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Research Article

MACROINVERTEBRATE DIVERSITY IN A SUBTROPICAL HIGH-PRESSURE ZONE (SHPZ) MAN-MADE LAKE: GOREANGAB DAM, WINDHOEK, NAMIBIA

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ABSTRACT

This research investigated the diversity and distribution of macro invertebrate assemblages of a sub-tropical high-pressure belt man-made lake, the Goreangab Dam, in Windhoek, Namibiain order to develop a respective index of biotic integrity as a baseline of determining and monitoring the health status of the dam. Macro invertebrates samples were collected biweekly, over a period of two months (August and September 2019) from 8 stations along the bank of the dam. Collected macroinvertebrate samples were sorted live, counted and identified to the lowest taxonomic level possible. The Shannon Weiner index (*H'*), Simpson's index (*D*) and Pielou Evenness index (*J'*) were used in analysing macroinvertebrates diversity. A total of nine different macroinvertebrate species belonging to different orders were recorded during the sampling period. *Chironomus plusmosus* (larvae) had the highest composition (19%) and *Arctocorisa arguta* with the lowest composition (6%). Anthropogenic activities have a huge impact on the distributions of the macroinvertebrate assemblages according to the tolerance of water pollution. The fact that the *C. plusmosus* (larvae) are the highest in composition shows that the water body is unhealthy and at this stage only supports the life of species that are tolerant to water pollution.

Keywords: Ecological modelling, Macroinvertebrate diversity, Man-made lake, Water quality.

INTRODUCTION

The Goreangab Dam is known to be a polluted water body arising from anthropogenic activities and habitat degradation as a result of economic development and urbanization (Gresens *et al*., 2009). However, little research has been conducted on the macroinvertebrate assemblages and their environmental relationships. Aquatic macroinvertebrate abundance increases with conductivity, altitude and water temperature (Reiss *et al.*, 2015). This shows that habitat diverseness is the greatest predictor of macroinvertebrate assemblages, but species richness can be predicted based on climatic changes and topographical features. Sustainable use of freshwater systems requires background of the spatial distribution of water body types, how their physico-chemistry varies across the landscape and the total contribution that it has on the biodiversity. Differences in the habitat complexity, physio-chemical parameters and the constantly varying influence of living interactions will lead to distinct freshwater habitat types supporting different faunal assemblages (Hauer, 1996). Macroinvertebrates of freshwater systems have a particular (low) saline content that they have adapted to and when this content increases, it affects the macroinvertebrates and at the same time forces them to migrate or acclimatize to new conditions in order to survive (Schneider & Frost, 1996). Despite their apparent vulnerability, there is little published information on the general ecology and biodiversity of small non-perennial freshwater system macroinvertebrates. This study has arisen largely from the need to inaugurate baseline data on the macroinvertebrate diversity in a sub-tropical high-pressure belt man-made dam, in order to make room for future biological monitoring of impacts that can arise due to hydraulic fracturing activities and climatic change. In order to sample the maximum diversity and

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abundance of freshwater macroinvertebrates, the study strictly focused on the period where peak rainfall coincides with the warmest temperatures throughout the dam.

The structure of macroinvertebrate communities has been a popular subject of much research in freshwater ecosystems (Boven & Brendonck, 2009). Potential benefits of research on macroinvertebrates include the quick evaluation of biological resources for maintenance purposes with the use of indicator organisms, the measuring of physical and chemical parameters of the water, the detection of pollution through differences between predicted and actual macroinvertebrate assemblages (Hauer, 1992). Macroinvertebrates are an important component of freshwater systems and they play a very crucial role in conserving the structural and functional integrity of freshwater ecosystems (Flores & Zafaralla, 2012). They alter the geographical and physical conditions of the sediments that promote detritus, decomposition and the nutrient cycle, in order to allow energy transfer among trophic levels (Lim *et al.*, 2018). Macroinvertebrate communities are being affected by habitat complexity, because complex habitats provide a variety of ecological niches, which causes macroinvertebrates to be highly vulnerable to the loss of the habitat that they are adapted to (McGoff & Sandin, 2012).Consequently, habitat deterioration will severely decrease the diversity and composition of macroinvertebrate assemblages. Thus, identifying the possible factors regulating macro invertebrate structure, diversity, and distribution can aid the development of more prescriptive maintenance and management strategies for freshwater ecosystems. The research was assessed to analyse the macroinvertebrate biodiversity, composition and abundance and to determine the physicochemical parameters of a man-made dam in a sub-tropical high-pressure ecological belt, which plays a vital role in macroinvertebrate diversity.

