

Macroinvertebrate communities associated with littoral zone habitats and the influence of environmental factors in Malilangwe Reservoir, Zimbabwe

T. Dalu^{(1,2)*}, B. Clegg⁽³⁾, T. Nhiwatiwa⁽¹⁾

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ABSTRACT

Key-words:

Macroinvertebrates, diversity, Malilangwe reservoir, macrophyte cover, conductivity, water level

The aim of our study was to investigate macroinvertebrate communities so as to understand factors and processes structuring macroinvertebrate communities in a small reservoir, Malilangwe reservoir over seven months (April to October). Sampling was performed by active sweep netting and searching soil sediments. Water temperature, conductivity, dissolved oxygen, pH, ammonia, nitrogen, phosphorus, chemical oxygen demand and macrophyte cover were determined. In total, forty-two macroinvertebrate families belonging to 10 orders were identified amongst 13 macrophyte species and sediments. Thiaridae and Physidae (Mollusca) were the dominant and most abundant taxa (57.71%) and there were followed by the Hemiptera (27.31%). High indices for sites 1 to 3 for the Simpsons index, the Shannon-Weaver index and evenness were recorded, while low indices were observed for sites 4 to 5, with significant differences being observed among the study site using the Kruskal-Wallis ANOVA test ($p < 0.05$). Redundancy Analysis revealed that among environmental factors, hydrologically linked parameters such as conductivity, water level and macrophyte cover had the strongest influence on macroinvertebrate distribution.

RÉSUMÉ

Les communautés de macro-invertébrés associées aux habitats de la zone littorale et l'influence des facteurs environnementaux dans le réservoir Malilangwe, Zimbabwe

Mots-clés :

macro-invertébrés, biodiversité, réservoir Malilangwe, macrophytes, conductivité

Le but de notre étude était d'étudier les communautés de macro-invertébrés de manière à comprendre les facteurs et les processus qui structurent ces communautés dans un petit réservoir, réservoir Malilangwe, au cours de sept mois (avril à octobre). L'échantillonnage a été effectué par balayage actif et prospection des sédiments. La température de l'eau, la conductivité, l'oxygène dissous, le pH, l'ammoniac, l'azote, le phosphore, la demande chimique en oxygène et la couverture de macrophytes ont été déterminés. Au total, quarante-deux familles de macro-invertébrés appartenant à 10 ordres ont été identifiées dans les 13 espèces de macrophytes et les sédiments. Thiaridae et Physidae (Mollusca) étaient les taxons dominants et les plus abondants (57,71 %), suivis par les Hemiptera (27,31 %). Des valeurs élevées pour les sites de 1 à 3 de l'indice de Simpson, de

(1) Department of Biological Sciences, University of Zimbabwe, PO Box MP167, Mt. Pleasant Harare, Zimbabwe

(2) Zoology and Entomology, Rhodes University, PO Box 94, Grahamstown 6140, South Africa

(3) Malilangwe Wildlife Reserve, P. Bag 7085, Chiredzi, Zimbabwe

* Corresponding author: dalutatenda@yahoo.co.uk

l'indice de Shannon-Weaver et de la régularité ont été observées, tandis que des indices faibles ont été observés pour les sites 4 à 5, avec des différences significatives observées entre les sites d'étude en utilisant le test ANOVA de Kruskal-Wallis ($p < 0,05$). L'analyse de redondance a révélé que parmi les facteurs environnementaux, les paramètres liés à l'hydrologie tels que la conductivité, le niveau de l'eau et la couverture de macrophytes ont la plus forte influence sur la distribution des macro-invertébrés.

INTRODUCTION

Macroinvertebrates are the most diverse and abundant organisms in freshwater aquatic systems and are a key component of aquatic ecosystem function (Kratzer, 2002). Macroinvertebrates distribution and community is strongly dependent on the composition and structure of vegetation and macroinvertebrates are recognized as an essential food source for juvenile fish and amphibians in aquatic systems (Takhelmayum and Gupta, 2011). Lakes with well-developed macrophyte communities are characterised by more diverse communities of zooplankton, benthos and fish (Kouamé *et al.*, 2011). Some species of the major secondary producers such as rotifers, cladocerans and insect larvae are commonly found in both pelagic and vegetated areas, whereas others are exclusively found within vegetation stands (Curtis, 1991; Skoroszewski and de Moor, 1999; Rocha-Ramirez *et al.*, 2007; Kouamé *et al.*, 2011).

Diverse invertebrate communities exist among the submersed vegetation of ponds, pools and lakes. The abundance of phytophilous invertebrates in an aquatic ecosystem is defined by many factors including macrophyte morphology, substrate texture and epiphytic algal growth, community composition and defensive chemicals (Hann, 1995; Skoroszewski and de Moor, 1999; Kratzer, 2002; Albertoni *et al.*, 2007).

Water levels fluctuations occur naturally in lakes and reservoirs as a result of seasonal imbalances between the amounts of water entering via inflow, precipitation, runoff and/or groundwater inputs and water leaving the lake via evaporation, seepage and/or outflow (Zohary and Ostrovsky, 2011). Lakes and reservoirs fluctuate seasonally between maximum levels during the rainy season and minimum levels usually at the end of the dry season in tropical regions such as Zimbabwe. Extreme or untimely water level fluctuations can have undesirable effects on the ecosystems (Bond *et al.*, 2008). Human exploitation of water resources can lead to increased annual and inter-annual water level fluctuations, at times, far beyond natural amplitudes and/or irrespective of the natural hydrological cycle. A range of natural features of the water level regime are often impacted, not only the amplitude of fluctuation but also the timing of the minimum and maximum water levels and the rates of water level increase and decline (Gasith and Gafny, 1990; Zohary and Ostrovsky, 2011).

