemical parameters, phytoplankton, diversity

Introduction
The phytoplankton community structure in reservoirs demonstrates particular annual biological characteristics (Pongswat *et al.,* 2004) [23]. Phytoplankton species composition, numerical abundance, spatial distribution and total biomass are in direct relation with biological and environmental factors. Variations among physicochemical characteristics influence the phytoplankton abundance; different phytoplankton species exhibit different environmental selectivity, (Mkare *et al.*, 2010) [16].
Phytoplankton community structure has been adopted as an important biological indicator due to its ability to respond rapidly and predictably to a wide range of pollutants and environmental changes (Kitsiou & Karydis, 2001) [14]. Furthermore, study of shallow reservoirs concerning the behavior of abiotic and biotic factors is of particular importance as a management tool. Understanding the phytoplankton community structure provides insight into the overall ecology reservoirs and may be useful in the conservation and management of these valuable and climatically sensitive systems (Salm *et al.,* 2009) [25]. Knowledge on the changes in phytoplankton species composition across time and space can provide warning signals of degrading conditions and the possible causes. Based on the above factors, the current study was carried out to determine temporal and spatial variations in phytoplankton species composition, distribution, abundance, and diversity as one of the tools of evaluating the water quality of Baharini Reservoir.

Materials and Methods
Study site description
Baharini Reservoir is located 8 km West of Eldoret town, Uasin Gishu County, Kenya.

The County extends between longitudes 30° 50' and 35° 37' East and latitudes 0° 35' and 0° 55' North. The reservoir's maximum depth is 3 m and was constructed in 1902 through the establishment of a dam across a run-off channel and is mainly rain fed with one surface outlet. The reservoir is subjected to temporal fluctuations in water volume with high water volume in the rainy season and less water in the dry season due to high evaporation. Its catchment area is characterised by agricultural activities, urban settlement, and mining activities. Water from the reservoir is used for domestic, agriculture, fisheries, and recreational activities. The reservoir is an important ecosystem providing a habitat for birds and turtles.

Sample collection

Standard methods as described in APHA, (2005) [3] were followed for the determination of water quality parameters. Water samples were collected from three sampling sites (Figure 1) at monthly intervals for the determination of selected physical and chemical parameters and phytoplankton species composition. Triplicate samples of the parameters were collected. Surface water temperature, pH, DO, and conductivity were determined *in-situ*. Temperature and DO were determined using a calibrated HANNA DO meter (HI9143)**.** pH was determined with a portable digital pH meter (Model 8519; Clarkson Laboratory & Supply Inc., CA, USA) and conductivity measured using conductivity meter (LF 96). Secchi depth visibility was determined using 25 cm diameter black and white Secchi disk. Water samples for nutrient determination were collected using 250 ml plastic bottles. The samples were used to determine; nitrates, nitrites and dissolved reactive phosphorus according to APHA (1995) [2] standard procedures using HACH spectrophotometer model DR/820. All the chemical analyses were done at the University of Eldoret Biotechnology laboratory, Eldoret, Kenya, immediately after the sample collection. For phytoplankton analyses, 10 litres of water were drawn from the surface and 0.5 m using a graduated bucket and a Van Dorn sampler respectively. The collected water samples were sieved through a plankton net (60 μm mesh size and 30 cm diameter) and concentrated to 250 ml. Lugol's solution was added to arrest cell activity. Bottles were properly labeled at each location, transported to the laboratory, and left to stand for 24 hrs to sediment the phytoplankton. The 250 ml samples for phytoplankton analysis were further concentrated to 10 ml sub-sample for quantitative analysis. One millilitre of the concentrated sample was placed in a Sedgwick Rafter cell and phytoplankton identified and counted using an Olympus inverted microscope (IMT-2, Model). The number of phytoplankton per ml was determined using the formula adapted and modified from Boyd, (1990). Taxonomic identification followed the literature and keys of Prescott, Lange-Bertalot, John, Nwankwo, 2006 [20].

Data Analysis

Statistical analysis of the data was performed with two-way ANOVA (SPSS version 20). The mean values of the physicochemical parameters for the sampling sites and months were tested independently for each parameter. The spatial and temporal variations in phytoplankton abundance were analysed using non-parametric Kruskal Wallis ANOVA. The independent interrelationships between physicochemical parameters and phytoplankton abundance were determined using Spearman's Correlation. All statistical analyses were done at 95% level of confidence. To calculate species diversity, quantitative data of the phytoplankton were analyzed by the Shannon-Wiener index ($H' = -\sum P_i \ln P_i$) from the abundance data (Shannon & Wiener, 1963) and evenness ($J' = H'/\ln S$).

