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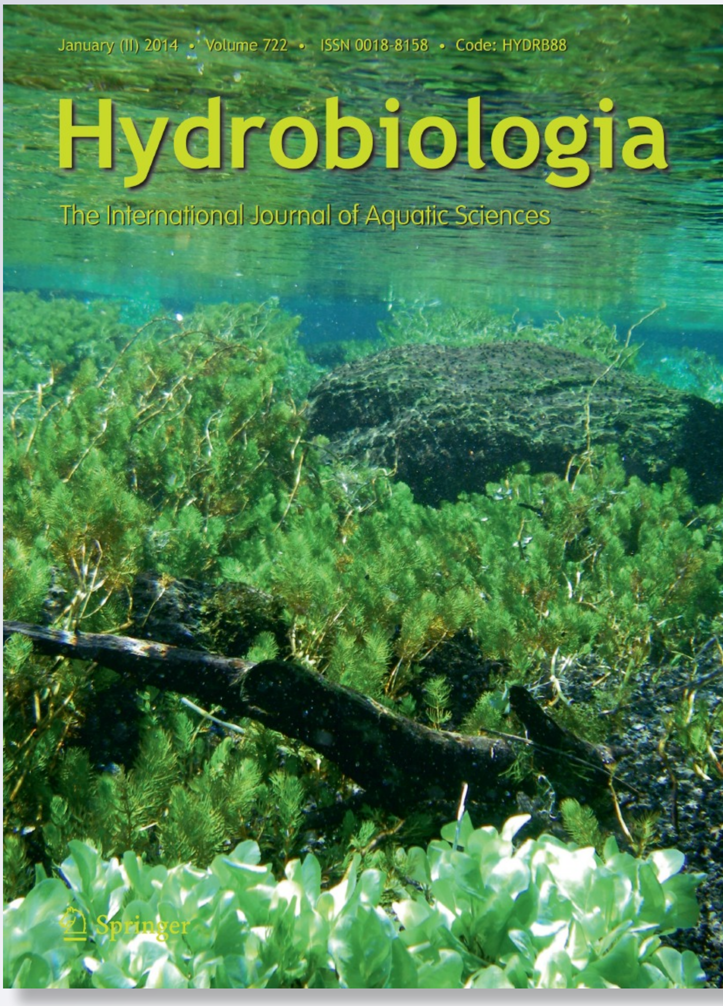

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PRIMARY RESEARCH PAPER

Use of biological monitoring tools beyond their country of origin: a case study of the South African Scoring System Version 5 (SASS5)

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Abstract Biological monitoring tools are largely lacking for many countries, resulting in adoption of tools developed from other countries/regions, but in many instances, their applicability to the new system has not been explicitly evaluated. The objective of the study was to test the applicability of the South African Scoring Systems Version 5 (SASS5) to urban streams in Zimbabwe. The study evaluated the relationship between water quality variables and SASS5 indices/ metrics [(SASS and average score per taxon (ASPT)] and found high degree of concordance between water chemistry parameters and SASS5 metrics, indicating that both SASS and ASPT scores are sensitive to detect environmental changes. This result can be attributed to occurrence of ubiquitous macroinvertebrate taxa sharing similar environmental tolerances with those recorded for South African systems. The applicability of SASS5 metrics need to be tested across different geographical and climatic regions in the country (taking into consideration seasonal variations that are important drivers of benthic faunal assemblages in lotic systems) and disparities among the regions compared for the adoption of the index in the entire country. The SASS5 metrics can also be further strengthened by (a) taking into account the relative abundance of taxa and (b) also improving on its ability to reflect other forms of perturbations besides eutrophication and organic pollution such heavy metal pollution.

Keywords Macroinvertebrates · Stream monitoring · Metric scores · Pollution · Urban streams

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T. Bere (✉) · B. B. Nyamupingidza
Department of Wildlife and Safari Management, Chinhoyi University of Technology, Off Harare-Chirundu Rd, P. Bag 7724, Chinhoyi, Zimbabwe
e-mail: taubere@yahoo.com; tbere@cut.ac.zw

Introduction

Streams draining urban areas receive large quantities of raw and partially treated industrial and sewage effluents daily leading to stream health deterioration, loss of primary biodiversity and eutrophication. This is especially true in developing countries that are characterised by unplanned growth and development of cities coupled with resource limitations. For example, in Zimbabwe, industrial and sewage effluent (most of which is untreated) and sewage spillages from burst pipes find their way into urban streams daily (Bere, 2007; Ndebele-Murisa, 2012).

