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WATER QUALITY, COMPOSITION AND ABUNDANCE OF PHYTOPLANKTON IN RELATION TO WATER HYACINTH IN THE NORTHEASTERN PART OF LAKE TANA, ETHIOPIA

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ABSTRACT

Water hyacinth (Eichhornia crassipes (Mart) Solms), a perennial and stoloniferous aquatic herb, is non-indigenous to Lake Tana. Its presence in the lake was recognized during the last three to four years and it has become a threat to the lake ecosystem. To assess the lake water quality, composition and abundance of phytoplankton, samples were collected from three weed-infested and three non-infested sites from September 2012 to May 2013. Sampling was carried out four times (once in each four seasons). In this investigation, the effect of water hyacinth on physico-chemical characteristics of the lake water was not significant. However, its effect on some parameters such as TDS, temperature, specific conductance, total hardness, Secchi depth, PO4-P, NO3-N and NH3-N were manifested. A total of 68 phytoplankton species were identified. The phytoplankton community was dominated by Chlorophyceae (mainly Chlamydomonas sp.) in the weed-infested sites and Bacillariophyceae in the non-infested sites. Small density difference was observed between the two sites. However, significant variations of Shannon's index (H') and species evenness (j) of phytoplankton were observed between the two sites with higher mean value in the non-infested sites than weed-infested sites. Short infestation time and control intervention through physical removal contributed to minimize its effect. However, environmental conditions are currently favorable for its optimum growth and further proliferation might be going on and even spreading to new areas which were not infested before. This may exacerbate the effect of water hyacinth in future and therefore, continuous follow up and designing sustainable management strategies including biological agents, regulation of agricultural and urban wastes and even removal of the weed through utilization should get due attention.

Keywords: Abundance, Composition, Lake Tana, Phytoplankton, Water hyacinth.

1. Introduction

Water hyacinth, *Eichhornia crassipes* (Mart.) Solms, which originated in South America, is one of the world's most rampant invasive aquatic plants. The weed spread throughout the world in the late 19th and early 20th century (Wilson *et al*., 2005). Recently, it has invaded freshwater systems of over 60 countries of the five continents. Water hyacinth is one of the five invasive alien plants found in Ethiopia (Firehun Yirefu *et al*., 2007) and has been recognized as the most damaging aquatic weed since its first appearance in 1965 (Rezene Fessehaie, 2005). The weed tends to spread out over water bodies where hydrological or nutrient conditions have been altered by human activities (Barret, 1989). It is widespread in tropical and subtropical water bodies where nutrient levels are often high due to agricultural runoff, deforestation, and insufficient wastewater treatment. Its success as an invader is attributed to its ability to outcompete native vegetation and phytoplankton for light and nutrients. Nutrients and temperature are considered to be the strongest determinants of the growth and reproduction of water hyacinth (Wilson *et al*., 2007). Salinity constraints generally limit water hyacinth's establishment in coastal areas and within estuaries (Mangas-Ramirez and Elias-Gutierrez, 2004).

Though it is not obvious when and how the weed entered into Lake Tana, it appeared during the last three to four years in some pocket grazing and farm wet areas near the mouth of Megech River and proliferated and covered shoreline habitats from Rib to Dirma River mouths. According to the ANRS BOEPLAU survey report (2012), the weed has occupied 20,000 ha of the lake area and extended up to 1 km inwards.

Similarly, Ayalew Wondie *et al*. (2012) reported that the infested area expanded to more than 10% of the shoreline areas in the north-eastern part of the lake. This study was, therefore, designed to determine the extent of the effect of water hyacinth on the composition and abundance of phytoplankton in association with water quality in the lake ecosystem.

2. Materials and Methods

2.1. The study area

Lake Tana is the largest (3150 km^2) freshwater body situated in the north-western highlands of Ethiopia at an elevation of 1800 m. It has a volume, maximum and mean depth of 28 km^3, 14 m and 8 m, respectively. Its water level depends on the volume of the outflow to Blue Nile River and the recently constructed Tana-Beles hydropower and irrigation scheme and, the volume of inflow from the tributary rivers especially in the main rainy season. The lake has eight permanent inflowing rivers (Gilgel Abay, Rib, Gumara, Dirma, Megech, Gelda, Arno-garno and Infranz), which contribute more than 95 percent of the inflow (Tenalem Ayenew, 2009). It is a growth corridor both nationally and internationally, which is potentially used as the source of hydropower generation, irrigation, navigation, fishery industry and ecotourism. It is meso-oligotrophic, turbid and frequently mixed lake with short duration of thermocline (Ayalew Wondie *et al*., 2007). It is one of the 250 lake region of the world least affected by human influence (Lake Net, 2004). However, its watershed is recently affected by anthropogenic-associated climate change through siltation, recession agriculture, water level fluctuation and overall biodiversity decline due to habitat degradation. Currently, it is highly infested by the highly invasive weed, water hyacinth. According to Ayalew Wondie *et al*. (2012), water hyacinth covered over 10% of the lake shoreline area in the north-eastern part of the lake in September 2011. The

distribution of the weed has reached 15% of the lake shore area in 2012.

The Lake Tana climate is characterized by four seasons: post-rainy season, main rainy seasons, dry season and pre-rainy season. The rainfall pattern of the lake region is uni-modal. Mean annual rainfall varies from 947.9 to 1274.2 mm with a mean value of 1102.1 mm. Long-term rainfall distribution data indicates that most of the rain occurs in July followed by August. The mean annual air temperature of the Lake area varies between 19.02°C and 22.68°C. Maximum temperature occurred in March and April and the minimum in December and January.

2.2. Sampling protocol

Sampling was carried out once during each of the four seasons. Sampling stations were selected on the basis of the extent of invasion by the weed and subsequently categorized as infested and non-infested stations. The non-infested sites were free from weed infestation or supported very few hyacinth plants (Table 1 and Fig. 1).

Table1. Description of sampling stations.

Stations/ Local Name	**Site descriptions**	**Depth Range (m)**	**Coordinates**	
			Latitude	**Longitude**
Water hyacinth infested site				
Addisgie Dingie (Ad)	close to Megech river mouth	0.42-0.62	12° 16' 15.3"N	37° 22' 55.7"E
Achera (Ac)	close to a farm land	0.56-1.21	12° 16' 59.9"N	37°21' 43.5"E

Kerigna (Kr)	a sand beach close to a farm land	0.28-1.60	12° 07' 29.4"N	37° 36' 22.1"E
Non- weed infested site				
Rib (Rb)	close to Rib river mouth	0.15-0.60	12° 02' 24.9"N	37° 35' 53.8"E
Dirma (Dr)	close to Dirma river mouth	0.65-1.50	12° 15' 49.6"N	37° 18' 18.5"E
Debresina (Db)	conserved wetland close to the monastery of Debre-Sina	0.98-2.30	12° 14' 33.5"N	37° 18' 01.2"E

2.3. Measurement of physico-chemical parameters

Dissolved Oxygen (DO), pH, specific conductance, Total Dissolved Solid (TDS), salinity and temperature were measured *in situ* using YSI 556 multi-probe system. Transparency of the water was measured by lowering a 30 cm diameter circular disc (Secchi disc) with a calibrated cable into the water column. Measurements of Ammonia (NH_3-N), Phosphate (PO_4-P) and silica (SiO_2) were based on an indophenol, Palintest Phosphate LR method and Ammonium molybdate, respectively, in the form of tablet at 640 nm wave length. Nitrate (NO_3-N) and Total hardness tests were done based on Palintest Nitratest method and a colorimetric method using Hardicol No. 1and No. 2 tablets, respectively, at 570 nm wave length and were carried out using a portable water analysis kit (Wagtech international, Palintest transmittance display photometer 5000). Nutrient analyses were made in the

shore area immediately after sample collection using water samples filtered through Whatman GF/F.

