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Impact of water hyacinth (*Eichhornia crassipes*) on water quality and phytoplankton community structure in the littoral region of Koka Reservoir, Ethiopia

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Abstract
Invasion of aquatic habitats by non-native species is a global environmental challenge with serious ecological, social and economic consequences demanding urgent action. Water hyacinth's (*Eichhornia crassipes*) appearance in Koka Reservoir was reported in 1965 and has become a threat to the aquatic ecosystem. Even though there were several limnological and fish related studies, the effects of water hyacinth on water quality and phytoplankton composition and abundance in Koka Reservoir have not been addressed. To assess its effect on water quality, composition and abundance of phytoplankton in the reservoir, samples were collected from three weed-infested and three non-infested sites from March to July 2018. The phytoplankton community, which constituted of 62 species, was dominated by Bacillariophyceae followed by Cyanophyceae and Chlorophyceae at both weed-infested and non-infested sites. The variations in the Physico-chemical parameters, abundance and species richness (d) of phytoplankton between the two sites were significant, with higher mean values in the non-infested sites ($P<0.05$). The existing infestation level of water hyacinth poses a significant effect on water quality, composition, and abundance of phytoplankton. Therefore, continuous monitoring of Physico-chemical and biological water quality parameters and the development of a sustainable management strategy are deemed imperative.

Keywords: Community structure, ecosystem, food web

Introduction

Invasion of aquatic habitats by non-native species, such as aquatic weeds, is a global environmental challenge with serious ecological, social and economic consequences demanding urgent action (Williamson 1999; Xu *et al*. 2012) [44, 45]. Water hyacinth, *Eichhornia crassipes* (Martius) Solms, is one of the world's most rampant invasive aquatic plants recognized as one of the top 10 worst weeds in the world (Mironga 2014) [27]. Recently, the adverse impacts of water hyacinth on the environment and biodiversity of aquatic ecosystems have received due attention in most continents including Asia, Australia, Africa and North America (Dagno *et al*. 2012) [8]. Water hyacinth prevents the growth and abundance of native macrophytes, phytoplankton, and zooplankton affecting biodiversity, fisheries, and livelihoods (Villamagna and Murphy 2010; Gichuki *et al*. 2012) [41, 13]. It affects the overall structure and function of the ecosystem.

In Ethiopia the weed was first encountered in the Koka Reservoir in 1965 and spread over the various water bodies of the country (Taye Tessema *et al*. 2009). [38] Several investigators have monitored the diversity and abundance of phytoplankton and zooplankton under water hyacinth mats in comparison with those of the open water in several ecosystems including Lake Tana (Chukwuka and Uka 2007; Samir *et al.* 2013; Mironga *et al*. 2014) [6, 27]. These studies have reported the significant adverse effects of water hyacinth on the composition and abundance of phytoplankton and zooplankton. However, a study on a similar aspect of the Koka Reservoir has not been conducted.

Koka Reservoir provides several ecological and economic services. A number of investigators have conducted research on several aspects of the ecosystem including water quality, plankton ecology, fish ecology, fishery, and even food web structure (Melaku Mesfin, 1988; Elizabeth Kebede and Willen, 1998) [24, 9]. None of these studies have, however, attempted to assess the impact of the weed on phytoplankton community structure and water quality in the littoral region of the reservoir.

Therefore, the main objective of the present study was to evaluate the effects of different levels of infestation of the weed on water quality and phytoplankton composition and abundance in the littoral region of the reservoir compared to open water sites. We measured a selected set of physico-chemical parameters, phytoplankton biomass, and water hyacinth at three sampling sites in both the littoral region and the open water of the reservoir.

Materials and Methods

Description of the study area

Koka Reservoir, also known as Lake Galilea, is found in south-central Ethiopia in the Shewa Zone of the Oromia Region, approximately 100 km southeast of Addis Ababa. The reservoir, with a total water spread area of 180 km^2 (BirdLife International, 2008) [3], is located at a geographical position of 08°26` N and 39° 10` E and at an altitude of 1590 m a.s.l. is characterized by a bimodal rainfall pattern, with a short minor rainy period (Mar-May) and long major rainy period (Jun-Sep) and with mean surface water temperature of 19^{o}C and continuously mixing water column.

Sampling protocol

The study was conducted for five consecutive months from March to July 2018, representing minor and major rainy periods. Sampling was carried out once a month from weed-infested littoral sites and non-infested open water sites. A total of six sampling sites were selected, three for weed-infested (heavily infested site 4 (HIS4), moderately infested site 5 (MIS5) and low infested site 6 (LIS6)), and three for non-infested (non-infested site 1(NIS1), non-infested site 2 (NIS2), and non-infested site 3 (NIS3)), each sampling sites having a replica of three sampling points. The three weed infested sites were selected based on the level of infestation of water hyacinth, to determine the level of infestation, three replicates of quadrats for each site (0.5m by 0.5m) were randomly laid across 25m transect and an abundance of above-water of the weed within each quadrat was estimated. Afterward, abundance ratings of 100, 50 and 10 plants (individuals) per 0.25m^2 quadrat were assigned to level of infestation: 0-10=low level; 11-50=moderate level and 51-100/0.25m^2=heavy level.