In many developing countries, the assessment of stream ecological health and water quality tend to be biased towards the analysis of physical and chemical properties, with biological monitoring largely being neglected (e.g. Czerniawska-Kusza, 2005; Bonada et al., 2006; Ndebele-Murisa, 2012). However, physical and chemical measures provide only a fragmented overview of the state of aquatic systems, because sporadic or periodic sampling, commonly practised in developing countries due to the budget constraints, cannot reflect fluxes of effluent discharge. In contrast, biological monitoring may give a more time-integrated indication of the water quality reflecting conditions that are not present at the time of sample collection and analysis (Karr, 1991; Buss et al., 2002; Bonada et al., 2006). Biological monitoring is a fast and cost effective approach for assessing the effects of environmental stressors, and thus a particularly essential tool for the management of rivers in developing countries (Buss et al., 2002; Nhapi, 2008; Ndebele-Murisa, 2012).

Macroinvertebrates are used for biological monitoring worldwide, but their use is limited in Southern Africa, with the exception of South Africa (e.g. Chutter, 1998; Dickens & Graham, 2002). This is due to inadequate requisite infrastructure, lack of skilled personnel and poor policies or strategies for environmental management. However, in South Africa, the South African Scoring System (SASS), developed by Chutter (1998) and modified by Dickens & Graham (2002) to Version 5 (SASS5), has been used extensively for biological monitoring. SASS is a result of the modification of the Biological Monitoring Working Party (BMWP; Walley & Hawkes, 1996) to suit South African river systems (Chutter, 1998; Dickens & Graham, 2002). Macroinvertebrate families are given scores ranging from 1 to 15 in increasing order of their sensitivity to water quality changes, with the results being expressed both as an index score and as average score per recorded taxon (ASPT) value (Dickens & Graham, 2002). SASS has been rigorously tested and is widely used as a tool for assessing river health conditions in South Africa. In addition, SASS has been adopted by a number of Southern African countries, such as Zimbabwe, Zambia and Mozambique, to assess water quality and ecological health of lotic systems.

There are concerns regarding transfer of indices developed in one geographic region into another as there may be faunal differences among regions and potential environmental differences that may modify species responses to environmental changes (e.g. Bonada et al., 2006; Ziglio et al., 2006; Tonkin et al., 2013). Endemic macroinvertebrate taxa may also occur in different regions, necessitating development of region specific indices (Rosenberg & Resh, 1993; Bonada et al., 2006; Ziglio et al. 2006). Strict testing of borrowed indices is therefore required to ensure that the scores give a realistic reflection of the specific type of environmental conditions in geographic region being assessed.

This study evaluated the applicability of SASS5 beyond South Africa. In particular, we asked to what extent SASS5 metrics detect changes in water quality and ecological conditions in four urban streams in Chinhoyi Town, Zimbabwe. Though SASS has been previously used in assessment of water quality and ecological conditions of streams elsewhere in the country, in many instances, its applicability to these systems has not been explicitly evaluated. We hypothesised that the metrics will be sensitive in detecting water pollution and ecological impairment in the study region because occurrences of ubiquitous macroinvertebrate taxa that probably have similar environmental tolerances to those recorded for South African systems. As in many towns in Zimbabwe, sewage treatment facilities in Chinhoyi Town are heavily overloaded or obsolete. Therefore, streams in the study area receive raw or semi-treated domestic and industrial as well as diffuse pollutants in run-off during storm events. The town also expanded without taking into account environmental, geographical and topographical factors leading to deforestation, erosion and siltation. This unplanned growth, typical of many Zimbabwean cities and towns, has had several negative environmental impacts including deterioration of stream health, loss of primary biodiversity and eutrophication.

Materials and methods

Study area and study design

The study was carried out in four streams draining the town of Chinhoyi in northern Zimbabwe (Fig. 1). The area has a mean annual temperature of 24.5 ± 5.1°C, with a mean monthly maximum of 29.9 ± 6.5°C recorded in October and November and a mean monthly minimum of 18.9 ± 5.8°C recorded in July (Meteorological Services Department of Zimbabwe; data from 1965 to 2012). In 2012, the Zimbabwe National Statistics Agency) estimated the population of Chinhoyi at 79,368 inhabitants.