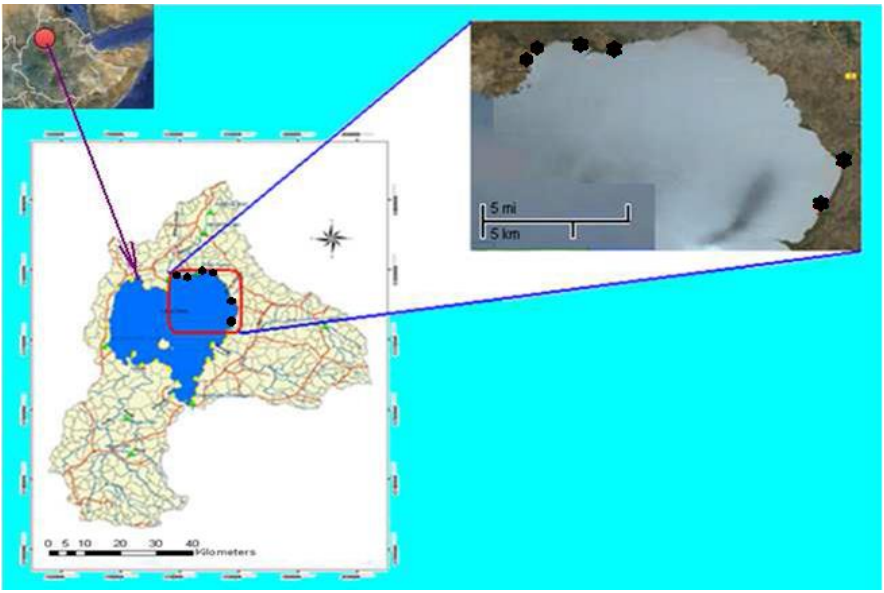


Fig. 1. Map of Lake Tana and its catchment areas with sampling sites indicated as black points (stars).

2.4. Biological sampling

Water hyacinth: Three samples of the weed were collected from randomly selected sampling points with the quadrat method along transect. Biomass estimation of the weed included its leaves and roots. The dry weight of the weed collected from 0.0625 m^2 quadrat was determined after drying up to 105°C for about 24 hours using dry oven (Wetzel and Likens, 1991).

Phytoplankton: One liter of lake water was collected from each station and immediately fixed with Lugol's iodine solution.

The samples were allowed to stand for a minimum of 24 h before decanting the supernatant. The supernatant was removed carefully until 30 ml aliquot remained. Concentrated samples were properly shaken and 1 ml sub-samples were taken and transferred into a Sedgwick-Rafter counting chamber using a stampel pipette. Identification and enumeration (estimation of abundance) were carried out under a binocular biological microscope (model, Ceti Max) with a magnification of 100-400x. Replicates of the samples were analyzed in a similar manner. Enumeration of phytoplankton was made in the laboratory using the following formula (Lind, 1979):

$$\text{No. of algal units per liter} = \frac{\text{algal units/ml of concentrate} * 1000}{\text{Concentration factor}}$$

Where,

$$\text{Concentration factor} = \frac{\text{volume of lake water filter (ml)}}{\text{volume of concentrate (ml)}}$$

Identification of phytoplankton genera or species was done using keys including Gasse (1986); Komarek and Kling (1991); Komarek and Anagnostidis (2000); Taylor *et al*. (2007). Particularly, for Diatom species identification, aliquots were immersed for 48 hours in a cooled 30% H_2O_2 solution in 5 to 20 ml proportion of aliquot and H_2O_2 solution was used to clean the scums from the frustule for clear vision of decorated structure of the frustule.

2.5. Statistical analysis

Spatial and temporal variations of measured physico-chemical parameters were analyzed using One-way Analysis of Variance (ANOVA) at 95% significance level ($p<0.05$). Causal relationships (correlation) among physico-chemical and biological parameters were assessed and mean numbers and standard errors for each physico-chemical parameter were calculated using statistical software (SPSS version 20). Non-parametric Kruskal–Wallis test was employed to see temporal differences of organisms counted, whereas the Mann–Whitney test was used for pair-wise comparisons when testing spatial variations between the two sites. To see differences among study sites, with respect to nutrient loading, Principal Components Analysis (PCA) was employed using PAST software. The relationship between the abundance of phytoplankton taxa with physico-chemical variables was assessed by using a multivariate analysis tool, Redundancy Analysis (RDA), using CANOCO for windows version 4.5 and then verified by Pearson's correlations. To determine the suitability of the method used in this analysis, Detrended Correspondence Analysis (DCA) was employed. Since the length of the longest gradient was less than 3, RDA was employed. Moreover, to describe the diversity and distribution of phytoplankton community, the following diversity indices were employed.

Shannon-Weaver index

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

$$H' = -\sum_{i=1}^{s} piln(pi)$$

Where; H'=Shannon-Weiner Index, i=counts denoting the i^{th} species ranging from 1 to i., pi=proportion that the i^{th} species represents in terms of 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) of each sample was evaluated using the equation:

$$j = \frac{H'}{Hmax}$$

Where; H'=Shannon-Weaver Index, H_{max}=antilogarithm of the number of species in the population.

Species richness index (d)

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

$$d = \frac{S-1}{ln\ N}$$

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

3. Results

3.1. Physico-chemical features

Values of physico-chemical parameters recorded in this study are shown in Tables 2 and 3. The mean surface water temperature recorded for the weed-infested sites (23.17±0.863) was slightly higher than that of the non-infested sites (22.43±0.691). The lowest mean surface water

temperature was recorded during the dry season in both sites, while the highest was recorded during the rainy and post-rainy seasons for the non-infested and weed-infested sites, respectively. Post-rainy season and dry season showed significant temporal variations in surface water temperature ($p<0.05$) in the non-infested sites. However, there was no significant temporal variation within the weed-infested sites and spatial variation between the weed-infested and non-infested sites.

The mean transparency (Secchi depth) value recorded for the two study sites was not statistically significant. Higher mean value was recorded for the non-infested sites (27.54±4.09 cm) than for the weed-infested sites (23.42±2.95 cm). The minimum value was recorded from the non-infested sites at Rb in the post-rainy season and from the weed-infested sites at Kr in the pre-rainy season. The mean Secchi depth of the dry season differed significantly from that of the pre-rainy season in the non-infested sites.

The mean values of pH and Total Dissolved Solids (TDS) recorded in this study were 7.966±0.140 and 101±2.05 for the weed-infested sites and 7.963±0.220 and 111.5±9.23 for the non-infested sites, respectively. Statistically, there was no significant spatial difference between the two sites. But, the rainy and post-rainy seasons, which had the lowest pH values differed significantly from the dry and pre-rainy seasons in the weed-infested sites. Similarly, the post-rainy season with one of the lowest recorded pH values, showed significant variation from the pre-rainy season ($p<0.05$). In the weed-infested sites, the rainy season with the lowest TDS value also showed significant variation from the rest of the seasons.