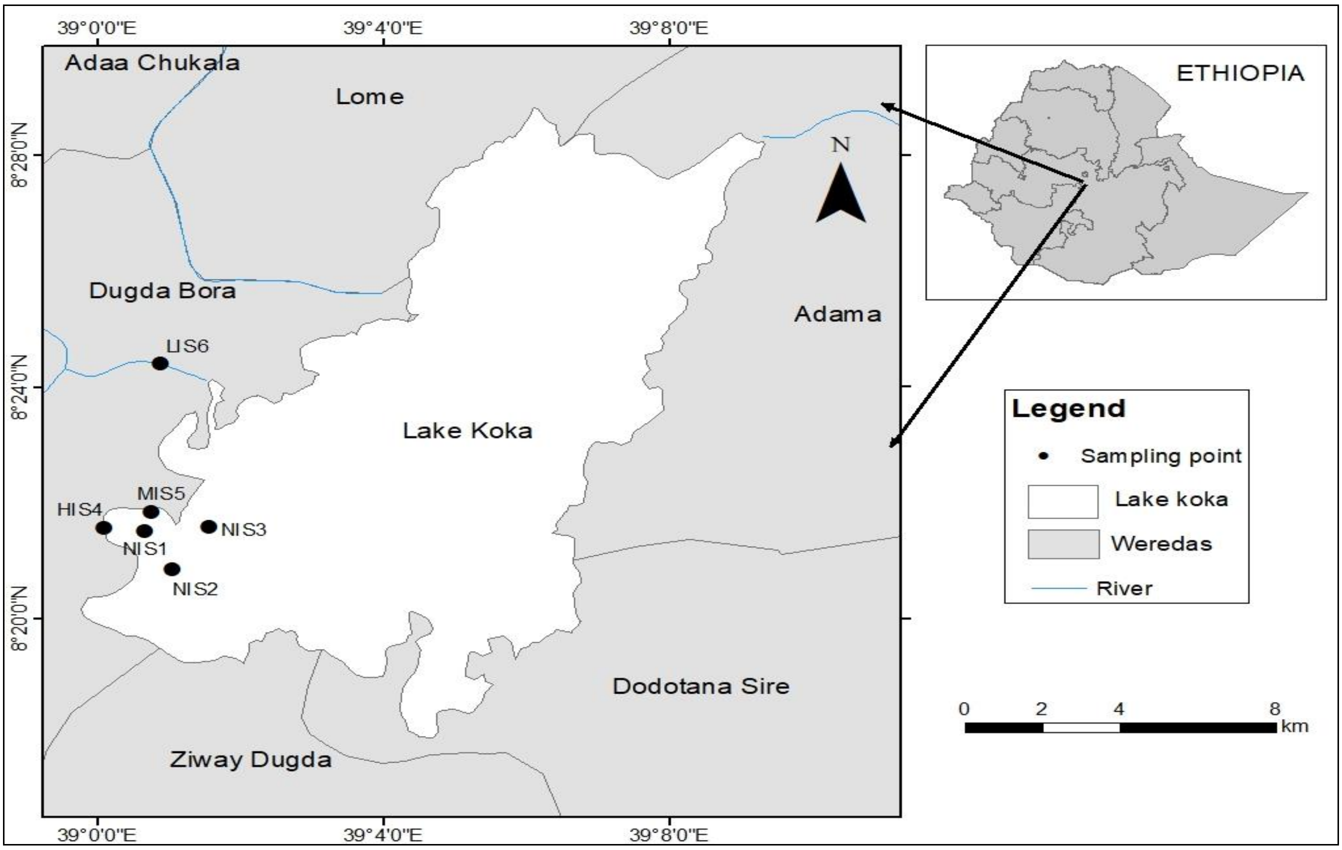

Fig 1: Map of Koka Reservoir with sampling sites indicated as closed ovals. Enset: The Location of the study area in Ethiopia

Measurement of physicochemical parameters

Dissolved Oxygen (DO), pH, specific conductance, and temperature were measured *in situ* using a multi-metric probe (HQ40d), while turbidity was measured using a turbidimeter (OAKTON T-100). Transparency of the reservoir water was estimated with a standard Secchi disk following the procedure described in APHA (1999). Samples filtered with glass fiber filters (GF/F) were used for the analysis of all nutrients except total phosphorus. Concentrations of Soluble Reactive Phosphate-phosphorus (SRP, PO4-P), Total Phosphorus (TP), (SiO_2), Ammonia (NH_3 + NH_4^+-N), Nitrate (NO_3-N) and Nitrite (NO_2-N) were determined in the laboratory using standard methods (APHA, 1999). Total dissolved solids (TDS) and Total suspended solids (TSS) were also determined gravimetrically in the laboratory following the procedures of the standard method 2540 D (APHA, 1999).

Collection of biological samples and their analysis

Water hyacinth

Three samples of water hyacinth were collected from randomly selected sampling points with the quadrat method along a transect. Aboveground biomass of the weed was estimated from the plant material collected from within 0.25m^2 quadrats. The dry weight of water hyacinth was determined after drying to constant weight at 105 °C for 24 hours using an oven (Wetzel and Likens, 1991).

Phytoplankton

Phytoplankton samples were collected from each site using a bucket for shallow weed-infested sites ranged from 0.5-1.5m and bottle sampler (Kemmerer) for open and deep littoral sites ranged from 1.5-3.0m. The samples were filtered using a 15µm mesh size net. The collected samples were immediately fixed with Lugol's iodine solution. Concentrated samples were properly mixed and 1 ml sub-samples were taken and transferred to a Sedgwick-Rafter counting chamber. Identification and enumeration (estimation of abundance) were carried out under a binocular inverted biological microscope at a magnification of 40-400x. Phytoplankton species were identified using various identification keys (Gasse 1986; Komarek and Kling 1991; Komarek and Anagnostidis, 2000; and Taylor *et al*. 2007) [12, 19, 20, 39]. Enumeration of phytoplankton was made following the procedures outlined in Hötzel and Croome (1999) [16]. The abundance of phytoplankton taxa was calculated as follows;

$$C[cells\ /\text{mL}] = \frac{\text{N}*\text{1000mm3}}{\text{A}*\text{D}*\text{F}*\text{Concentration factor}} \quad \text{.................. (Equation 1)}$$

Where:
N = number of individual counted A = area of the field (mm^2)
D = depth of a field (Sedgwick-Rafter chamber depth) (mm)
F = number of fields counted.

$$Concentration\ factor = \frac{\text{volume of lake water filtered (ml)}}{\text{volume of concentrate (ml)}} \text{........... (Equation 2)}$$

Shannon-Weaver index

The Species diversity index (H') (Shannon and Weaver, 1949) of each sample was evaluated using the equation:

$$H' = -\sum_{i=1}^{n} \text{piln(pi)} \text{ .... (Equation 3)}$$

Where; H'=Shannon-Weaver Index, i=counts denoting the i^{th} species ranging from 1 to i., pi=proportion that the i^{th} species represents in terms of a number of individuals with respect to the total number of individuals (N) in the sampling space as a whole.

