The impact of water quality deterioration on macroinvertebrate communities in the Swartkops River, South Africa: a multimetric approach

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The impact of water quality deterioration on macroinvertebrate communities in the Swartkops River, South Africa: a multimetric approach

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A multimetric approach, using 21 metrics representing five categories — abundance, composition, richness, diversity and biotic indices — was applied to investigate the impacts of water quality deterioration on macroinvertebrate communities in the Swartkops River. Macroinvertebrates were sampled seasonally between August 2009 and July 2010 using the South African Scoring System version 5 (SASS5) protocol at one reference site upstream of Uitenhage and three downstream sites. Assessment of water quality impacts on macroinvertebrates was based on the discriminatory ability of metrics between the reference and impaired sites, and on their correlation with the physico-chemical variables. The metrics’ discriminatory ability was explored using box plots, and their relationships with water chemistry variables elucidated with Pearson’s correlation. Trichoptera abundance, %Chironomidae + Oligochaeta, %Ephemeroptera–Trichoptera–Odonata–Coleoptera (ETOC), %Trichoptera, Ephemeroptera–Plecoptera–Trichoptera (EPT) richness, ETOC richness, Margalef’s family richness index, equitability, Shannon and Simpson diversity indices, SASS5 score and average score per taxon (ASPT) discriminated between the reference and impaired sites, and also exhibited significant correlations ($p < 0.05$) with water chemistry variables. Conversely, Gastropoda abundance, EPT abundance, ETOC abundance, EPT:Chironomidae ratio, %EPT, %Corixidae, %Oligochaeta + Hirudiniae, Chironomidae + Oligochaeta abundance and Hemiptera + Diptera richness did not discriminate between the reference and impaired sites.

Keywords: ASPT, biomonitoring, diversity, richness, SASS

Introduction

Surface freshwater resources in most parts of South Africa are limited and are increasingly being subjected to pollution, consequently impacting on their ecological functions (NWRS 2004, Oberholster et al. 2008). The Swartkops River, in the Eastern Cape province of South Africa, is no exception. It drains a heavily industrialised catchment, which has led to deterioration of its water quality due to pollution resulting from various human activities.

The anticipated further industrialisation of the Eastern Cape, and increased urbanisation of the population within the Swartkops River catchment (DWAF 2003, NWRS 2004), may result in further deterioration in the water quality of the river. Therefore, there is an urgent need for proactive measures in order to incorporate the increasing water demand and pollution problems into management plans so as to conserve the river and its biota.

Historically, the assessment of water quality in freshwater ecosystems has usually been through the measurement of physico-chemical variables; but such measurements alone cannot provide ecological information, because the synergistic effects of pollution on aquatic biotic community may not be fully and easily assessed (Rosenberg and Resh 1993, Kasangaki et al. 2006). Among aquatic biota, macroinvertebrates are an important component of the ecosystems, because they serve as a critical intermediate pathway for the transportation and utilisation of energy and matter. Also, individual taxa respond differently to a variety of pollutants and are able to provide an indication of water quality over varying time periods (Wallace and Webster 1996, Bonada et al. 2006, Odume and Muller 2011). Macroinvertebrate-based biomonitoring approaches, including single biotic indices such as the South African Scoring System (SASS version 5; Dickens and Graham 2002), multimetric indices such as the index of biotic integrity (IBI-12) (Böhmer et al. 2004) and multivariate techniques such as the Australian River Assessment System (AUSRIVAS) (Turak et al. 2004) have been developed and applied to assess water quality of rivers and streams (Jorgenson et al. 2005, Bonada et al. 2006). In addition, invertebrates also have potential utility in assessing other environmental pressures such as sedimentation (Extence et al. in press).

A multimetric approach combines a range of indices and metrics representing different aspects of macroinvertebrate communities to elucidate and interpret impacts of impaired water quality on aquatic ecosystems (Ravera 2001, Klemm et al. 2002, Böhmer et al. 2004, Camargo et al. 2004, Vlek et al. 2004, Baptista et al. 2007, Moya et al. 2011). A multimetric approach using macroinvertebrates is particularly useful because it allows integration of ecological information from individual, population, community and ecosystem levels to provide a better picture of the impact of impaired water quality on macroinvertebrate community...
structures. The combination of metrics reduces the weaknesses of individual single metric, but their selection needs careful consideration to avoid redundancy (Ofenböck et al. 2004).