Table 2. Mean±SE, minimum and maximum values of the physico-chemical parameters of the water hyacinth-infested and non-infested sites (Abbreviations, RS=rainy season, PORS=post-rainy season, DS=dry season, PRS=pre-rainy season).

Site	Parameter	Season						
		RS	PORS	DS	PRS	Mean± SE	Max	Min
Weed-infested sites	T°(°C)	24.4	22.6	21.8	23.9	23.17± 0.86	27.68	17.21
	pH	7.5	7.7	8.3	8.3	7.966± 0.140	8.46	7.03
	Sp. cond (µS cm^{-1})	141	152	148	159	150±3.8	168	118
	TDS(mg L^{-1})	92	103.7	102.3	106	101± 2.05	109	83
	Sal (mg L^{-1})	60	70	73.33	76.67	70±2.1	80	60
	DO (mg L^{-1})	6.4	6.1	7.2	6.0	6.42± 0.403	9.57	4.79
	Secchi Depth (cm)	20	23	34	17	23.42± 2.95	49	11
Non	T (°C)	22.1	24.9	19.8	22.9	22.43± 0.69	28.25	18.01

pH	7.8	7.2	8.1	8.7	7.963± 0.220	8.84	6.04
K_{25} (µS cm^{-1})	154	163	153	154	155±7.4	208	126
TDS (mg L^{-1})	126.3	105.3	110	104.3	111.5± 9.23	205	86
Sal (mg L^{-1})	63.3	76.67	76.67	73.33	72.5± 2.79	90	60
DO (mg L^{-1})	6.3	5.9	8.1	6.4	6.68± 0.349	9.4	4.6
Secchi Depth (cm)	25	23	44	18.3	27.54± 4.09	53	2

Though not statistically significant, mean specific conductance (K_{25}) and salinity showed variations between the two sites. Higher mean values of specific conductance and salinity were recorded for the non-infested sites (155±7.4 µS cm^{-1} and 72.5±2.79 mg L^{-1}, respectively) than for the weed-infested sites (150±3.8 µS $cm^{-1}$and 70±2.1 mg L^{-1}, respectively). Although specific conductance did not exhibit significant seasonal variation in both sites, the salinity of the rainy season differed significantly from those of the other seasons ($p<0.05$).

Although not statistically significant, mean dissolved oxygen (DO) concentration also showed variation between the two sites, with the non-infested sites exhibiting relatively higher dissolved oxygen concentration (6.68±0.349) than the weed-infested sites (6.42±0.403). But, in the non-infested sites, the highest mean concentration of the dry season showed significant difference from that of the post-rainy season ($p< 0.05$).

Concentration of inorganic nitrogen species [Nitrate (NO_3-N) and Ammonia (NH_3-N)] showed spatial variation although ANOVA results showed the variations to be not statistically significant ($p>0.05$) (Table 3). In the non-infested sites, the mean value of NO_3-N (1.485±0.345) was slightly higher than that in the weed-infested sites (1.124±0.153). On the other hand, the mean value of NH_3-N was slightly higher in the weed-infested sites (0.173±0.092) than in the non-infested sites (0.15±0.038) (Table 4). Both NO_3-N and NH_3-N did not show significant seasonal variation in the weed-infested sites. In non-infested sites, however, pre-rainy season differed significantly from the rainy and post-rainy seasons in NO_3-N concentration ($p<0.05$).

Table 3. Concentrations of nutrients recorded for the study sites.

Parameter	Weed-infested sites			Non-infested sites			p-value
	Mean±SE	Max	Min	Mean±SE	Max	Min	
NO_3-N (mg L^{-1})	1.124 ±0.153	2.2	0.24	1.485±0.345	3.52	0.24	0.349
NH_3-N (mg L^{-1})	0.173±0.092	1.15	0.0	0.15±0.038	0.41	0.0	0.816
PO_4-P (mg L^{-1})	0.951± 0.449	4.4	0.0	0.65±0.56	6.8	0.0	0.679
SiO_2 (mg L^{-1})	0.26±0.043	0.56	0.04	0.699±0.281	3.6	0.16	0.137
Total Hardness (mg L^{-1})	58.58±3.39	80	42	70.5 ±11.57	195	45	0.334

Mean concentrations of soluble reactive phosphate (PO_4-P) and Silica (SiO_2) showed small variations between the two sites. Higher mean value of PO_4-P concentration was recorded in the weed-infested sites (0.951±0.449 mg L^{-1}) than in the non-infested sites (0.65±0.56 mg L^{-1}). However, during the rainy and post-rainy seasons, when the weed biomass was higher, lower mean value of PO_4-P (0.34 mgL^{-1}) was recorded for the weed-infested sites than for the non-infested sites (0.83 mg L^{-1}). In the weed-infested sites, the highest concentration of PO_4-P was recorded during the dry season following the reduction in weed biomass while the lowest occurred during the post-rainy season concomitantly with the highest weed biomass (Fig. 2). In the non- infested sites, while the highest PO_4-P concentration was recorded during pre-rainy season, the lowest was observed during dry and post-rainy seasons. On the other hand, higher mean value of SiO_2 concentration was recorded in the non-infested sites (0.699±0.281 mg L^{-1}) than in the weed-infested sites (0.26±0.043 mg L^{-1}). In the weed-infested sites, the highest and lowest values of SiO_2 concentration were recorded during post-rainy and pre-rainy seasons, respectively. In the non-infested sites, however, the highest SiO_2 concentration was recorded during the rainy season, while the lowest was observed during dry and pre-rainy seasons (Fig. 3). Statistically, there were no significant spatial variations in PO_4-P and SiO_2 concentrations ($p>0.05$) (Table 3). But, the highest mean PO_4-P concentration of the dry season differed significantly from those of the rest of the seasons in the weed-infested sites ($p<0.05$).

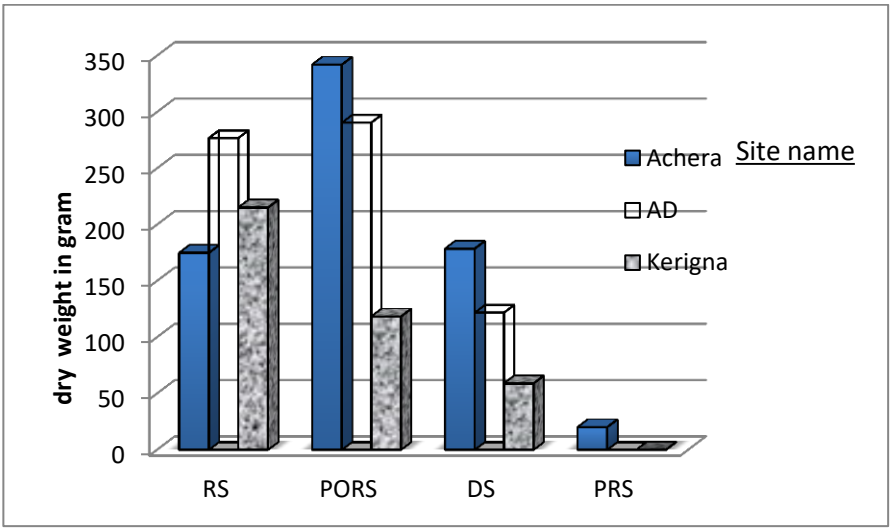


Fig. 2. Seasonal trends of water hyacinth biomass in the weed-infested sites (Abbreviation: AD=Adisgie-Dengie, RS=rainy season, PORS=post rainy season, DS=dry season, PRS=pre-rainy season).

