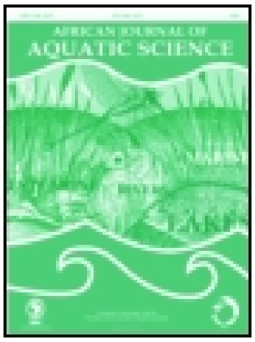

African Journal of Aquatic Science

ISSN: 1608-5914 (Print) 1727-9364 (Online) Journal homepage: http://www.tandfonline.com/loi/taas20

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African Journal of Aquatic Science 2017, 42(2): xxx–xxx
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This is the final version of the article that is published ahead of the print and online issue

AFRICAN JOURNAL OF AQUATIC SCIENCE
ISSN 1608-5914 EISSN 1727-9364
http://dx.doi.org/10.2989/16085914.2017.1336074

Physico-chemical limnology and plankton dynamics of Mazvikadei, a tropical reservoir in Zimbabwe

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The limnology of Mazvikadei Reservoir, northern Zimbabwe, was investigated in 2015 to determine whether it had changed since filling in 1990. The reservoir is characterised by low algal biomass, low nutrients (i.e. N and P) and high water clarity/transparency. Fifty-four species of phytoplankton were recorded, comprising Bacillariophyta, Chlorophyta, Cyanophyta, Desmids, Dinophyta and Euglenophyta. Chlorophyta numerically dominated in the hot dry season, whereas Bacillariophyta, Desmids, Dinophyta and Euglenophyta dominated in the cool dry season. Species richness was highest at the onset of the cool dry season, in response to high nutrient concentrations. Phytoplankton abundance and composition were significantly correlated with temperature, nitrates and total nitrogen. Nineteen zooplankton species were recorded, including Copepoda, Cladocera and Rotifera. Overall, Cladocera were numerically dominant and became most abundant during the cool dry season. Rotifers and copepods dominated during the hot dry season. The zooplankton abundance was correlated with reactive phosphorus and phytoplankton abundance. The trophic state of Mazvikadei Reservoir seems to have stabilised and to have assumed the physico-chemical characteristics and plankton community typical of an oligotrophic lake.

Keywords: aging, mature, oligotrophic, phytoplankton, trophic status, zooplankton

Introduction

Knowledge of the limnological status of a reservoir can be used as an important tool to institute appropriate management strategies. Reservoirs created by artificially damming streams or rivers often create highly productive aquatic ecosystems after their initial impoundment (Lourantou et al. 2007; Molisani et al. 2010). The physico-chemical process of aging in a reservoir is controlled by latitude, reservoir volume, water retention time, quantity of organic matter accumulated during filling, activities in the drainage basin and the quantity of suspended materials (Jorgensen et al. 2005). The trophic upsurge that occurs following reservoir filling is transient and its duration varies depending on the degree of alteration in the hydrological regime, the amount of nutrient loading and reservoir characteristics (Ostrofsky and Duthie 1980; Jorgensen et al. 2005). It can last from 5 to 20 years, is characterised by high levels of nutrients and biological productivity and provides abundant food and high quality habitat (Kimmel et al. 1990; Kalff 2002). The trophic upsurge is followed by a less productive, non-equilibrium trophic depression, which is a more stable trophic state that yields a more stable community composition and community (Kalff 2002).

The trophic depression, characterised by reduced productivity, occurs after nutrient input has stabilised and can range from 3 to 30 years, although its onset is not clearly defined (Houel et al. 2006), because watershed activities that lead to increased nutrient input can cause new episodes of trophic upsurge (Ostrofsky and Duthie 1980; Holz et al. 1997). The reservoir can achieve oligotrophy after watershed stabilisation, thereby assuming a mature stabilised state (Lourantou et al. 2007). As the reservoir ages, plankton communities respond to trophic upsurge and depression perturbations according to their specific physiological requirements (Scharf 2002). Specific plankton community associations better adapted to different water trophic states consequently emerge during a reservoir's lifetime (Ostrofsky and Duthie 1980; Reynolds 2000; Wilk-Wozniak 2003).

The establishment of artificial impoundments in Zimbabwe provided opportunities to undertake limnological studies as far back as the late 1950s (Sanyanga and Mhlanga 2004). However, these studies focused primarily on Lake Kariba and Lake Chivero, which have been extensively studied compared with other reservoirs in the country (Sanyanga and Mhlanga 2004; Mhlanga et al. 2006).

Agricultural expansion within the catchment of Mazvikadei Reservoir could have altered the limnology of this reservoir since the last studies on it by Masundire in 1992. Multiple reservoir uses and watershed-based human activities bring changes in nutrient loadings that can induce modification on the reservoirs' trophic status, phytoplankton assemblages and physico-chemical conditions (Molisani et al. 2010). During its first year of filling Masundire (1992) undertook a basic limnological study to assess physico-chemical parameters and the zooplankton communities that had established in the reservoir. A more detailed study approximately two decades later should indicate the changes that have taken place in the reservoir. At this time, knowledge of the status of the limnology of Mazvikadei Reservoir is patchy, despite its widespread recognition as an important tourist resort, as well as a source of potable and irrigation water. Knowledge of the changes in the water quality and the biota of the reservoir can be used as an important tool to institute appropriate management strategies for the reservoir.

Masundire (1992) postulated an increase in productivity in the Mazvikadei Reservoir, in response to an increase in agricultural activities, in particular crop production and the use of artificial fertilisers within the catchment. Eutrophication resulting from diffuse sources, such as run-off from livestock feedlots or agricultural land fertilised with organic and inorganic fertilisers (Adekunle 2009) is a major threat to aquatic ecosystems. This can result in trophic changes in a reservoir, which affect the structural and functional properties of the ecosystem (Gulati 1983). This would be reflected by the alteration of phytoplankton species and abundances as they respond first to water quality changes, thereby initiating a chain reaction that is successively reflected within the zooplankton functional groups (Whitton and Patts 2000). The sensitivity of zooplankton to man-made and natural changes make zooplankton a useful indicator of the trophic status of conditions in a reservoir whereas phytoplankton have a very short generation time and thus respond rapidly to shifts in the environment (Willén 2000).

The main research objective was to determine whether Mazvikadei reservoir has attained the physico-chemical conditions and plankton community of a stabilised mature oligotrophic lake after two decades. It was hypothesised that the physico-chemical limnology and the plankton community of the reservoir have changed in response to the aging of the reservoir and watershed activities.

Materials and methods

Study area

This study was undertaken at Mazvikadei Reservoir (17°13′14″ S and 30°23′30″ E) on the Mukwadzi River in Banket, north-west of Harare (Figure 1). Dam construction was completed in 1988 and the reservoir filled for the first time in 1990. The wall is an earth-filled embankment of 63.5 metres in height, making it the second highest dam wall in Zimbabwe. The reservoir has a storage capacity of 360 million m^3 and a surface area of 2 300 ha at full capacity. The maximum depth of the reservoir is 58 m, the mean depth is 15.9 m, the maximum width is 2 km and the shoreline length is 116 km, with a shoreline development index of 6.8. The reservoir is surrounded by commercial agricultural land and it provides water for farm irrigation. It is also a popular weekend resort, because of its proximity to Harare, Zimbabwe's capital. Most of the reservoir's catchment lies on granitic rock and, in some parts, soil with metamorphosed sediments. The catchment also includes part of the Great Dyke, characterised by serpentine soils with high levels of magnesium, nickel and chromium content (Masundire 1992). Macrophytes, such as *Nymphaea* sp. and *Phragmites* sp., are common along the banks of the reservoir, whereas submerged macrophytes, such as *Lagarosiphon major* and *Potamogen crispus*, are abundant.

Sampling was undertaken monthly from May to October 2015, covering two of the seasons that occur in Zimbabwe: cool-dry (May to August) and hot-dry (September to October). Eight sampling sites were selected along the length of the reservoir, based mainly on depth and location (Figure 1) in order to capture the distinct longitudinal gradients linked to the reservoir's river-lake hybrid nature (Kimmel et al. 1990). The sampling stations were situated on the long axis of the reservoir from the inflow of the Mukwadzi River to the dam wall.

Environmental parameter measurements

Integrated water samples were collected with a Ruttner sampler at 1 m intervals from the bottom to the surface of the reservoir. All the samples collected at each depth were integrated and subsamples were taken for laboratory analysis. Measurement of pH and temperature, conductivity and Total Dissolved Solids, dissolved oxygen and percentage oxygen saturation were measured on-site using a pH meter (WTW PH 340i, Weilheim, Germany), conductivity meter (WTW Cond 330i, Weilheim, Germany) and an oxygen meter (WTW Oxi 330i, Weilheim, Germany), respectively. Water transparency was measured using a Secchi disk. Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were determined using standard methods (Bartram and Ballance 1996).

Nitrate-nitrogen was determined by the cadmium reduction method (EPA Method 353.2). Ammonia was determined by the EPA method 350.1. Total nitrogen was determined by the cadmium reduction method. Reactive phosphorus was determined by the USEPA PhosVer 3 method 8048. Total phosphorus was determined by the USEPA PhosVer 3 with the acid persulfate digestion method 8190 using unfiltered water samples. These methods are described in detail in Bartram and Balance (1996).

Plankton sampling

Zooplankton and phytoplankton subsamples were collected using 64 µm and 20 µm plankton nets of 40 cm diameter, respectively. Water collected at 1 m depth intervals was mixed in a bucket, after which 20 litres were filtered through the plankton nets to collect zooplankton and phytoplankton subsamples. The concentrated samples were collected in labelled 250 ml bottles. Zooplankton was preserved with 70% alcohol and phytoplankton with Lugol's iodine solution. The samples were taken to the laboratory for identification and abundance estimation under an inverted microscope (OLYMPUS CKX41). The density of phytoplankton and zooplankton was determined by counting the numbers present in three 25 ml subsamples from each site, and then the numbers per litre were estimated. Phytoplankton was identified using keys in Prescott (1970), Iltis (1980), Canter-Lund and Lund (1995). Zooplankton was identified using keys in Elenbaas (1994) and Fernando (2002).