Aquatic macroinvertebrate assemblages and communities can act as good indicators of the prevailing hydrological regime and water quality in aquatic systems. Several studies on macroinvertebrates, focused on community composition or association with the plant community, have been carried out on large water bodies in Zimbabwe such as Lake Kariba (Begg, 1970; Machena and Kaustky, 1989; Mhlanga and Siziba, 2006; Phiri *et al.*, 2011a, 2011b). This current study is the first to be carried out on the Malilangwe Reservoir macroinvertebrate community. The aim was to characterize the freshwater macroinvertebrate communities found in the littoral zones of the reservoir to assess if monthly/seasonal changes in environmental parameters have impacts on macroinvertebrate communities. The role of environmental factors on taxon richness, diversity, relative abundance, distribution and dominance of macroinvertebrates was also investigated.

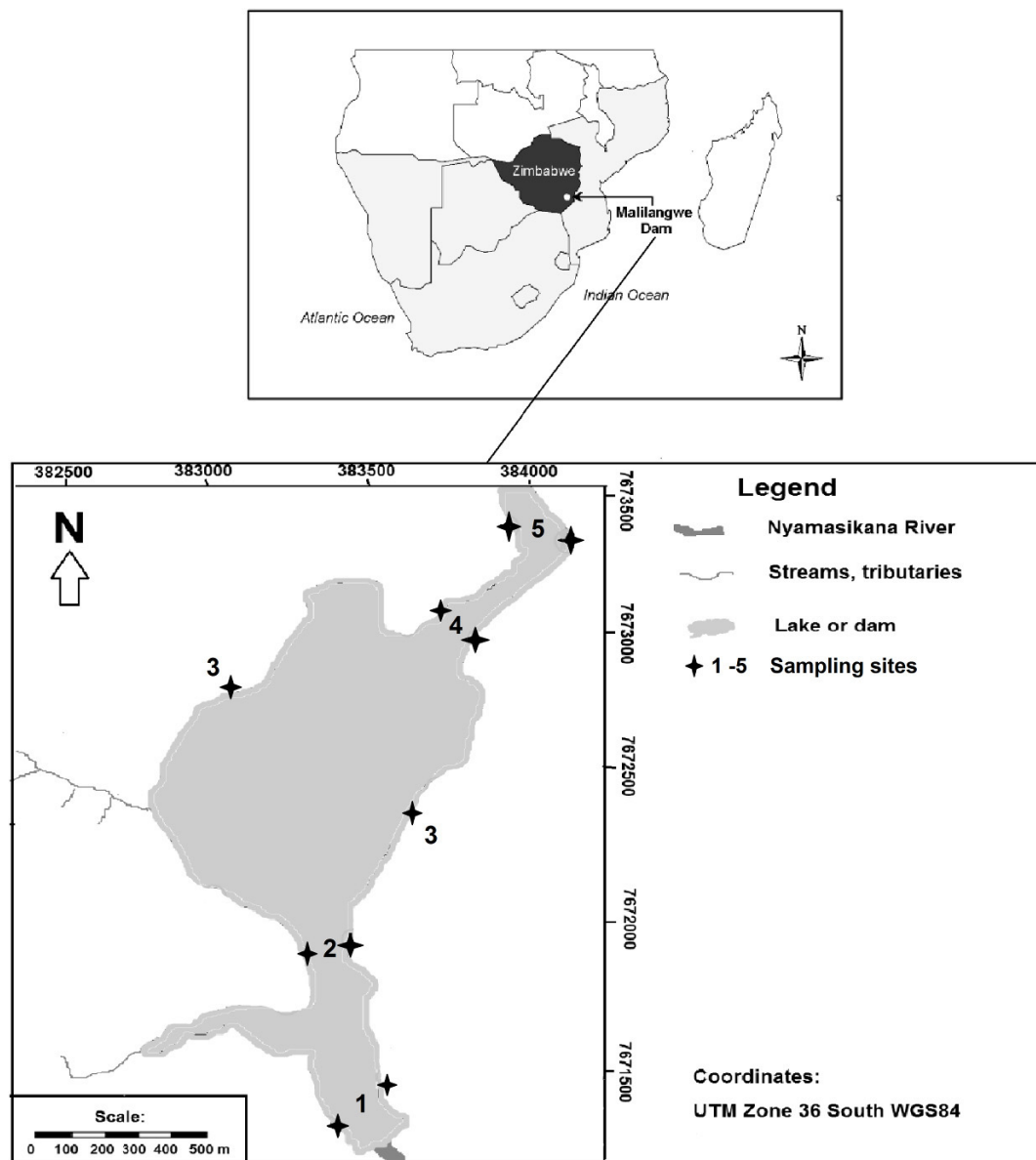


Figure 1
Location of littoral zone sampling sites around Malilangwe Reservoir, Zimbabwe.

STUDY AREA

Malilangwe Reservoir is located in the Chiredzi District, south-eastern lowveld region of Zimbabwe ($20^{\circ}58' 21^{\circ}02' S$, $31^{\circ} 47' 32^{\circ}01' E$) (Figure 1). Mean annual rainfall calculated from a 56 year record (1951–2010) collected at Malilangwe Head Quarters is approximately 562 mm, but is very variable both within and between seasons. Approximately 84% of rainfall occurs between November and March (Clegg, 2010). The average annual rainfall for Malilangwe is extremely erratic and the lowveld area is prone to drought (Davy, 2005). Temperatures are high with most daily maxima in excess of $32^{\circ} C$ throughout the year and peak temperatures during hot spells in the summer often over $45^{\circ} C$. Winters are generally cool, with temperatures ranging from $5\text{--}26^{\circ} C$ with frost virtual absent (Traill, 2003). The annual average evaporation has been estimated at ca. 2000 mm (Kelly and Walker, 1976).