Total hardness showed small spatial variation, with the mean value for the non-infested sites (70.5±11.57) being higher than that for the weed-infested sites (58.58±3.39). At the non-infested sites, marginally higher minimum and maximum values of total hardness were recorded (Table 3). Seasonally higher total hardness was recorded in the dry and rainy seasons in the weed-infested and non-infested sites, respectively (Fig. 4). However, there was no statistically significant spatial and temporal variation in total hardness.

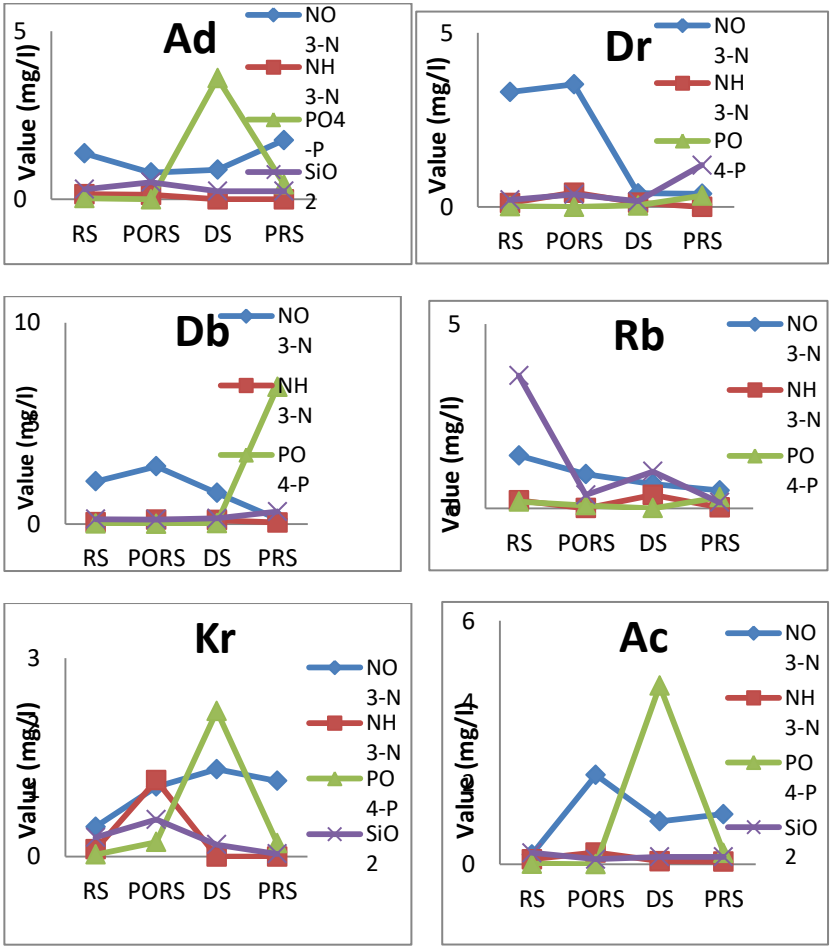
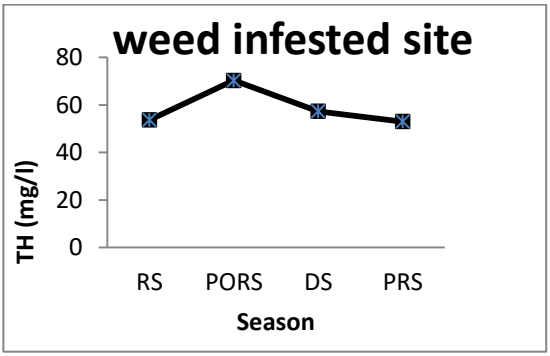


Fig. 3. Seasonal trends of nutrient concentrations in the study sites. (Abbreviations; DR=Dirma, Rb=Rib, Db=Debre-Sina, Kr=Kerigna, Ac=Achera, Ad=Adisgie-Dengie, RS=rainy season, PORS=post rainy season, DS=dry season, PRS=pre-rainy season).



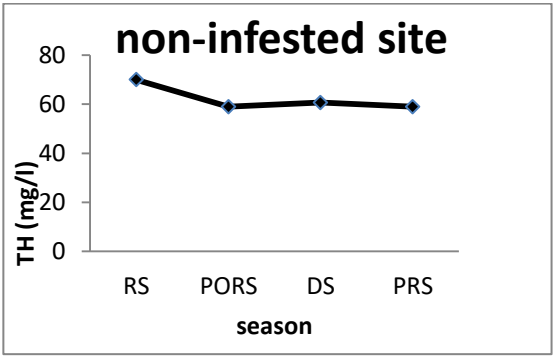


Fig. 4. Seasonal trends of total hardness concentration of the two study sites (Abbreviation: RS=rainy season, PORS=post-rainy season, DS=dry season, PRS=pre-rainy season).

3.2. Ordination of nutrients versus sites

Principal component Analysis (PCA) (Fig. 5) categorized the sampling sites based on the principal nutrient loading. In this

analysis, the first two components (Axes) accounted for 76% of the total variation. The first component accounted for 47.5% and the second accounted for 28.5% of the explained variance. Axis 1 was positively correlated with silica (0.56) and total hardness (0.58) with an eigen value of 2.38. Axis 2 was also positively correlated with nitrate (0.51) with an eigen value of 1.43 (Table 4). Results of the PCA show positive correlation of sites Rb and Dr of the non-infested sites with Axis 1 and their discrimination from other sites due to high loading of silica and total hardness. Sites Db and Ac of the non-infested and weed-infested sites, respectively, showed negative correlation with Axis 1 and were discriminated from other sites due to high loading of phosphate. Sites Ad and Kr of the weed-infested site showed positive and negative correlation with Axis 2, respectively and were discriminated from other sites due to high loading of nitrate and ammonia, respectively. This indicates that sites infested with hyacinth were discriminated from non-infested sites with nitrogen and phosphorous loading as compared to all the non-infested sites except site Db.

