SPATIAL AND TEMPORAL VARIATIONS IN THE DISTRIBUTION OF BENTHIC MACROINVERTEBRATES ALONG THE VUVU RIVER, SOUTH AFRICA

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ABSTRACT

Benthic macroinvertebrates are widely known as important organisms for biomonitoring of water quality due to their visibility to the naked eye, ease of identification, rapid life cycles and sedentary habits. The aim of the study was to assess the condition or health of the Vuvu River using the South African Scoring System (SASS) Version 5 Biomonitoring Method for Rivers. This was achieved by determining the abundance and diversity of benthic macroinvertebrates, and also assessing the influence of water quality parameters on the distribution of benthic macroinvertebrates along the Vuvu River. Samples were collected and identified at the Vuvu River, Elundini Area in the Mount Fletcher district over a period of three months. Water quality parameters, which included dissolved oxygen, temperature, pH and electrical conductivity, were also measured *in situ*. The three-way analysis of variance (ANOVA) showed that benthic macroinvertebrates were more diverse upstream than at the downstream sites. Results on biotope level revealed that Stones-In-Current (SIC) had significantly higher macroinvertebrate diversity than Gravel Sand and Mud (GSM) with the former being twice the number of benthic macroinvertebrates than the latter. Electrical conductivity showed no significant differences among sites and throughout the sampling period. Although there was a significant increase in mean temperature from July to October which also increased downstream, there was no noticeable relationship between macroinvertebrate distribution and temperature changes. pH values increased downstream and varied from 8.22 to 9.35, indicating alkaline condition. These results serve as baseline information about the condition of the Vuvu River and that benthic macroinvertebrates can be used as monitors of the river ecosystem.

Keywords: benthic macroinvertebrates, site, biotope, diversity, water quality parameters.

1 INTRODUCTION

Rivers are sources of water for people worldwide and are known to reflect both the climatic and physical characteristics of their catchments [1]. The quantity and quality of clean freshwater depends on the conditions in the river. The ecological health of a river can be expressed in terms of its biological attributes and physico-chemical properties [2]. These components can indicate degradation, transformation and/or improvement. Benthic macroinvertebrates, in particular, are used to assess the biological integrity of riverine ecosystems and are considered to be a good reflection of a river's prevalent water quality [3]. They are often the taxa group of choice for biotic indices as they are visible to the naked eye, found throughout the length of the river, easy to collect and identify, have limited mobility and have relatively rapid life cycles. In addition, benthic macroinvertebrate families vary in their degree of sensitivity to organic and inorganic pollution [4]. Thus, their presence or absence can be used to make inferences about pollution levels.

In any aquatic ecosystem, physico-chemical parameters such as pH, temperature, dissolved oxygen and electrical conductivity can positively or negatively affect benthic macroinvertebrates, depending on their source [5]. Once any of these parameters becomes

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excessive, a long or short-term shift in the abundance and composition of benthic macroinvertebrate communities may arise [6].

In South Africa, macroinvertebrate bio-assessment has been widely used in River Health assessments to date and is known as the South African Scoring System (SASS) Version 5 [7]. It is used to assess changes in water quality based on the presence of families of aquatic invertebrates and their perceived sensitivity to water quality changes [8] where a score of “1” indicates highly tolerant taxa and 15 indicates highly sensitive taxa. The lack of effective management of catchments has been found to have a negative impact on both provision of water services and ecological status of river systems resulting in high siltation and reduction of freshwater biodiversity. Consequently, rivers are highly vulnerable to degradation which might result from impacts of land use and other activities such as pollution, overgrazing and soil erosion [9].

Despite the fact that there is an increasing demand of fresh water from rising human population on one hand and scarcity of permanent standing water bodies on the other [10], South Africa’s new water law recognises that basic human and environmental needs should be met and that the exploitation of water in all aspects (quality, quantity and reliability of supply) that must be sustainable in the long term. Scientists have therefore devised a variety of techniques to assess and monitor water quality in river systems in an attempt to conserve water in rivers for future generations [3], [4], [7], [11]. Some of the tools devised include legislation, land use planning and conservative management.

The majority of people living in Mount Fletcher are highly dependent on subsistence farming for their livelihoods. This results in uncontrolled stocking which might lead to high levels of overgrazing and consequently soil erosion. In most instances, soil erosion in these rangelands occurs within catchments along the rivers and this can contribute to high levels of turbidity [12] and deterioration of water quality. As there is little or no information available about the status of rivers in this area, this study was intended to investigate the spatial and temporal variations of benthic macroinvertebrates in the Vuvu River to provide baseline information for its future monitoring and management. This was achieved by determining the abundance and diversity of benthic macroinvertebrates, and also assessing the influence of water quality parameters on the distribution of benthic macroinvertebrates along the Vuvu River.