Malilangwe Reservoir is an impounded river, created in 1964 and is used as a water supply for the Malilangwe wildlife reserve community. It is a gravity section masonry dam with a surface area of 211 hectares and maximum volume of $12 \times 10^6 \text{ m}^3$ at full capacity with volume development of 0.95. The maximum depth of the reservoir is 14.30 m, mean depth is 4.54 m, shoreline length is 9415 m with a shoreline development of 1.83. Flanked by rocky hills on most of its sides, the Reservoir has a rocky substrate with few sandy bays. The reservoir has few marginal plants including *Azolla filiculoides*, *Panicum repens*, *Ludwigia stolonifera*, *Potamogeton* sp., *Schnoeplectus corymbosus*, *Cyperus* sp. and *Phragmites mauritanus* (Barson et al., 2008; Dalu, unpub. data). Five sampling sites were selected based on differences in vegetation type and cover, substrate type, position in relation to the inflow and outflow points. Two stations were selected for each site, on the eastern and western costs of the reservoir. Site 1 was located in the deepest part and next to the dam wall (depth = 1.05 eastern shore and 0.60 western shore). Site 2 was located between the two hills (depth = 0.85 eastern shore and 0.35 western shore), site 3 was located on the littoral zones of the open waters (depth = 0.60 eastern shore and 0.45 western shore), site 4, was the point where the reservoir narrows into a river channel (depth = 0.25 eastern shore and 0.30 western shore) and site 5 was located where the Nyamasikana River enters the reservoir (depth = 0.30 eastern shore and 0.50 western shore).

MATERIALS AND METHODS

> BASIC WATER QUALITY MEASUREMENTS

Integrated water sample along the water column was collected in the morning at each site on a monthly basis (April to October) with measurements of pH, conductivity, total dissolved solids (TDS), water temperature and dissolved oxygen (DO) done using a pH, conductivity and DO meter (HACH, LDO, Germany). Water transparency was measured using a Secchi disk. Chemical oxygen demand (COD), nitrogen and nitrates and total and reactive phosphorus were determined using standards methods from Environmental Protection Agency (EPA), Hach and Standard Methods. Water level was measured from the dam spillway level to the water surface on a monthly basis using a tape measure and water volume estimated using calculations by Thackeray and Leuci (unpub. data) and Dalu (unpub. data). The seasonal pattern of stratification of the water column was determined by measuring water temperature and dissolved oxygen at 1 m depth intervals using an oxygen meter (LDO HQ20, HACH). Measurements were done once a month throughout the three seasons; hot-wet (April), cool-dry (May to August) and hot-dry (September to October) from the deepest point of the reservoir (Site 1) and it should be noted that the sampling strategy did not consider spatial variations due to time limitations, hence one site was selected. The macrophyte flora and physical character of the area was surveyed by wading and by boat. Wading was done in zigzag manner across the littoral zone length, frequently investigating all the macrophyte species present. At sites where the water was too deep to wade, a boat was used. Percentage macrophyte cover of all species present within transect was recorded. Identification of the macrophytes were done up to species level where possible using field identification guides by Sainty and Jacobs 1988) and also with the help of a local experts such as Bruce Clegg and Mark Hyde and Bart Wursten of Zimbabwe Flora (www.zimbabweflora.co.zw).

> MACROINVERTEBRATE SAMPLING

Sampling was carried out at the end of each month for the five selected sites but no samples were collected in May for site 5 due to presence of a large herd of hippos. Macroinvertebrates were sampled semi-quantitatively using a nylon hand net (mesh size 500 μm , dimension 30 \times 30 cm) with an aluminium rim and a handle which could be extended to allow sampling distance of up to 1.5 m. At each sampling station, macroinvertebrates were

collected by submerging the sampling net and sweeping a demarcated 10 m transect. This involved walking through the water dragging the net through the macrophyte vegetation. The kick-net was carefully lifted out of the water to prevent the escape of agile animals.

Benthic macroinvertebrates were collected at each station using a mud grabber along the littoral areas. The benthic sample was collected by pouring and washing the sample through a 1.5 mm mesh sieve and removing organisms for identification and counting. For each site, macroinvertebrates collected from the two littoral zones (eastern and western shores of the reservoir) and the two benthic samples were then pooled to constitute a single sample. The samples were preserved in a 70% alcohol solution in 250 mL plastic containers for identification to family level using several keys, including Gooderham and Tsyrlin (2002) and Gerber and Gabriel (2002a, 2002b). Although species level identification is desirable, family level identification is often the only achievable for studies in Sub-Saharan Africa region. Even though information is lost due poor taxonomic resolution, several studies have demonstrated that family level classification for macroinvertebrates can produce meaningful results (Bailey *et al.*, 2001; Kratzer, 2002; Nhiwatiwa *et al.*, 2009; Kouamé *et al.*, 2011). Relative abundance (%) was calculated as the number of one macroinvertebrate taxa per total number of macroinvertebrates of a given site.

DATA ANALYSIS

> PHYSICOCHEMICAL CHARACTERISTICS

Analysis of physicochemical characteristics between sampling stations for the study months was carried out using SysStat ver. 12 and the data followed an ordinal rating, which violates various ANOVA assumptions. Hence, the data was not normal as confirmed by the Shapiro-Wilk normality test. Therefore, the non-parametric test, Kruskal Wallis ($p < 0.05$) was carried out to test the differences in physicochemical characteristics between sampling stations after pooling all values for each site so as to assess if they were any significant differences between the study sites (H_0 : no difference between five sampling points) using SysStat ver. 12 (Systat, 2007).

> DIVERSITY INDICES

Two main indices were used, the Shannon-Weaver index (H) (Shannon and Weaver, 1949) and the Simpson's index (D) (Simpson, 1949) to analyse the macroinvertebrate communities collected during each sampling occasion for the study sites:

$$H = - \sum p_i \ln p_i$$

$$D = \sum [n(n-1)/N(N-1)].$$

The Simpson's index was used to analyse for dominance whilst the Shannon-Weaver was used to estimate richness and diversity. The Evenness (E) is a measure of how similar the abundance of different taxa is. A Hutchenson (1970) criterion for the comparison of the diversity values was used to express differences between the values of diversity of sites. The null hypothesis (H_0): $H'_1 = H'_2$ (the diversity of site one is statistically equal to that of site two). The t value is calculated as:

$$t = \frac{H'_1 - H'_2}{\sqrt{S^2_{H'_1} + S^2_{H'_2}}}$$

> ASSESSMENT OF TAXA DOMINANCE AND DIVERSITY

Rank abundance is a measure of biodiversity and the curves are important as they are a measure of evenness as they are used to study the distribution of abundance among taxa in a sample. Rank Abundance Analysis for the ten most abundant macroinvertebrate taxa was carried out using PC-ORD for Windows 5 (2006) to assess the distribution of abundance among taxa in the samples.