In this study, the impacts of water quality deterioration on Swartkops River macroinvertebrate communities were investigated using a multimetric approach. The investigation was undertaken by evaluating the performance of 21 metrics, based on their ability to discriminate between reference and impacted sites, and their correlation to measured water chemistry variables. The selected metrics and indices are based on taxonomic groupings, and are perceived to be more reliable than metrics based on other groupings such as functional feeding groups (Klemm et al. 2002, Gabriels et al. 2010).

Materials and methods

Study area
The Swartkops River, Eastern Cape, South Africa, which rises in the Groot Winterhoek mountains, is an important ecological asset, supporting an estuary that provides an important breeding habitat for water birds and fish (Taljaard et al. 1998). However, since it drains several urban and industrial areas, it suffers human-induced impacts such as industrial and domestic effluent discharges plus drainage from agricultural land, which directly or indirectly contribute to the deterioration of its water quality (DWAF 1996; 2003). The municipal areas of Uitenhage, Despatch and KwaNobuhle all lie within the Swartkops River catchment (Binning and Baird 2001). The pattern of rainfall in the catchment is highly variable, with a minimum monthly average of 60 mm, and the highest usually falling between the months of June and October (Haigh 2002, van Eeden and van Jaarsveld 2006). The Swartkops Basin consists of an upper base of Cretaceous shale and mudstone, overlain by marine sedimentary deposits in the high-lying regions and by various alluvial deposits on the floodplain (Fromme 1988).

The natural vegetation of the catchment is dominated by Bushveld and Succulent Thicket (Kleynhans et al. 2005), which has been extensively impacted by the encroachment of exotic or invader species such as wattle (Acacia spp.) and gum trees (Eucalyptus spp.) (DWAF 1996). In the Swartkops River system, particularly at Uitenhage and Despatch, there are extensive and dense growths of common reed (Phragmites australis), water hyacinth (Eichhornia crassipes) and Kariba weed (Salvinia molesta) (DWAF 1996).

Sampling sites
The study was conducted seasonally over a period of one year between August 2009 and July 2010 at four sampling sites (Figure 1). It was important to select a reference site in the same ecoregion as the other sites, because of natural variation among macroinvertebrate communities in different ecoregions (Kleynhans et al. 2005). Site 1 (33°45′08.4″ S, 25°20′32.6″ E), upstream of Uitenhage, was chosen to represent the least-impacted conditions (reference site). This was done in accordance with recommendations for the selection of reference sites (Reynoldson et al. 1997, Dallas 2000), and was also based on expert judgement, taking into consideration the availability of macroinvertebrate habitats, extent of impacts (by visual inspection), accessibility and location within the same ecoregion level II as the other sampling sites. Within the accessible areas in the Swartkops River catchment, this site represented the best available condition. Site 2 (33°47′29.0″ S, 25°24′26.4″ E) was located in the industrial city of Uitenhage, where surrounding land use included livestock farming and other agricultural practices such as crop cultivation. Site 3 (33°47′11.8″ S, 25°25′53.9″ E) was located further downstream but also within Uitenhage, where surrounding human impacts included industrial and wastewater effluent discharges and agricultural activities. Site 4 (33°47′34.0″ S, 25°27′58.7″ E) at Despatch was impacted by agricultural and municipal runoff. A fifth site, intended for the monitoring of potential system recovery, was not able to be selected because the tidal limit, between the estuary and the freshwater section at Perseverance, was only a short distance downstream of Site 4 (Figure 1).