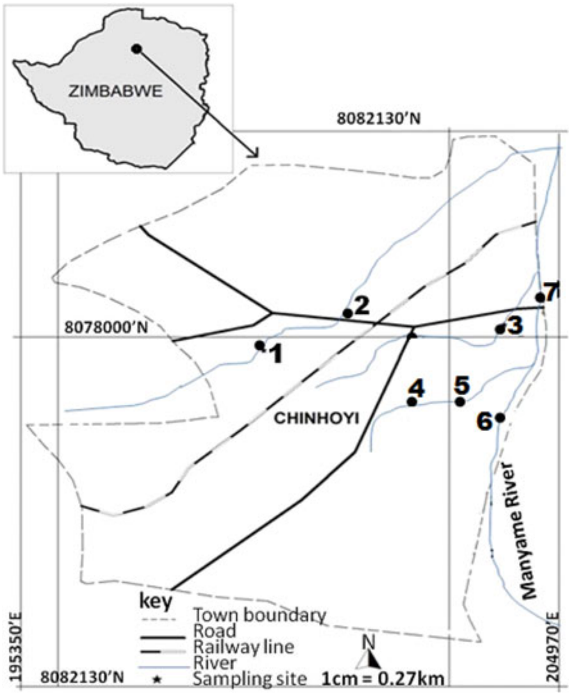

Fig. 1 Map of the study area and sampling sites *S1–S7*

Seven sites were sampled in different streams draining Chinhoyi Town (Fig. 1). The criterion for selecting sampling sites was to evaluate the impact of breakdown in municipal service delivery (especially sewage treatment) on water quality and the associated macroinvertebrate communities in streams. Site 1 (S1) is located in the upstream reaches of Muzari Stream in relatively less polluted low-density suburbs acting as a 'reference' while site 2 (S2) is located in town centre where uncollected garbage and effluent from broken sewage pipes finds its way into the stream. Site 3 (S3) and 5 (S5) are located just after sewage effluent discharge points in Cold Stream and Katanga Stream respectively. Site 4 (S4) is located further upstream of Katanga Stream to assess the impact of sewage effluent on macroinvertebrate communities at S5. Sites 6 (S6) is located upstream of the large Manyame River in relatively less polluted area, while site 7 (S7) is located further down along the same river. Large flow volumes in the Manyame River (the upper reaches of which drains less polluted commercial farms) are expected to have a dilution effect on pollutants at sites 6 and 7. Sampling sites were reaches of 20–30 m long each, comprising relatively homogeneous riffle sections. Riffle areas were selected during sampling, as they are relatively shallow and were favourable due to their vulnerability to physical and chemical impacts (Ziglio et al., 2006). Monthly sampling of macroinvertebrates and water chemistry was carried out from May to July 2012.

Water quality sampling and analysis

At each site, dissolved oxygen (DO), conductivity, temperature, pH and turbidity were measured in the middle of the stream at a depth of 20–30 cm below the surface of the water using appropriate portable probes (YSI, Yellow Springs, OH, USA) (Table 1). Water samples were collected at each site at a water depth of 20–30 cm during the day using acid-cleaned 100 ml polyethylene containers (APHA, 1988). In the laboratory, the concentrations of ammonium, nitrites and soluble reactive phosphates (SRP) were determined using a Hach DR/2010 spectrophotometer (Hach Company, 1996–2000). Iron and manganese were analysed using flame atomic absorption spectrometry analytical methods (Varian Australia Pty Ltd, Victoria, Australia). Calcium levels were determined by ethylenediamine tetraacetic acid titrimetric method following APHA (1988).

Macroinvertebrates sampling and analysis

At each site, macroinvertebrates collection and stream health inference was done following the SAAS5 protocol. Where available, three major habitats identified by Dickens & Graham (2002) were sampled. Stones, bedrock or any solid object in fast-flowing water were sampled by kicking, dislodging and collecting the invertebrates into to the net (mesh size 500 µm) for approximately 2 min. Stones, bedrock or any solid object in slow-flowing water were sampled for approximately 1 min by kicking, turning or scraping them with the hand and/or feet, whilst continuously sweeping the net through the disturbed area. Samples collected in fast- and slow-flowing water were then combined into a single stones habitat sample.

A total length of approximately 2 m of marginal vegetation spread over more locations was sampled by pushing the net vigorously into the vegetation, moving backwards and forward through the same area. Macroinvertebrates in aquatic vegetation such as water hyacinth (*Eichhornia crassipes* (Mart.) Solms) and

Table 1 Means (±SD) of physical and chemical variables recorded at all the sites (S1–S7) from May to July 2012