Chlorophyll *a* was determined by the acetone extraction method (Golterman et al. 1978). Integrated water samples were used for extraction of chlorophyll *a* in 90% acetone using the spectroscopic method of Golterman et al. (1978).

Data analysis

Diversity indices (i.e. Shannon–Wiener index, Simpson) were calculated for phytoplankton and zooplankton using PAST version 2.0 (Hammer et al. 2001). The Kruskal–Wallis test statistic was used to test for differences among

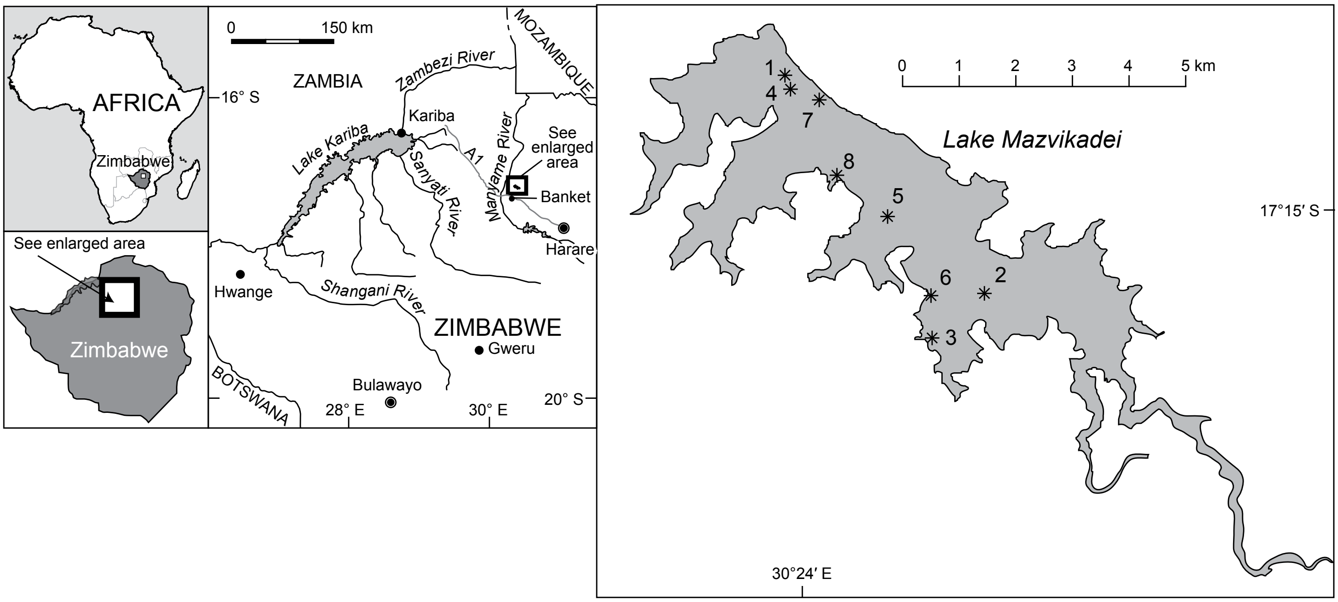

Figure 1: Map of Mazvikadei Reservoir, north eastern Zimbabwe, showing positions of sampling sites ⁎

the diversity for the study months ($p < 0.05$). Kruskal–Wallis tests ($p < 0.05$) were done to test for differences in physico-chemical characteristics between sites and between months using the computer software STATISTICA version 7 (StatSoft 2004).

A Principal Component Analysis (PCA) was done to determine the relationship among the limnological variables measured at different sites and times. Prior to the multivariate analysis, all physico-chemical variables, except pH (already a logarithm), were log transformed to reduce skewness in the data. The datasets were consistently linear in nature (Detrended Canonical Analysis). Therefore, a Principal Component Analysis (PCA) was used in order to obtain an overall assessment of the possible relations among the limnological variables measured at different sites and times in Mazvikadei Reservoir.

Redundancy Analysis (RDA) was carried out to identify environmental factors that influenced the phytoplankton and zooplankton communities using the statistical program Canoco ver. 4.5. Prior to analysis zooplankton and phytoplankton data were tested for linearity using Detrended Correspondence Analysis (DCA) (Lepš and Šmilauer 2003) and were found to be consistently linear in nature. RDA is a constrained linear ordination method based on significant ($p < 0.05$) forward selected environmental variables using 999 Monte Carlo Permutations. The first step in the Redundancy Analysis (RDA) was to identify significant explanatory variables (environmental factors) using Forward Selection procedures (999 Monte Carlo permutations). Once these variables were identified for both the phytoplankton and zooplankton communities, the selected variables were applied to the RDA procedure and their significance tested using Monte Carlo permutations. Fifty-four phytoplankton, 19 zooplankton and 15 environmental variables were used in the analysis.

The Carlson Trophic State Index (TSI) (Carlson 1977), which uses chlorophyll *a*, Total phosphorus (TP) and Secchi depth, was used to calculate monthly and overall TSI values for Mazvikadei. When classifying lake trophic state, priority is given to the TSI value associated with chlorophyll, because it is the most accurate of the three variables in predicting algal biomass. However, any of the three variables can theoretically be used to classify a lake. The formulae for calculating TSI values for chlorophyll *a*, Secchi disk and TP were:

Chlorophyll *a*: $\text{TSI (CHL)} = 9.81 \ln(\text{CHL}) + 30.6$
Secchi disk: $\text{TSI (SD)} = 60 - 14.41 \ln(\text{SD})$
Total phosphorus: $\text{TSI (TP)} = 14.42 \ln(\text{TP}) + 4.5$

Results

Physico-chemical variables

Temperature showed a similar trend at all the sites, being high during the hot dry season (September to October) and low during the cool dry season (May to August) (Figure 2a). The trend in pH was similar at all the sites, the average pH being 8.6 (Figure 2b; Table 1). The average conductivity in the reservoir was 262.6 µS cm^{-1} (Table 1). Conductivity increased from May to August, with values ranging from 251.4 to 267.9 µS cm^{-1}, dropping in September and October to range between 253.2 and 261.2 µS cm^{-1} (Figure 2c), followed by a significant increase in October. Total Dissolved Solids (TDS) concentrations followed the same trend as conductivity, the average TDS concentration being 165.2 mg l^{-1} (Figure 2d; Table 1). The average Secchi disk transparency in the reservoir was 4.4 m and followed a similar trend at all the sites, with the highest and the lowest values in July and October, respectively (Figure 2e). Chemical Oxygen Demand (COD) concentrations ranged from 8 to 31 mg l^{-1} (Figure 2f). The Biological Oxygen Demand (BOD) followed an almost similar trend at all the sites, the average BOD being 1.9 mg l^{-1} (Figure 2g; Table 1). The average chlorophyll *a* concentration in the reservoir was 0.0021 mg l^{-1}, with the highest concentrations >0.004 mg l^{-1} being recorded

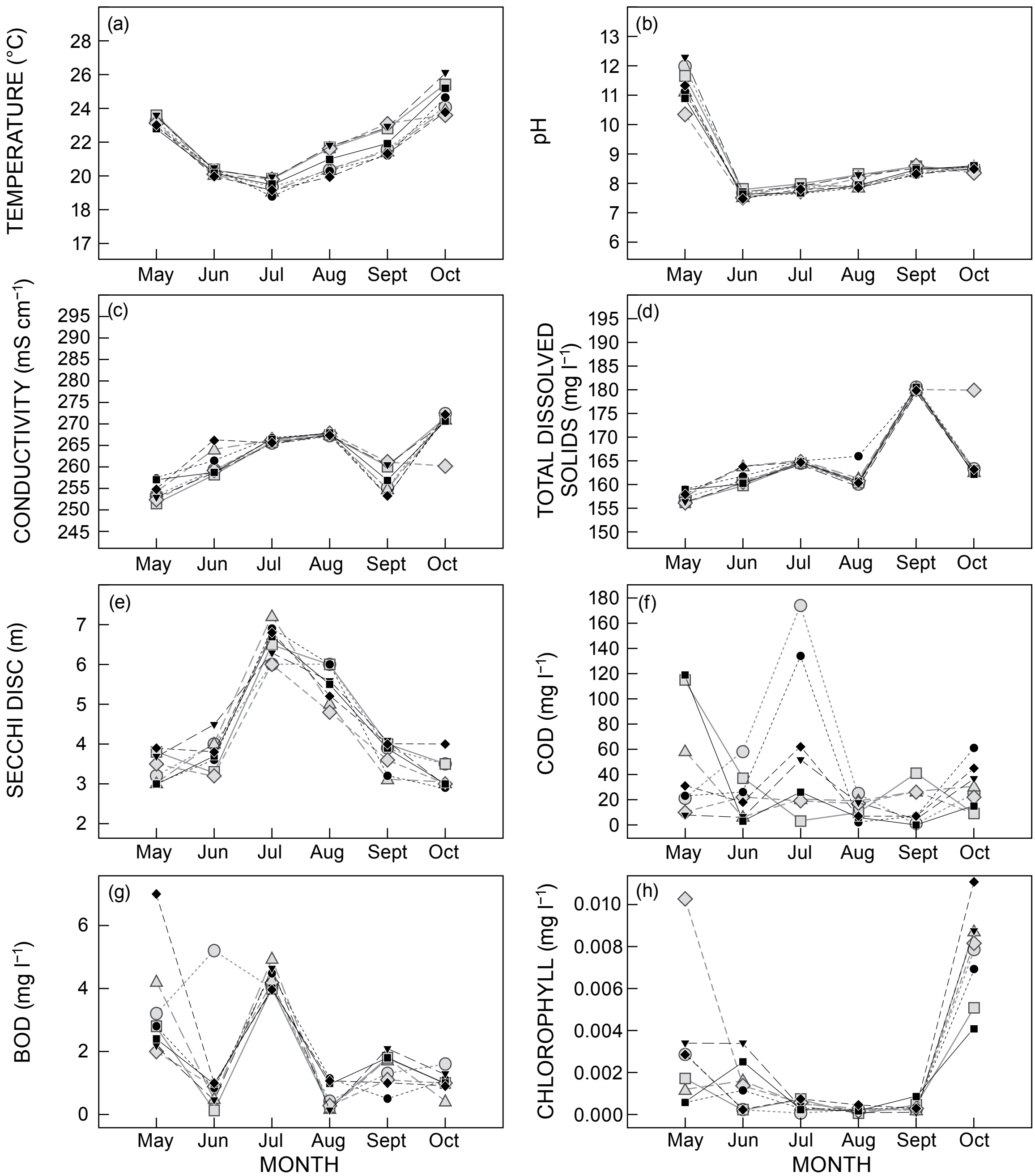

Figure 2: Changes in (a) temperature, (b) pH, (c) conductivity, (d) total dissolved solids, (e) transparency, (f) chemical oxygen demand, (g) biological oxygen demand and (h) chlorophyll *a* in Mazvikadei reservoir from May to October 2015. Site 1 ●; Site 2 ○; Site 3 ▼; Site 4 ∆; Site 5 ■; Site 6 □; Site 7 ♦; Site 8 ◊