MATERIALS AND METHODS

Study area

The Goreangab Dam (22°31′0″S, 17°1′0″E/22.51667°S, 17.01667°E) is in the north-western suburbs of Windhoek, the capital of Namibia. The dam was constructed in 1958 to alleviate the water supply problems to Windhoek (Brand & Toribara, 1973), with an average capacity of 3.6 million cubic metres of water. The general climatic conditions around the dam are that of Subtropical High-Pressure Zone (SHPZ), characterized by semi-permanent high atmospheric pressure. Two main rivers, the Arebusch and the Gammans Rivers, contribute the bulk of the catchment water supply to the dam. A total of 8 stations along the bank of the dam were sampled biweekly during the study period from 13 August to 27 September 2019. The stations were randomly selected and approximately 200 metres apart (Figure 1). All the stations were geo-referenced using the Garmin® global positioning system.

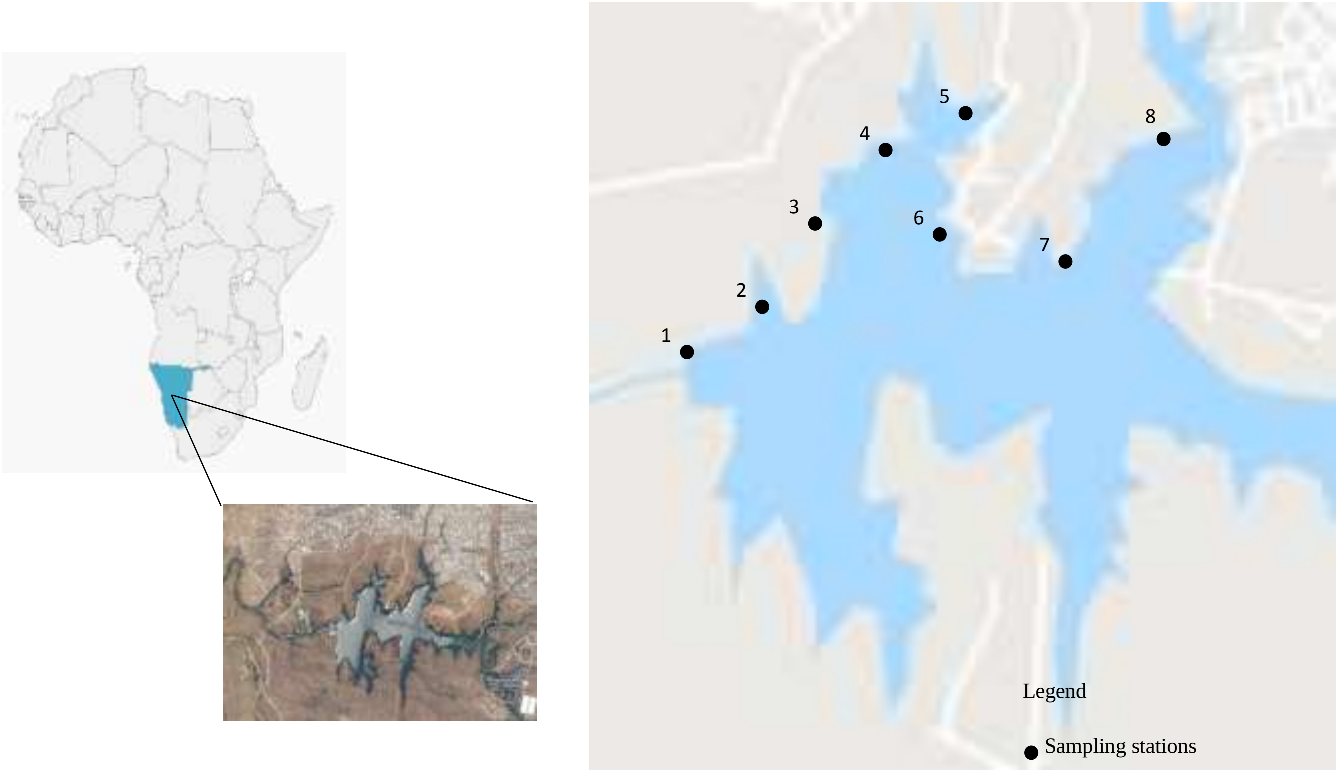

Figure 1. Map of the Goreangab Dam showing the sampling stations.

Sampling: Physicochemical parameters

Selected water physicochemical parameters were taken *in-situ* using appropriate meters. The parameters measured included temperature, pH, turbidity, conductivity and light intensity. During each visit at each sampling stations, these parameters were taken in triplicates and the mean (± SE) calculated for statistical analysis.