Parameter	Site						
	S1	S2	S3	S4	S5	S6	S7
Water T (°C)	19.8 ± 4.4	19.3 ± 4.5	22.6 ± 3.1	21.1 ± 4.1	21.9 ± 3.8	23.3 ± 3.7	22.8 ± 4.6
Conductivity (μS cm^{-1})	70.2 ± 15.6^{a}	68.0 ± 2.3^{a}	85.0 ± 4.3^{a}	40.4 ± 6.9^{b}	68.2 ± 17.2^{a}	30.4 ± .3^{c}	31.0 ± 2.9^{c}
DO (mg l^{-1})	6.1 ± 0.7^{a}	5.5 ± 0.7^{a}	3.0 ± 0.8^{b}	5.4 ± 0.6^{a}	3.6 ± 1.1^{b}	7.1 ± 0.3^{c}	7.2 ± 0.5^{c}
pH	7.4 ± 0.2	7.3 ± 0.0	7.0 ± 0.1	7.4 ± 0.1	7.1 ± 0.1	7.7 ± 0.1	7.8 ± 0.3
Turbidity (NTU)	3.5 ± 2.1^{a}	4.0 ± 1.8^{a}	61.3 ± 17.7^{b}	2.2 ± 1.6^{a}	37.2 ± 6.7^{b}	1.5 ± 0.7^{c}	1.1 ± 0.3^{c}
NO_2^- (mg l^{-1})	0.9 ± 1.3^{a}	0.8 ± 1.5^{a}	15.2 ± 8.1^{b}	0.8 ± 1.5^{a}	11.1 ± 6.6^{b}	0.5 ± 0.8^{a}	0.1 ± 0.1^{c}
NH_4^+ (mg l^{-1})	0.4 ± 0.3^{a}	0.6 ± 0.3^{a}	9.6 ± 8.2^{b}	2.6 ± 3.9^{c}	8.1 ± 8.3^{b}	1.9 ± 0.4^{d}	0.3 ± 0.2^{a}
SRP (mg l^{-1})	<0.1	<0.1	3.3 ± 5.8^{a}	0.1 ± 0.2^{b}	2.2 ± 2.6^{a}	0.3 ± 0.6^{b}	<0.1
Ca^{2+} (mg l^{-1})	9.1 ± 1.1^{a}	6.8 ± 1.3^{a}	4.2 ± 2.0^{b}	3.9 ± 1.2^{b}	5.2 ± 1.2^{b}	4.3 ± 2.0^{b}	4.0 ± 4.2^{b}
Fe^{2+} (mg l^{-1})	0.03 ± 0.04^{a}	0.20 ± 0.2^{b}	1.1 ± 0.6^{c}	0.1 ± 0.2^{b}	0.4 ± 0.4^{b}	0.20 ± 0.3^{b}	0.04 ± 0.1^{c}
Mn^{2+} (mg l^{-1})	0.13 ± 0.2^{a}	0.22 ± 0.4^{a}	1.04 ± 1.2^{b}	0.57 ± 1.0^{b}	0.51 ± 0.5^{b}	<0.02	0.02 ± 0.0^{a}

Different letters denote significant differences obtained through Tukey's post hoc comparison test

Hydrocotyle spp. were sampled by pushing the net repeatedly against and through the vegetation under the water over an area of approximately one square metre. Samples collected in fast- and slow-flowing water were then combined into a single vegetation habitat sample.

Gravel, sand, mud, silt and clay were stirred by shuffling or scraping with the feet, whilst continuously sweeping the net over the disturbed area to catch dislodged biota, avoiding collection of unnecessary material. Samples collected in fast- and slow-flowing water were then combined into a gravel, sand and mud habitat sample. Specimens that may have been missed by the sampling procedure were 'hand-picked' for approximately 1 min. Snails and fast moving pond skaters were also noted.

The samples from the three habitats were washed accordingly to remove excess debris. Macroinvertebrates were then identified to family (in some cases class) level following studies by Thirion et al. (1995) and Gerber & Gabriel (2002) and counted. Those that could be identified in the field were returned to the stream, while those that could not be identified immediately (very few in most cases) were stored in 10% formalin in polythene bottles and transported to the laboratory for identification.

Number of taxa present at each site was recorded. SASS scores were calculated by summing the quality scores of all the families present at a given site, irrespective of abundance (Dickens & Graham, 2002). The ASPT was calculated for each site following SASS protocol by dividing the SASS score by number of taxa (Dickens & Graham, 2002).

Data analysis

Analysis of variance (ANOVA) with Tukey's post hoc HSD tests was used to compare means of physical and chemical variables among sampling sites after testing for normality (Shapiro–Wilk test) and homogeneity of variance (Levene's test). Data on SASS and ASPT scores were not normally distributed (Shapiro–Wilk test; $P > 0.05$) and could not be transformed accordingly. Thus, a Kruskal–Wallis test was used to compare means of scores among sampling sites. Spearman's rank correlation was used to determine the relationship between the calculated SASS and ASPT scores and measured physical and chemical water quality data.