Results

Physicochemical parameters

Spatial and seasonal variations in the physicochemical parameters measured in Baharini reservoir over the study period are presented in Table 1. The physicochemical parameters (temperature, DO, pH, conductivity, and Secchi depth) did not differ significantly ($p>0.05$) among sampling stations. However, there were significant ($p<0.05$) seasonal variations, lower mean values were recorded during the rainy season compared to the dry season.

Table 1: Spatial and seasonal variations in physicochemical parameters at Baharini Reservoir over the study period (Mean ±SEM)

Parameter	Temperature (°C)	DO (mg. L⁻¹)	pH (standard units)	Conductivity (µS/cm × 100)	Secchi Depth (cm)	Nitrites (mg. L⁻¹)	Nitrates (mg. L⁻¹)	Phosphorus (mg. L⁻¹)
Station	**A**	**B**	**C**	**P-values**				
Season	Rainy	Dry		Rainy		Dry	Rainy	Dry
Temperature (°C)	19.61±0.41a	19.54±0.46a	19.56±0.44a	0.795	20.33±0.19b			
DO (mg.L⁻¹)	18.58±0.06a	18.50±0.04a	18.55±0.05a	0.557				
pH (standard units)	7.62±0.15a	7.65±0.11a	7.67±0.08a	0.760	8.04±0.49b			
Conductivity (µS/cm × 100)	15.83±1.96a	15.67±1.91a	15.67±1.91a	0.598				
Secchi Depth (cm)	55.50±7.67a	59.50±7.96a	56.50±7.58a	0.583	73.22±2.70b			
Nitrites (mg.L⁻¹)	0.032±0.006a	0.031±0.007a	0.032±0.007a	0.797	0.051±0.003b			
Nitrates (mg.L⁻¹)	8.13±1.52a	8.03±1.51a	8.10±1.52a	0.798	12.57±0.78b			
Phosphorus (mg.L⁻¹)	2.09±0.06a	2.06±0.05a	2.09±0.06a	0.776	2.20±0.08b			

Means with the same superscript along the columns are not significantly different at $p<0.05$

Phytoplankton community

A total of 30 species distributed in 5 algal classes were identified (Table 2). Chlorophyceae had the highest number of species (12), followed by Cyanophyceae (7), Bacillariophyceae (4), Euglenophyceae (4) and Dinophyceae (3). Of the 30 species, 17 were present throughout the study period, 8 appeared occasionally during the sampling period and 5 appeared only during the dry season.

Table 2: Phytoplankton composition of Baharini reservoir during study period ((√) = present; (−) = absent)

Class	Species	Season					
		Rainy			Dry		
		Months					
		September	October	November	December	January	February
Bacillariophyceae	*Cyclotellameneghiniana*	√	√	√	√	√	√
	Gryrosigma kutzingi	√	√	√	√	–	–
	Melosira granulate	√	√	√	√	√	√
	Surirela ovalis	√	√	√	–	–	√
Chlorophyceae	*Ankistrodesmus falcatus*	√	√	√	√	–	√
	Chlamydomonus sp.	–	–	–	–	√	√
	Cosmarium leave	√	√	√	√	√	√
	Crucigenia rectangularis	√	√	√	√	√	√
	Hydrodictyon sp	–	–	–	–	√	–
	Lagerheimia quadriseta	–	–	√	√	–	–
	Pediastrum boryanum	√	–	√	√	√	√
	Protococcus sp.	√	√	√	√	√	√
	Scenedesmus quadricauda	√	√	√	√	√	√
	Sphaerocystis schroeteri	√	–	–	√	√	√
	Spirogyra sp.	–	–	√	√	√	√
	Tetrum minutum	–	–	–	√	√	√
Cyanophyceae	*Anabaena sp.*	√	√	√	√	√	√
	Aphanizomenon flos-aquae	√	√	√	√	√	√
	Chroococcus minimus	√	–	√	√	√	√
	Chroococcus dispersum	√	√	√	√	√	√
	Microcystis aeruginosa	√	√	√	√	√	√
	Microcystis flos-aquae	√	√	√	√	√	√
	Spirullina spirulinoides	–	–	–	√	√	√
Dinophyceae	*Ceratium hirundinella*	√	√	√	√	√	√
	Glenodinium oculatum	√	√	√	–	–	√
	Peridinium bipes	√	√	√	√	√	√
Euglenophyceae	*Euglena acus*	√	√	√	√	√	√
	Phacus longicauda	√	√	√	√	√	√
	Strombomonas acuminate	√	√	√	√	√	√
	Trachelomonas sp.	√	√	√	√	√	√

The phytoplankton abundance among sampling sites did not differ during the study period (Figure 1 A). However, there were significant (p<0.05) differences at sampling depths, where highest abundance was recorded at the surface at all sampling stations. Seasonal variation in phytoplankton abundance was significant (p<0.05) higher values were recorded during the dry season both at the surface and 0.5m (Figure 1 B).