Equitability or evenness (j)

Species equitability or evenness (Pielou, 1969) [28] of each sample was evaluated using the equation:

$$j = \frac{\text{H}'}{\text{Hmax}} \text{ .... (Equation 4)}$$

Where; H'=Shannon-Weaver Index, Hmax=antilogarithm of the number of species in the population.

Species richness index (d)

The Species richness index (d) proposed by Margalef (1951) [22] was used to evaluate the community structure of each sample by applying the following equation:

$$d = \frac{\text{S}-1}{lnN} \text{.................................. (Equation 5)}$$

Where; d=Species Richness Index, S=number of species in the population, N=total number of individuals in the population.

Estimation of phytoplankton biomass as chlorophyll-a

Index of algal biomass, chlorophyll-a concentration, was also estimated according to the monochromatic method of Lorenzen (1967) [21] as described in Wetzel and Likens (2000) [43].

Statistical analysis

Spatial and temporal variations of measured physicochemical parameters were analyzed using one-way Analysis of Variance (ANOVA) at a 95% significance level ($P< 0.05$). Causal relationships (correlation) among physicochemical and biological parameters were assessed and mean numbers and standard errors for each physicochemical parameter were calculated using statistical software (SPSS version 20). Tukey test was employed to determine the temporal differences of phytoplankton counts and physicochemical parameters, while pair-wise comparisons were made when testing variations between the sites. To see differences among study sites, regarding nutrient loading, Principal Components Analysis (PCA) was employed using PAST software. The relationship between the abundance of taxa of phytoplankton with physicochemical parameters was assessed by using a multivariate analysis tool, Redundancy Analysis (RDA), using CANOCO for Windows version 4.5.

Results

Physico-chemical parameters

Most of the hysicochemical parameters recorded in this study showed both spatial and temporal variations (Tables 1 and 2). The mean surface water temperatures recorded for the HIS4 (24.62±0.617) MIS5 (22.94±0.934) and LIS6 (23.86±0.723) sites were slightly higher than those of the non-infested open water sites, NIS1 (22.52±0.695), NIS2 (22.84±0.705) and NIS3 (22.26±0.675) did not significantly differed (P>0.05). The mean transparency (Secchi depth) value recorded for the two study sites showed statistically significant variation ($P<0.05$, Table 2), with the mean value recorded for the non-infested sites (20.54±3.41cm) exceeding that of the weed-infested sites (14.8±3.56cm). The mean values of pH and Total Dissolved Solids (TDS) recorded in this study were 8.34±0.423 and 676.66±180.49 for the non-infested sites and 8.32±0.092 and 643.33±137.44 for the weed-infested sites, respectively. Statistically, there was no significant spatial difference (P>0.05, Table1) between the two sites in the levels of TDS and pH although relatively higher values of TDS and pH were recorded in the non-infested sites.

Table 1: Mean ±SE, minimum and maximum values of the physicochemical parameters recorded for the water hyacinth-infested and non-infested sites

Parameters	Non-infested sites			Weed-infested sites		
	Mean±SE	Min	Max	Mean±SE	Min	Max
T(˚C)	22.54±0.37	20.2	24.8	23.8±0.46	21.3	26.3
pH	8.34±0.42	5.56	9.74	8.32±0.09	8	8.86
K_{25}(µScm^{-1})	118.7±5.13	77.2	139.8	138.6±8.58	80.2	210.7
TDS (mg/L)	676.66±180.5	100	1300	643.33±137.4	200	1100

TSS (mg/L)	127±20.73	40	260	258.47±45.85	107	820
DO (mg/L)	6.86±0.21	5.46	8.67	3.77±0.375	1.1	6.46
Secchi depth(cm)	19.6±1.57	10	27	13.2±1.55	5	26
Salinity (mg/L)	89±3.85	57.9	104.85	103.55±6.89	60.15	158
Turbidity (NTU)	98±4.48	50	120	194.8±25	100	380

The mean values of TSS and turbidity recorded in this study were 127±20.74 mg/L and 98±4.48 NTU for the non-infested sites and 258±45.85 mg/L and 194.8±25 NTU for the weed-infested sites, respectively. Both TSS and turbidity showed significant spatial variations ($P<0.05$, Table 1). Dissolved oxygen (DO) concentration exhibited a statistically significant spatial variation between the non-infested and infested sites ($P<0.05$, Table 1, Figure 2). The mean dissolved oxygen (DO) concentration of the non-infested sites (6.86±0.725 mg/L) was higher than those of HIS4, MIS5 and LIS6 sites (2.88±1.42, 3.61±1.33, and 4.814±1.11mg/L, respectively). The highest value of dissolved oxygen (DO) concentration was recorded at the non-infested sites (8.67 mg/L) while the minimum was observed at the HIS4 site (1.10 mg/L). Statistically significant spatial variation ($P< 0.05$) was also recorded between HIS4 and LIS6 sites. Though not statistically significant, mean (K_{25}) and salinity showed variations between the two sites (Table 2) with higher values of electrical conductivity and salinity occurring at the weed-infested sites (210.7 µS cm^{-1} and 158 mg/L, respectively) than at the non-infested sites (139.8µS $cm^{-1}$and 104.63 mg/L, respectively). The concentrations of inorganic nitrogen species, Nitrate, (NO_3-N) and Ammonia (NH_3+ NH_4^+-N)), showed statistically significant variations between the non-infested and weed-infested sites ($P<0.05$, Table 2, Appendix 1). In the non-infested sites, the mean value of nitrate (211.33±11.36 µg/L) was slightly higher than those of the HIS4 and MIS5 sites (152.±4.89 µg/L, 138±6.78 µg/L, respectively). The mean value of ammonia was slightly higher in the non-infested sites (46.93±7.2 µg/L) than in the HIS4 and MIS5 sites (44.6±7.4 µg/L, 43.2±5.47 µg/L, respectively)