Detrended correspondence analysis (DCA) was applied on macroinvertebrate data set to determine the length of the gradient. The DCA revealed that the gradient was >3 SD, thus justifying the use of unimodal ordination techniques (Ter Braak & Verdonschot, 1995). Thus, canonical correspondence analysis (CCA) was used to examine the direct effect of the physical and chemical (pollutant) characteristics of the water on variation in taxon composition among sampling sites as a means of identifying possible indicator taxa that were sensitive to water pollution. Preliminary CCA identified collinear variables and selected a subset by removing variables that had a variance inflation factors larger than 20 from the analysis (Ter Braak & Šmilauer, 2002). CCA was performed using the programme CANOCO 4.5 (Ter Braak & Šmilauer, 2002). All other statistical tests were performed with Palaeontological Statistics Software Version 2.16 (Hammer et al., 2012).

Results

Water quality

There were no significant differences in temperature and pH among sampling sites (ANOVA, $P > 0.05$) (Table 1). Conductivity was significantly lower at Manyame River sites S6 and S7 compared to the rest of the sites (ANOVA, $P < 0.05$) (Table 1). Turbidity, nitrite and SRP were significantly higher at S3 and S5 which were affected by sewage effluent compared to the rest of the sites (ANOVA, $P < 0.05$). Raw sewage could be seen flowing at S3 and S5 as well as piles of uncollected garbage/refuse along the stream banks and even in the streams at sites S3, S4 and S5. Ammonium and manganese levels were significantly higher at S3, S4 and S5 compared to the rest of the sites (ANOVA, $P < 0.05$). DO levels were significantly lower at S3 and S5 compared to the rest of the sites, with S6 and D7 having significantly higher values of the same compared to the rest of the sites (ANOVA, $P < 0.05$). Vast stretches before S6 and S7 displayed suitable conditions for the self-purification of streams (Bere, 2007). Iron levels were significantly higher at S3 compared to the rest of the sites (ANOVA, $P < 0.05$). Calcium levels were significantly higher at sites S1 and S2 compared to the remaining sites (ANOVA, $P < 0.05$).

Community composition in relation to environmental variables

A total number of 26 families representing the orders Decapoda, Plecoptera, Ephemeroptera, Odonata, Hemiptera, Coleoptera, Diptera, Gastropoda and Pelecypoda as well as classes Hirudinea and Oligochaeta were found. The total number of families varied between 4 and 11 among the sites sampled during the study period (Table 2). During each sampling, the maximum number of families (6–11) was found at sites S6 and S7 (less polluted in terms of physical and chemical variables). Taxa more sensitive to pollution such as Baetidae, Heptageniidae and Potamonautidae were recorded at S6 and S7 (Table 2). The minimum number of families (2–4) was observed at sites S3 and S5 (most polluted in terms of physical and chemical variables). Taxa less sensitive to pollution such as Oligochaeta, Chironomidae, Musidae and Syrphidae were recorded at these sites.

In CCA, axis 1 and 2 explained 42.7 and 24.0% of the variation, respectively, (Fig. 2). DO and pH were positively associated with the first axis while ammonium and turbidity levels (positively correlated with nitrite, SRP and manganese) were negatively associated with the first axis. DO and pH were also positively associated with the second axis, while conductivity and calcium levels were negatively associated with the second axis.

CCA axis 1 and 2 separated the sites into roughly three groups based on pollution levels. The first group

Table 2 SASS and ASPT index values and number of taxa recorded at the seven sites in streams draining Chinhoyi town from May to July 2012

Sampling site	Sampling period								
	May			June			July		
	SASS	ASPT	Taxa	SASS	ASPT	Taxa	SASS	ASPT	Taxa
S1	26	3.7	7	45	5	9	32	6.4	5
S2	15	3.0	5	17	4.3	4	18	3.6	5
S3	9	2.3	4	3	1.5	2	8	2.0	4
S4	16	3.2	5	7	2.3	3	21	3.5	6
S5	11	2.8	4	4	1.3	3	13	2.6	5
S6	45	6.4	7	47	7.8	6	60	7.5	8
S7	64	7.1	9	49	7	7	66	6.0	11