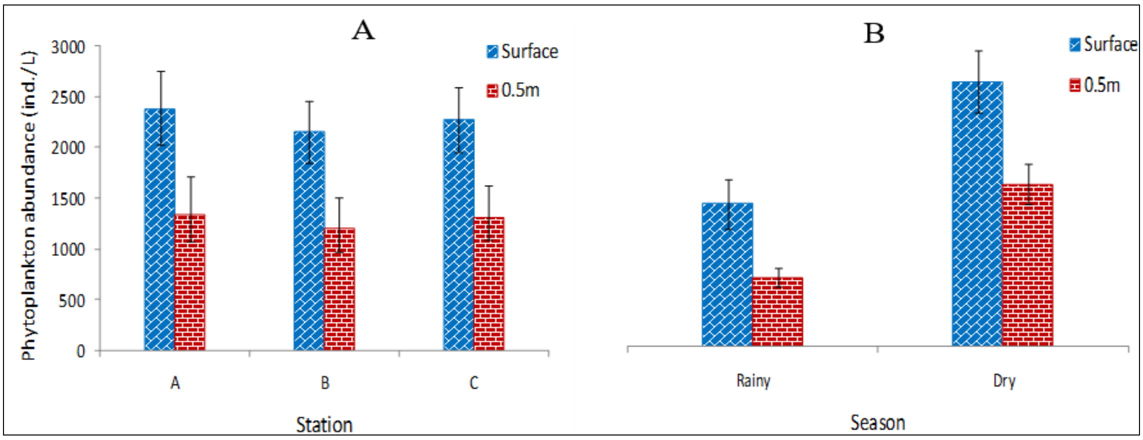

Fig 1: Spatial (A) and seasonal (B) variations in phytoplankton abundance at Baharini Reservoir during the study period (Mean ± SEM).

There were significant (P<0.05) monthly variations in class abundance (Figure 3). Bacillariophyceae and Cyanophyceae had significantly (P<0.05) higher means in October 2013 and January 2014 respectively. Dinophyceae and Euglenophyceae exhibited low class abundance throughout the study period. Significantly (p<0.05) higher means were recorded in February 2014.

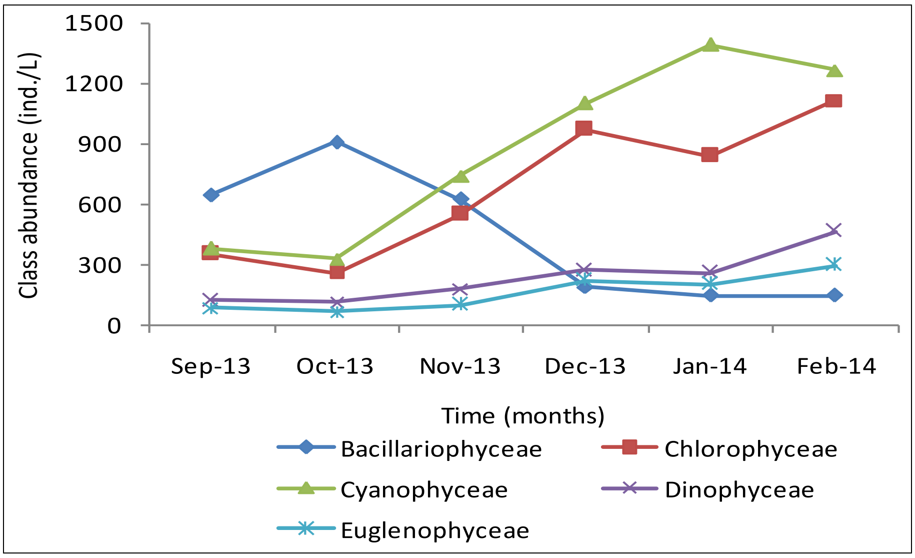

Fig 2: Monthly variations in class abundance at Baharini Reservoir during the study period (Mean ± SEM)

Phytoplankton diversity

Species diversity and evenness (Shannon Wiener) did not differ significantly (p>0.05) among the sampling site (Table 3). However, there were significant (p<0.05) seasonal variations; significantly higher values were recorded during the dry season (Table 4). Species diversity and evenness ranged between 2.21 to 3.12 and 0.79 to 0.95 respectively during the study.