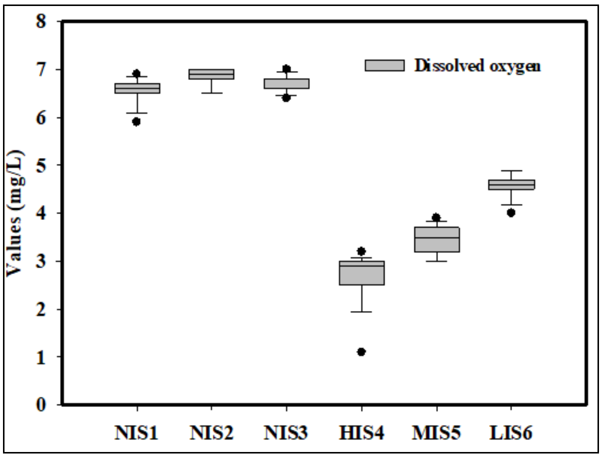

Fig 2: Spatial trends of oxygen concentrations at the study sites

Mean concentrations of soluble reactive phosphate-phosphorus (PO_4-P, SRP) and Silica (SiO_2) showed statistically significant differences between the non-infested sites and weed-infested sites ($P<0.05$, Table 2). Mean SiO_2 concentrations recorded for HIS4 and MIS5 (7.1±4.6 and 6.12±3.75) were broadly similar to that observed for the non-infested sites (6.84±1.94 mg L^{-1}) while the mean silica level determined for LIS6 (28.23±3.83 mg L^{-1}) was about 4 to 4.5 times those of all other sites. The mean values of silica showed significant variation between non-infested and infested sites ($P<0.05$, Table 2).

Table 2: Minimum (Min), maximum (Max) and mean concentrations of nutrients recorded for the study sites

Parameter	Non-infested sites			Weed-infested sites			p-value
	Mean±SE	Max	Min	Mean±SE	Max	Min	
NO3-N (µg L-1)	211.33±6.54	260	170	159±4.58	180	140	0.00
NH3-N (µg L-1)	46.93±3.89	75	32	43.9±4.35	65	29	0.07
PO4-P (µg L-1)	168.1±17.78	248.9	53.96	149.8±20.25	258.7	53.9	0.00
SiO2 (mg L-1)	5.1±1.6	17.69	1.15	6.60±2.75	24.45	0.02	0.00

Phytoplankton composition and abundance

During the study period, 62 taxa belonging to the six taxonomic classes Cyanophyceae (blue-green algae, 12), Bacillariophyceae (diatoms, 16), Chlorophyceae (green algae, 27), Euglenophyceae (euglenoids, 5), Cryptophyceae (cryptomonads, 1) and Dinophyceae (dinoflagellates, 1) were identified (Table 3). The species composition and abundance of weed-infested and non-infested sites showed statistically significant differences regarding most taxonomic groups ($P<0.05$, Figure 4, Appendix 2). Bacillariophyceae, Cyanophyceae, and Chlorophyceae had higher densities in the non-infested sites (190473, 67116 and 48058 Cells mL^{-1}) than in the weed-infested sites (51366, 20900, 14416 Cells mL^{-1}), respectively. Bacillariophyceae was the most dominant group both in the non-infested and weed-infested sites, with a maximum density of 190,473 and 51366 cells mL^{-1} and with percentage contributions of 60% and 52% to the total phytoplankton counts at the two sites, respectively (Figure 3). *Aulacoseira granulata*, *Cylindrospermopsis* spp., *Microcystis aeruginosa*, *Synedra ulna*, *Anabaena* spp. and *Closterium acutum* were the most common taxa at both sites. The density of phytoplankton taxa showed statistically significant spatial differences between the weed-infested and non-infested sites and also among the weed-infested sites ($P<0.05$), with much higher abundance in the non-infested sites (Figure 4).

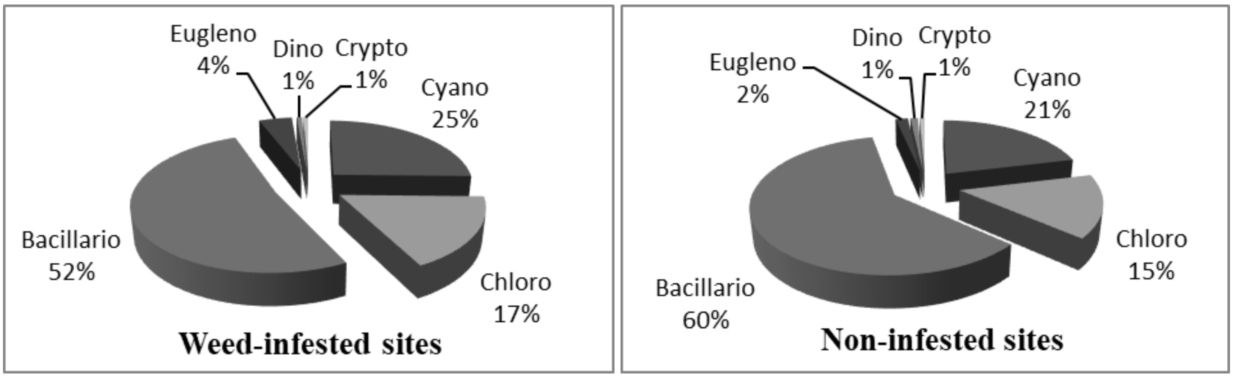

Fig 3: Percentage contribution of phytoplankton classes to the total phytoplankton counts. (Cyano=Cyanophyceae, Chloro= Chlorophyceae, Bacillario= Bacillariophyceae, Eugleno= Euglenophyceae, Dino= Dinophyceae, Crypto= Cryptophyceae)

Table 3: Phytoplankton taxa identified during the study period.