Macroinvertebrates

Sampling of macroinvertebrates was done is all eight stations using a portable laboratory grab (Ponar®) and a 500 µm mesh size hand-held scoop net on aluminium frame and a 135 cm aluminium handle. Scooping was done in the opposite direction of water flow. Collection of macroinvertebrates was done in identified biotopes (water column, bottom sediments and emergent vegetation) within each sampling station. In each sampling station, a total of three grabs (for bottom sediment biotope) and three scoops of macroinvertebrate samples were taken. Collected samples washed on site, sorted and then preserved in 70% ethanol before being transported to the laboratory for counting and identification. In the laboratory, the macroinvertebrates were sorted into different orders and identified to their species level with the aid of the macroinvertebrate field guide manual by Gerber & Gabriel, (2002).

Table 1. Checklist and distribution of macroinvertebrates on survey areas in the Goreangab Dam. (August - September, 2019) Shading indicates presence.

No		13-Aug-19								27-Aug-19								17-Sep-19								27-Sep-19							
	Mcroinvertebrates	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8
1	*Chironomus plumosus* (larvae)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2	*Arctocorisa arguta*		■	■	■	■	■	■	■	■				■	■	■	■	■				■	■	■	■	■	■	■					
3	*Nepa cinerea*	■	■		■			■	■	■	■	■	■	■	■	■		■	■	■	■	■	■		■	■	■	■	■	■		■	■
4	*Notonecta glauca*	■	■		■	■	■	■			■	■	■			■	■	■	■			■	■		■	■	■	■	■				
5	*Aphidoletes aphidimyza*	■	■	■	■	■	■	■	■	■	■		■			■	■	■	■			■			■	■							
6	*Ancronyx schillhammeri*	■	■		■	■	■				■		■	■	■	■	■	■				■	■	■	■	■			■	■	■	■	
7	*Simulium trifasciatum*						■	■	■	■						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
8	*Gerris lacustris*	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					■	■	■	■	■	■	■				
9	*Culiseta longiareolata* (larvae)											■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Shading indicates presence.

Macroinvertebrate diversity in the dam was evaluated using the Shannon-Wiener diversity index (*H*') and Simpson index (*D*'), while species evenness was evaluate using the Pielou evenness index. The Shannon-Wiener diversity index was used to compute and analyse the evenness and abundance of the macroinvertebrate assemblages across the dam. A diversity index is a quantitative measure that shows how many different types (such as species) there are in the community, and simultaneously takes into account how evenly the basic entities (such as individuals) are distributed among those types (Stirling & Wilsey, 2001). The species richness per sampling station was evaluated using the Simpson index (*D*) as it gives more account to the dominant species within a community/ecosystem. The Shannon's index and Simpson index per station were computed using Equation 1 and 2 respectively (Krebs, 1972).

$$H = -\sum_{i=1}^{s} p_i \ln p_i \qquad \text{………………………….. Equation 1}$$

$$D = \sum_{i=1}^{n} (p_i)^2 \qquad \text{…………………..……………Equation 2}$$

Where:

pi = Proportion of the macro invertebrates per sampling station made up of species *i*.

ln = Natural logarithm of *pi*

s = Number of species in sample

Species evenness refers to how close in numbers each species is in each environment. It is a diversity index that quantifies how equal the community is numerically. The Pielou evenness index was computed using Equation 3 (Krebs, 1994).

$$J' = \frac{H}{ln(S)} \qquad \text{………………………………….. Equation 3}$$

Where:

H = the Shannon Weiner index

ln(S) = the natural logarithm of species richness (Krebs, 1994).

Statistical data analysis

Statistical analyses were performed using Excel© (2016), IBM SPSS© Statistics (version 24) and PAST (Version 3.21) software. All the data were found to be normally distributed. The data on physicochemical parameters were summarized into descriptive statistics and presented as mean and standard error (SE) and graphically represented. Spatial variations in the mean water physicochemical parameters between the different stations were tested using repeated measure analysis of variance (MANOVA) at 0.05 *p* level. Similarly, significant differences in macro invertebrate diversity among the different stations were analysed using MANOVA at 0.05 p level. Tukey post hoc tests were used to establish direction of the detected differences in the statistical analysis. Results with p-values ≤ 0.05 were considered statistically significant.