in October (Figure 2h). Dissolved oxygen and percentage oxygen saturation followed the same trend at all the sites throughout the sampling period (Figure 3a, 3b). The average dissolved oxygen concentration and percentage oxygen saturation for Mazvikadei Reservoir were 5.9 mg l^{-1} and 76.9%, respectively (Table 1).

The average nitrate concentration in the reservoir was 0.01 mg l^{-1}, and ranged from 0.0006 to 0.028 mg l^{-1} (Figure 3c). The average ammonia concentration was 0.0112 mg l^{-1} (Table 1). Ammonia concentrations were low and almost constant from May to October (Figure 3d). Total phosphorus concentrations were low throughout the sampling period, the average concentration being 0.065 mg l^{-1} (Figure 3e). Reactive phosphorus (RP) concentration ranged between 0.045 and 0.12 mg l^{-1}, the average concentration being 0.019 mg l^{-1} (Figure 3f; Table 1). Total nitrogen concentrations showed a similar trend at all the sites from May to October, with an average concentration of 0.085 mg l^{-1} and the highest concentrations occurring in May (Figure 3g).

Table 1: Limnological variable values (mean ± SD) at eight sites in Mazvikadei reservoir in May–October 2015. AMM = Ammonia, RP = Reactive Phosphorus, NITR = Nitrate, TP = Total Phosphorus, TN = Total Nitrogen, TRANS = Transparency, BOD = Biological Oxygen Demand, COD = Chemical Oxygen Demand, Chl *a* = Chlorophyll *a*, COND = Conductivity, TDS = Total Dissolved Solids, TEMP = Temperature, DO = Dissolved Oxygen, % SAT = Percentage Oxygen Saturation

Variable	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7		Site 8	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
AMM (mg l^{-1})	0.0146	0.0099	0.0116	0.0026	0.0107	0.0016	0.0105	0.0007	0.0103	0.0004	0.0104	0.0009	0.0107	0.0004	0.0106	0.0004
RP (mg l^{-1})	0.0207	0.0220	0.0147	0.0220	0.0187	0.0228	0.0314	0.0437	0.0175	0.0225	0.0116	0.0174	0.0199	0.0293	0.0173	0.0269
NITR (mg l^{-1})	0.0210	0.0340	0.0119	0.0095	0.0064	0.0040	0.0092	0.0052	0.0062	0.0041	0.0053	0.0035	0.0115	0.0083	0.0088	0.0070
TP (mg l^{-1})	0.02	0.01	0.06	0.08	0.02	0.01	0.03	0.02	0.09	0.20	0.03	0.02	0.03	0.02	0.24	0.43
TN (mg l^{-1})	0.08	0.07	0.10	0.10	0.08	0.04	0.08	0.04	0.09	0.07	0.09	0.07	0.08	0.04	0.08	0.05
TRANSP (m)	4.27	1.73	4.43	1.25	4.53	1.22	4.22	1.66	4.30	1.49	4.52	1.37	4.62	1.19	4.02	1.16
BOD (mg l^{-1})	1.81	1.53	2.62	1.82	1.81	1.62	1.98	2.09	1.87	1.20	1.66	1.52	2.49	2.51	1.58	1.39
COD (mg l^{-1})	42.17	49.53	50.67	63.13	20.50	19.95	26.50	17.46	28.17	45.49	35.83	41.86	28.33	22.07	19.33	5.50
Chl a (mg l^{-1})	0.0016	0.0026	0.0019	0.0031	0.0027	0.0033	0.0020	0.0033	0.0014	0.0016	0.0014	0.0019	0.0026	0.0043	0.0035	0.0045
pH	8.51	1.34	8.73	1.62	8.89	1.70	8.53	1.32	8.54	1.22	8.80	1.43	8.54	1.41	8.45	1.01
COND (µS cm^{-1})	263.04	6.93	262.13	7.45	262.95	6.62	262.74	6.94	262.92	6.11	262.33	7.20	263.21	7.52	261.17	5.55
TDS (mg l^{-1})	165.86	7.32	164.57	8.26	164.45	8.11	165.10	7.85	164.76	8.03	164.12	8.28	165.13	7.67	167.19	10.35
TEMP (°C)	21.37	2.08	21.45	1.86	22.50	2.26	21.34	1.91	21.77	2.05	22.29	2.09	21.20	1.85	21.89	1.65
DO (mg l^{-1})	5.69	0.86	5.61	0.69	6.55	1.08	5.44	0.52	6.09	1.03	6.46	0.99	5.30	0.68	6.48	0.98
% SAT	73.33	10.96	72.47	8.00	84.71	14.68	69.68	6.20	78.44	13.71	84.69	14.43	67.58	8.55	84.52	11.52

There were significant differences ($p < 0.05$) among the sites for dissolved oxygen and percentage oxygen saturation. None of the other variables was significantly different among the sites (Table 2). There were significant differences between the sampling months for all the variables ($p < 0.05$), except for ammonia (Table 2).

Principal Component Analysis

The first four ordination axes accounted for 73.8% of the cumulative variance of the environmental data. The first two axes accounted for 53.0% of the total variation, with axes one and two each explaining 35.3% and 17.8%, respectively (Figure 4). There was a clustering of sites sampled in the same month, which suggests changes in water quality among the different sampling occasions, although the extent of the differences varied. May, July and October were distinct, whereas the other months were similar, but were nevertheless clustered separately. In May, there were increasing levels of reactive phosphorus, total nitrogen and pH, whereas July was characterised by increasing ammonia and Secchi disc transparency. In October, the sampling sites were characterised by high water temperature and levels of chlorophyll *a*.

Phytoplankton community

Chlorophytes (63.3%) were abundant in the hot dry season months of September and October (Figure 5a). Bacillariophytes (44.1%) were abundant in the cool dry season months of May and June. Dinophytes (46.9%) were abundant in the cool dry season months of July and August. Cyanophytes (20.1%), Desmids (18.2%) and Euglenophytes (1.7%) were most abundant in May. The percentage composition of Bacillariophytes, Desmids and Cyanophytes decreased gradually from May to September, whereas a significant increase in all the three groups was observed in October. However, Chlorophytes increased gradually from July to October. The total ind. l^{-1} was high in May, but decreased in June and July, increasing again in August (Figure 5b). The highest number of ind. l^{-1} for the whole sampling period was observed in September, when there was a peak of >60 000 ind. l^{-1} at the beginning of the hot dry season. The phytoplankton numbers decreased in October. Individual species within the phytoplankton groups that contributed significantly in terms of abundance were *Ceratium* sp.*, Heleochloris* sp.*, Heleochloris mucosa, Coelastrum* sp.*, Cymatopleura* sp.*, Gyrosigma* sp.*, Fragillaria* sp.*, Pinnularia* sp. and *Straurastrum tetracerum.*

Species richness was greatest (36 species) in May and low in June and August with a mean of 27 species (Table 3). The monthly means (± SD) of diversity indices of phytoplankton in Mazvikadei Reservoir (Table 4) followed the same trend, being high in May, decreasing in July and increasing in the hot dry season months of September and October. There were significant differences among the different sampling months for the diversity indices: (Shannon–Wiener index H = 14.54, p = 0.0125; Simpson H = 14.53, p = 0.0125; Evenness H = 21.06, p = 0.0008). These results were analysed using Mann–Whitney pairwise comparisons to identify the months that were significantly different. These comparisons were similar for both the