	Non-infested sites	**Infested sites**
Blue green algae	*Anabaena flos- aquae* Bréb. *A. philippinesis* *A. spiroides* Kleb *A. torulosa* *Anabaenopsis* spp. *Aphanizomenon gracile* Lemm *Cylindrospermopsis africana* Kom. and Kaling *C. raciborskii* Wolosz. *Microcystis aeruginosa* (Kütz) Kütz M. *flos-aquae* Kütz. *M. panniformis (Kom) Komárková-Legnerová* *M. wesenbergii* (Komárek) Komárek	*Anabaena flos- aquae* Bréb. *Aphanizomenon gracile* Lemm *Cylindrospermopsis africana* Kom. and Kaling *Microcystis aeruginosa* (Kütz) Kütz
Green algae	*Actinastrum hantzschii Lagerh.* *Ankistrodesmus braunii* *A. convolutes* *A. nannoselene* *Ankyra judai* *Chlorella* sp. *Closterium acutum v.variable (lemm.) krieg* *Closterium dianae* *Chlamydomonas ambigua* *Cosmarium* spp. *Oocystis* spp. *Pediastrum simplex* Meyen *P. boryanum* (Turp.) Meneghini *P. duplex* *P. gracillium* *Scenedesmus acuminatus var. minor* G.M.Smith *S. granulate* *S. quadricauda* (Turp).Breb. *Selenastrum* spp. *Staurastrum cingulum* *S. obesum* *S. upplandich* *Tetraedron* spp.	*Actinastrum hantzschii Lagerh* *Ankistrodesmus nannoselene* *Ankyra judai* *Closterium dianae* *Chlamydomonas ambigua* *Cosmarium* spp. *Monorophidium griffithii* *Oocystis* spp. *Pediastrum duplex* *Scenedesmus acuminatus* *S. angularis* *S. guadricauda* *Staurastrum obesum* *S. upplandich* *Selenastrum* spp.
Diatoms	*Aulacoseira granulata* (Ehr.) Simons. *Cyclotella cemta* *C. melosiroids* *Cymbella* spp. *Diatoma kenuis* *Diploneis ovalis* *Eunotia zasuminensis* *Fragilaria construes* *F. pinnatta* *F. virescens* *Gyrosigma* spp. *Melosira ambigua* *M. granulate* *Navicula* spp. *Nitzschia* spp. *Synedra ulna (Nitzsch.) Lange Bert*	*Aulacoseira granulata* *Cyclotella cemta* *Diatoma kenuis* *Fragilaria construes* *F. pinnatta* *Gyrosigma obtusatum* *Melosira ambigua* *Navicula* spp. *Nitzschia* spp. *Synedra ulna (Nitzsch.) Lange Bert*
Euglenophyceae	*Euglena acus Her*	*Euglena acus Her*

	E. oxyuris schmarda *Phacus longicauda (Ehr.) Duj.* *P. tortus* *Strombomonas* sp.	*Phacus longicauda (Ehr.) Duj.*
Dinophyceae	*Peridinium inconspicuum*	
Cryptophyceae	*Cryptomonas* spp.	

Higher mean values of Shannon-Weaver's index (H') and species richness (d) of phytoplankton were recorded for the non-infested sites than for the weed-infested sites while the slightly higher mean value of species evenness (j) was recorded in the weed-infested sites. The values of Shannon-Weaver's index, species evenness (j) and species richness (d) at both sites were lower in April while they reached their maximum during June. Species richness (d) showed a significant difference between the two sites ($P<0.05$). Shannon-Weaver's index (H') and species evenness (j) showed significant temporal differences ($P<0.05$, Table 4).

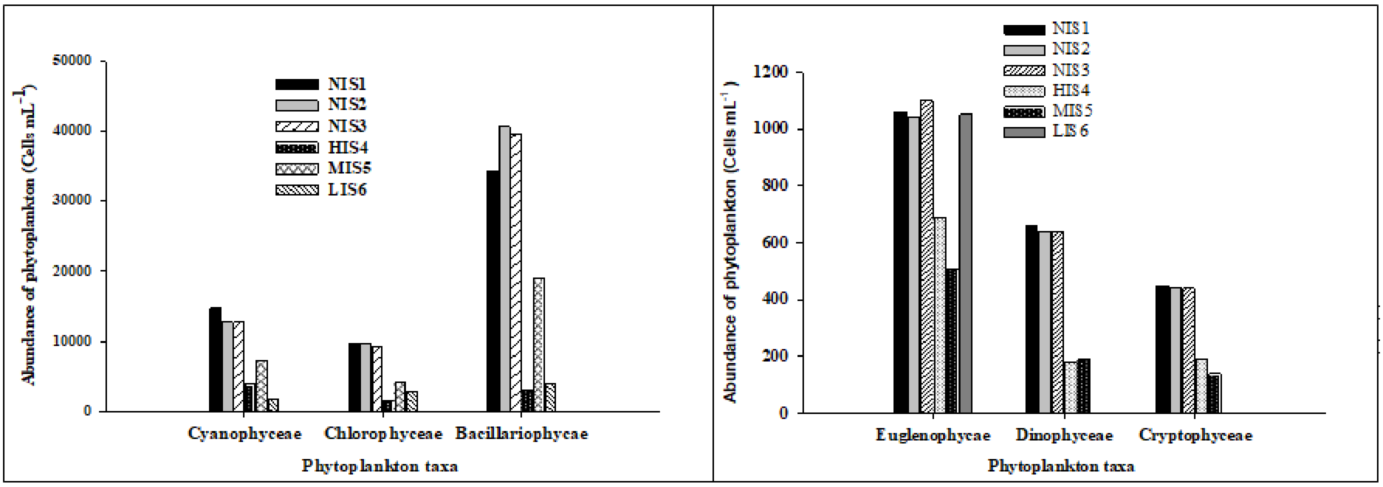

Fig 4: Spatial trends of phytoplankton abundance (abbreviations: NIS1=non-infested site 1, NIS2=non-infested site 2, NIS3= non-infested site 3, HIS4=heavily infested site 4, MIS5=moderately infested site 5, LIS6=low infested site 6)

Table 4: Results of diversity indices computed for phytoplankton species.