2 MATERIALS AND METHODS

2.1 Study sites

Sampling was conducted in the Vuvu River which is located in Elundini area, Mount Fletcher district of the Eastern Cape Province of South Africa. Five sites referred to as V_1 (30 36’ 07.27” S; 28 12’ 25.76” E); V_2 (30 36’ 06.82” S; 28 12’ 43.99” E); V_3 (30 36’ 10.30” S; 28 13’ 00.91” E); V_4 (30 36’ 04.41” S; 28 13’ 18.30” E) and V_5 (30 36’ 03.84” S; 28 13’ 33.57” E) were randomly selected on the basis of the presence or absence of riffles (Fig. 1). The sites V_1 and V_2 were referred to as upstream sites while (V_3) to (V_5) as downstream sites based on anthropogenic activities. The upstream sites were characterized by steep slopes with patches of alien invasion by black wattle (*Acacia meansii*), narrow shaded river bed and natural grassland.

The downstream sites were dominated by human settlement, small scale farming, overgrazing resulting in erosion, steep slope dongas, and livestock dipping tank nearby river.

2.2 Sampling

Samples were collected monthly, from August to October 2010. Samples for September could not be collected due to logistic reasons and only data from the other three months (July, August and October) were collected. Within each site, benthic macroinvertebrates were collected from two biotopes i.e. Stones-In-Current (SIC) and Gravel, Sand and Mud (GSM) using a SASS net which was held against the direction of the water current. Before and after netting in each site, one minute “hand-picking” was carried out to look for animals that might have been missed out during kick- and-shuffle. The sample on the net was then carefully transferred to a white SASS tray containing water for sorting. All invertebrates found within the white SASS tray were identified to family level using field identification guides [13]. Animals which could not be identified were collected and preserved in 70% alcohol for later identification in the laboratory. The number of benthic macro-invertebrate families found were counted and used to estimate species diversity. The number of individuals per family were counted and used to estimate relative abundance (1 = 1; A = 2–10; B = 10–100; C = 100–1000; D > 1000).

In each site, water quality parameters (pH, Electrical Conductivity and Temperature) were measured *in situ* using the Eutech Cyberscan Series 600 portable water quality meter. Water flow, turbidity, riparian land use, disturbances in the river such as sand mining, cattle drinking, floods as well as any signs of pollution e.g. smell and colour of water, dead fish, were noted.

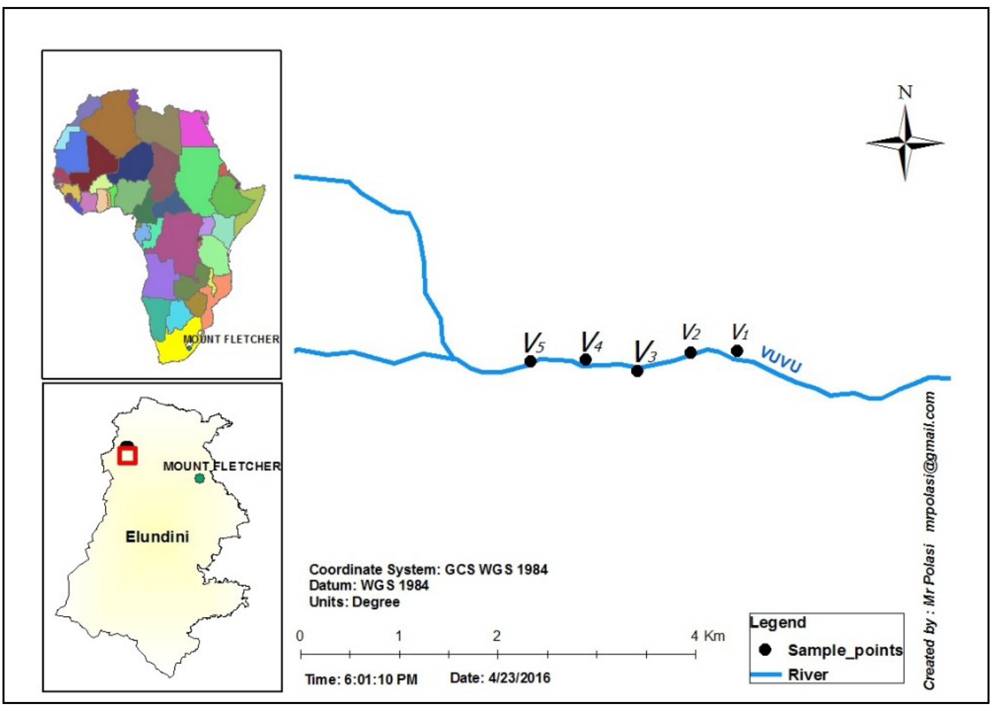

Figure 1: Map showing study sites along the Vuvu River.