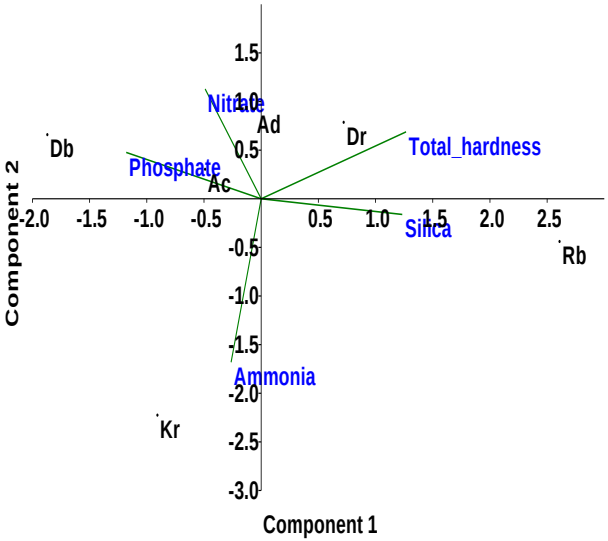


Fig. 5. Biplot of principal component analysis with ordering nutrients in relation to sites (Abbreviations: Ac=Achera, Ad=Adisgie-Dengie, Kr=Kerigna, Dr=Dirma, Db=Debre-Sina and Rb=Rib).

Table 4. Correlation coefficients of nutrients with the first two principal component axes.

Site	**Axis 1**	**Axis 2**
Nitrate	-0.22	0.51
Ammonia	-0.12	-0.77
Phosphate	-0.54	0.22
Silica	0.56	-0.07
Total Hardness (TH)	0.58	0.31

3.3. Biological features

3.3.1. Phytoplankton composition and abundance

The abundance and species composition of Phytoplankton identified in this study are shown in Table 6. In this study, 68 phytoplankton species, which belong to 7 classes, 33 families and 35 genera, were identified. Among these identified taxa, Bacillariophyceae (Diatoms), with 30 species was the most diverse group followed by Chlorophyceae (green algae) with 18 species, Euglenophyceae, Cyanophyceae (blue greens), Cryptophyceae, Zygnematophyceae and Dinophyceae, with 8, 7, 5, 3 and 1 species, respectively. The species composition of weed-infested and non-infested sites showed differences with regard to some taxonomic groups. Chlorophyceae, Cyanophyceae, Cryptophyceae and Dinophyceae had higher densities in the weed-infested sites (108100, 7900, 11800 and 4900 algal units/L), than in the non-infested sites (15200, 3000, 7900 and 1100 algal units/L), respectively. In the non-infested sites, Bacillariophyceae was the most dominant group with a maximum density of 62900 algal units/L, and with percentage contribution of 68% to the total phytoplankton counts in the site (Fig. 6 and Table 6).

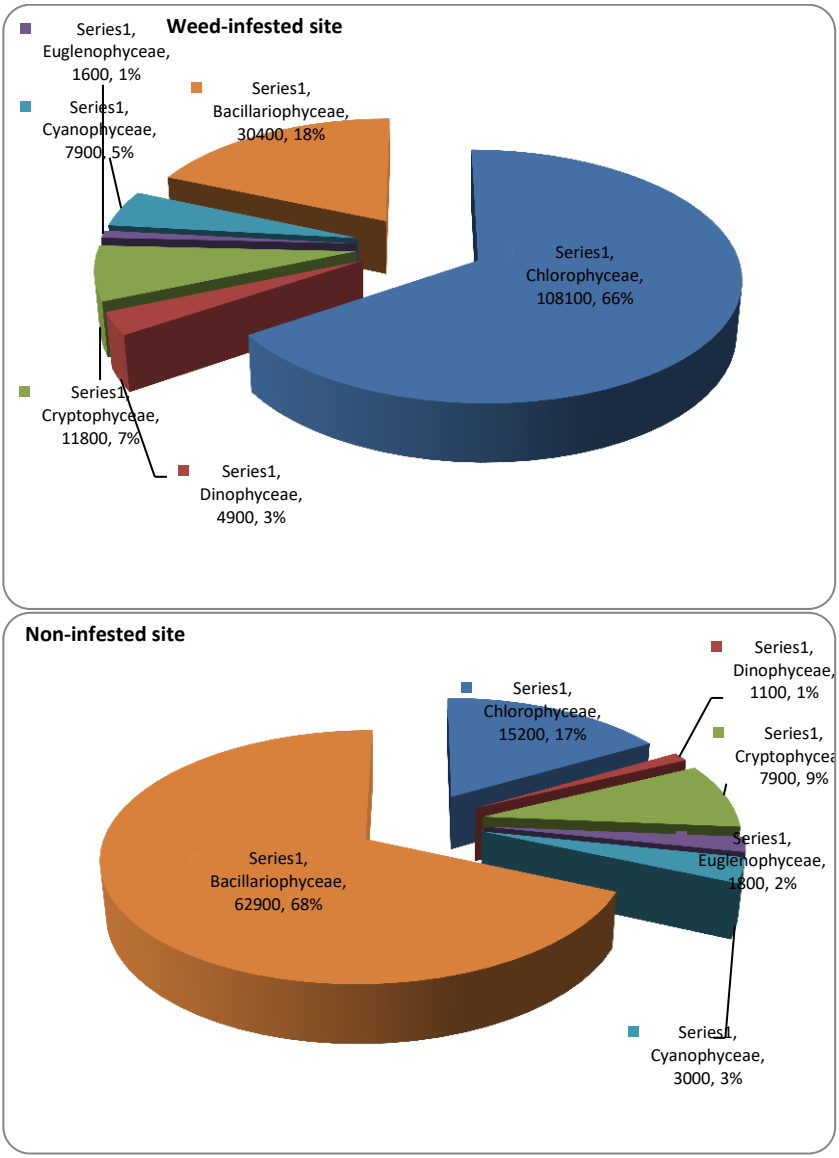
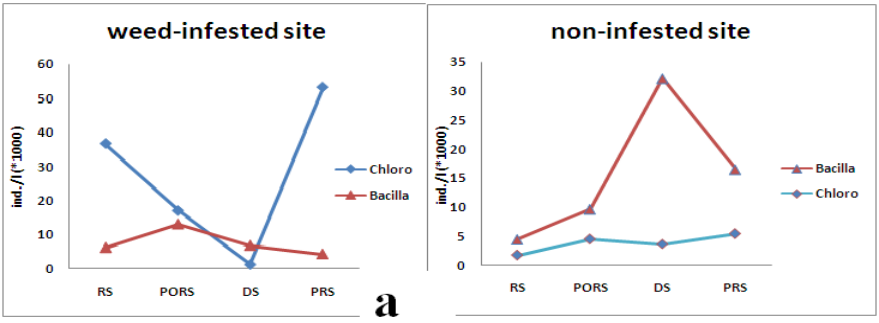


Fig. 6. Percentage contribution of phytoplankton classes to the total phytoplankton counts.

Cryptomonas obovata, *Melosira distans* var, *Nitzchia* sp. and *Schroederia setigera* were the most common taxa in both sites. The density of *Closterium* sp., *Cymbella cistula*, *Euglena* sp., *Fragilaria ulna*, *Navicula cuspidata*, *Navicula radiosa*, *Navicula* sp., *Oocystis* sp. and *Pinnularia* sp. was higher in the non-infested sites. Similarly, the density of *Chlamydomonas* sp., *Cryptomonas marssonii*, *Cryptomonas ovata*, *Cyclotella* sp., *Microcystis aeruginosa*, *Microcystis flos-aquae*, *Mougeotia* sp., and *Peridinium gatunense* were higher in the weed-infested sites than in the non-infested sites. However, apart from the small differences in the abundance of phytoplankton taxa, there were no significant spatial variations (Mann-Whitney test, $p>0.05$, $n=24$). Some algal species such as *Ankistrodesmus* sp., *Gloeocapsa* sp., *Monoraphidium* sp. *Staurastrum* sp. and *Surirella* sp., were found only in the non-infested sites, while others such as *Anabaena* cf. *inaequalis*, *Aulacoseira ambigua*, *Euglena spirogyra*, *Melosira varians* and *Phacus trypanon* were found only in the weed-infested sites.