RESULTS AND DISCUSSION

The spatial variations in the mean water physicochemical values are presented in Figure 2. The results obtained showed less spatial variations in the concentrations of hydrogen ions (pH), conductivity and temperature between the different stations ($p > 0.05$), this signifying that there were similarities in these parameters for the various stations. The mean pH values ranged between 7.32 and 7.75 and the mean conductivity values ranged from1.60 ± 0.12 to 1.93 ± 0.05 mS/cm. Lowest temperature values were recorded at the beginning of August with a mean value of 21.48 ± 0.56ºC and the highest values were recorded at the end of September with mean value of 23.01± 1.08ºC. There was no significant differences ($p > 0.05$) in temperatures amongst the stations is directly related to prevailing climatic conditions and riparian vegetation. The mean light intensity (0.13 ± 0.02 lux) was highest at the beginning of September in stations 4 and 5 compared to the other stations ($p < 0.05$). Macroinvertebrates belonging to 3 orders and 9 species were identified in the samples collected from the 8 sampling stations. Macroinvertebrates of the Diptera and Hemiptera, were the most dominant of all macroinvertebrate taxa, contributing 46 and 43% respectively, of the total macroinvertebrate abundance. On the species level, larvae of *Chironomus* was the most dominant (19%), which was closely followed by adults of *Gerris lacustris* (15%), with adults of *Arctocorisa arguta* being the least recorded species (Figure 3). The checklist of collected macroinvertebrate per sampling dates and stations is presented in Table 1. Larvae of *Culiseta longiareolata* was completed absent during the first sampling date (13 August 2020) in all stations, however, they were subsequently present is all stations during subsequent sampling. Larvae of *Chironomus plumosus* were present during every sampling in all stations. Significant temporal and spatial variations in macroinvertebrate diversity were observed for all other collected macroinvertebrates in allthe stations ($p < 0.05$). The total number of all macroinvertebrate species collected is presented in Figure 4 and the values of Simpson index (*D'*), Pielou evenness (*J'*) and the Shannon Weiner index (*H'*) of macroinvertebrates analysed is presented in Table 2.The Shannon Weiner index (*H*') shows that there was a high diversity of macroinvertebrates at stations 3, 5, 6, 7 and 8 ($p< 0.05$).The lowest diversity was recorded at stations 1, 2 and 4. The Simpson's index shows that there is infinite diversity amongst all the stations. Station 5 had the highest diversity and station 1 the lowest (Figure 5). Closer examination of analysed data indicated that the higher the richness index, the lower the number of individuals within a station (Figure 6).

Results obtained from this investigation has revealed less spatial variations in the concentrations of hydrogen ions (pH), conductivity and temperature between the different stations ($p > 0.05$), this signifying that there were similarities in these parameters for the various stations. Mean pH values indicates weakly basic conditions during the months of sampling, this is in confirmation that most freshwater aquatic system pH ranges between 7 and 8 if such water bodies are relatively not pollution (Alavaisha *et al*., 2019; Lepori *et al*., 2003). Values of conductivity values signify low salt concentrations in the dam during the months of sampling, while non-spatial temperature values indicate uniformity in the riparian vegetation cover. Similar observations were reported by Eady *et al*. (2013) and Yan *et al*. (2016), when they investigated the relationship between water temperature predictability and aquatic macroinvertebrate assemblages in two South African streams. Light intensity plays a major role when it comes to macroinvertebrate assemblages, because a larger concentration of algae leads to the provision of nutrients for macroinvertebrates (Hawkins *et al*., 1982), therefore higher light intensity levels and corresponding gradual temperature increase would significantly lead to increased macroinvertebrate biomass. The turbidity has no intrinsic physical, chemical or biological significance (Alavaisha *et al*., 2019). Nonetheless, the macroinvertebrate assemblages mostly preferred the clear water compared to more turbid water. This is because turbid water limits the ability of algae to photosynthesize and this directly affects the macroinvertebrates diversity. Macroinvertebrates are a useful indicator of an aquatic system health. Macroinvertebrate samplings are relatively quick, inexpensive, and can indicate the presence (or absence) of pollutants in a water body. They have predictable community composition under natural conditions and provide a snapshot of long-term conditions. Some macroinvertebrates are especially useful for targeted sampling due to their high sensitivity to environmental changes and pollutants. For quantification, models compare the taxa observed at the site to the taxa expected in the absence of human-caused stress.

Table 2. Summary of mean Simpson index (*D'*), Pielou evenness (*J'*) and the Shannon Weiner index (*H'*) of macroinvertebrates analysed on surveyed stations in the Goreangab Dam (August - September, 2019).