Table 3: Spatial variation in species diversity and evenness during the study (Mean ± SEM)

Station	Shannon-Weiner index	
	Diversity	Evenness
A	2.76±0.066^{a}	0.87±0.011^{a}
B	2.77±0.064^{a}	0.86±0.014^{a}
C	7.74±0.052^{a}	0.86±0.014^{a}
P-values	0.729	0.840
Rainy	2.66±0.054^{a}	0.83±0.009^{a}
Dry	2.85±0.028^{b}	0.90±0.006^{b}
P-values		

Values with the same latter superscript in the same column are not significantly different at P<0.05

Bacillariophyceae abundance had significant (p<0.05) negative correlations with all physicochemical parameters (Table 5). Chlorophyceae, Euglenophyceae abundance and Chlorophyll-*a* had significant (p<0.05) positive correlations with all physicochemical parameters except Phosphorus. Cyanophyceae abundance had significant (p<0.05) positive correlations with all physicochemical parameters except Phosphorus and Nitrites. Dinophyceae abundance had significant (p<0.05) positive correlations with Secchi depth and Phosphorus.

Table 4: Correlation coefficients between physicochemical parameters and phytoplankton abundance of Baharini Reservoir during the study period (* = significant correlation at α = 0.05)

Parameter	Abundance				
	Bacillariophyceae	Chlorophyceae	Cyanophyceae	Dinophyceae	Euglenophyceae
Temperature (^{0}C)	-0.50*	0.45*	0.41*	0.03	0.53*
pH	-0.48*	0.32*	0.38*	0.09	0.50*
DO (mg.L^{-1})	-0.49*	0.42*	0.44*	0.21	0.55*
Conductivity (µS./cm)	-0.43*	0.47*	0.33*	0.16	0.57*
Secchi depth (cm)	-0.47*	0.49*	0.24*	0.24*	0.49*
Phosphorus (mg.L^{-1})	-0.36*	0.15	0.04	0.33*	0.07
Nitrites (mg.L^{-1})	-0.37*	0.41*	0.08	0.04	0.36*
Nitrates (mg.L^{-1})	-0.49*	0.51*	0.31*	0.17	0.48*

Discussion

The physicochemical parameters in this reservoir displayed considerable seasonal variation in relation to the prevailing environmental conditions. Similar observations were made by Schageri & Oduor, (2004) [26] and Mkare *et al.* (2010) [16] at Lake Naivasha and Chepkanga dam respectively.

Lower water temperatures were recorded during the rainy season. Similar observations in temperature have been reported at Lake Nakuru by Okoth *et al.*, (2009) [19]. This possibly results from thicker cloud cover during wet season.

The pH of the reservoir water was slightly alkaline with higher pH values recorded during the dry season. This was attributed to increased photosynthetic activity of phytoplankton as well as reduced mixing in this season. Araoye and Okoth *et al.*, (2009) [19] reported similar findings at Asa Lake and Lake Nakuru respectively. Dissolved oxygen concentration was significantly high during the dry season, and this was attributed to enhanced photosynthetic activities and strong wind driven surface currents which increased diffusion of atmospheric oxygen across the air-water interface. Similar observations were reported by Adon, *et al.*, (2011) [1] and Onyema & Popoola (2013) [22]. Light availability (Secchi disc depth) was lower in the rainy season compared to the dry season during the study. This may be linked to the effect of rainfall; low transparency in the reservoir during the rainy season is because of silt particles brought in by floodwaters. This finding agrees with those of Ezra and Nwankwo (2001) [9], Ibrahim *et al.* (2009) [10], Okoth *et al.* (2009) [19], Onyema, *et al.* (2008) and Onyema & Popoola (2013) [22], who reported lower transparency during the rainy season.