Diversity indices	Non-infested sites		Weed-infested sites		p-value
	Range	Mean±SE	Range	Mean±SE	
H`	1.12 - 3.1	2.25±0.204	1.43 – 2.49	2.14±0.089	0.137
j	0.34 – 0.91	0.67±0.06	0.55 – 0.97	0.78±0.04	0.165
d	2.35 – 2.62	2.53±0.03	1.11 – 2.5	1.7±0.13	0.00

The relationship between physicochemical parameters and density of phytoplankton taxa

The relationship between phytoplankton taxa and physicochemical parameters is shown in Figure 5. In this Redundancy Analysis, the first two axes accounted for 98.5% of the cumulative percentage variance in species–environmental relationship. The first axis accounted for 97.1% of the variance, and showed strong positive correlations with silica, specific conductance, salinity, temperature, and TSS, while it was negatively correlated with phosphate, TDS, Nitrate, DO and pH levels. However, axis 2, which accounted for 1.4% of the variance, was correlated positively with silica, TSS, TDS and temperature and negatively with nitrate, phosphate, pH, DO, specific conductance and salinity.

The density of Bacillariophyceae was positively correlated with dissolved oxygen, and nitrate (r = 0.461, $P<0.05$, 0.546, $P<0.01$, respectively) and negatively correlated with TSS and temperature (r=-0.484 and 0.405, $P<0.05$). Cyanophyceae was also positively correlated with dissolved oxygen and pH (r=0.725, $P<0.01$, r=0.400, $P<0.05$, respectively) and negatively correlated with temperature (r=-0.444, $P<0.05$). Chlorophyceae was positively correlated with dissolved oxygen and nitrate (r=0.729, $P<0.01$, r=0.478, $P<0.05$, respectively) and negatively correlated with specific conductance and salinity (r=-0.491 and r=0.491, $P<0.05$). Euglenophyceae was, however, positively correlated with specific conductance and salinity (r = 0.533 and 0.533, $P<0.01$). Dinophyceae was positively correlated with dissolved oxygen and pH (r = 0.506 and r=0.423, $P<0.05$), while Cryptophyceae was positively correlated with dissolved oxygen and TSS (r = 0.467 and r=0.468, $P<0.05$) and negatively correlated with electrical conductivity and salinity (r=-0.467, and r=0.467, $P<0.05$)

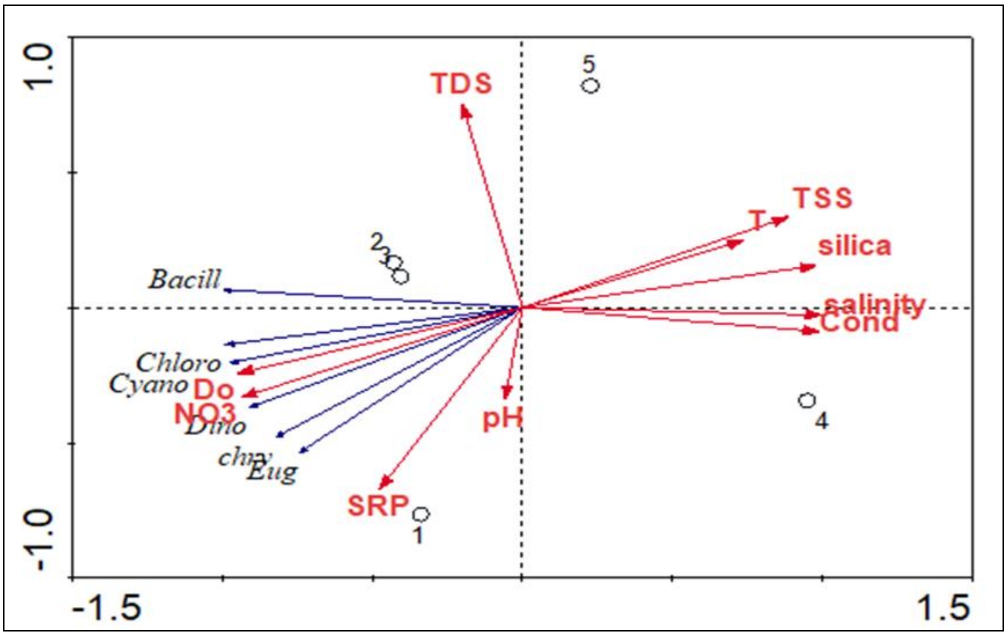

Fig 5: *Ordination diagram of Redundancy Analysis (RDA) of the first two ordination axes summarizing the relationship between physicochemical variables and phytoplankton taxa (Abbreviations; 1=NIS1, 2=NIS2, 3=NIS3, 4=HIS4, 5=MIS5, TDS=total dissolved solid, TSS= total suspended solid, Cond=specific conductance, NO3= Nitrate, T=Temperature, SRP=Soluble reactive phosphate-phosphorus, DO=Dissolved Oxygen, Bacill=Bacillariophyceae, Chloro=Chlorophyceae, Cyano=Cyanophyceae, Dino=Dinophyceae, Chry=Cryptophyceae, Eug=Euglenophyceae).*

Discussion

Physico-chemical parameters

Significant spatial and temporal variations were observed in all physicochemical parameters except temperature measured during this study (Tables 2 and 3). The absence of significant spatial variation in water temperature at the non-infested sites may be attributable to the polymictic nature of the reservoir, which mixes with strong turbulence every day. However, the condition at the weed-infested sites could be associated with the presence of water hyacinth, which may deter the heat transfer between surface water and the atmosphere, minimizing temperature variation in the area. Similar results were reported by Schreiner (1980) and Mironga, *et al*. (2012) [26] in their study on South Georgia Pond and Lake Naivasha, Kenya, respectively. The lowest mean Secchi depth recorded for the weed-infested sites seems to reflect water hyacinth's effect associated with its capacity to reduce wind-induced mixing due to the complex structure of its leaves and roots, which make particles remain suspended in the water column thereby reducing water transparency, the extensive mat coverage of water hyacinth prevents both organic and inorganic matters from settling down to the bottom (Chukwuka *et al*., 2008; Mironga *et al*., 2012) [7, 26]. The high concentration of dissolved solids and suspended particulate matters, which enter the reservoir through its feeder rivers, may have also contributed to the lowest Secchi depth recorded for the weed-infested sites during the study period. Turbulence due to wind-induced mixing, water input through tributary rivers from the catchment area and relatively high phytoplankton density seem to be the main factors responsible for the low water transparency during the pre-rainy and rainy months. Higher values of TSS and turbidity of the weed-infested sites may be an indication of the effect of water hyacinth on the water quality of the reservoir. The highest values of TSS and turbidity recorded at both sites in June and July, respectively, are attributable to the disturbance of the reservoir by runoff from the surrounding catchment and feeder rivers.