Stations	*D'*	*J'*	*H'*
1	11.23	1.68	1.77
2	13.02	1.59	1.77
3	15.00	1.57	1.85
4	13.43	1.61	1.82

5	14.97	1.58	1.86
6	14.35	1.60	1.86
7	14.45	1.59	1.85
8	13.69	1.65	1.88

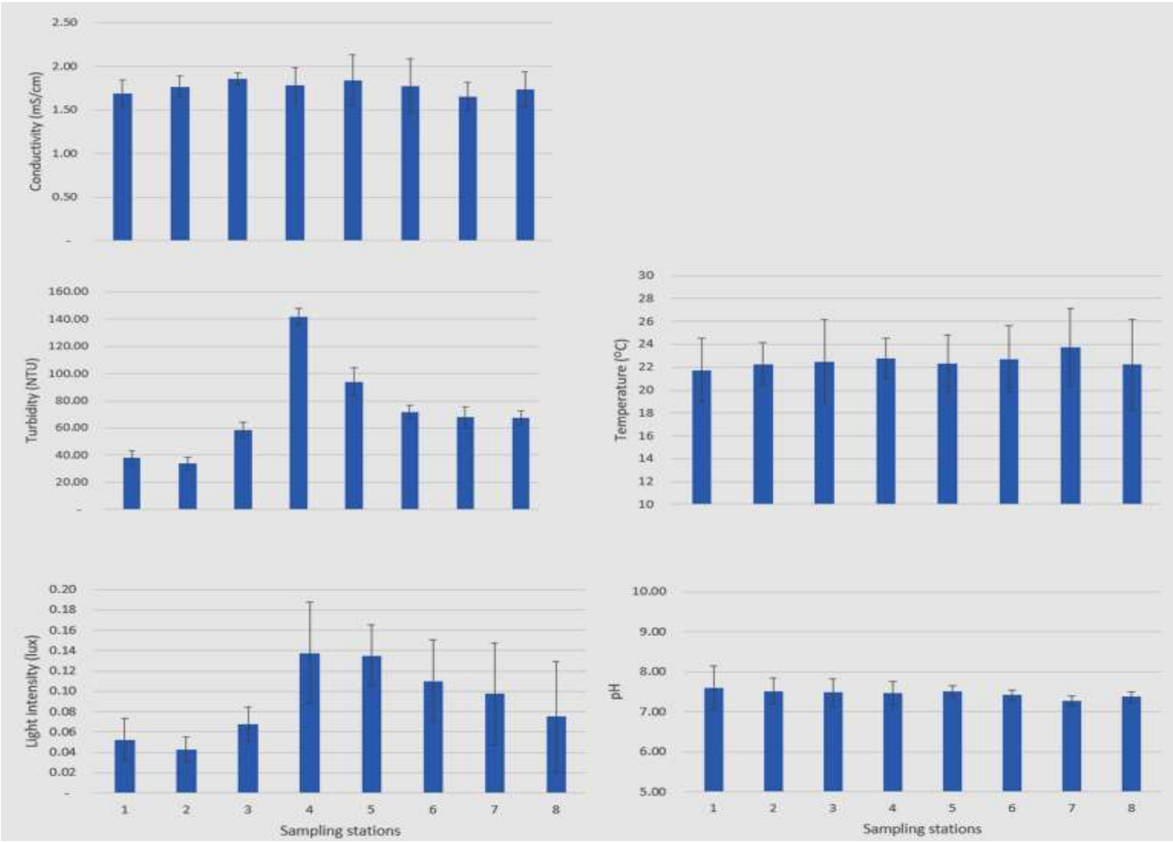

Figure 2. Spatial variations in mean water physicochemical parameters (mean ± SE) of the Goreangab Dam during the sampling period.

Macroinvertebrate groups and metrics responded predominantly to specific or different environmental stressors acting at the same site. Natural water gets polluted when the contaminant material disturbs the natural equilibrium of living organisms near or in the water when it makes the water unsafe for human consumption or recreational purposes (Kerfoot *et al*., 1999). It is evident that human activities are the most driving factors of water pollution in addition to the natural factors. Anthropogenic activities originate from different sources such as industries and farming practices that affect the water quality. Macroinvertebrates are referred to as water quality indicators, because they are affected by the physical, biological and chemical conditions of the waterbody (Teixeira, 2010). They can be tolerant, sensitive and somewhat tolerant to pollution. These organisms can therefore tolerate changes in water quality and high loads of pollution. Of which under polluted conditions, the community structure may simplify in favour of tolerant species, but the abundance of a certain species may increase but the diversity and species richness decreases drastically (Pennino *et al*., 2013).