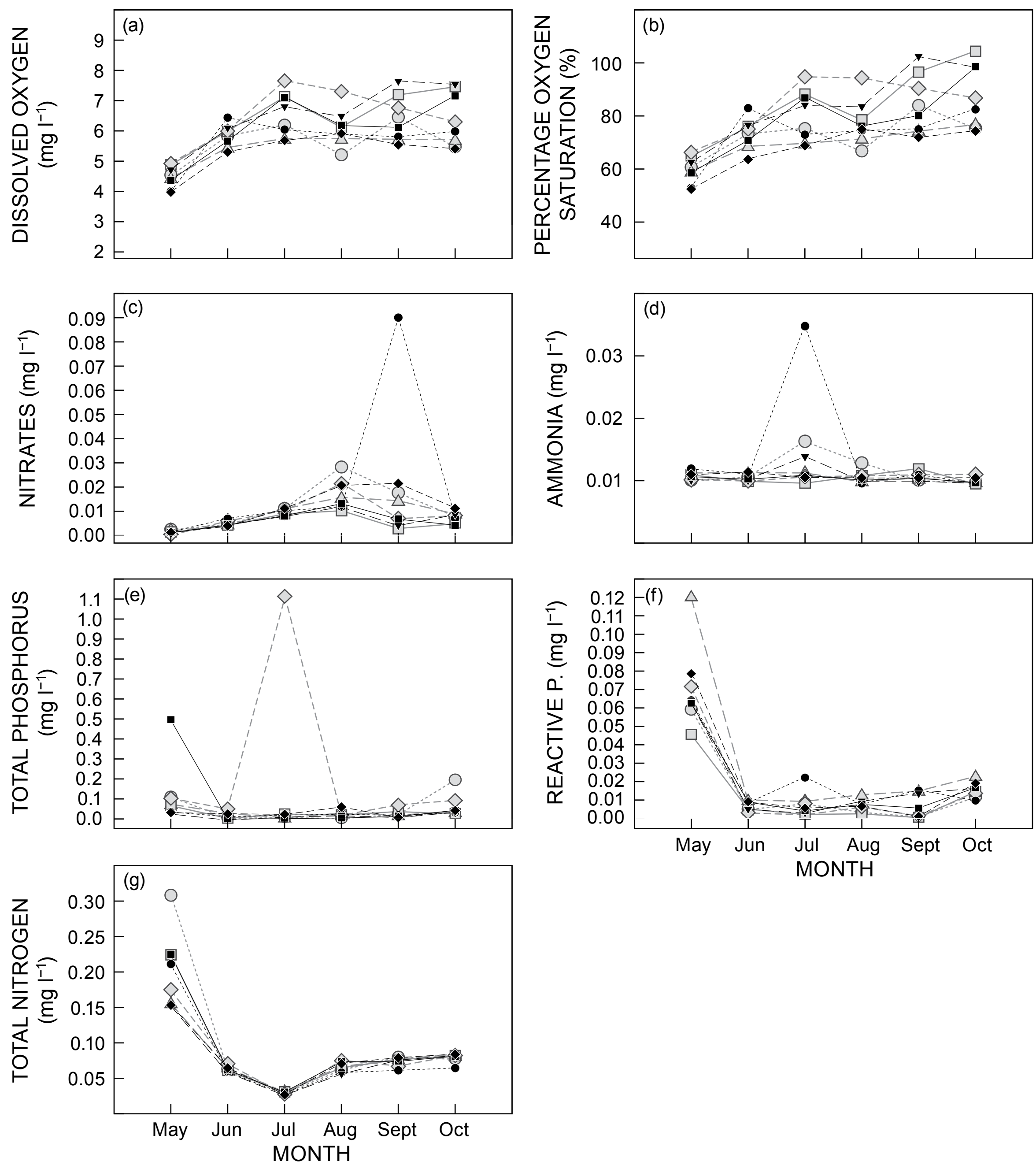

Figure 3: Changes in (a) dissolved oxygen, (b) percentage oxygen saturation, (c) nitrates, (d) ammonia, (e) total phosphorus, (f) reactive phosphorus and (g) total nitrogen in Mazvikadei reservoir from May to October 2015. Site 1 ●; Site 2 ○; Site 3 ▼; Site 4 ∆; Site 5 ■; Site 6 □; Site 7 ♦; Site 8 ◊

Shannon–Wiener index and Simpson's indices, with significant differences between May and June and also between October and July and August.

The phytoplankton communities were more even in May, June and October. Evenness was low from July to September when two or three groups of phytoplankton became dominant. For evenness, there were significant differences between October and both August and September. May and June were both significantly different from August and September.

Forward selection using Monte Carlo permutations identified temperature, nitrates and total nitrogen as the only significant variables influencing the phytoplankton community dynamics (F-ratio = 2.903, p = 0.002). The first four axes accounted for 21.2% of the variance in the phytoplankton species data, with axes one and two explaining 9.3% and 6.4%, respectively. Of the variance in the species-environment relationship, axis one accounted for 43.9%, whereas axes two, three and four accounted for 30%, 18.8% and 7.3%, respectively. Nitrates and total

Table 2: Kruskal–Wallis ANOVA results for significant differences (p < 0.05) among sampled sites, and temporal differences for sampled water quality variables in Mazvikadei reservoir in May–October 2015. * = significant difference, TDS and % oxygen saturation covary with conductivity and dissolved oxygen, measured as mg l^{-1}, respectively. BOD = Biological Oxygen Demand, COD = Chemical Oxygen Demand

	Differences among months		Differences among sites	
Variable	H	*p*	H	*p*
Ammonia (mg l^{-1})	10.37	0.065*	3.213	0.865
Reactive Phosphorus (mg l^{-1})	29.00	<0.0001*	7.153	0.413
Nitrate (mg l^{-1})	33.73	<0.0001*	4.432	0.729
Total Phosphorus (mg l^{-1})	20.87	<0.0001*	8.411	0.298
Total Nitrogen (mg l^{-1})	40.65	<0.0001*	2.396	0.935
Transparency (m)	36.63	<0.0001*	3.225	0.863
BOD (mg l^{-1})	32.44	<0.0001*	1.971	0.961
COD (mg l^{-1})	11.78	0.038*	2.944	0.891
Chlorophyll *a* (mg l^{-1})	31.94	<0.0001*	1.834	0.969
pH	42.57	<0.0001*	1.493	0.983
Conductivity (µS cm^{-1})	40.05	<0.0001*	0.480	0.998
Total Dissolved Solids (mg l^{-1})	-	-	-	-
Temperature (°C)	42.86	<0.0001*	2.289	0.942
Dissolved Oxygen (mg l^{-1})	22.47	0.0004*	14.94	0.037*
Percentage Oxygen Saturation	-	-	-	-

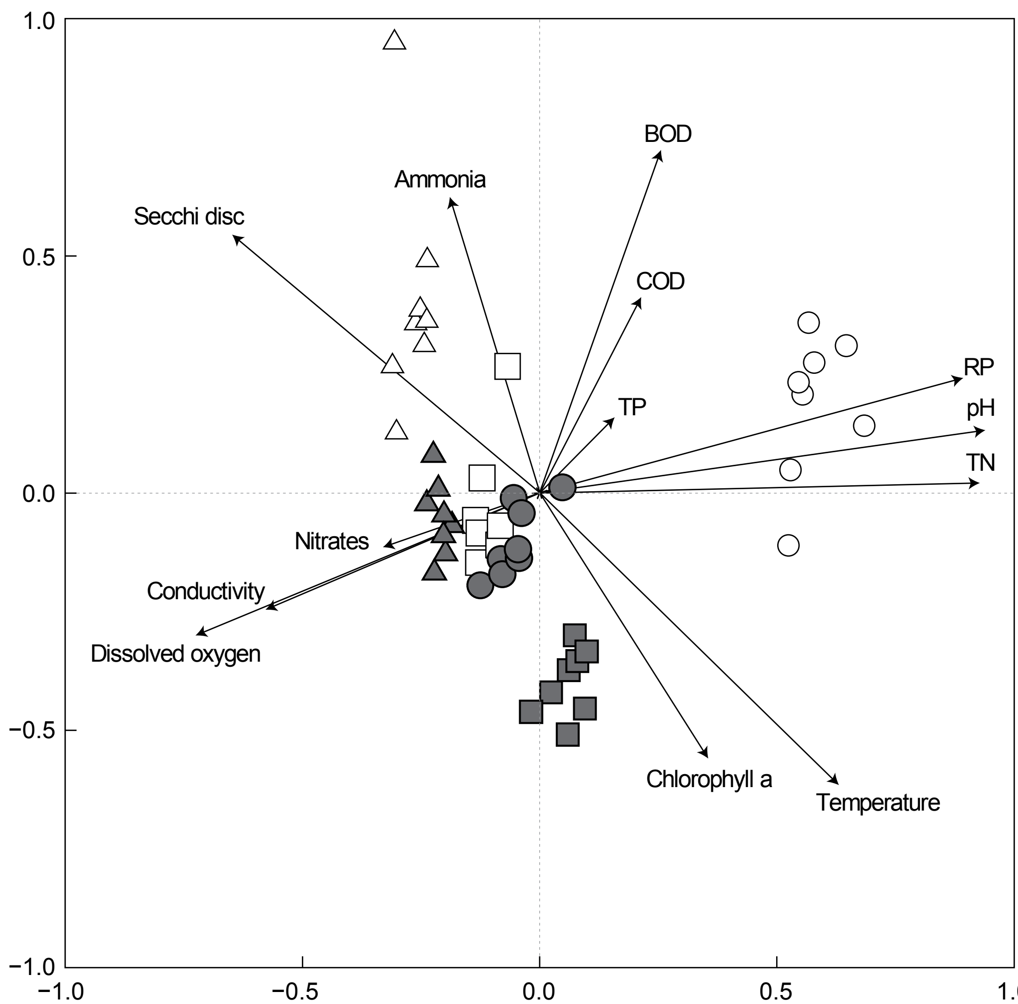

Figure 4: PCA plot showing relationships among limnological variables measured at sampling sites in Mazvikadei Reservoir from May to October 2015 – M – May ○, JN – June □; JL – July ◊; A – August ▲; S – September ●; O – October ■