Although not statistically significant, the relatively lower pH values recorded at the weed-infested sites, when algal biomass was lower and when weed biomass was higher, may have resulted from the CO_2 contributed by the incoming water from agricultural areas through runoff and decomposition of organic matter by bacteria. The relatively high pH values of the non-infested sites, particularly those recorded during May, coincident with high phytoplankton densities; seem to be associated with the removal of carbon dioxide by algal communities through their intense photosynthetic activities and the consequent increase in pH (Atobatele and Ugwumba, 2008) [2].

The relatively low mean TDS value recorded for the weed-infested sites is in line with the substantial capacity of Water hyacinth to remove TDS from the water surface through accumulation by means of its complex root structure (Borges *et al*., 2008; Gamage and Yapa 2001) [4, 11]. Lower mean values of TDS at weed-infested sites were also reported by other authors (Chukwuka and Uka 2007; Borges *et al*. 2008) [6, 4].

During this investigation, considerably lower dissolved oxygen concentration was observed at the weed-infested sites, which was markedly lower at the highly weed-infested site (1.1 mg^{-1}) than that recorded for the non-infested sites (8.67mg^{-1}). This is primarily related to the large mat of the weed that blocks sunlight from the atmosphere thereby affecting photosynthesis in the water column, consumption of dissolved oxygen during decomposition of organic matter that emanated from its biomass coupled with the relatively higher temperature, and the prevention of gaseous exchange between the atmosphere and the surface water by thick mat of the weed. The results of the present study are in line with the findings of the different studies documented by some investigators (McVea and Boyd, 1975; Rommens *et al*., 2003; Chukwuka *et al.*, 2008; Mironga *et al*., 2012) [25, 32, 7, 26]. The highest oxygen concentration recorded in June (8.67 mg/L) for the non-infested sites may be associated with phytoplankton bloom dominated by the cyanobacterial genus *Microcystis*.

The observed lower concentration of SRP and nitrate at the weed-infested sites is in agreement with the contention that water hyacinth assimilates large quantities of nutrients affecting nutrient availability in the water column, which may stress the growth of other plants and algae ((McVea and Boyd, 1975; Schreiner, 1980; Pinto and Greco, 1999) [25]. Water hyacinth, compared to other macrophytes, has a high nutrient uptake rate and the ability to accumulate vast amounts of nutrients in its tissue (Rezania *et al*., 2013) [31]. This property of the weed may have a significant effect on the concentrations and turnover rates of nutrients in the reservoir (Pinto and Greco, 1999) [29]. Similar results were observed by Marshall (1997) [23] in Lake Chivero (Uganda) and Mironga *et al.* (2012) [26] in Lake Naivasha (Kenya). Higher nutrient concentrations were recorded at the non-infested sites than at the weed-infested sites. However, a higher concentration of silica was observed at the weed-infested sites, which may have resulted from the low abundance of diatoms (Bacillariophyceae).

Phytoplankton composition and abundance

In the present study, we identified 62 phytoplankton species, which is a lower taxa number compared to the historical data reported by Elizabeth Kebede and Willen (1998, 72 species) [9]. Fasil Degefu *et al*. (2011) [10] also documented that cyanobacteria (*Anabaena* and *Microcystis* spp.) were the dominant taxa during their study period. In the present study, however, Bacillariophyceae, *Aulacoseira granulata* and *Synedra ulna*, in particular, were the most dominant taxa. Thus, *Aulacoseira granulata* accounted for 45.64% and 29.16% of the total phytoplankton abundance at the non-infested and weed-infested sites, respectively. Diatoms are denser than the aquatic medium due to the presence of siliceous frustules and consequently, *Aulacoseira granulata* is a rapidly sinking planktonic diatom (Reynolds, 1994) [30]. The dominance of such sinking diatoms could be explained by the polymictic nature of the reservoir.

Koka Reservoir is a frequently mixing strongly turbulent ecosystem, which enables diatoms to return to the water column after sinking to the reservoir's bottom. Furthermore, the high nutrient concentration and its adaptation to low light conditions (Reynolds, 1994) [30] might favor its dominance and abundance at both sites of the reservoir even though there was variation in its abundance between the two sites. Other studies have also reported that it is the most common diatom species in shallow mixing lakes and in deeper lakes during high turbulence (Kilham and Kilham, 1975; Hecky and Kling, 1987) [18, 15]. Cyanophyceae, constituted primarily by *Microcystis* and *Anabaena spp.*, was the second dominant taxon at both sites. Its dominance may be associated with several environmental factors such as low light (Smith, 1986) [37], high temperature (Shapiro, 1990) [36], low carbon dioxide or high pH (Caraco and Muler, 1998) [5] and high total phosphate (Watson *et al.*, 1997) [42].

The third dominant group of phytoplankton at both sites was Chlorophyceae, which was constituted largely by *Oocystis, Closterium acutum, Actinastrum hantzshii,* and *Chlamydomonas* spp. Both Chlorophyceae and Cyanophyceae were relatively more abundant at the weed-infested sites than the non-infested sites.