> ASSESSMENT OF THE INFLUENCE OF ENVIRONMENTAL FACTORS ON MACROINVERTEBRATE COMMUNITIES

To determine whether to use linear or unimodal methods for the analysis, Detrended Canonical Correspondence Analysis (DCCA) was used. The lengths of the gradients were examined and since the longest gradient was shorter than 3.0, a linear constrained method was deemed the most appropriate choice (ter Braak, 2002). Redundancy Analysis (RDA) is a constrained linear ordination method based on significant ($p < 0.05$) forward selected environmental variables. A total of 499 Monte Carlo Permutations were used for RDA analysis. The software Canoco (ver. 4.5) was used for the analysis (ter Braak, 2002).

RESULTS

> ENVIRONMENTAL VARIABLES

Water level at the beginning of April was 9.42 m or $7.02 \times 10^6 \text{ m}^3$ in volume and in October; it was 8.12 m or $4.82 \times 10^6 \text{ m}^3$ in volume. Water level decreased at an average of 18.57 cm depth per month which corresponds to about $3.14 \times 10^5 \text{ m}^3$ for the reservoir from April to October 2011, with a total of 1.3 m depth or $2.19 \times 10^6 \text{ m}^3$ of water being lost due to drawdown and evaporation (Table I). June recorded the least decrease in water level of 9 cm whilst October had the highest decreases (25 cm).

Table I summarizes the mean values of environmental variables in the Malilangwe reservoir for study period. Secchi disk transparency was the unique variable exhibiting significant variability amongst the study sites ($p < 0.05$) whilst other environmental parameters were not spatially significantly different ($p > 0.05$). Secchi disk readings ranged between 0.2–1.7 m. Dissolved oxygen (DO) values increased between May to August before dropping in September to October. Well oxygenated water was found throughout the cool-dry season ($7\text{--}9 \text{ mg}\cdot\text{L}^{-1}$) due to complete mixing of the water body (turn-over) while the reservoir was stratified during the hot-wet and -dry season. Low DO levels of up $2 \text{ mg}\cdot\text{L}^{-1}$ were recorded during September to October for sites 1 and 2 bottom waters. Lowest water temperature occurred from May to September after which there was rapid increase. Water temperatures decreased from April to October with low temperature average being recorded in June ($19.3 \text{ }^\circ\text{C}$). Temperatures then increased from June to September ($27.6 \text{ }^\circ\text{C}$). Highest temperatures were recorded in October ($28.4 \text{ }^\circ\text{C}$) and lowest in June ($18.8 \text{ }^\circ\text{C}$) (Table I).

Ammonia and total nitrogen decreased during the cool-dry season, during May to July as it was being used by algal blooms which were observed during this period. Low levels of total nitrogen ($TN = 0.68 \text{ mg}\cdot\text{L}^{-1}$) were recorded during June. Ammonia values were high for March ($0.40 \text{ mg}\cdot\text{L}^{-1}$) while in August and October recorded high values ($0.11 \text{ mg}\cdot\text{L}^{-1}$ and $0.26 \text{ mg}\cdot\text{L}^{-1}$). Low values of ammonia were observed during the hot-wet season. Nitrate was low during the hot-wet season with low values being observed in July ($0 \text{ mg}\cdot\text{L}^{-1}$) but increased from August ($0.01 \text{ mg}\cdot\text{L}^{-1}$) to October ($0.03 \text{ mg}\cdot\text{L}^{-1}$). Nitrate was high in March ($0.07 \text{ mg}\cdot\text{L}^{-1}$) and June ($0.04 \text{ mg}\cdot\text{L}^{-1}$). Total dissolved solutes (TDS) were in the range $226.7\text{--}344.9 \text{ mg}\cdot\text{L}^{-1}$ for the study months, with higher values from April to July. Conductivity concentrations increased from April ($358 \text{ }\mu\text{S}\cdot\text{cm}^{-1}$) to June ($376 \text{ }\mu\text{S}\cdot\text{cm}^{-1}$), decreased to a low of $338.4 \text{ }\mu\text{S}\cdot\text{cm}^{-1}$ in July before increasing to a high to a peak of $433.3 \text{ }\mu\text{S}\cdot\text{cm}^{-1}$ in October (Table I). The increase

Table 1
Average \pm standard deviation of the measured environmental variables in Mailiangwe Reservoir (April to October 2011). * Significant ($p < 0.05$). Note: p -values are associated with sampling sites.