2.3 Statistical analysis

Three-way Analyses of Variance (ANOVA) were used to test the effect of month, site and biotope nested within site on the number of benthic macroinvertebrate families found in the Vuvu River. Two-way ANOVA were used to test the effect of water quality parameters; i.e. temperature, pH and electrical conductivity on the diversity of benthic macroinvertebrate families found. Prior to the use of ANOVA, the data were tested for normality and homogeneity of variances using Kolmogorov–Smirnov [14] and Cochran [15] tests. Post-hoc tests were used following significant differences from ANOVA results.

3 RESULTS

3.1 Site and biotope effect

A total number of 19 benthic macroinvertebrate families were found (Appendix 1). The results of the 3-way Analysis-of-variance (ANOVA) showed significant differences ($P < 0.05$) on site and biotope in the number of families/diversity of macroinvertebrates. There were no significant differences ($P > 0.05$) between the interaction of month and biotope (Table 1).

There were significant differences ($P < 0.05$) in the number of families among sites (Table 1). Post-hoc tests revealed significant differences ($P < 0.05$) between Site 2 and 4 (see asterisks in Fig. 2). Site 2 almost doubled the number of families in Site 4. This reflected the fact that the highest and lowest number of families was 7 ± 1.5 and 4 ± 1.5 found in Site 2 and Site 4, respectively. There were also significant differences ($P < 0.05$) in the number of families between biotopes (Table 1). The number of benthic macroinvertebrate families was significantly two times greater in SIC than GSM. The mean number of families found in SIC and GSM were 7.3 and 3.4, respectively.

Table 1: Results of three-way ANOVA based on mean number of benthic macroinvertebrate families found in the Vuvu River (* indicates significant effect at $p < 0.05$).

Sources of variation	SS	df	MS	F	*P*
Month	3.466	2	1.733	1.762	0.232
Site	55.133	4	13.783	14.016	0.001*
Biotope	116.033	1	116.033	34.636	< 0.001*
Month × site	7.866	8	0.983	0.293	0.954
Month × biotope	16.266	2	8.133	2.427	0.130
Error	40.200	12	3.350		

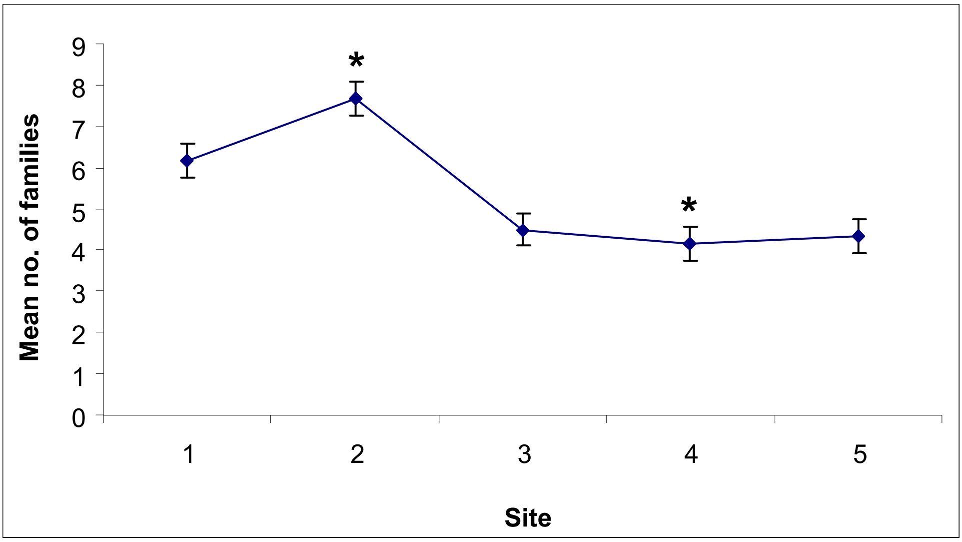

Figure 2: Mean number (±SE) of benthic macroinvertebrate families at the Vuvu River (* indicate sites with significant difference at $p < 0.05$).