Physico-chemical variables
Water chemistry analyses were carried out at the four sampling sites once per season over a period of one year: in late August (spring) and late November (summer) 2009, and in March (autumn) and July (winter) 2010. Mid-channel subsurface dissolved oxygen (DO), turbidity, pH, electrical conductivity and temperature were measured on-site using Cyberscan DO300, Orbeco-Hellige 966, Cyberscan pH 300 and Cyberscan Con 300 meters, and a mercury-in-glass thermometer, respectively. Mid-channel water samples were collected, preserved and analysed in the laboratory for nitrate-nitrogen (NO$_3$-N), nitrite-nitrogen (NO$_2$-N), ammonium-nitrogen (NH$_4$-N), orthophosphate-phosphorus (PO$_4$-P), total inorganic nitrogen and five-day biochemical oxygen demand (BOD$_5$). NO$_3$-N and NO$_2$-N were analysed according to Velghe and Cleaeyes (1983) and APHA et al. (1971), respectively. Spectroquant® phosphate and ammonium concentration test kits were used to analyse for orthophosphate-phosphorus and ammonium-nitrogen according to manufacturer’s instructions. Total inorganic nitrogen (TIN) concentration was obtained by the summation of the individual concentrations of nitrate, nitrite and ammonium (Palmer et al. 2005). BOD$_5$ was analysed according to APHA (1992), while phytoplankton chlorophyll a and periphyton were analysed fluorometrically using a Turner Design 10-AU digital fluorometer, according to Arar and Collins (1997). All chemical analyses were conducted for three replicates for each sample and then averaged.

Macroinvertebrate sampling
 Concurrent with the physico-chemical sampling, macroinvertebrate samples were collected at the four sampling sites in accordance with the SASS5 protocol (Dickens and Graham 2002), which requires the collection of macroinvertebrates from three distinct biotopes: stones (in-current and out-of-current), vegetation (marginal and aquatic vegetation) and sediment (gravel, sand and mud; GSM). Macroinvertebrate sampling was undertaken using a 30 cm × 30 cm, 1 000 μm mesh net. Although the SASS5 protocol requires the collection of only one sample from each biotope, three replicates each were taken from each of the three biotopes (stones, ...
vegetation and GSM) making a total of nine replicate samples from each site per season. This was necessary to assess the samples using selected metrics, diversity indices and to provide for robust statistical analysis of the data. Macroinvertebrate families present were identified on-site using identification keys by Gerber and Gabriel (2002), and the samples were then preserved in 70% ethanol and transported to the laboratory for sorting, further identification, and abundance counts.

**Macroinvertebrate metrics**

In this study, 21 metrics in five categories: abundance (number of individuals), composition (or relative abundance), richness (number of taxa), diversity, and biotic indices were selected (Table 1). The selection of metrics was based on their ability to discriminate between impaired and unimpaired sites (Klemm et al. 2002, Ofenböck et al. 2004, Vlek et al. 2004, Baptista et al. 2007, Gray and Delaney 2008) and their varying sensitivity to water quality impairment. In the SASS5 system, widely used for biological monitoring of water quality in South Africa, macroinvertebrate families are awarded scores based on their perceived sensitivity in the range of 1 to 15 in increasing order of their sensitivity to water quality impairment. SASS5 results are expressed both as an index score (i.e. SASS5 score) and as an average score per recorded taxon (ASPT). The SASS5 score is calculated by adding the scores of all recorded taxa, while the ASPT value is calculated by dividing the total SASS5 score by the number of recorded taxa (Dickens and Graham 2002). The latter is more independent of factors such as sampling size and seasons than is the SASS5 score.

Two categories of diversity indices, dominance and information statistics, were employed. Dominance indices, such as the Simpson index, are weighted towards the abundance of the commonest families, while information-statistics indices, such as the Shannon index, reflect individual taxon abundance and still assign greater weight to the commonest families (Clarke and Warwick 1994, Gray and Delaney 2008).

**Statistical analyses**

Evaluation of the performance of the metrics was based on their discriminatory ability, and their correlation to water chemistry variables. Discriminatory ability was defined as the ability of individual metric to discriminate between Site 1 (reference site) and Sites 2, 3 and 4. Metric discriminatory abilities were evaluated using box plots with Statistica version 9. The degree of overlap of medians and the interquartile ranges (IQRs) between Site 1 (reference site) and downstream sites was considered an indicator of selected metrics discriminatory ability (Klemm et al. 2002). Two levels of metric discrimination were considered satisfactory. The first sets of metrics were those in which there was no overlap in IQRs between Site 1 and Sites 2, 3 and 4 while the second sets were those in which there was an overlap in the IQRs, but the medians were outside the IQRs (Baptista et al. 2007). Among the selected metrics, only those that discriminated Site 1 (i.e. reference site)
from all three downstream sites were retained for further analysis. To test for a metric’s ability to detect subtle differences between sites, the same criteria were used to assess whether metrics that distinguished Site 1 from Sites 2, 3 and 4, were able to distinguish between the three downstream sites (i.e. Sites 2, 3 and 4). Metrics that satisfactorily discriminated Site 1 from the downstream sites were further confirmed using a Kruskal-Wallis test. Sensitivity of metrics with satisfactory discriminatory ability to differences in water chemistry variables was examined using Pearson’s correlation analysis. One-way analysis of variance (ANOVA) was used to test the null hypothesis that there is no statistically significant difference ($p > 0.05$) in the means of the water chemistry variables between the four sampling sites. When water chemistry variables were significantly different, the Tukey honestly significant different (HSD) test was used to indicate sites that differed. Prior to correlation and ANOVA analyses, data (except pH) were log-transformed ($x + 1$) to meet the assumption of normality.