Parameter	Units	Apr		May		Jun		Jul		Aug		Sep		Oct		p value
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Dissolved Oxygen	mg·L ⁻¹	7.8	0.3	7.0	0.3	7.9	0.3	8.5	0.5	5.6	0.4	5.6	1.0	5.3	1.1	0.69
Temperature	°C	26.9	0.7	24.4	0.1	21.6	0.3	19.3	0.5	20.9	2.1	22.5	2.1	27.6	0.8	0.98
Conductivity	μS·cm ⁻¹	358	6.2	358.3	3.4	367	1.3	376	2.2	338.4	22.5	360.3	34.1	433.3	5.9	0.85
pH		7.9	0.3	7.9	0.1	8.6	0.2	8.9	0.1	7.5	0.4	7.8	0.7	7.5	0.3	0.92
Total dissolved solutes	mg·L ⁻¹	344.9	1.8	278.4	1.9	284.7	0.8	292.2	1.6	226.7	8.0	228.1	19.8	252.6	1.0	0.99
Reactive phosphorus	mg·L ⁻¹	0.1	0.1	0.2	0.1	0.6	0.1	0.1	0.02	0.1	0.03	0.7	0.3	0.8	0.1	0.91
Nitrogen	mg·L ⁻¹	0.8	0.6	1.1	1.0	0.7	0.5	1.0	0.9	0.4	0.1	0.9	1.2	1.2	1.1	0.65
Ammonia	mg·L ⁻¹	0.1	0.05	0.2	0.2	0.03	0.02	0.1	0.1	0.1	0.03	0.002	0.04	0.1	0.1	0.92
Nitrate	mg·L ⁻¹	0.1	0.01	0.03	0.02	0.03	0.01	0.0	0.0	0.01	0.0	0.0	0.01	0.02	0.01	0.98
Chemical oxygen demand	mg·L ⁻¹	56.8	15.3	26.1	4.0	19.5	1.2	27	21.4	86.6	20.8	35.1	14.8	25.2	23.9	0.50
Total phosphorus	mg·L ⁻¹	0.01	0.1	0.2	0.05	1.4	0.3	0.1	0.0	0.3	0.1	2.5	1.5	1.9	0.2	0.88
Secchi depth	m	1.1	0.5	1.6	0.4	1.0	0.3	1.2	0.5	1.3	0.2	1.1	0.1	0.7	0.3	0.01*
Macrophyte cover	%	97.2	0.1	21.8	0.1	23.5	0.9	33.5	0.2	34.1	0.2	57.7	0.2	63.2	0.1	0.91
Water level decreases	m	-0.17		-0.25		-0.09		-0.16		-0.17		-0.21		-0.25		

in conductivity could be attributed to water level decreases which induced evaporation-driven concentration of dissolved material in the water.

Macrophyte cover changed with changes in seasons from the dominant emergent macrophytes in the hot-wet season to dominant submerged macrophytes in the hot-dry season. In April, sites 1 and 2 had similar macrophyte species composition namely; *Cyperus* sp., *Ludwigia stolonifera*, *Phragmites mauritianus*, *Potamogeton crispus* and *Schoenoplectus corymbosus*. Site 3 had all the species found in site 1 and 2 with the exception of *P. crispus*. *Panicum repens* and *Azolla filiculoides* were only recorded in site 4 and 5 respectively plus the above named species excluding *P. crispus*. At sites 1, 2 and 3, *L. stolonifera* was the most dominant species in terms of distribution and in site 4 and 5, *A. filiculoides* and *S. corymbosus* were the most dominant. During the cool-dry season (May to August 2011), a larger proportion of the littoral zone had no macrophytes growing (>65%). There was a decline in species number from hot-wet season (7 species) to the cool-dry season (4 species), and the remaining species were *A. filiculoides*, *L. stolonifera*, *P. mauritianus* and *P. crispus*. *Ludwigia stolonifera* had the widest distribution occurring at all the study sites, whilst *P. crispus* was less distributed. During the hot-dry season (September to October), six macrophyte species not recorded before were identified namely; *Marsilea* sp., *Ceratophyllum demersum* *Najas* sp., *Potamogeton pusillus*, *Potamogeton tricarinatus* and *Persicaria decipiens*. The dominant macrophyte species at sites 3, 4 and 5 was *C. demersum*, while in site 1 and 2, *P. Pusillus* and *P. mauritianus* were the most dominant species respectively.

> MACROINVERTEBRATE DIVERSITY

A total of 16,777 individual macroinvertebrates belonging to 42 families and 10 orders were collected from the sites. The mean relative abundance (%) of the macroinvertebrates and total number of identified families collected from each sampling site are shown in Table II. More macroinvertebrate families were sampled at sites 1–4 (30–33) than in sites 5. Mollusca constituted 57.71% of the total sample and other common taxa included the Hemiptera (27.31%), Diptera (4.93%), Arachnida (3.22%) and Odonata (3.12%). The most common family taxa were Odonata (9 families), Hemiptera (8) and Mollusca (7) (Table II). There was a notable increase in abundance of the Mollusca group during the cool-dry season.

Macroinvertebrate taxa composition and abundance at the study sites also changed from April to October. Sites 1, 2, 3 and 4 had taxa richness of 32, 33 and 30 respectively, while site 4 and 5 had a richness of 24 and 26, respectively. Sites 1 and 2 had macroinvertebrate families only unique to these sites (Teloganodidae, Pisauridae and Platycnemidae). Sites 1 to 3 had Lymnaeidae, site 2 had Calopterygidae, site 3 had Pyralidae and Hydrophilidae and site 4 had Ancyliidae and Sphaeridae which were unique to the sites (Table II).

Site 1 and 2 had almost similar dominance indices (Shannon-Weaver = 1.784 and 1.750 respectively) and dominance decreased in site 4 to 0.953 before increasing to 1.293 in site 5 (Table II). The Simpson's diversity index for site 1, 2 and 3 was 0.754, 0.742 and 0.729 respectively and it decreased to 0.414 in site 4. Site 5 had a Simpson's diversity index of 0.593. Evenness for the first three sites (1, 2 and 3) was similar (0.277, 0.271 and 0.277 respectively) and decreased for site 4 (0.154). Site 5 had an evenness of 0.201 (Table II). Thus sites closer to the dam not only have a greater number of taxa present, but the individuals in the community are distributed more equitably among these taxa. Using the Hutchenson (1970) criterion for the comparison of the diversity values, site 4 was found to be the most significantly different ($p < 0.05$) from the rest whilst there were no significant differences amongst other sites.

> MACROINVERTEBRATES TAXA RANK DOMINANCE ANALYSIS

The rank analysis of the 10 most dominant macroinvertebrate families in Malilangwe Reservoir are shown in Table III and Figure 2. Overall, Thiaridae was the most dominant taxa ($n = 6389$)

Table II

Relative percentage abundances of macroinvertebrates at the sampling sites on the Malilangwe Reservoir for April to October 2011.