3.2 Water quality parameters

ANOVA results showed significant differences ($P < 0.05$) in temperature among months (Table 2). Post-hoc tests revealed that all months were significantly different from one another. Temperature showed an increasing trend from the beginning to the end of the sampling period (Fig. 3). The highest and lowest mean temperatures were 11.2ºC and 20.8ºC found in July and October, respectively. Although there were significant differences ($P < 0.05$) in mean temperature (Table 2) among sites, Post-hoc tests showed that only site 1 was significantly different from the other four sites (Fig. 4).

The results of a two-way ANOVA showed significant differences ($P < 0.05$) among months on mean Ph values (Table 3). Post-hoc tests showed that significant differences occurred between July and October with mean pH values of 8.9 and 8.6, respectively (Fig. 3). The pH also showed significant differences ($P < 0.05$) in pH among sites (Table 3)Post-hoc tests showed that site 1 was significantly different from site 3, 4 and 5 (Fig. 4). ANOVA results showed no significant differences ($P > 0.05$) in conductivity among sites and months (Table 4).

Table 2: Results of the two-way ANOVA based on mean temperature in the Vuvu River (* indicates significant effect at $P < 0.05$).

Sources of variation	**SS**	**df**	**MS**	**F**	***P***
Month	233.296	2	116.648	41.603	< 0.001*
Site	45.129	4	11.282	4.024	0.045*
Error	22.431	8	2.804		

Table 3: Results of the two-way ANOVA based on mean pH in the Vuvu River (* indicates significant effect at $P < 0.05$).

Sources of variation	SS	df	MS	F	*P*
Month	0.816	2	0.408	5.14	0.037*
Site	2.557	4	0.639	8.05	0.007*
Error	0.635	8	0.079		

Table 4: Results of the two-way ANOVA based on mean electrical conductivity in the Vuvu River.

Sources of variation	SS	df	MS	F	*P*
Month	8.661	2	4.330	1.014	0.405
Site	17.227	4	4.306	1.008	0.457
Error	34.167	8	4.270		

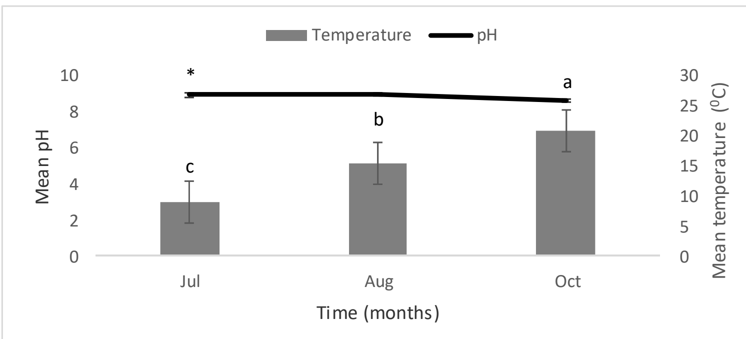

Figure 3: Monthly mean (±SE) pH and temperature along the Vuvu River. * denotes month with significant difference and letters above the bars indicate homogenous groups.

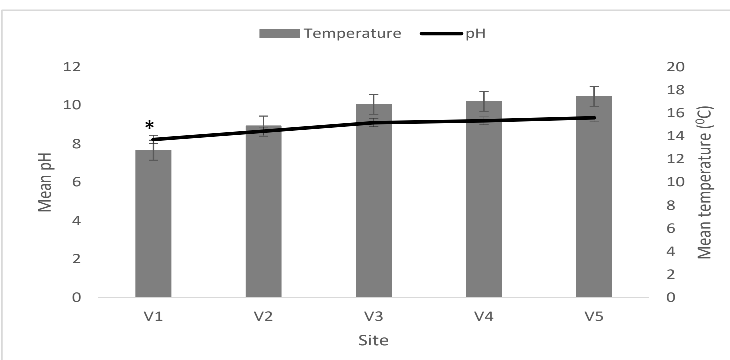

Figure 4: Mean (±SE) pH and temperature among sites along the Vuvu River (* indicate site with significant difference).

4 DISCUSSION

This study showed that upstream sites were mostly dominated by benthic macroinvertebrates that have high sensitivity scores and there was also higher benthic macroinvertebrate diversity observed upstream than at the downstream sites. The occurrence of highly sensitive families upstream signifies a healthy aquatic environment [16] and this may be attributed to less or minimal human activities. Pires et al. [17] found that sensitive macroinvertebrates were most abundant at sites where water quality was good. According to Seager and Abrahams [18], the structure of benthic macroinvertebrate community responds to organic pollution and alteration of water quality with a decrease in the number of more sensitive taxa. This was the case even in this study. Dallas and Day [19] also found that polluted sites had lower diversity and higher abundance of benthic macroinvertebrates. Similarly, Depiereux et al. [20] found that Dipterans (Chironomidae, Simuliidae, Tipulidae) were associated with poor water quality as they are more resistant to pollution. This variation in diversity across sites could also be due to natural variability [21].