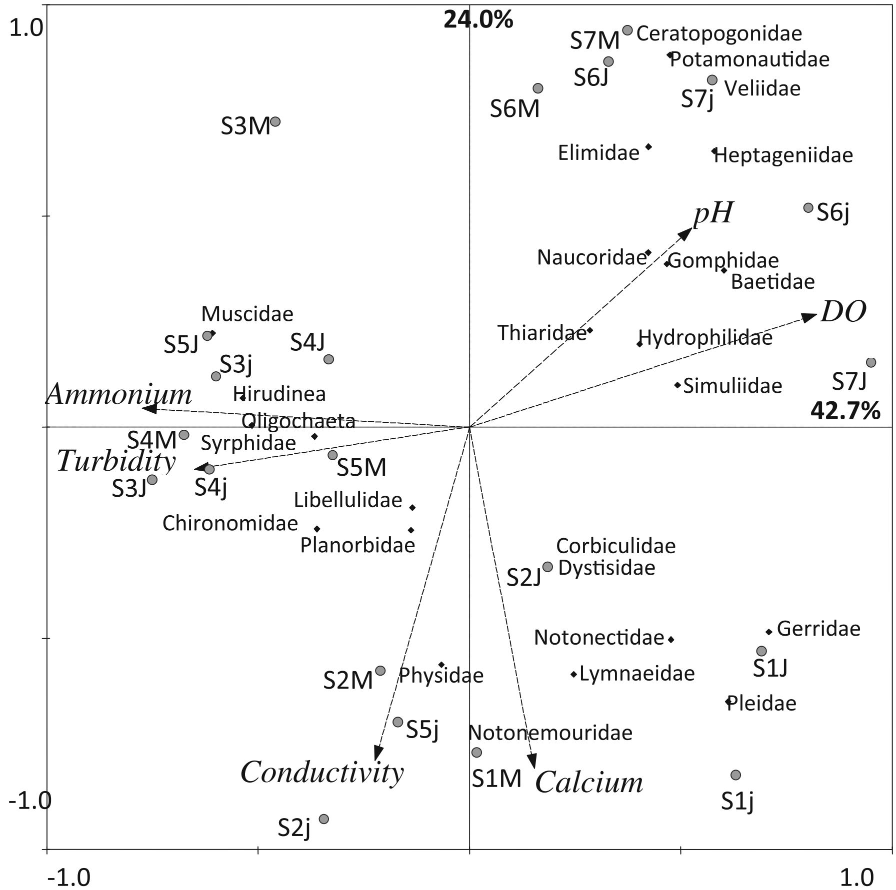

Fig. 2 CCA biplot showing effects of six selected environmental variables on macroinvertebrate family structure in seven sampling sites during three sampling periods (*S1M* site sampled in May, *S1J* site sampled in June, *S1j* site sampled in July)

consisted of less polluted sites S6 and S7 that were positively associated with the first and second axis in the top right quadrant (Fig. 2). Macroinvertebrate taxa characterising these sites include relatively pollution sensitive families such as Heptagenidae, Baetidae, Elmidae, Naucoridae and Gomphidae. Few pollution tolerant families were also recorded at these sites e.g. Potamonautidae. The second group consisted of highly polluted sites S3, S4 and S5 that were negatively associated with the first axis. Macroinvertebrate taxa characterising these sites include pollution tolerant taxa such as Chironomidae, Hirudinea, Muscidae, Oligochaeta and Syrphidae. The third group consisted of sites S1 and D2 as well as site S5 in July. These sites were negatively associated with the second axis. Macroinvertebrate taxa characterising these sites include pollution sensitive family Notoneumouridae as well as high to moderately pollution tolerant families such as Gerridae, Notonectidae, Pleidae, Dystiscidae, Lymnaeidae, Physidae and Corbiculidae.

SASS biological indication

Presence/absence of taxa sensitive to pollution among the sample sites had a direct impact on the results obtained during the water quality and ecological health assessment—SASS and ASPT index values (Table 2). Generally, all the sites had SASS scores below 100 with the highest score of 66 recorded at site S7 in July and the lowest score of 3 at site S3 in May indicating a general deterioration in water quality among the sites sampled. The less polluted sites S6 and S7 had significantly high SASS (45–66) and ASPT (6.4–7.8) indices compared to the rest of the sites (Kruskal–Wallis, $P < 0.05$). Based on the ASPT index values, ecological health at these sites ranged from good to fair with relatively preserved water quality characteristics and high habitat diversity. Significantly low SASS (3–13) and ASPT (1.3–2.8) indices were recorded at sites S3, S4 and D5 compared to the rest of the sites (Kruskal–Wallis, $P < 0.05$), indicating a very poor ecological state with signs of major deterioration in water quality and low habitat diversity. The SASS and ASPT index values were significantly correlated (Spearman test, $P < 0.05$) with DO, conductivity, pH, turbidity, nitrite, ammonium, SRP and manganese, but not with water temperature, calcium and iron levels (Table 3).