Order / Family	Site				
	1	2	3	4	5
Annelida					
Hirudinae	0.84	0.23	0.46	1.47	2.01
Oligochaetae	–	–	1.09	1.57	1.53
Arachnida					
Hydracarina (Hydrachnellae)	3.69	5.97	2.98	–	2.65
Lycosidae	0.24	0.03	–	–	–
Tetragnathidae	0.03	0.16	0.06	–	–
Pisauridae	0.03	0.03	–	–	–
Coleoptera					
Curculionidae	–	0.10	0.09	0.03	–
Dytiscidae	0.27	0.59	0.57	0.07	0.36
Elmidae	0.19	0.20	0.29	0.16	0.08
Hydrophilidae	–	–	0.03	–	0.20
Hydraenidae	0.14	0.36	0.09	–	0.52
Diptera					
Culicidae	–	–	–	0.03	0.08
Chaoboridae	7.00	6.27	3.49	2.09	1.20
Chironomidae	0.14	0.46	0.40	1.21	1.57
Ephemeroptera					
Baetidae	1.33	2.79	0.11	0.49	0.52
Teloganodidae	0.03	0.03	–	–	–
Hemiptera					
Belostomatidae	0.68	1.18	0.86	0.13	0.32
Corixidae	9.34	11.48	8.91	6.64	13.45
Gerridae	0.08	0.03	0.23	0.03	0.04
Naucoridae	0.33	0.69	0.77	0.07	0.84
Nepidae	0.38	0.62	0.14	0.03	0.12
Notonectidae	21.55	19.85	17.50	7.07	10.76
Pleidae	0.41	0.20	0.09	0.13	0.04
Veliidae	0.11	–	–	–	0.12
Lepidoptera					
Pyralidae	–	–	0.03	–	–
Mollusca					
Ancylidae	–	–	–	0.07	–
Corbiculidae	0.03	0.07	0.74	1.34	0.04
Lymnaeidae	8.44	1.38	6.24	–	–
Physidae	13.98	18.90	13.49	5.33	8.03
Planorbidae	–	–	3.01	–	–
Thiaridae	26.25	24.02	35.11	69.21	54.15
Sphaeriidae	–	–	–	1.28	–
Odonata					
Aeshnidae	0.62	0.20	0.11	–	0.04
Calopterygidae	–	0.39	–	–	–
Chlorolestidae	1.14	0.85	0.49	–	–
Coenagrionidae	1.95	2.40	2.18	1.01	1.12
Gomphidae	0.11	0.13	0.14	0.16	0.16
Lestidae	0.14	0.07	–	–	–
Libellulidae	0.27	0.13	0.32	0.36	0.04
Platycnemidae	0.08	0.16	–	–	–
Protoneuridae	0.19	–	–	–	–

Table II

Continued.

Order / Family	Site				
	1	2	3	4	5
Trichoptera					
Hydropsyche	–	0.03	–	–	–
Total	3814	3152	3622	3049	3140
Number of taxa	32	33	30	24	26
Shannon-Weaver index	1.784	1.750	1.688	0.953	1.298
Simpsons index	0.754	0.742	0.729	0.414	0.593
Evenness	0.277	0.271	0.277	0.154	0.201

Table III

Rank abundance of macroinvertebrate taxa for the different study sites (Rel. ab. = relative abundance).

Family	Site 1		Site 2		Site 3		Site 4		Site 5	
	Rank	Rel. ab.	Rank	Rel. ab.	Rank	Rel. ab.	Rank	Rel. ab.	Rank	Rel. ab.
Physidae	3	515	3	576	3	471	5	63	4	200
Thiaridae	1	967	1	732	1	1226	1	2115	1	1349
Coenagrionidae	8	72	7	73	9	76	–	–	10	28
Hydrachnellae	7	136	6	182	8	104	–	–	5	66
Corixidae	4	344	4	350	4	311	3	203	2	335
Notonectidae	2	794	2	605	2	611	2	216	3	268
Oligochaetae	–	–	–	–	10	38	6	48	8	38
Hirudinae	–	–	–	–	–	–	7	45	6	50
Chironomidae	–	–	–	–	–	–	10	37	7	39
Baetidae	9	49	8	85	–	–	–	–	–	–
Chlorolestidae	10	42	10	26	–	–	–	–	–	–
Chaoboridae	6	258	5	191	6	122	4	64	9	30
Lymnaeidae	5	311	9	42	5	218	–	–	–	–
Planorbidae	–	–	–	–	7	105	–	–	–	–
Sphaeriidae	–	–	–	–	–	–	9	39	–	–
Corbiculidae	–	–	–	–	–	–	8	41	–	–

and the Oligochaeta the least dominant ($n = 124$). For sites 1 and 2, the 10 dominant families were the same with Thiaridae family being the most dominant while Chlorolestidae was the least dominant. The rank order changed from the fifth family to the ninth for sites 1 and 2. In site 4, Thiaridae was most dominant while Chironomidae was the least dominant. At site 5, Thiaridae was the most dominant with Coenagrionidae being the least dominant. Thiaridae, Physidae, Notonectidae, Corixidae and Chaoboridae were dominant across all the five sites, with the first four being the top four dominant families in the respective sites while Chaoboridae varied in position in the top 10 rank abundance between fifth and ninth (Table III).

> INFLUENCE OF ENVIRONMENTAL FACTORS ON MACROINVERTEBRATE COMMUNITIES

The results of the RDA (Figure 3) showed that the first two RDA axes accounted for 82.3% of the taxon-environment relationship whilst also accounting for 16.9% of the variance in the taxon data (Table IV). Forward selection revealed that from the input environmental variables listed in Table I, macrophyte cover, water levels and conductivity were significant in explaining patterns of occurrence and abundance of macroinvertebrate taxa in Mallangwe (Figure 3). All three factors and all interactions had a significant impact on the macroinvertebrate communities. In April and May, macroinvertebrate communities and abundance were influenced and positively associated by percentage macrophyte cover while the rest of the months (July, August and October) macroinvertebrate communities and abundance were negatively associated and influenced by water level and conductivity. Macroinvertebrate communities and abundance in June and September were less strongly correlated with the three environmental