The number of benthic macroinvertebrate families found in SIC doubled those found in GSM across all sites. One of the main factors affecting colonisation of benthic macroinvertebrates is substratum interaction with current velocity which results in great mobility in the substratum, generating an unstable habitat for benthic macroinvertebrates to settle in the GSM [22]. Another factor could be that excessive runoff that causes erosion on the catchment changes the abiotic condition of the benthos particularly increasing nutrients [23] and sediment loads [24]. Erosion of the un-vegetated catchment along the Vuvu River could be one of the main reasons for the occurrence of decreased number of benthic macro-invertebrate families on the GSM. Similarly, low diversity of benthic macroinvertebrates in GSM was found in Talamachita River [22].

4.1 Water quality parameters

The results indicated a significant increase in temperature from July to October. This was expected as temperate countries like South Africa, generally, have low temperatures in winter with temperature increasing towards summer. Although temperature has been implicated as a primary factor affecting spatio-temporal variations and life history patterns of aquatic invertebrates [25], in the current study there was no noticeable relationship between benthic macroinvertebrate distribution and temperature changes. Tyokumbur et al. [26] also found a weak correlation between invertebrates such as Dipterans, Odonata and Gastropoda and water temperature. They attributed this effect to macroinvertebrates' physiological adaptation to anoxic conditions created by high temperatures that tend to reduce the amount of dissolved oxygen.

There were significant differences observed in pH among months and also between upstream and downstream sites. August had the highest values and October the lowest. The mean pH values for this study ranged between 8.22 and 9.35 and also increased in the upstream–downstream direction. In contrast, Esteves [27] found the mean pH values to vary from values of 6 to 8. This reflects a more alkalinic condition downstream than upstream. This can be explained by the dissociation of urinal ammonium (NH_4) from cattle drinking points downstream. Ammonium is harmful for sensitive macroinvertebrates [28] and may result in decrease in macroinvertebrate diversity and the number of sensitive taxa. Moreover, the run-off of pesticides from the cattle-dipping tank along the catchment may also be another contributing factor. High pH values are also associated with increase in production of algae [29], which reduces macroinvertebrate diversity and sensitive taxa. In this study visible brown and green algae were noted to occur downstream where pH values were higher. Electrical conductivity showed no significant differences among sites and throughout the sampling period. The lack of significant differences among sites was interesting as one would expect a significant increase due to the erosion gradient that occurs along the river banks.

In conclusion, pollution tolerant benthic macroinvertebrates were more dominant downstream than upstream. Benthic macroinvertebrate families can be used as bio-monitors and to classify river systems as being healthy or not. These results provide baseline information for future monitoring and management of this river.

Such information may play an important role in the protection and remediation of ecosystems.

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APPENDIX 1

Family composition and abundance of benthic macroinvertebrates in each of the five sites (V1, V2, V3, V4 and V5) found along the The Vuvu River throughout the sampling period. (SS = Sensitive Score; abundance scale: 1 = one individual, A = 2–10, B = 10–100, C > 100.

Family	**SS**	**V1**			**V2**			**V3**			**V4**			**V5**		
		J	**A**	**O**	**J**	**A**	**O**	**J**	**A**	**O**	**J**	**A**	**O**	J	**A**	**O**
Turbellaria	3	B	B			A	A		1	A		1	A	B	1	1
Potomonautidae	3		1		A	A	A									1
Beatidae	4					A		B	A	A	A	B	C	B	A	A
Beatidae	4		B	A			B									
Caenidae	6			A	1		A	A	1						1	
Heptageniidae	13	B	B	B	B	B	B		1							
Tricorythidae	9	A	B	A	B	B	B	A	B	A	A	A	1	A	A	A
Leptophlebiidae	9	B	B	A	B	B	1	A								
Gomphidae	6					1	1								1	
Tipulidae	5						A						1			
Hydropsychidae	4				A			A		B				B		
Hydropsychidae	6		1			A				B			C			B
Chironomidae	2		1	A	1	A	1	A	B	B	B	C	B	C	C	C
Simuliidae	5	A	B	A	A	B	A	A	A	B	1	A		A	B	1
Aeshnidae	8	A	B	B	B	B	A	A	A	A	A	1		1		
Culicidae	1											1		1		A
Oligocheata	1										1			A		1

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