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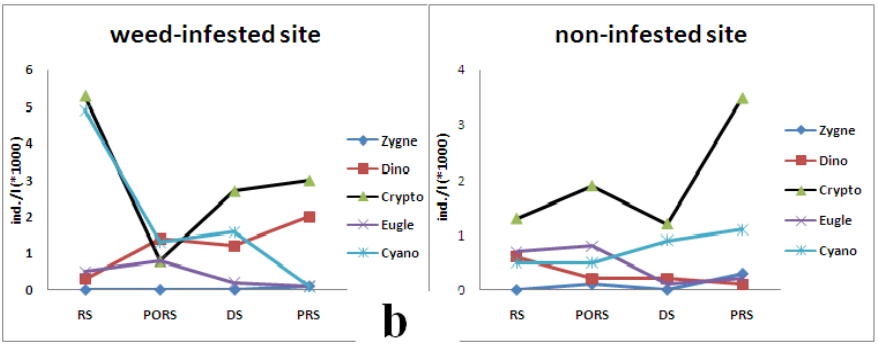

Fig. 7. Seasonal trends of abundance of phytoplankton taxa (mean of three stations): a) dominant groups, b) other groups (Abbreviations; Zygne=Zygnematophyceae, Dino=Dinophyceae, Crypto= Cryptophyceae, Eugle=Euglenophyceae, Cyano=Cyanophyceae, Bacilla=Bacilariophyceae and Chloro=Chlorophyceae).

As shown in Fig. 7, different seasonal patterns were observed for phytoplankton taxa in the two sites. The dominant taxon, in the weed-infested sites, Chlorophyceae, increased in density during the rainy and pre-rainy seasons, but declined sharply during dry season when the dominance of Baciliarophyceae occurred. In the non-infested sites, Baciliarophyceae showed dominance throughout the study period with its highest peak occurring during the dry season. *Cyclotella* sp. from the infested sites and *Microcystis aeruginosa* from the non-infested sites showed significant seasonal variation (Kruskal Wallis test, $p<0.05$).

Higher mean values of Shannon-Weaver's index (H'), species evenness (j) and species richness (d) of phytoplankton were recorded for the non-infested sites than for the weed-infested sites. The values of both Shannon-Weaver's index and

species evenness in the weed-infested sites reached their maximum during the dry season and declined to their minimum during the pre-rainy season. In the non-infested sites, however, their maximum values were recorded during the rainy season and their minimum values during post-rainy and dry seasons. Similarly, the maximum value of species richness (d) was recorded during the dry season while its minimum was observed during the post-rainy season in weed-infested sites. In non-infested sites, however, the maximum value of species richness was recorded during the rainy season and the minimum during the pre-rainy season. Shannon's index (H') and species evenness (j) showed significant differences between the two sites (Table 5). However, there were no significant temporal variations in all stations.

Table 5. Results of diversity indices computed for phytoplankton species.

Diversity indices	**Weed-infested sites**		**Non-infested sites**		
Mean ± SE	**Range**	**Mean ± SE**	**Range**	**Mean ± SE**	**p-value**
H'	0.47- 2.61	1.87±.194	1.45-2.92	2.37±.115	.037
j	0.11-0.61	0.44±0.046	0.34-0.68	0.55±0.03	.035
d	11.39-22.06	16.95±1.00	12.52-25.06	18.36±1.03	.335

Table 6. Phytoplankton composition and their relative abundance [RA (%)], observed in the weed-infested and non-infested sites (mean of the three stations).

Taxa	Infested sites		Non-infested sites		Taxa	Infested sites		Non-infested sites	
	algal unit/L ($*10^2$)	RA%	algal unit/L ($*10^2$)	RA%		algal unit/ L($*10^2$)	RA%	algal unit/L ($*10^2$)	RA%
Bacillariophyceae	**304**	**18.45**	**629**	**68.15**	*Melosira cf. agassizii*	9	0.55	0	-
Aulacoseira ambigua	2	0.12	0	-	*M. distans var*	50	3.03	44	4.77
A. granulata	9	0.55	14	1.52	*M. varians*	1	0.06	0	-
Cyclotella sp.	16	0.97	4	0.43	*Navicula cuspidata*	38	2.31	216	23.40
Cymbella cistula	1	0.06	9	0.98	*N. radiosa*	29	1.76	65	7.04
C. minuta	2	0.12	0	-	*N. schroeteri*	10	0.61	10	1.08
C. tumida	0	-	4	0.43	*Navicula sp.*	24	1.46	46	4.98
Cymbella sp.	1	0.06	2	0.22	*Nitzschia sigma*	0	-	8	0.87
Fragilaria brevistriata	1	0.06	0	-	*Nitzschia sp.*	56	3.40	87	9.43
Fragilaria cf. construens	1	0.06	1	0.11	*Pinnularia sp*.	1	0.06	28	3.03
F. ulna	12	0.73	22	2.38	*Surirella biserrata*	0	-	2	0.22
Fragilaria sp.	2	0.12	2	0.22	*S. spinifera*	0	-	1	0.11
Gomphonema lanceolatum	4	0.24	4	0.43	*Surirella sp.*	0	-	1	0.11
Gor Table 6 continued		0.49	6	0.65	*Synedra berolinensis*	26	1.58	15	1.63
Gyr		0.06	8	0.87	*S. dorsiventralis*	0	-	1	0.11
G. scalproides	0	-	29	3.14					

Taxa	Infested sites		Non-infested sites		Taxa	Infested sites		Non-infested sites	
	algal unit/L (*10^2)	RA%	algal unit/L (*10^2)	RA%		algal unit/L (*10^2)	RA%	algal unit/L (*10^2)	RA%
Cyanophyceae	**79**	**4.79**	**30**	**3.25**	**Cryptophyceae**	**118**	**7.16**	**79**	**8.56**
Anabaena cf. inaequalis	2	0.12	0	-	*Cryptomonas erosa*	3	0.18	1	0.11
Aphanothece sp.	4	0.24	1	0.11	*C. marssonii*	32	1.94	18	1.95
Gloeocapsa sp.	0	-	1	0.11	*C. obovata*	56	3.40	55	5.96
Microcystis aeruginosa	42	2.55	8	0.87	*C. ovata*	20	1.21	3	0.33
M. flos-aquae	22	1.33	4	0.43	*C. rostratiformis*	7	0.42	2	0.22
Oscillatoria sp.	9	0.55	13	1.14	**Chlorophyceae**	**1081**	**65.59**	**152**	**16.47**
Pseudanabena sp.	0	-	3	0.33	*Ankistrodesmus sp*.	0	-	1	0.11
Euglenophyceae	**16**	**0.97**	**18**	**1.95**	*Chlamydomonas sp*.	1015	61.59	63	6.83
Euglena acus	1	0.06	1	0.11	*Closterium acutum*	0	-	8	0.87
E. spirogyra	1	0.06	-		*Closterium cf. kuetzingii*	1	0.06	0	-
E. tripteris	5	0.03	1	0.11	*C.limneticum*	1	0.06	0	-
Euglena sp.	4	0.24	12	1.30	*Closterium sp.*	7	0.42	17	1.84
Phacus curvicauda	2	0.12	0	-	*Crucigenia sp.*	2	0.12	3	0.33
P. longicauda	1	0.06	1	0.11	*Dictyosphaerium sp.*	7	0.42	10	1.08
P. trypanon	1	0.06	0	-	*Microspora sp.*	0	-	1	0.11
Phacus sp.	1	0.06	3	0.33	*Monoraphidium cf. minutum*	0	-	2	0.22
					Monoraphidium sp.	0	-	4	0.43