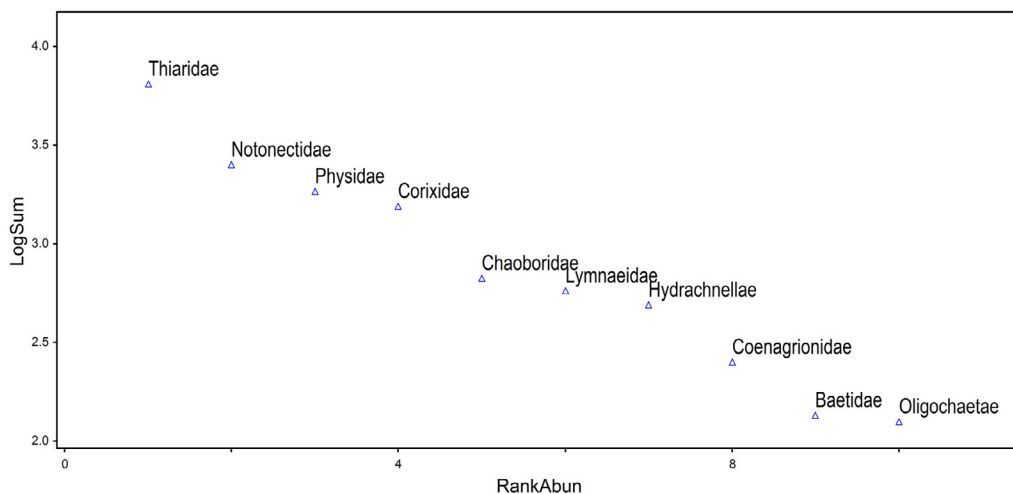


Figure 2
Rank abundance for the 10 dominant macroinvertebrate families in Malilangwe Reservoir (April to October 2011).

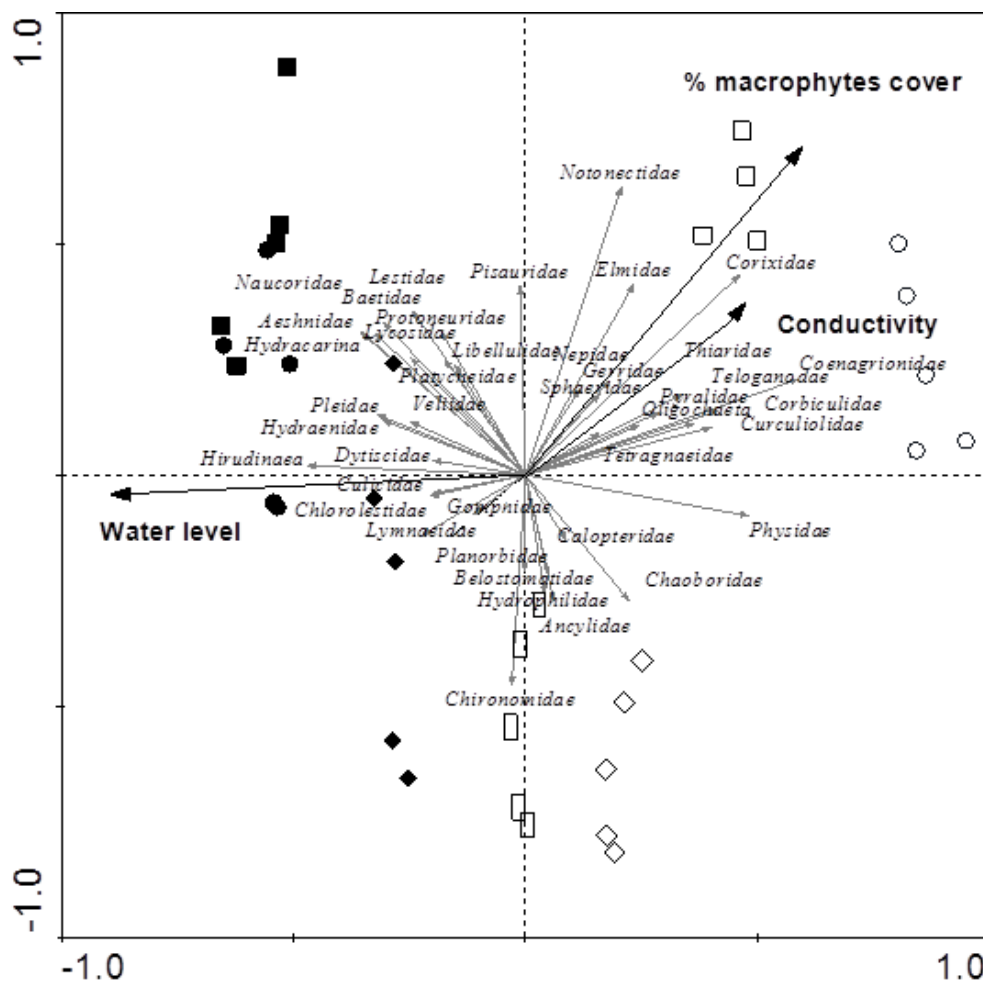


Figure 3
(RDA macroinvertebrate taxa-environmental relations. Significant variables water level, conductivity and macrophyte cover are shown as vectors. (○ = A, □ = M, ◇ = Jn, □ = JL, ● = Ag, ■ = S, ◆ = O).

Table IV

Interactive and individual effects of explanatory variables for macroinvertebrates in Malilangwe Reservoir (April to October 2011).

Explanatory variables	% species variation explained	F-ratio	p value
All significant variables together			
Water level \cap macrophyte cover \cap conductivity	16.9	2.027	0.002
Interactive effects			
Water level \cap macrophyte cover	7.1	2.399	0.002
Water level \cap conductivity	7.1	2.442	0.002
Macrophyte cover \cap conductivity	6.3	2.180	0.002
Individual effects			
Conductivity	5.0	1.800	0.012
Water level	7.0	2.517	0.002
Macrophyte cover	5.9	2.128	0.002

parameters (Figure 3). According to the results and RDA analysis (Figure 3), macroinvertebrate communities in the Reservoir were less influenced by most water quality variables with the exception of conductivity which showed a strong environmental gradient and had a structuring effect on macroinvertebrate communities with macrophyte cover and water level fluctuations.