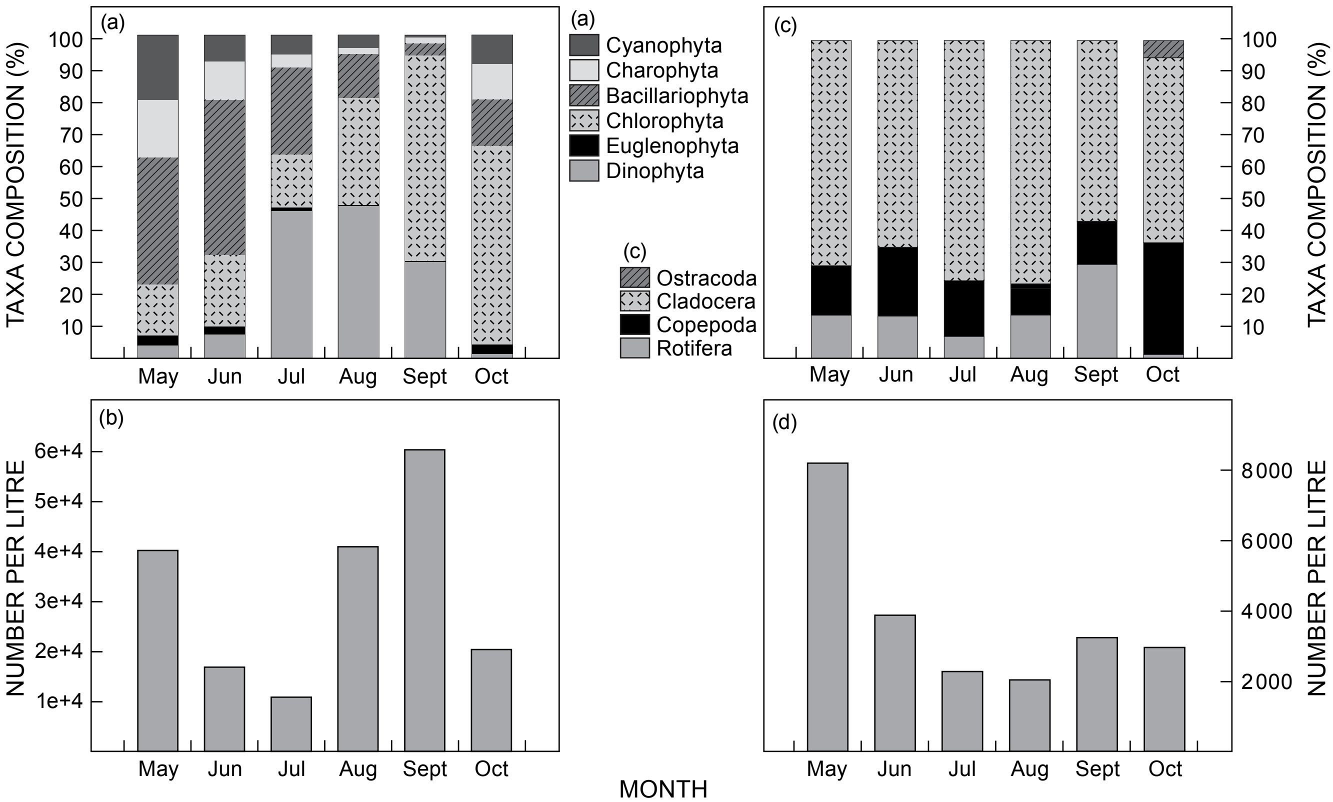

Figure 5: Temporal changes in (a) phytoplankton percentage composition, (b) phytoplankton total abundance, (c) zooplankton percentage composition and (d) zooplankton total abundance in Mazvikadei Reservoir from May to October 2015

nitrogen concentrations had a strong clustering effect on the phytoplankton community (Figure 6). With the exception of May, the rest of the months were all clustered around the origin (Figure 6).

Zooplankton community structure

Rotifers (29.6%) were abundant in September, whereas Copepods were most abundant (35.1%) in October. Cladocerans occurred in the highest proportion relative to other zooplankton taxa in all of the months, and especially in the cool dry season months of June and July (mean proportion 74.9%) (Figure 5c). Ostracods (5.4%) were observed only during the hot dry season month of October. The total abundance of zooplankton was initially high (8 200 ind. l^{-1}) in May, but then declined to <4 000 ind. l^{-1} from June to August (Figure 5d). Finally, the total abundance of zooplankton increased again to an average of 3 100 ind. l^{-1} in the warm months of September to October. The relative abundance of zooplankton during the sampling period is summarised in Table 5 and Figure 5c. The individual species in the zooplankton groups that contributed significantly in terms of abundance were *Bosmina longirostris, Brachionus fortificula, Keratella cochlearis, Thermocyclops eminii, Daphnia pulex, Daphnia longispina* and *Diaphanosoma excisum*.

The Shannon–Wiener index and Simpson diversity indices were high in May, decreased between June and August and then rose in September and October (Table 6). There were no significant differences among the different sampling months for the diversity indices: (Shannon–Wiener index H = 9.02, p = 0.108; Simpson H = 7.51, p = 0.186). Mann Whitney pairwise *post hoc* analysis revealed that significant differences were mainly between May and July, August and September for these two indices. The zooplankton community structure was fairly even from May to October (Table 6). There were significant differences in evenness in the zooplankton population (H = 11.39, p = 0.044). Mann–Whitney pairwise *post hoc* comparisons revealed significant differences between May and July and between August and October.

Reactive phosphorus and phytoplankton abundance were identified in the forward selection statistical procedure as significant variables (F-ratio 4.230, p = 0.002). The first four axes accounted for 35.3% of the variance in the zooplankton species data, with axes one and two explaining 12.1% and 3.7%, respectively. Of the variance in the species-environment relationship, axis one accounted for 76% and axis two for 24.3%. The species-environment analysis depicted in Figure 7 does not go beyond the first two axes and so is a two-dimensional relationship.

Samples collected in May 2015 were associated with higher concentrations of certain species, which include *Ceriodaphnia* sp., *Daphnia pulex*, *Bosmina longirostris*, *Polyathra* sp., *Brachionus fortificula*, *Diaphanosoma excisum* and *Eucyclops* sp. In the same quadrant, there is also the influence of phytoplankton abundance as a significant factor on the zooplankton community. The August,

Table 3: Monthly abundance (ind. l^{-1}) of phytoplankton species in Mazvikadei Reservoir in May–October 2015

Taxon	May	June	July	August	September	October
Dinophyta						
Ceratium sp.	1 400	1 280	5 040	19 480	18 160	280
Peridinium sp.	240	0	0	40	40	0
Euglenophyta						
Euglena sp.	280	320	120	160	200	600
Tetraedron trigonum	920	80	0	0	0	0
Trachelomonas sp.	0	0	0	0	0	0
Chlorophyta						
Amphora sp.	280	120	0	160	40	280
Ankistrodesmus sp.	80	0	0	0	0	0
Chlorella sp.	0	40	0	240	80	760
Chroococcus sp.	960	0	0	0	0	0
Coelastrum sp.	440	80	40	400	1 000	400
Dictyosperarium sp.	80	0	0	40	0	0
Eudorina elegans	240	0	0	160	1 120	280
Eutetramorus planctonicus	0	0	40	0	240	1 200
Eutetramorus fotti	40	0	80	40	1 120	400
Gloeocystis sp.	80	120	480	880	680	0
Heleochloris mucosa	3 440	240	120	1 200	4 960	1 760
Heleochloris sp.	40	360	560	9 440	24 120	6 040
Korschpalmella miniata	160	0	0	0	320	0
Monoraphidium arcuatum	520	2 680	80	200	280	320
Oocystis sp.	40	0	120	360	3 520	0
Pediastrum boryanum	0	160	40	120	80	200
Pediastrum duplex	0	0	120	40	40	160
Pediastrum simplex	80	0	0	40	0	0
Radiococcus nimbatus	0	0	0	80	1 160	440
Scenedesmus sp.	0	0	80	320	80	480
Schroederia sp.	0	0	40	0	0	0
Bacillariophyta						
Achnanthes sp.	1 160	280	240	80	0	0
Cocconeis sp.	400	0	0	0	0	0
Cymatopleura sp.	640	320	40	200	160	280
Cymbella sp.	1 120	120	400	0	120	80
Diatoma vulgaris sp.	280	320	80	960	240	80
Eunotia sp.	160	40	0	120	80	0
Fragilaria sp.	880	1 360	1 080	1 200	520	800
Frustulia sp.	720	1 560	0	40	120	440
Gyrosigma sp.	1 800	1 000	520	840	360	1 120
Navicula sp.	160	40	80	400	40	0
Nitchzia linearis	840	240	80	280	120	80
Pinnularia sp.	6 760	2 520	280	760	360	0
Synedra sp.	920	400	160	720	80	80
Surirella sp.	80	0	0	0	0	0
Desmids						
Arthrodesmus sp.	80	0	0	0	0	0
Closterium setaceum	160	920	320	400	320	1 560
Cosmarium sp.	1 720	40	0	0	0	0
Spirogyra sp.	40	80	0	0	0	0
Staurastrum gracile	0	0	0	0	0	80
Staurastrum tetracerum	5 320	760	40	80	280	640
Cyanophyta						
Anabeana sp.	0	1 280	520	280	120	640
Anabaena spiroides	320	0	0	40	0	0
Chroococcus sp.	2 360	0	0	0	0	0
Gomphosphaeria sp.	960	0	0	120	0	0
Merismopedia sp.	40	80	0	280	0	200
Microcystis aeruginosa	800	0	0	0	40	40
Oscillatoria sp.	3 280	0	120	840	160	400
Unidentified filamentous	320	0	0	0	0	0
Total number of taxa (*n*)	36	29	26	31	34	31
Individuals l^{-1}	40 240	16 920	10 920	41 000	60 360	20 440
Simpson's index	0.921	0.907	0.749	0.697	0.7351	0.8831
Shannon–Wiener index	2.928	2.685	2.118	1.828	1.837	2.762
Evenness	0.519	0.505	0.32	0.201	0.1847	0.5106

October and several September sites were clustered together. The effect of phytoplankton abundance is also evident in these sites. Species such as *Ectocyclops* sp., *Keratella cochlearis, Thermocyclops eminii, Daphnia pulex* and *Oncocypris* sp. were dominant in August and October. June and July were not strongly associated with the dominance of many species, except a small increase in *Trichocera* sp. and *Mastigodiaptomus* sp.