Discussion

Community composition in relation to environmental variables

Reliable SASS score metrics development requires clear understanding of data sets in terms of the major environmental gradients underlying presence or absence of taxa at a given site (Dickens & Graham, 2002). From the CCA results, site were separated into three groups based on pollution levels and tolerance of macroinvertebrates to pollution demonstrating the capacity of macroinvertebrates to act as indicators of different levels of pollution as has been demonstrated elsewhere (Walley & Hawkes, 1996; Dallas & Day, 2004; Bonada et al., 2006; Chakona et al., 2008; Ndebele-Murisa, 2012). Sites S6 and S7, with relatively good water quality were characterised by macroinvertebrate of the families Heptagoenidae and Baetidae known to be relatively sensitive to pollution due to their need for unpolluted water with high DO and low siltation (Lemny, 1982; Dickens & Graham, 2002; Ndebele-Murisa, 2012). In contrast, sites S3, S4 and S5 with bad water quality were characterised by macroinvertebrate taxa that are known to be pollution tolerant such as Chironomidae, Hirudinea, Muscidae, Oligochaeta and Syrphidae (Dickens & Graham, 2002; Czerniawska-Kusza, 2005; Chakona et al., 2008). These organisms have haemoglobin in their bodies, which enable them to increase oxygen uptake in eutrophic and organically enriched waters, hence increasing their chances of survival (Lemny, 1982; Rosenberg & Resh, 1993; Pires et al., 2000).

Table 3 Spearman's rank correlation coefficients between environmental variables and SASS and ASPT index values of seven sites in streams draining Chinhoyi Urban, Zimbabwe

Parameter	Metric	
	SASS	ASPT
Water T (°C)	–	–
Conductivity (μS cm^{-1})	−0.75	−0.75
DO (mg l^{-1})	0.90	0.93
pH	0.94	0.94
Turbidity (NTU)	−0.64	−0.70
NO_2^-(mg l^{-1})	−0.65	−0.72
NH_4^+(mg l^{-1})	−0.67	−0.72
SRP (mg l^{-1})	−0.60	−0.66
Ca^{2+} (mg l^{-1})	–	–
Fe^{2+} (mg l^{-1})	–	–
Mn^{2+}(mg l^{-1})	−0.82	−0.87

Numerical values indicate significant correlations at $P \leq 0.05$

The ability of the CCA to separate sites based on pollution levels and the resultant macroinvertebrate communities in this study demonstrate the applicability of multivariate techniques in assessing water quality of lotic systems. Multivariate approaches have been used in United Kingdom (Wright et al., 1993) and Australia (Smith et al., 1999) within biomonitoring programmes, respectively, River Invertebrate Prediction and Classification System and Australian River Assessment System.

Applicability of SASS5 to the study area

The significant correlations between SASS and ASPT index values and physical and chemical characteristics of streams recorded in this study indicate the success; the SASS may be used to reflect general changes in water quality and ecological health of lotic systems of Zimbabwe. Values of the SASS and ASPT indices showed significant differences between relatively less polluted sites S6 and S7 and heavily polluted sites S3, S4 and S5. Although there may be concerns as to the feasibility of transferring data with regard to ecological tolerance limits of macroinvertebrates (and hence macroinvertebrate-based biotic indices) from one geographic region into another, all the macroinvertebrates encountered in this study are ubiquitous taxa that were also used in SASS5 (Dickens & Graham, 2002) as we hypothesised. These taxa are well documented in regional literature, especially from Zimbabwe and South Africa (e.g. Dickens & Graham, 2002; Dallas & Day, 2004; Chakona et al., 2008; Ndebele-Murisa, 2012). For that reason, SASS may be used in the study area as it is based on the ecology of widely distributed or cosmopolitan taxa. Corresponding ranges of taxa richness and presence/absence as well SASS and ASPT index values (water quality and ecological health assessment) are thought to be determined by the same factors in Zimbabwe, and reflect the natural and anthropogenic disturbances in study streams. Thus, SASS and ASPT indices are useful for monitoring water quality in the study region.

The present results indicate that SASS and ASPT indices can be applied beyond their country of origin—South Africa. Indeed, over the last decade, an increasing effort has been devoted to designing a more effective use of macroinvertebrates as monitoring and assessment tools for water quality and ecological health of streams in Zimbabwe with SASS and ASPT indices being widely applied (Phiri, 2000; Chakona et al., 2008; Ndebele-Murisa, 2012). The applicability of SASS and ASPT indices beyond their country of origin demonstrated in this study is in agreement with environmental management and monitoring tools used in Europe such as the BMWP (Walley & Hawkes, 1996), which are applicable on a large scale (e.g. across ecoregions) with only a few regional adaptations (Niemi & McDonald, 2004). Another example is the ASPT index, conserved in SASS5, which is extensively used in Europe where it was initially developed as well as in other parts of the world with little modifications (Bonada et al., 2006). In Australia, the stream invertebrate grade number average level, adapted from ASPT version of BMWP, the same way as SASS, was originally developed and tested in one ecoregion. A revised version of the same has been found to be applicable to the entire continent with slight modification (Chessman, 2003).