Functional evenness may be seen as the degree to which the biomass of a community is distributed in niche space in order to allow effective utilization of the entire range of resources available to it (i.e. within the niche space that it encompasses). This investigation recorded that the species in all the stations were evenly distributed, although the highest evenness was recorded in station 1 with 1.68. Assuming resource availability is even throughout the niche space, the lower functional evenness will then indicate that some of the niche space, while occupied by macroinvertebrates is under-utilized, station 3 had the lowest evenness with 1.57. This will tend to decrease the productivity and reliability of the ecosystem, which will then increase an opportunity for invaders (Paul, 2008). High functional divergence indicates a high degree of nichedifferentiation, and thus low resource competition it is therefore safe to say that communities with high functional divergence may have an increased ecosystem function as a result of more efficient resource use. Studies have long been intrigued by the fact that small – scale species richness can vary subsequently among communities (Griffith *et al*., 2005; Jun *et al*., 2016). This can be related to species richness including geographic factors such as scale of observation, available species pool and dispersal patterns and biotic factors such as competition and predation, as well as the abiotic environmental factors such as site resource availability, disturbance and physical conditions. An increase in the individual number of species decreases the richness of the community.

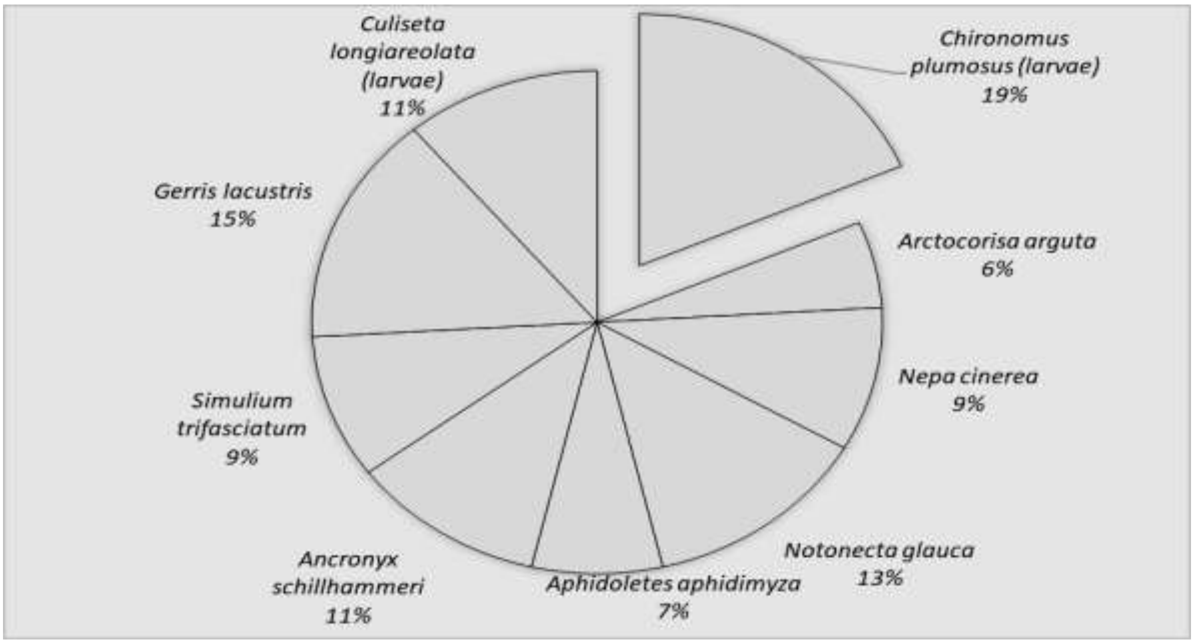

Figure 3. Distribution of macroinvertebrate species in 8 stations along the bank of Goreangab Dam (August - September 2019).