**Results**

**Physico-chemical variables**

Means, standard deviations and ranges of physico-chemical variables at the four sites during the four sampling seasons are presented in Table 2. ANOVA and the HSD test revealed that DO was statistically significantly different between the sampling sites except between Sites 1 and 2. Electrical conductivity (EC) was significantly higher at all downstream sites while turbidity at Site 3 differed significantly ($p < 0.05$) from the rest of the sampling sites. Five-day biochemical oxygen demand (BOD₅) and total inorganic nitrogen (TIN) were significantly higher at Sites 3 and 4. Also, ANOVA revealed that there was a statistically significant difference ($p < 0.05$) in orthophosphate-phosphorus (PO₄-P) between the four sampling sites, but the Tukey (HSD) post hoc test could not be conducted to distinguish sites responsible for the observed differences, because PO₄-P was detected only once at Site 1.

**Discriminatory ability of metrics**

Of the 21 metrics evaluated, 12 were considered to have satisfactory discriminatory ability, distinguishing between Site 1 and the downstream Sites 2, 3 and 4 (Figure 2), and were further confirmed by a Kruskal-Wallis test ($p < 0.05$). These 12 metrics included Trichoptera abundance, %Chironomidae + Oligochaeta, %ETOC, %Trichoptera, EPT richness, ETOC richness, Margalef’s family richness index, equitability, Shannon and Simpson diversity indices, SASS5 score and ASPT value. Conversely, Gastropoda
Table 2: Mean, standard deviation and range (in brackets) of physico-chemical water quality variables \((n = 4)\) measured in the Swartkops River between August 2009 and July 2010; \(p\)-values are shown only for variables that showed significant differences between sites. Different superscript letters per variable across sites indicate significant differences, established using Tukey HSD test, while the same superscript letter indicates no significant difference.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
<th>Site 4</th>
<th>(p)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved oxygen (mg l(^{-1}))</td>
<td>6.07 ± 1.13(^a)</td>
<td>6.99 ± 1.84(^a)</td>
<td>3.26 ± 0.54(^c)</td>
<td>2.17 ± 1.3(^c)</td>
<td>0.001</td>
</tr>
<tr>
<td>pH</td>
<td>6.61 ± 1.17</td>
<td>7.12 ± 1.08</td>
<td>7.36 ± 0.42</td>
<td>7.27 ± 0.56</td>
<td></td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>17.88 ± 4.44</td>
<td>17.71 ± 7.72</td>
<td>20.13 ± 4.49</td>
<td>18.55 ± 5.43</td>
<td></td>
</tr>
<tr>
<td>Electrical conductivity (mS m(^{-1}))</td>
<td>32.58 ± 4.69(^a)</td>
<td>407.5 ± 84.5(^{bcde})</td>
<td>212.78 ± 79.9(^{cd})</td>
<td>268.5 ± 37.6(^{cd})</td>
<td>0.000</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>8.75 ± 7.89(^a)</td>
<td>6.15 ± 1.47(^a)</td>
<td>115.63 ± 139.2(^b)</td>
<td>9.35 ± 11.22(^a)</td>
<td>0.012</td>
</tr>
<tr>
<td>Total inorganic nitrogen (TIN; mg l(^{-1}))</td>
<td>0.171 ± 0.039(^a)</td>
<td>1.567 ± 2.26(^a)</td>
<td>7.2 ± 2.5(^a)</td>
<td>6.34 ± 3.6(^a)</td>
<td>0.011</td>
</tr>
<tr>
<td>Orthophosphate phosphorus (PO(_4)-P; mg l(^{-1}))</td>
<td>0.013(^a)</td>
<td>1.11 ± 0.56(^a)</td>
<td>7.46 ± 4.05(^a)</td>
<td>7.59 ± 1.35(^a)</td>
<td>0.001</td>
</tr>
<tr>
<td>Chlorophyll a phytoplankton (µg l(^{-1}))</td>
<td>0.856 ± 0.72(^a)</td>
<td>3.82 ± 2.88(^a)</td>
<td>2.51 ± 0.97(^a)</td>
<td>1.95 ± 0.53(^a)</td>
<td>0.000</td>
</tr>
<tr>
<td>Chlorophyll a periphyton (µg cm(^{-2}))</td>
<td>37.02 ± 2.37(^a)</td>
<td>308.0 ± 119.2(^b)</td>
<td>421.87 ± 92.55(^c)</td>
<td>410.0 ± 114.7(^c)</td>
<td>0.028</td>
</tr>
</tbody>
</table>