Table 6 continued

Taxa	Infested site		Non-infested site	
	algal unit/L (*10^2)	RA%	algal unit/L	RA%

				(*10$^{2)}$
Mougeotia sp.	16	0.97	8	0.87
Oocystis sp.	5	0.30	14	1.52
Scenedesmus intermedius	1	0.06	0	-
S. quadricauda	0	-	1	0.11
Scenedesmus sp.	1	0.06	0	-
Schroederia setigera	19	1.15	19	2.06
Sphaerocystis sp.	6	0.36	1	0.11

3.3.1. Relationship between physico-chemical variables and density of phytoplankton taxa

The relationship between phytoplankton taxa and physico-chemical variables is shown in Fig. 8 below. In this Redundancy Analysis the first two axes accounted for 78.7% of the cumulative percentage of variance in species-environmental relationship (Table 7). The first axis accounted for 43.6% of the variance, and showed strong positive correlations with total hardness, TDS, salinity and silica concentrations. Similarly, axis 2, which accounted for 35.1% of the variance, was positively correlated with ammonia, temperature, pH and specific conductance.

Table 7. Results of Redundancy Analysis (RDA) for the relationship between environmental variables and phytoplankton taxa using the first two Axes.

Parameter	**Axis1**	**Axis 2**
Eigen values	0.436	0.351
% variance of species-environment relation	43.6	35.1
Temperature	-0.56	0.62
pH	0.47	0.81
Specific conductance	0.42	0.74
Salinity	0.84	0.36
Dissolved Oxygen	0.45	-0.69
Secchi depth	-0.20	-0.90
Total Dissolved Solid	0.72	0.54
Silica	0.87	0.37
Nitrate	-0.12	-0.75
Ammonia	-0.55	0.72
Phosphate	-0.47	-0.53
Total Hardness	0.76	-0.02

Density of Bacillarophyceae was strongly correlated with salinity, silica and TDS ($r=0.94$, 0.98, 0.98, $p<0.01$, $n=6$). Euglenophyceae, was similarly strongly correlated with pH, specific conductance and TDS ($r=0.72$, 0.99 and 0.93), respectively. Chlorophyceae was strongly correlated with ammonia and temperature ($r=0.92$ and 0.82) while, Cyanophyceae was strongly correlated with ammonia ($r=0.89$, $p<0.05$).

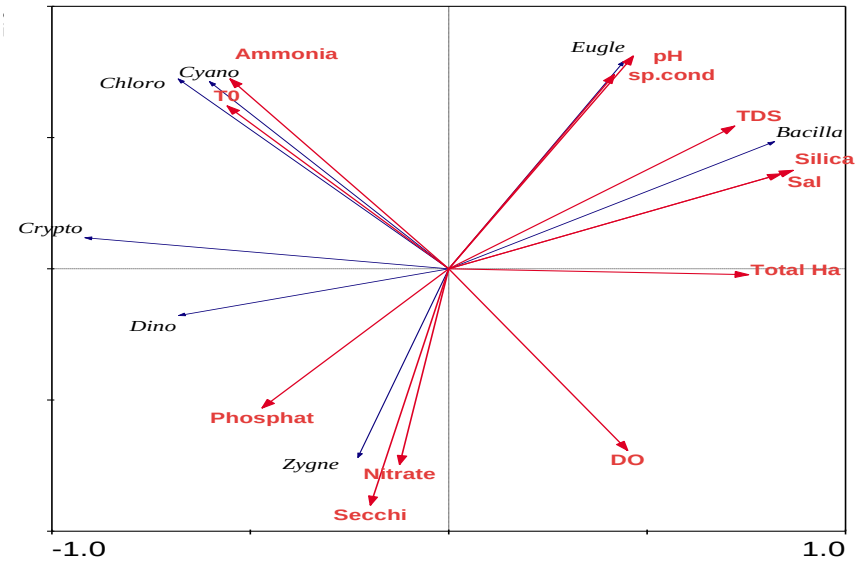

Fig. 8. Ordination diagram of Redundancy Analysis (RDA) of the first two ordination axes summarizing the relationship between physico-chemical variables and phytoplankton taxa. (Abbreviations; Chloro= Chlorophyceae, Cyano=Cyanophyceae, Crypto=Cryptophyceae, Dino=Dinophyceae, Zygne=Zygnematophyceae, Eugle= Euglenophyceae, Bacilla=Bacillarophyceae, T0=Temperature, DO= Dissolved Oxygen, sal=salinity, TDS=Total Dissolved Solids, Total Ha=Total Hardness, Sp. cond=Specific conductance).

4. Discussion

4.1. Physico-chemical parameters

There was no remarkable spatial variation in physico-chemical parameters measured during this study. As trends on the lake region show, the minimum value of air temperature was recorded during the dry season (December and January) concomitantly with the low lake water temperature of this season (Eshete Dejen *et al*., 2004; Ayalew Wondie, 2006). The observed seasonality of surface water temperature in this study also followed a similar trend. The absence of significant variation in temperature in the weed-infested sites is attributable to the presence of water hyacinth, which may deter the heat transfer between surface water and the atmosphere, thereby reducing wind-induced mixing and minimizing temperature variation in the weed-infested sites. Similar results were reported by Schreiner (1980) and Mironga, *et al*. (2012) in their study on South Georgia Pond and Lake Naivasha, Kenya, respectively. Mehra *et al*. (1999) have also reported a profound influence of floating water hyacinth mats on diurnal temperature fluctuation. Influence on diurnal dynamics of temperature may also affect the dynamics of oxygen and carbon dioxide in the water, which in turn affects the maintenance of ecosystem processes (Tafangenyasha *et al*., 2010).

The lowest mean Secchi depth recorded for the weed-infested sites seem to reflect water hyacinth's effect associated with its capacity to reduce wind mixing due to its complex structure of leaf and root and hold suspended particles including phytoplankton to stay suspended on the water thereby reducing water transparency (Chukwuka and Uka 2007; Mironga *et al*., 2012). High concentration of dissolved solids and suspended particulate matter, which might enter into

the lake through feeder rivers, may have also contributed to the lowest Secchi depth recorded for both sites during the rainy season. Turbulence due to wind-induced mixing, water input through tributary rivers from lake catchment and higher phytoplankton density were the main factors responsible for lowering water transparency during the pre-rainy season.