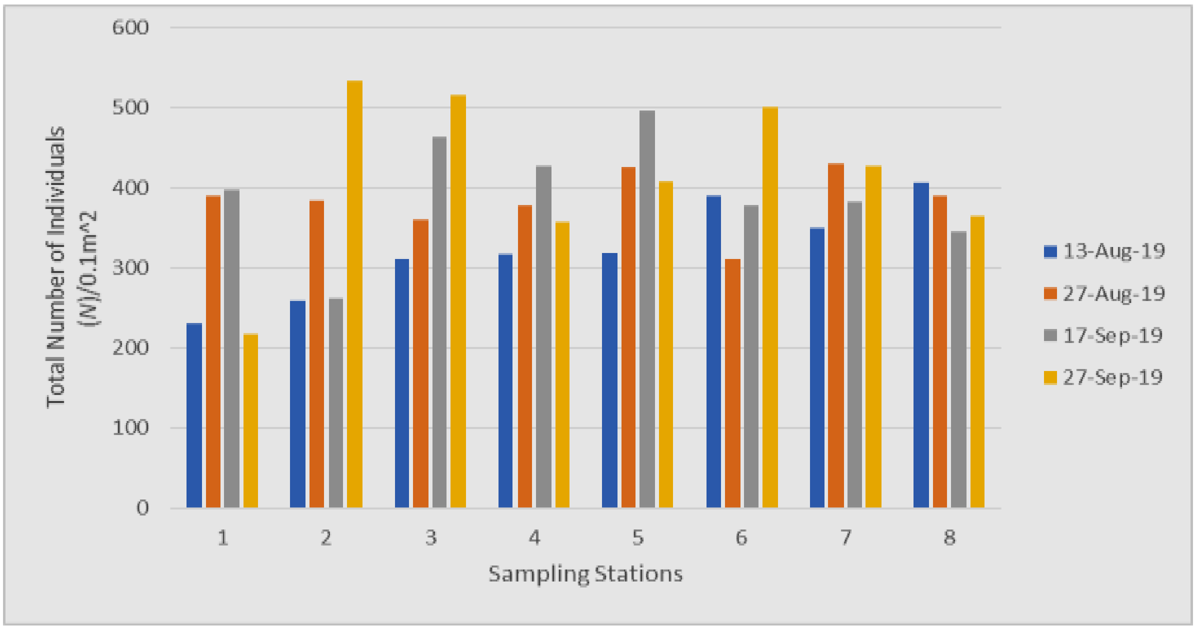

Figure 4. Total number of individual (*N*) organisms found in the Goreangab Dam (August-September 2019).

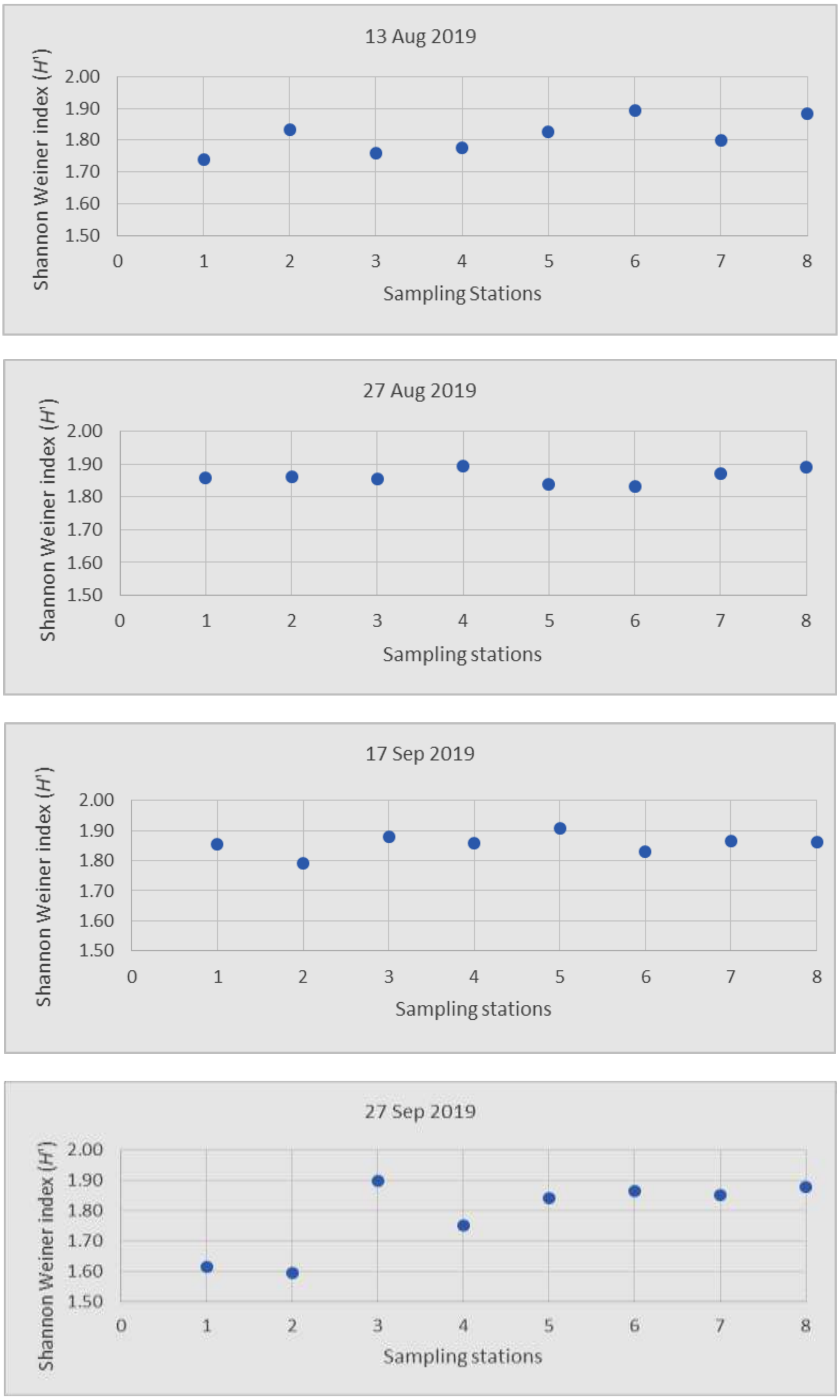

Figure 5. Spatial variations in Shannon Weiner index (*H*') of macroinvertebrates in the Goreangab Dam (August - September 2019).