The presence and subsequent collapse of water hyacinth had an adverse effect on the aquatic ecosystem through degradation of its environmental quality (John-Stephen *et al*., 2009) [17]. The composition and abundance of the phytoplankton community could also change due to the nutrients released from the decomposed water hyacinth plant. In comparison with weed-infested sites, non-infested sites had higher phytoplankton diversity and taxa richness. This observed disparity could be attributed to the allelopathic effect of water hyacinth on some algal species besides competition for nutrients and light (Gross, 2003) [14]. The existence of a high diversity of species, usually represented by fewer individuals, is characteristic of a stable ecosystem (Türkmen and Kazanci, 2010) [40]. However, a few species with a high number may occur when habitats or niches are constrained by physical or chemical factors. Similarly, the observed higher density of few phytoplankton species such as *Aphanizomenon electus, Anabaena* spp., *Scenedesmus* spp., *Oocystis* spp., *Closterium acutum*, *Actinastrum hantzshii, Synedra ulna* and *Chlamydomonas* at the weed-infested sites also indicates a perturbation of the site. Species of phytoplankton like *Pediastrum simplex*, *Pediastrum duplex*, *Pediastrum boryanum*, *Cosmarium* sp., *Fragilaria pinnate*, *Cymbella* species, and *Diploneis ovalis* were not encountered in the samples collected from the HIS4 and were rarely found at the MIS5 and LIS6 of the weed-infested sites, while *Gyrosigma obtusatum* and *Monoraphidium griffithii* were encountered only in the samples collected from the weed-infested sites. This finding demands further study to explain how some species were found only in some parts of the ecosystem.

Conclusions and Recommendations

Water hyacinth biomass in Koka Reservoir varied both spatially and temporally with the highest weed biomass occurring during the rainy months (June and July). Due to the lack of control or absence of intervention measures, its density was increasing throughout the sampling period (March-July). The existing infestation level of water hyacinth poses a significant effect on water quality, composition, and abundance of phytoplankton. Environmental conditions like nutrients are favorable for its proliferation. Statistically significant spatial differences in most physicochemical characteristics of the reservoir, composition, and abundance of phytoplankton were observed between the non-infested and weed-infested sites. The observed marked effect of the weed on the reservoir’s ecosystem was due to its high density, extensive mat coverage, lack of control intervention campaign and extent of accumulation of its detritus. The further proliferation will continue to occur and the weed may even spread to new areas and worsen its effect. 20% of koka reservoir is infested by water hyacinth and it needs an urgent management action, i.e., physical removal as an immediate solution and proper planning for an integrated approach to this problem, which includes the use of biological agents such as beetles and insects. The situation also points out the need for the development of sustainable management of agricultural and industrial wastes.

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1. Appendix

Appendix 1: One-way ANOVA test results of spatial variations in physicochemical features.

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Nitrate	Between Groups	5953266.667	5	1190653.333	2023.773	.000
	Within Groups	14120.000	24	588.333		
	Total	5967386.667	29			
Nitrite	Between Groups	14887.767	5	2977.553	6.512	.001
	Within Groups	10973.200	24	457.217		
	Total	25860.967	29			
Ammonia	Between Groups	4274.800	5	854.960	4.216	.007
	Within Groups	4867.200	24	202.800		
	Total	9142.000	29			
Soluble reactive phosphorus	Between Groups	1140018.128	5	228003.626	7.557	.000
	Within Groups	724150.327	24	30172.930		
	Total	1864168.455	29			
Total phosphorus	Between Groups	1895231.006	5	379046.201	2.934	.033
	Within Groups	3100569.296	24	129190.387		
	Total	4995800.303	29			
Silica	Between Groups	2130.513	5	426.103	6.775	.000
	Within Groups	1509.462	24	62.894		
	Total	3639.975	29			
Total suspended solid	Between Groups	230042.667	5	46008.533	2.560	.054
	Within Groups	431347.200	24	17972.800		
	Total	661389.867	29			
Total dissolved solid	Between Groups	309000.000	5	61800.000	.473	.793
	Within Groups	3138000.000	24	130750.000		
	Total	3447000.000	29			
Temperature	Between Groups	19.955	5	3.991	1.457	.240
	Within Groups	65.724	24	2.739		
	Total	85.679	29			
Dissolved oxygen	Between Groups	81.800	5	16.360	13.689	.000
	Within Groups	28.682	24	1.195		
	Total	110.482	29			
pH	Between Groups	.954	5	.191	.337	.886
	Within Groups	13.603	24	.567		
	Total	14.556	29			
Specific conductance	Between Groups	4441.448	5	888.290	1.092	.390
	Within Groups	19522.163	24	813.423		
	Total	23963.611	29			
Turbidity	Between Groups	133387.031	5	26677.406	8.830	.000
	Within Groups	72512.312	24	3021.346		
	Total	205899.343	29			
Secci Depth	Between Groups	338.000	5	67.600	1.640	.188
	Within Groups	989.200	24	41.217		
	Total	1327.200	29			
Salinity	Between Groups	2498.655	5	499.731	1.092	.390
	Within Groups	10981.895	24	457.579		
	Total	13480.550	29			

Appendix 2: Phytoplankton density differences between infested and non-infested sites.

Anova					
	Sum of Squares	**df**	**Mean Square**	**F**	**sill**
Cyanophyceae Between Groups	7.224E8	5	1.445E8	13.425	uuu
Within Groups	2.583E8	24	1.076E7		
Total	9.807E8	29			
Chlorophyceae Between Groups	3.557E8	5	7.114E7	12.392	uuu
Within Groups	1.378E8	24	5741062.500		
Total	4.935E8	29			
Bacillariophyceae Between Groups	6.549E9	5	1.310E9	3.522	LEI r.
Within Groups	8.926E9	24	3.719E8		
Total	1.548E10	29			
Euglenophyceae Between Groups	1517416.667	5	303483.333	.789	
Within Groups	9233000.000	24	384708.333		
Total	1.075E7	29			

Dinophyceae Between Groups	2169750.000	5	433950.000	2.610	051
Within Groups	3991000.000	24	166291.667		
Total	6160750.000	29			
Chryptophyceae Between Groups	*930666.667*	5	186133.333	2.485	959
Within Groups	1798000.000	24	74916.667		
Total	*2728666.667*	29			

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