The highest pH values recorded during pre-rainy season coincident with high phytoplankton densities in both sites seem to be associated with the removal of carbon dioxide by algal communities (and macrophytes) through their intense photosynthetic activities with consequent increase in pH (Atobatele and Ugwumba, 2008). The relatively lower pH values recorded in the weed-infested sites during the rainy and post-rainy seasons, when weed biomass was higher, may have resulted from CO_2 contributed further by incoming water from agricultural areas through runoffs and decomposition of organic matter by bacteria. pH of both sites showed significant seasonal variation within a range, which was optimum for the growth of water hyacinth and other organism that live in the lake (Weiner, 2007; Ndinwa *et al*., 2012).

Water hyacinth has substantial capacity to remove TDS from the water surface through accumulation (Borges *et al*., 2008; Gamage and Yapa 2001). The relatively low mean TDS value recorded in the weed-infested sites reflects this accumulation effect of water hyacinth by its complex root structure. The lower mean values of both specific conductance and salinity recorded in the weed-infested sites are also consistent with the results of studies documented by Uka and Chukwuka (2007) and Borges *et al*. (2008), which attributed the decrease in these chemical parameters to the assimilation of ions by water hyacinth.

The present cover of water hyacinth mat did not cause notable decrease in dissolved oxygen concentration due to the presence of lower mat size especially after the removal campaign and the shallowness and consequent frequent mixing of the lake water. Different studies reported an inverse relationship between dissolved oxygen and water hyacinth cover (McVea and Boyd, 1975; Rommens *et al*., 2003; Chukwuka *et al*., 2008; Mironga *et al*., 2012). This relation may not be always true, because it depends on thriving of the weed cover for longer time and the high COD and BOD resulting from its death and subsequent decomposition. During this investigation, relatively lower mean value of dissolved oxygen concentration was observed in the weed-infested sites. The lower dissolved oxygen concentration in the presence of abundant algal populations seems unlikely. However, the presence of abundant zooplankton and macro-invertebrates, which were harbored by the water hyacinth mat and relatively higher temperature coupled with the presence of water hyacinth, which obviously hindered gaseous exchange between the atmosphere and water, might be the causes of the low dissolved oxygen concentration.

Different studies have traced the blooming of water hyacinth populations in a water body to nutrient enrichment (Barret, 1989; Bartodziej and Leslie, 1998; Wilson *et al*., 2005). The weed also grows very well in water polluted with organic contaminants and high concentrations of plant nutrients (Chunkao *et al*., 2012; Ndimele, 2012). Depending on the extent of cover and density, water hyacinth has the potential to significantly reduce nutrient concentrations especially during rapid growth through assimilation (McVea and Boyd, 1975; Schreiner, 1980; Pinto and Greco, 1999; Mironga *et al*., 2012).

The observed higher concentration of PO_4-P and NO_3-N in the weed-infested sites especially during the dry season followed the declining of water hyacinth cover probably due to its decomposition. This indicates that water hyacinth somehow affects nutrient availability in the water column, which may stress growth of other plants. Similar observations were made by Marshall (1997) in Lake Chivero (Uganda) and Mironga *et al.* (2012) in Lake Navashia (Kenya). Similarly, the higher mean NH_3-N concentration recorded in the weed-infested sites probably resulted from the decomposition of water hyacinth as organic decomposition serves as source of NH_3-N in a water body (Lind, 1979).

Because of their direct contact with influxes and runoffs that come from the catchment, inshore site especially those, which are close to river mouths are considerably richer in nutrient concentration than offshore sites. In non-infested sites, particularly site Rb, which faced high siltation problem following the high silt load during the rainy and pre-rainy seasons, the concentration of silica was substantially high. Relatively higher concentration of nitrate was also recorded in the river mouths during the rainy season.

4.2. Phytoplankton composition and abundance

According to Ayalew Wondie (2006), diatoms were dominant during the dry and rainy seasons until the dominance shifted to blue-greens during the post-rainy season. In the present study, dominant populations of Chlorophyceae in the weed infested sites, persisted during the rainy and pre-rainy seasons, but declined sharply during the dry season coinciding with the dominance of Bacillariophyceae which is probably attributed to wind-induced mixing in the lake. The presence and subsequent collapse or senesce of water hyacinth had negative effect on aquatic environment through deteriorating environment quality (John-Stephen *et al*., 2009). The composition and abundance of phytoplankton community could also change due to the released nutrients from the decomposed water hyacinth plant. In this study, the higher relative abundance of pollution-tolerant *Chlamydomonas* species and blue green algae of the genus *Microcystis* under water hyacinth mat also suggests saprobic conditions in the sites as they are an indicator species for such conditions (Jindal and Sharma, 2011). The highest diatom abundance was observed in the non-infested sites particularly at Rb concomitantly with the highest silica concentration in the site.

In comparison with non-infested sites, sampling sites with water hyacinth generally had lower phytoplankton diversity, uneven distribution of species and lower taxa richness. This disparity could be attributed to allelopathic effect of water hyacinth on some algal species in addition to competition for nutrients and light (Gross, 2003). Existence of high diversity of species, in most cases represented by fewer individuals, is characteristic of a stable ecosystem (Türkmen and Kazanci, 2010). However, a few species with 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 *Chlamydomonas* and *Microcystis* in the weed-infested sites than in the non-infested sites also indicates perturbations in the sites.

5. Conclusion and Recommendations

5.1. Conclusion

Although all the spatial variations in water quality were not statistically significant, significant temporal variations in some physico-chemical characteristics of the lake were observed in this study. The observed minimal effect of the weed on the lake's water quality was due to the age of the mat formed and the extent of accumulation of detritus. The older the mat, the more the quantity of detritus that can be accumulated in the site and the more the effect imposed on the aquatic environment (Schreiner, 1980). On the other hand, due to the short infestation time and weed biomass reduction due to physical removal, marked disparity was not observed between the weed-infested and non-infested sites.

However, the effect of water hyacinth on some physico-chemical parameters of the lake water was manifested. For example; nitrate levels were relatively lower in the water hyacinth-infested sites as compared to non-infested sites and an increase in both nitrate and phosphate concentration was observed following the reduction of weed biomass. Its effect on TDS, temperature, specific conductance, total hardness, Secchi depth and NH_3-N was also manifested.

Presence of water hyacinth in the lake imposed a shift in the composition and abundance of phytoplankton community as compared to non-infested sites and even deviations from trends previously reported for the lake by Ayalew Wondie (2006) were noted. Dominance of pollution tolerant species along with low species diversity in the weed-infested sites reflects influence of water hyacinth on phytoplankton assemblage. The dominant *Chlamydomonas* species, which probably had the ability to modulate nutrient uptake and photosynthetic activity depending on environmental conditions (Grossman, 2000; Giovanni and Giorgio, 2004) was favored by the presence of water hyacinth.

In general, except its effect on phytoplankton diversity and distribution the existing water hyacinth biomass did not show severe problem in the lake ecosystem. However, environmental conditions are currently favorable for its optimum growth, further proliferation might occur and the weed may even spread to new areas and worsen its effect.

5.2. Recommendations

The situation in the lake points out the need for continuous follow up and development of sustainable management strategies. The management strategies should focus on an integrated approach, which includes biological agents (giving special emphasis to native species of the beetle family Dytiscidae and Hydrophylidae), regulation of agricultural and urban wastes and even removal of the weed through utilization should get due attention.

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