Generally, significantly low correlation was observed between metal levels (calcium and iron), and the SASS and ASPT index values compared to that between other variables (especially those related to eutrophication and organic pollution) and all the index scores. This is expected since SASS is designed to monitor organic pollution and eutrophication with no provision for assessment of metal contamination; underlining a clear vision to develop macroinvertebrate-based water quality monitoring protocols that incorporate the effects of metals or improve SASS in this manner.

The SASS and ASPT indices are based on macroinvertebrate identifications to family level. However, the degree of tolerance at the family level is related to the diversity of species and the tolerance range of individual species, therefore scores at the family level usually use intermediate values of species tolerance (Walley et al., 2001). Thus, SASS and ASPT index values may under- or overestimate water quality more than those based on species (Czerniawska-Kusza, 2005). This underlines a clear need to develop a species-level macroinvertebrate-based index for assessment of water quality and ecological health of streams in Southern Africa. The major hindrance is the lack of appropriate taxonomic identification guides as well as the time-consuming dentification requiring specialised expertise currently limited in the region. However, the advantage of developing a species-based macroinvertebrate metric is an increased resolution with potential capacity of reflecting pollution types currently poorly reflected by the SASS, such as metal pollution. Indeed, the species level based Austrian index of saprobity, is considered to be more accurate for Austrian conditions than the ASPT index (Strubauer & Moog, 2001). The macroinvertebrate community index, derived from the BMWP, the same was as SASS, uses the genera level of identification and has been found to be more sensitive in assessing health of New Zealand lotic systems than foreign indices that use family level of identification (Stark & Maxted, 2007), emphasising the need for re-examining the level of taxonomic identification in SASS.

In addition, the SASS and ASPT indices use presence/absence of taxa in assessing water quality and ecological health of streams without taking into account the taxa's relative abundance. The ASPT, for instance, displays the average tolerance of all taxonomic groups represented within the study site, but does not take into consideration their relative amounts. However, changes in environmental factors may not be that severe causing stress and thus the disappearance of some taxa but may cause a change in community composition (Bonada et al., 2006). Macroinvertebrate taxa are also indicative of the upper limits of pollution that they can tolerate rather than the lower limit (Dallas & Day, 2004; Bonada et al., 2006). Thus, pollution-tolerant taxa may also occur in fairly clean water as was observed in our study. Simple incorporation of relative abundance of taxa in computing SASS and ASPT index values would certainly eliminate error associated ubiquitous taxa and non incorporation of changes in community composition and improve the resolution of these indices—something deemed necessary and has not been done in southern Africa.

Despite all these challenges, SASS in its current state may be adequate in terms of cost-efficiency and taxonomic expertise available. Results obtained in this study are in agreement with the considerations of many authors (e.g. Phiri, 2000; Chakona et al., 2008; Ndebele-Murisa, 2012) about the need and usefulness of the biotic index application in routine programmes of stream water quality monitoring in Zimbabwe.

Conclusions

Assessment of water quality and ecological health of urban streams based on SASS is useful in Zimbabwe for providing information on water quality impacts on lotic systems for management purposes. The SASS is applicable to the study area because many widely distributed macroinvertebrate taxa have similar environmental tolerances to those recorded for these taxa in South Africa. However, there is a need for strengthening of SASS by (a) taking into account the relative abundance of taxa and (b) also improving on the ability of SASS to reflect other forms of pollution besides eutrophication and organic pollution such heavy metal pollution. The applicability of SASS5 metrics need to be tested across different geographical and climatic regions in the country (taking into consideration seasonal variations that are important drivers of benthic faunal assemblages in lotic systems and biological monitoring) and disparities among the regions compared before the index can be adopted in the entire country. Meanwhile, SASS can be used to (a) gain support and recognition for macroinvertebrate-based approaches to water quality monitoring and ecological health assessment of streams in Zimbabwe, (b) provide an indication of water quality and ecological health and allowing for the dissemination of rapid, simplified and useful information to resource managers, conservationists and the general public and (c) allow for sample and data collection which can then be used later in the formulation of a macroinvertebrate-based biotic index tailored for Zimbabwe.

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