DISCUSSION

The aim of the study was achieved as highlighted by the results obtained. A total of 42 macroinvertebrate taxa were recorded demonstrating a relatively similar taxa richness when compared to other small Reservoir studies in other regions such as 43 families in Lake Taabo (Kouamé *et al.*, 2011), and 40 families in two lakes of the Paraná River floodplain (de Neiff and Carignan, 1997). Fewer taxa have been recorded from some Reservoirs in Zimbabwe such as 15 taxa in Lake Chivero (Brendonck *et al.*, 2003) and 11 taxa from Fletcher Reservoir (Mwabvu and Sasa, 2009). This could be attributed to the timing, location or many other sampling technique factors and anthropogenic impacts such as sewage discharge in Fletcher Reservoir and Lake Chivero. High taxon coexistence and frequency of occurrence contributed to greater diversity within Malilangwe Reservoir with higher taxon affinities occurring between taxa belonging to different orders possibly suggesting less competition. Nhiwatiwa *et al.* (2009) showed that resource partitioning among taxa of the different orders has been advanced as a primary reason why such coexistence and high affinities are possible.

Thiaridae and Physidae were the most dominant and abundant Mollusca across all the study sites, especially the Thiaridae family group. Both families (Thiaridae and Physidae) dominance may be attributed to the competitive advantage they have over the other snails of rapidly increasing their populations (Pointier *et al.*, 1989; Kouamé *et al.*, 2011).

Water level of the Reservoir was found to be a relevant and important ecologically variable for macroinvertebrate communities through increasing niche separation, thus allowing more taxa to coexist at higher abundances (Nhiwatiwa *et al.*, 2009). Changes in water levels also affected environmental variables such as macrophyte cover around the Reservoir. During the hot-wet season there was high abundance of macrophyte vegetation in the littoral zone and water level was high before dropping as the seasons changed. These observed changes in the macroinvertebrate communities, might explain the differences in taxon richness and abundance for the study sites. The differences in taxa composition, dominance and abundance among the sites indicated that the macroinvertebrate fauna and the suitability of the habitats maybe strongly influenced by local environmental parameters.

The Simpson's and Shannon-Weaver diversity indices also show that if the macroinvertebrates mostly in sites 1, 2 and 3 should suffer a disturbance, most of the taxa are abundant enough to survive such a disturbance such as macrophyte cover decreases, water

level fluctuations and increase or decrease in conductivity depending on the magnitude of the disturbance. If the disturbance is small enough, according to the intermediate disturbance hypothesis the diversity of species will be expected to increase in the reservoir (Brown and Lomolino, 1998). Typically the value of the Shannon-Weaver index ranges from 0.953 to 2.19. The maximum index takes its maximum when species richness increases (Brown and Lomolino, 1998). The data for the five sites indicates that they do not have the same taxa richness and abundance hence they are not even (similar or equitable). Therefore, it is seen that sites 1, 2 and 3 has higher diversity (taxa richness and abundance) than sites 4 and 5 maybe due to the former having a better macrophyte area cover. It is important to note that the use of suprageneric taxa abundances in the estimates of the values of diversity is debatable, because the values tend to be underestimated (O'Donnell *et al.*, 1995). Therefore, these values need to be treated with caution although they provide a useful comparative measure. Different levels of disturbance as highlighted above have different effects on macroinvertebrate diversity and if a water manager's goal is to preserve biodiversity in a given water system, he needs to be able to understand how diversity is impacted by different management strategies. Diversity indices provide more information than simply the number of species present, that is, they account for some species being rare and others being common hence they serve as valuable tools that enable biologists and water managers to quantify diversity in a community and describe its numerical structure (Brown and Lomolino, 1998).

Studies by Mwabvu and Sasa (2009) also showed a positive correlation between Physidae (*Bulinus africanus*) and conductivity ($r = 0.56$) while Efitre *et al.* (2001) reported that the Uganda lakes with higher conductivity and pH showed greater taxon richness and abundance of Mollusca. Therefore, high conductivity levels could have had an effect on Mollusca diversity in the Malilangwe Reservoir as it has been shown to be great importance for Mollusca shells (Mwabvu and Sasa, 2009).

Macrophyte cover was also identified as an important habitat variable influencing macroinvertebrate community in Malilangwe Reservoir. Our results indicate that with decrease in macrophyte cover, taxon diversity increased but the abundance of each individual family decreased. Macrophyte cover is of great importance as a refuge for macroinvertebrate taxa from predation, offer a substrate for living on and also for laying eggs in water medium (Amakye, 2001; Kratzer, 2002). However, our findings are similar to findings by Mwabvu and Sasa (2009) who observed the same situation in Fletcher Reservoir. Kovalenko *et al.* (2010) showed that the abundance of certain macrophytes could explain a small proportion of variability in macroinvertebrate communities. This was consistent with our study Reservoir, as a decline in macrophyte cover and abundance due to drawdown resulted in changes in macroinvertebrate communities, abundance and distribution. Kratzer (2002) studies in the Okefenokee Swamp showed that macrophyte cover changes and abundances affected macroinvertebrate communities and distribution. The low richness observed in site 4 and 5 could be due to less macrophyte cover which is used as refugia by macroinvertebrates.

The findings of the study have shown that differences in richness, abundance and distribution of macroinvertebrates in the Malilangwe Reservoir are influenced by hydrological regimes and environmental factors associated with strong gradients. Macroinvertebrates are highly adaptable to a broad range of ecological conditions hence only strong environmental gradients can have a structuring effect on their communities (Lounaci *et al.*, 2000; Chakona *et al.*, 2009; Nhiwatiwa, 2009). Therefore, the knowledge of the relationships between macroinvertebrates and their environment is of crucial importance in the understanding of the functioning of ecosystems.

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