Trophic State Index (TSI) calculations for Mazvikadei Reservoir

The TSI (CHL) and TSI (SD) both indicated that, overall, the reservoir was oligotrophic (TSI = 38.1), but was near borderline mesotrophic. However, TSI (TP) ranks the reservoir as eutrophic. Monthly trends for TSI (CHL) showed that for different months the index ranged from 16.1 (oligotrophic) to 50.5 (eutrophic). For TSI (SD), the index

Table 4: Monthly means (± SD) of diversity indices of phytoplankton and Kruskal–Wallis ANOVA and *post hoc* Mann–Whitney pairwise comparison results in Mazvikadei Reservoir in May–October 2015. Two different superscript letters indicate significant difference

	Shannon–Wiener (H)	Simpson (1-D)	Evenness
May^{a}	$2.175 \pm 0.319^{a,c}$	$0.833 \pm 0.055^{a,c}$	$0.599 \pm 0.076^{(a,d)(a,e)}$
June^{b}	1.925 ± 0.312	0.794 ± 0.086	$0.675 \pm 0.125^{(b,d)(b,e)}$
July^{c}	$1.646 \pm 0.442^{c,f}$	$0.699 \pm 0.154^{c,f}$	0.593 ± 0.203
August^{d}	$1.477 \pm 0.555^{d,f}$	$0.640 \pm 0.179^{d,f}$	$0.416 \pm 0.109^{d,f}$
September^{e}	1.626 ± 0.199	0.708 ± 0.053	$0.418 \pm 0.145^{e,f}$
October^{f}	1.937 ± 0.365	0.789 ± 0.078	0.682 ± 0.095

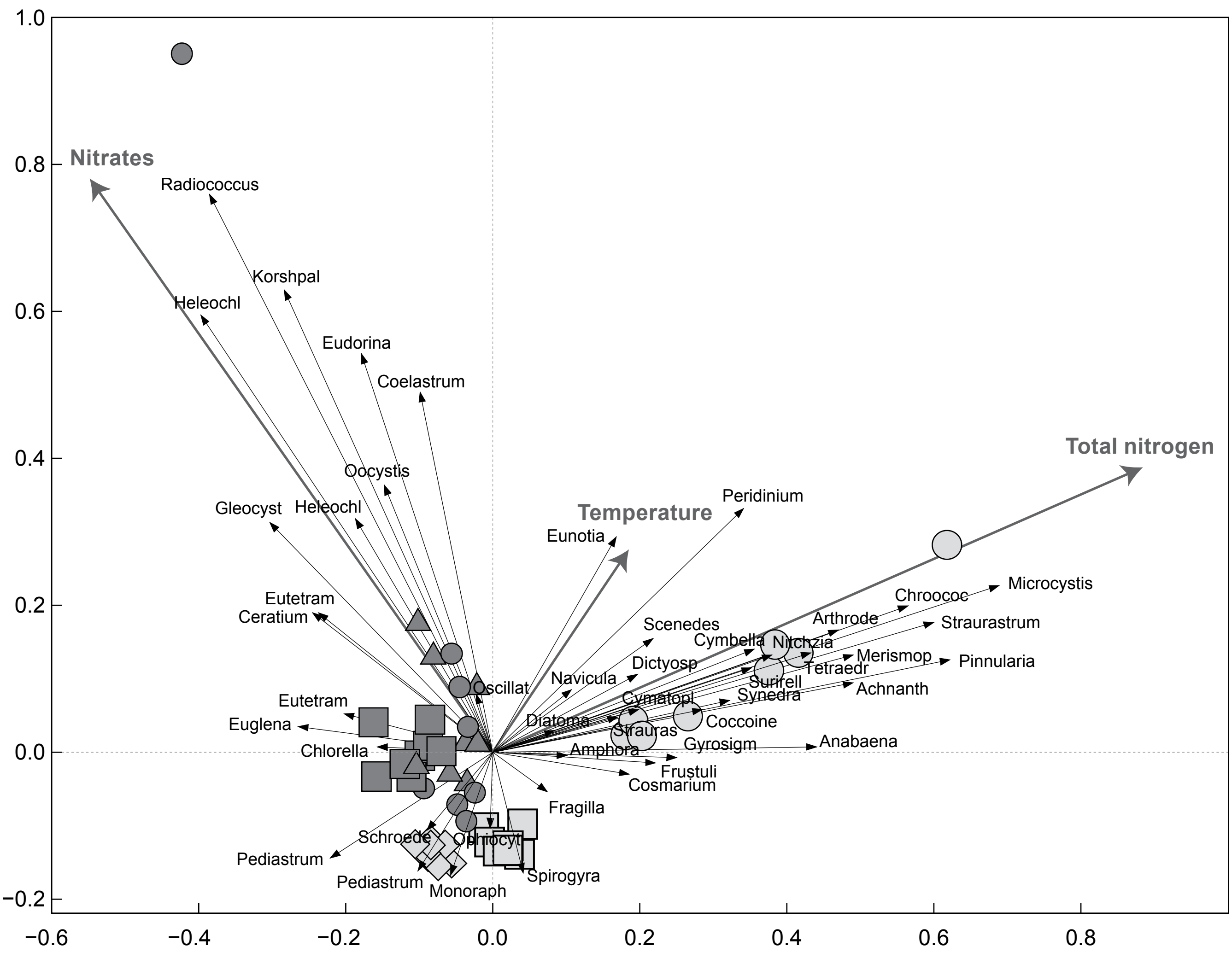

Figure 6: Redundancy Analysis (RDA) ordination showing relationship between significant environmental variables and phytoplankton communities in Mazvikadei Reservoir from May to October 2015. M – May ○, JN – June □; JL – July ◊; A – August ▲; S – September ●; O – October ■

ranged from 32.9 (oligotrophic) to 43.1 (mesotrophic) for different months. Finally, for TSI (TP) the index ranged from 44.2 (mesotrophic) to 72.8 (eutrophic) (Table 7).

Discussion

The current study generates information on the consequences of reservoir aging and provides insights into the sensitivity of the reservoir to watershed perturbations. All indices employed during this study showed that Mazvikadei Reservoir can be classified as an oligotrophic reservoir characterised by the low algal biomass, low concentrations of P and N, high Secchi disk clarity and low chlorophyll *a* concentration. Using TSI (CHL) as the priority index, in conjunction with TSI (SD), it can be concluded that Mazvikadei is an oligotrophic system. However, it is important to note that, for both these indices, the reservoir is near borderline mesotrophic. Why this is the case becomes apparent when analysing the monthly trends as well as the TSI (TP). It is also evident that nutrient loading is fairly high and increasing, but is not being quickly converted into algal biomass. Reasons for this could include rapid sequestration to the sediment, as oxygen levels are high. Moyo (2011) also noted that Mazvikadei was well oxygenated and that its trophic status bordered between oligotrophic and mesotrophic.

Mazvikadei Reservoir is well oxygenated. This contrasts with anoxic conditions detected in the water column during the filling phase (Masundire 1992). Dissolved oxygen in Mazvikadei is within the range recorded in Cleveland Reservoir (7.7 mg l^{-1}) (Ndebele 2009) and in the epilimnion of Lake Kariba (7.6–7.8 mg l^{-1}) (ILEC 1998), two other oligotrophic lakes in Zimbabwe. In 1988, Mazvikadei had a neutral pH ranging from 7.2 in May and 7.8 in August (Masundire 1992). The pH is now slightly alkaline (8.5) and is comparable to that of both Lake Kariba (Balon and Coche 1974) and Cleveland Reservoir (Ndebele 2009). The average conductivity in the reservoir has increased to 263.2 μS cm^{-1} and is now higher than the 160 μS cm^{-1} (range 146–158 μS cm^{-1}) recorded during the filling phase. It is also higher than the readings from both Cleveland Reservoir (114 μS cm^{-1}) (Ndebele 2009) and Lake Kariba (95 μS cm^{-1} in Basin 1 to 100 μS cm^{-1} in Basin 5 (Balon and Coche 1974). However, reservoir falls in Class 1, which,

Table 6: Monthly means (± SD) of diversity indices of zooplankton and Kruskal–Wallis ANOVA and *post hoc* Mann–Whitney pairwise comparison results in Mazvikadei Reservoir in May–October 2015. Two different superscript letters indicate significant difference

	Shannon–Wiener (H)	Simpson	Evenness
May[a]	1.453 ± 0.377	0.705 ± 0.110	0.742 ± 0.072
June[b]	1.274 ± 0.482	0.625 ± 0.171	0.774 ± 0.155
July[c]	1.015 ± 0.254[a,c]	0.590 ± 0.099[a,c]	0.888 ± 0.107[a,c]
August[d]	0.951 ± 0.603[a,d]	0.499 ± 0.312[a,d]	0.884 ± 0.118[a,d]
September[e]	1.211 ± 0.293[a,e]	0.640 ± 0.133[a,e]	0.824 ± 0.149
October[f]	1.445 ± 0.297	0.720 ± 0.111[e,f]	0.875 ± 0.106[a,f]

Table 5: Monthly abundances (ind. l^{-1}) of zooplankton species in Mazvikadei Reservoir in May–October 2015

Taxa	May	June	July	August	September	October
Rotifera						
Asplancha sp.	0	80	0	0	0	0
Brachionus caudatus	80	160	40	80	0	0
Brachionus fortificula	720	200	120	40	40	0
Keratella cohlearis	280	40	0	120	880	0
Polyarthra vulgaris	40	0	0	0	40	40
Trichocera sp.	0	40	0	40	0	0
Copepoda						
Ectocyclops sp.	40	0	0	80	40	0
Eucyclops neumanii	200	40	0	0	0	0
Eucyclops eucanthus	80	80	0	0	0	160
Thermocyclops eminii	40	240	120	120	200	320
Thermocyclops incicus	240	120	80	0	0	80
Mastigodiaptomus sp.	0	0	40	0	40	80
Nauplii	680	360	160	0	160	400
Cladocera						
Bosmina longirostris	2 200	1 760	760	800	1 320	1 040
Ceriodaphnia sp.	160	0	0	0	0	0
Daphnia longispina	1 520	40	0	0	0	0
Daphnia coronata	0	160	80	120	120	80
Daphnia pulex	1 040	520	880	560	400	440
Diaphanosoma excisum	880	40	0	40	0	160
Ostracoda						
Oncocypris sp.	0	0	0	0	0	160
Total number of taxa (*n*)	15	15	9	11	10	11
Individuals l^{-1}	8 200	3 880	2 280	2 040	3 240	2 960
Simpson's index	0.8482	0.7554	0.7264	0.7559	0.7368	0.8134
Shannon–Wiener index	2.141	1.94	1.607	1.784	1.638	1.986
Evenness	0.5673	0.4639	0.5542	0.5414	0.5143	0.6623