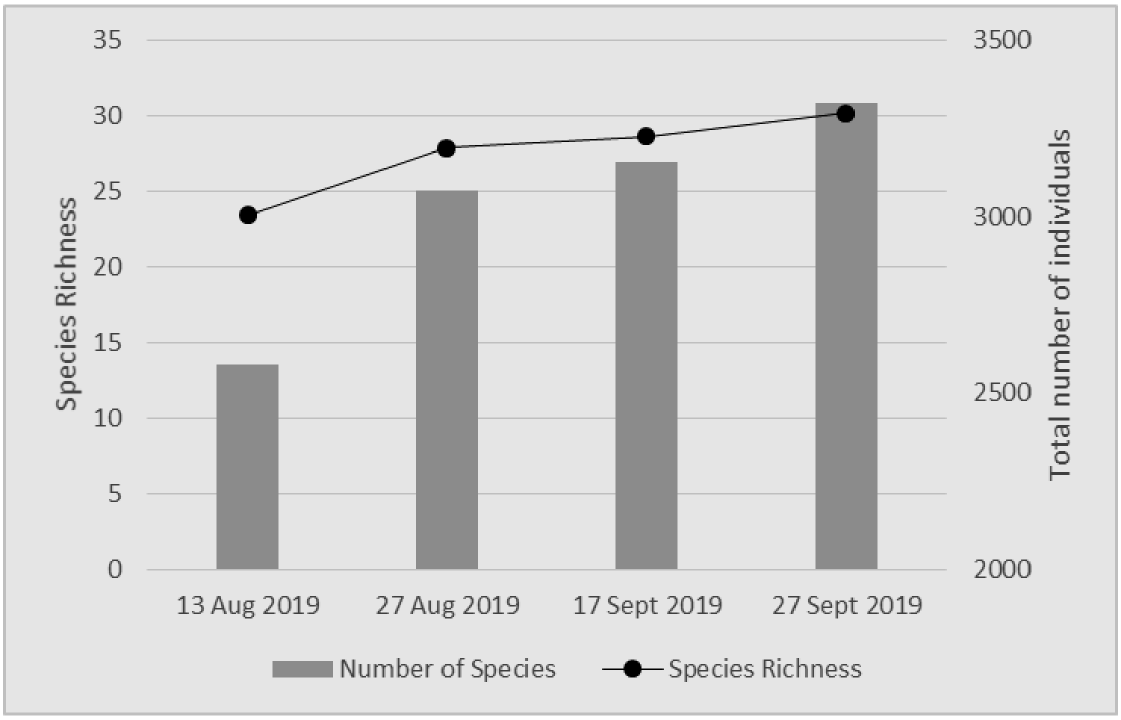

Figure 6. Relationship between temporal variations in number of individual species and species richness of macroinvertebrates in the Goreangab Dam.

A widely held hypothesis is that greater diversity increases ecosystem stability, because more specie rich communities have a broader range of adaptations and can thus respond better to stress, or disturbance experienced within the water body. There is a high diversity, composition and abundance of tolerant macroinvertebrates species in the Goreangab Dam, hence the Dam can be classified as unhealthy. Species richness can provide important information about the ecosystem and its water quality. In systems where the processes affecting species richness are well understood, allows this richness to be used as an indicator of community properties such as resource availability or the disturbance level of the water. The diversity of macroinvertebrates can be used to assess water pollution (Flores & Zafaralla, 2012; Orwa *et al*., 2015). Efforts to understand patterns of species distribution and diversity have provided useful means through which species distribution and diversity in the Goreangab Dam examines how fundamental ecological processes affect local communities and has therefore inspired a vast body of scientific research. Understanding of the different factors that influence species richness is particularly important for applying the concept to biodiversity conservation. The richest sites do not necessarily contain the rarest habitats, the highest levels of endemism or the species most threatened extinction. Finally, it is important to remember that while species richness represents a relatively simple measure of diversity, the two are not the same. Species richness must always integrate a scale of measurement and it is a species count per unit area, while on the other hand diversity is a broader concept that attempts to account for the variety of life in an ecosystem, not just of species butalso of all taxonomic levels and the functions, interactions and abundance of organisms. According to the analysis made, both local and landscape determined features affect macroinvertebrate distributions.

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