The nutrient concentration in the present study, are higher than those reported by Mkaire. This reflects the high-water residence time (Adon, *et al.*, 2011) [1] and evaporation in the dry season (Rangel *et al.*, 2012). Cyanophyceae genera *Anabaena* and *Aphanizomenon* (nitrogen fixing algae) higher abundance during the dry season indicates that N_2-fixation could be a significant source of internal nitrogen loading to the reservoir (Ba´rbara *et al.*, 2008) [6]. Phytoplankton assemblages showed a high level of periodicity. The variations in the composition of the phytoplankton species, with corresponding variations in environmental conditions (i.e., nutrient concentration, temperature, pH, dissolved oxygen concentration), suggest that different species exhibit different environmental selectivity and respond differently to environmental changes (Ngodhe *et al.*, 2014) [17]. The interaction of physicochemical parameters is responsible for the appearance and disappearance of phytoplankton species, including *Ankistrodesmus falcatus*, *Chlamydomonus sp.*, *Chroococcus minimus*, *Glenodinium oculatum*, *Gryrosigma kutzingi*, *Hydrodictyon sp.*, *Lagerheimia quadriseta*, *Pediastrum boryanum*, *Sphaerocystis schroeteri*, *Spirogyra sp.*, *Spirullina spirulinoides*, *Surirela ovalis* and *Tetrum minutum*. This agrees with the works of Mkare *et al.*, (2010) [16] who did similar work at Chepkanga Dam. The influence of various factors on the seasonal appearance of phytoplankton differs significantly with physical factors (such as temperature and light) being the most important and chemical factors (DO, pH, EC and nutrient level) being of lesser importance (Nowrouzi & Valavi, 2011) [18]. The abundance of phytoplankton was significantly high during the dry season thus corresponding to the period when higher temperature, transparency, pH, nutrients and ions concentration as well as reduced mixing in the reservoir were observed. This observation agrees with those of Atici & Olcay (2006), however, is contrary to those of Mustapha and Okoth *et al.*, (2009) [19], who reported increased phytoplankton cell density during the rainy season, rather than the dry season. According to Kalff, (2002) [13], precipitation can play a critical role in determination of limnological properties and phytoplankton dynamics in reservoirs by washing substantial quantity of allochthonous materials and nutrients from the catchment into the lake that can stimulate the growth and sustenance of phytoplankton populations, thereby increasing phytoplankton cell density.

Bacillariophyceae were abundant during the rainy season when low temperature and reduced transparency were recorded. Diatoms have a better ability to tolerate fluctuating light in turbulent waters (Johann *et al.*, 2007) [12]. They prefer a cool environment, occurring preferentially in temperatures below 18°C (Silva *et al.*, 2012) [24].

Cyanophyceae were the dominant group in Baharini reservoir during dry months when high water temperature, pH and nutrients concentrations occurred. This result agrees with those of Hassan, Khuantrairong & Traichaiyaporn, Salm *et al.*, (2009) [25] and Nowrouzi & Valavi, (2011) [18]. Cyanophyceae exhibit ‘K’ developmental strategy, therefore have the greatest productivity under high water temperature, pH and under optimal nutrient conditions (Islam *et al.*, 2012) [11]. Production of extracellular substances that inhibit or eliminate other algal species (Chindah *et al.*, 2007) [7] as well as the relative unpalatability of filamentous and colonial cyanobacteria may favor the selection of other algae on the part of zooplankton (Enio *et al.*, 2012) [8], thereby maintaining the dominance of cyanobacteria. The Shannon-Wiener diversity index ranged from 2.21 to 3.12 and evenness from 0.72 to 0.95. Diversity and evenness values were lower in the rainy and were attributed to lower number of species with unequal proportions of individuals. The reduced phytoplankton diversity in the wet season may be due to the low water clarity which reduced the amount of light available to the phytoplankton for photosynthesis (Onyema & Nwankwo 2006) [20] as well as a lesser possibility to stay in the euphotic zone due to mixing by floodwater. Higher diversity and evenness values recorded in the dry season were due to higher number of species with close proportions of individuals. Based on correlation analysis results; temperature, DO, pH, EC, transparency (Secchi depth) and nutrients (Phosphorus, Nitrates and Nitrites) had relations with phytoplankton abundance in Baharini Reservoir.

Conclusion

This study showed a spatial homogeneity of the physicochemical parameters in Baharini reservoir. The results also exhibited temporal heterogeneity of these parameters and could be attributed to climatic changes between months as well as seasons. The phytoplankton community structure in the reservoir exhibited both spatial and temporal variations. The vertical distribution of the phytoplankton is likely regulated by the availability of light in the water column whereas the temporal variations are influenced by seasonal variations in physicochemical parameters. Notably, the dominant species in dry season were *Microcystis*, which may produce toxins depending on the ambient conditions, presenting a risk of local toxin contamination.

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