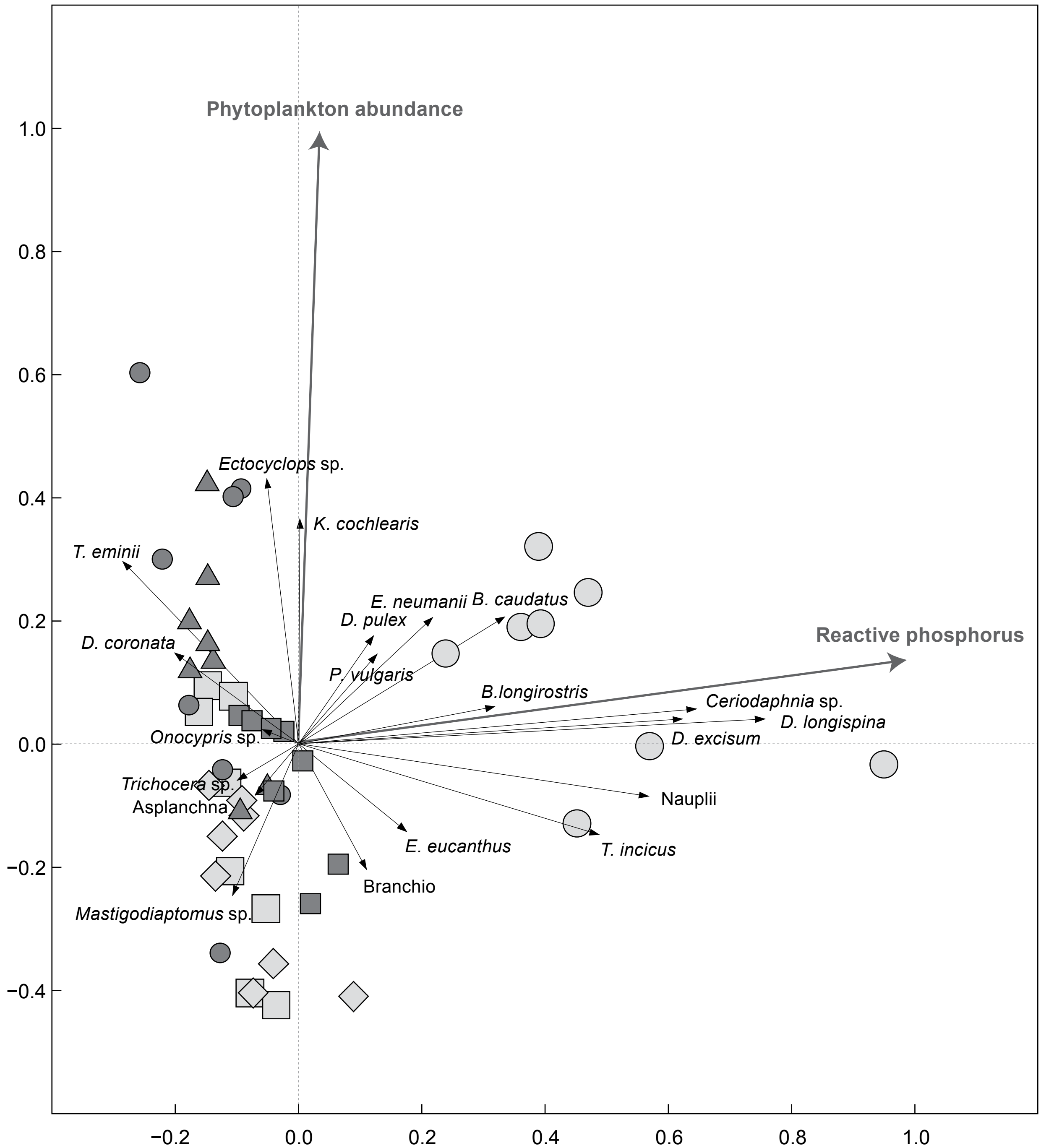

Figure 7: Redundancy Analysis (RDA) ordination showing relationship between significant environmental variables and zooplankton communities in Mazvikadei Reservoir from May to October 2015. M – May ○, JN – June □; JL – July ◊; A – August ▲; S – September ●; O – October ■

Table 7: Carlson Trophic State Index for Mazvikadei Reservoir in May–October 2015

	Month							
	May	June	July	August	September	October	Mean variable	Mean TSI
TSI (CHL)	41.1	33.5	22.4	16.1	20.1	50.5	2.14 µg l^{-1}	38.1
TSI (SD)	42.4	40.9	32.9	35.4	41.0	43.1	4.36 m	38.8
TSI (TP)	72.8	44.2	51.6	48.2	50.1	63.3	44.3 µg l^{-1}	58.8

according to Talling and Talling (1965), comprises soft water lakes and reservoirs with conductivities <600 µS cm^{-1}. Such lakes are fed by rivers of low salt content, which regionally include lakes Victoria and George (Talling and Talling 1965) and locally Kariba (Coche 1974, Magadza et al. 1987). The transparency of Mazvikadei has increased to 4.6 m from a transparency of 0.8 m and 3.3 m recorded in May and August 1988, respectively during the filling phase (Masundire 1992). Moyo (2011) recorded lower transparencies ranging from 1.8 to 3.1 m, which could have been influenced by the higher chlorophyll *a* concentrations recorded at that time. The improvement in water clarity is linked to the change in the trophic status of the reservoir. Both N and P were higher during the filling phase. The reservoir experienced a post-impoundment eutrophic or nutrient-rich phase, but has now assumed an oligotrophic or nutrient-poor phase.

Mazvikadei (2 300 ha) is included among the ten largest reservoirs in Zimbabwe (Marshall 2011), comparable in size to Manyuchi (2 833 ha), Manjirenji (2 023 ha) and Chivero (2 630 ha). Local reservoirs of similar size lack data to enable comparison, except for Chivero, which is hyper-eutrophic (Magadza 2003; Mhlanga et al. 2006). Limited data are available for comparatively smaller reservoirs, namely Malilangwe (211 ha) (Dalu et al. 2013), two small reservoirs on the Manwahuku river (5.7 ha upper dam, 2.5 ha lower dam) (Nhiwatiwa and Marshall 2007) and Cleveland (30 ha) (Ndebele 2009). Comparison with small systems presents challenges, because their limnology is primarily influenced by wide water level fluctuations linked to season flooding and water abstraction, which creates highly variable unpredictable aquatic environments (Nhiwatiwa and Marshall 2007). Short residence times in small reservoirs do not allow for the establishment of stable algal populations such that a clear seasonal cycle typical of large reservoirs is absent (Nhiwatiwa and Marshall 2007). Local comparison can be made with reservoirs that have also assumed an oligotrophic status, for example Cleveland (Ndebele 2009) and Kariba (Balon and Coche 1974), although Kariba is more like a ‘Great Lake’, because it is more or less the same size as Lake Albert (Lehman et al. 2013) and twice as large as Lake Kivu (Descy et al. 2012).

The phytoplankton community in Mazvikadei is comparable to those recorded in Cleveland Reservoir (Ndebele 2009) and Lake Kariba (Ramberg 1987, Cronberg 1997). In the current study, fifty four species were recorded in Mazvikadei. Dalu et al. (2013) recorded 98 phytoplankton species in Malilangwe Reservoir, categorised as a large reservoir, because it covers more than 200 ha (Miranda and Bettoli 2010), although it is smaller than Mazvikadei. Cleveland Reservoir, which is even smaller, supports 29 species (Ndebele 2009), whereas Lake Kariba (considered extremely large) supports 150 species (Cronberg 1997). It seems that, the larger the reservoir, the higher the niche availability, leading to higher species richness (Steinmann et al. 2011).

The highest phytoplankton species richness in May was related to the high nutrient concentrations, attributed to the import of dissolved ions via the river inflow that happened as a result of the late rains in 2015. An increased amount of suspended solids carried into the reservoir resulted in high concentrations of reactive phosphorus in the reservoir. When sediments were disturbed by the late rains and river inflow, the rate of phosphorus release may have increased (Wetzel 2001). Under the influence of wind-generated mixing there could also have been a partial mixing of the riverine layer and the epilimnion, providing a mechanism by which nutrients were redistributed vertically within the reservoir. Additional nutrients were released, which contributed to increased productivity in the reservoir during that period. Because the nutrients were assimilated with time, this resulted in a decrease in the species richness in the subsequent months after May. Evenness decreased during the cool dry season. This is a similar trend to that which was observed in Lakes Kariba, Malawi, Tanganyika and Victoria (Hecky and Kling 1981; Cocquyt and Vyverman 1994; Salonen et al. 1999; Descy et al. 2005; Ndebele-Murisa et al. 2010). A comparison can also be made with the phytoplankton community in Lake Kariba, which is now stable and exhibits a regular seasonal pattern linked to the nutrient dynamics in the lake (Ramberg 1987; Cronberg 1997). In Lake Kariba, diatoms (*Aulacoseira*, *Cyclotella* and *Synedra*) attain a maximum biomass at turnover in June–July. This was also observed in Mazvikadei. Diatoms in freshwater exhibit a ‘boom and bust’ lifestyle where, when there is high nutrient and light availability during the turnover period, their competitive edge allows them to dominate the phytoplankton communities quickly (Furnas 1990). Phytoplankton growth is dependent on temperature. Although the Dinophyta can adapt to a wide range of temperatures and light irradiance, they do thrive at lower temperatures (Baek et al. 2008) and hence that group dominated during the cool dry season.

Because of the limited sampling period of six months, phytoplankton seasonal succession was not depicted in Mazvikadei Reservoir. The sampling period from May to October reflects the results of only the cool dry and hot dry seasons. There was dominance of the Bacillariophyta and Dinophyta in the cool dry season and of Chlorophyta in the hot dry season. Generally, the phytoplankton community in Mazvikadei Reservoir was dominated by three groups: Chlorophyta, Dinophyta and Bacillariophyta. This is almost similar to the observation by Dalu et al. (2013) in Malilangwe Reservoir, where the community was dominated by Chlorophyta, Dinophyta and Cyanophyta. The importance of Cyanophyta was less in Mazvikadei, because of its lower trophic status. Cyanophyta dominate in nutrient-rich systems or during periods of high nutrient inputs (Holz et al. 1997; Mhlanga et al. 2006). Studies have indicated that if a lake becomes oligotrophic after watershed stabilisation, the dominant algal community will include Chlorophyta, Bacillariophyta and Dinophyta (Holz et al. 1997) as now typified in Mazvikadei. In Mazvikadei, Chlorophyta were abundant with respect to species representation. A similar observation was made in Malilangwe (Dalu et al. 2013) and in Cleveland Reservoir (Ndebele 2009).

The phytoplankton community in a reservoir indicates the lake’s trophic status (Yerli et al. 2012). Although there is no documented information on the phytoplankton community composition at the filling phase of Mazvikadei for comparison, the current community that has been established is characteristic of an oligotrophic system. Diatom species, such as *Nitchzia* spp. and *Fragillaria* spp., which were also observed in Lake Kivu, are normally associated with oligotrophic, phosphorus-deficient African tropical reservoirs (Sarmento et al. 2006). The low densities of Euglenophyta and Cyanophyta and the high densities of desmids were also an indication of oligotrophic conditions within the reservoir. It is comparable to that of Lake Kariba where the most common phytoplankton species in the lake are the two diatoms *Aulacoseira* spp. and *Synedra* spp. and the bluegreen alga *Cylindrospermopsis raciborskii* (Cronberg 1997). During the filling phase in Lake Kariba desmids and benthic diatoms, relics of the riverine community, were dominant. This could have also been the case in Mazvikadei during its eutrophic phase, but the water body has now matured and assumed a stable oligotrophic status.

Nitrates and total nitrogen had a strong clustering effect on the phytoplankton community, because a large proportion of total nitrogen contains dissolved organic nitrogen that can be readily converted into ammonia. This is the best form of nitrogen for assimilation by plants and algae, for the reason that they cannot use nitrogen in its elemental form (Ghaly and Ramakrishnan 2015). From the RDA analysis, from June to July most of the sites were clustered around the origin, suggesting a lack of major differences in the phytoplankton community during that period. This may be for the reason that there were no significant differences between the sites in terms of environmental variables and because the conditions were almost the same across all the sites, the community composition would also be almost similar. In the RDA analysis, the sites for May were distinctly clustered together. This may be a result of the nutrient release that happened because of the inflow caused by late rains in May. Throughout the sampling period, this event only happened in May and may have resulted in this distinct clustering, indicating a unique species community composition.

In 1992, eight rotifer species were recorded in Mazvikadei Reservoir that happened only in April, except for *Filinia opoliensis*, which was also recorded in August (Masundire 1992). Moyo (2011) recorded four rotifer species previously recorded by Masundire (1992), whereas during the current study, six rotifer species were recorded. Except for *Brachionus falcatus* and *Trichocera* sp., all other species recorded in 2015 were new for this reservoir. Masundire (1992) recorded four cladoceran species, *Daphnia longispina*, *Bosmina longirostris*, *Ceriodaphnia cornuta* and *Diaphanosoma excisum*. All species occurred in August and, except for *D. longispina*, the rest occurred in April. None of these species was recorded in May. In 1992 the most abundant species in April was *D. excisum*, whereas *B. longirostris* and *C. cornuta* were both common (Masundire 1992). Moyo (2011) also recorded the four cladocerans previously reported by Masundire (1992). During the current study, six cladocerans were recorded in May. The cladoceran species recorded in all three studies were *B. longirostris*, *D. longispina* and *D. excisum*. New species recorded during the current study were *Daphnia coronata* and *Daphnia pulex*. *Ceriodaphnia* sp. was also recorded in 2015. All the cladocerans, except *D. coronata*, occurred in May 2015, contrasting with Masundire's study, where no cladocerans were recorded in May 1988, because anoxic conditions then prevailed in the reservoir and which might have been unfavourable for cladocerans.

Masundire (1992) recorded two copepod species, one cyclopoid *Thermocyclops neglectus* and one calanoid *Thermodiaptomus syngenes* in Mazvikadei in 1988. These two species occurred in April and August, but were absent in May. In 1988, the most abundant species was *T. neglectus* followed by *T. syngenes*. Six new species of copepod were recorded in 2015, namely *Ectocyclops* sp., *Eucyclops neumanii*, *Eucyclops eucanthus*, *Thermocyclops eminii*, *Thermocyclops incicus* and *Mastigodiaptomus* species. Moyo (2011) did not observe these six species, but recorded the two copepods previously observed by Masundire (1992). This can be attributed to differences in sampling intensity and frequency.

The community of copepods in Mazvikadei has changed. Copepods can survive in a wide range of conditions and they have been recorded to survive even in low oxygen waters (Stickle et al. 1989). Calanoids, however, are more responsive to shifts in the external environment and so, when conditions were not favourable in the cool dry season, the calanoid *Matigodiaptomus* sp. was not observed. The high number of nauplii recorded in May can best be explained by the high food availability, which resulted in higher reproduction rates for the copepods.

The zooplankton community structure and species composition in Mazvikadei has changed from that observed during its filling phase. There are now 19 species, compared with the nine species recorded during the filling phase and the 10 reported by Moyo (2011), showing an increase in species richness over time. Since the filling phase, the phytoplankton community has also stabilised as the reservoir matured and the zooplankton community has responded to this, because the two are closely correlated. The absence of some species in 2015 may be attributed to the sampling frequency. Samples were taken only once a month, so some species could have been missed. The new species may also point to zooplankton succession in reservoirs as they age, with the pioneer species, such as *Ascormorpha* sp., being gradually replaced by the *Daphnia* sp. Zooplankton species richness in Mazvikadei Reservoir was lower than the 66 species recorded in Malilangwe Reservoir (Dalu et al. 2013).

As observed by Masundire (1992), cladocerans are still the dominant group, although rotifers and copepods are now also well represented. Rotifers and cladocerans also dominated the zooplankton community in Malilangwe Reservoir (Dalu et al. 2013). It would be expected that, because Mazvikadei is oligotrophic, it would be dominated by calanoids that can graze at low phytoplankton concentrations, but this was not the case (Isumbisho et al. 2006). Cladocerans became most abundant during the cold dry season (June and July) in Mazvikadei when they assumed 75% abundance. Cladoceran abundance and composition is dependent on temperature and predation rates. In cold oligotrophic lakes with low predation rates, cladocerans have a longer life span (Pietrzak et al. 2013). This may also be the reason why cladocerans were dominant during the cool dry season in Mazvikadei, an oligotrophic reservoir. Rotifers and copepods dominated during the hot dry season, because of high food availability, as they are grazers. Ostracods were observed only in September in the hot dry season, because ostracod eggs have a protective shell that allows them to become dormant. Once favourable conditions, such as warmer temperatures and food availability are prevalent, the eggs hatch (Fernando 2002).

A link between high phosphorus concentration and high phytoplankton biomass was observed in Mazvikadei in May 2015. The high phosphorus concentration could have been caused by turnover, which occurs in winter in most Zimbabwean reservoirs (Dalu et al. 2013; Ndebele-Murisa et al. 2014). Phosphorus is the primary nutrient limiting phytoplankton production in reservoirs and lakes (Sterner 2008), although colimitation by P and N is also important (Guildford and Hecky 2000; Dzialowski et al. 2005). Phosphorus could be a limiting factor in Mazvikadei, because Moyo (2011) recorded a high N:P ratio that he attributed to low P levels and consequently low chlorophyll *a* levels. Its increase thus resulted in an increase in phytoplankton growth. A trophic cascade effect then occurs, with high phosphorus levels resulting in increased phytoplankton growth, which in turn affects the amount of food available for the zooplankton, which will subsequently increase (Carpenter et al. 2001).

Mazvikadei Reservoir has matured and assumed the physico-chemical characteristics and plankton community typical of an oligotrophic lake. The limnological changes associated with the aging of Mazvikadei provide insights into the implications of the levels of watershed perturbation. More than two decades ago an increase in productivity was postulated in response to increased nutrient input from agricultural activities (Masundire 1992), as has been observed in other systems (Carpenter et al. 1998). It appears that Zimbabwe's land invasions in 2000 reduced agricultural activities within the catchment, such that the reservoir aging process has progressed from the trophic upsurge that happened after filling into the trophic depression and has now assumed typical oligotrophic characteristics. Although the current results imply that external nutrient loads remained constant during the past two decades, appropriate management measures should be instituted to avoid deterioration in water quality in future.

Acknowledgements — Technical and financial support by the Department of Biological Sciences, University of Zimbabwe, and by Chinhoyi Zimbabwe Parks, Wildlife and Management Authority staff are gratefully acknowledged. Special thanks go to Mr Lightfoot, Gold Dust township, Mazvikadei, for creating an enabling environment for this study to be successfully carried out. Mrs Eileen Musarurwa also provided financial support. Professor Isla Grundy, University of Zimbabwe, edited the manuscript.

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Manuscript received 9 June 2016, revised 26 April 2017, accepted 25 May 2017
Associate Editor: JC Taylor