\(^{a}\) The physico-chemical data have been presented previously in Odume et al. (2011; Table 1)

\(^{a}\) Variable detected once

abundance, EPT abundance, ETOC abundance, EPT: Chironomidae ratio, %EPT, %Corixidae, %Oligochaeta + Hirudinae, Chironomidae + Oligochaeta abundance and Hemiptera + Diptera richness could not discriminate Site 1 from the downstream sites and were therefore considered to have unsatisfactory discriminatory ability (Figure 3). Of the 12 metrics that separated Site 1 from the others, EPT richness, %Chironomidae + Oligochaeta, Margalef’s family richness index, Shannon diversity index, Simpson diversity index, equitability and SASS5 score were able to discriminate between Sites 2, 3 and 4.

**Environmental response of metrics**
With the exception of %Chironomidae + Oligochaeta, all metrics were negatively correlated with increasing concentrations of total inorganic nitrogen (TIN), orthophosphate-phosphorus (PO\(_4\)-P), five-day biochemical oxygen demand (BOD\(_5\)) and electrical conductivity (EC). However, increases in the concentrations of these variables favoured the dominance of %Chironomidae + Oligochaeta. The values for all 12 metrics, except %Chironomidae + Oligochaeta, increased with increased dissolved oxygen (DO), Pearson’s correlation revealed that INDO correlated negatively with %Chironomidae + Oligochaeta (Table 3). Of the 12 metrics, only equitability and EPT richness showed significant correlation with all the water quality variables, except with phytoplankton and turbidity, respectively. Percentage Trichoptera was not significantly correlated with DO.

**Discussion**

**Physico-chemical variables**
As noted by Odume and Muller (2011), the high organic loading and industrial effluent discharges at Sites 3 and 4 were evident in the levels of BOD\(_5\), TIN, PO\(_4\)-P, EC and DO. Discharges from the Uitenhage and Despatch waste water treatment works (WWTWs) were most likely the main contributors to the observed high organic loading at Sites 3 and 4. The large-scale growths and blooms of macrophytes, phytoplankton and periphyton apparent at the downstream sites, particularly at Sites 3 and 4, were indicative of eutrophic condition of the Swartkops River. The relatively high nutrient levels could be attributed to wastewater effluent discharges from the Uitenhage and Despatch WWTWs, as well as to runoff from informal settlements and agricultural land. In addition, previous studies (DWAF 1996, de Villiers and Thiart 2007, Odume and Muller 2011), reported relatively high nutrient levels in the Swartkops River, as was found this study.

The relatively high electrical conductivity at Sites 3 and 4 would probably have resulted from discharges from WWTWs and the automotive industry in the vicinity of these sites. In addition, the soil of the Swartkops River catchment being of marine origin could have resulted in naturally high EC levels. According to DWAF (1996), the main cause of high EC in the Swartkops River, apart from industrial sources, is the river’s natural geology and, as noted by Dallas and Day (2004), EC is one of the most important chemical variables that could profoundly impact macroinvertebrate community structure.

**Macroinvertebrate metrics**
An understanding of how deterioration in environmental water quality affects different aspects of macroinvertebrate communities is crucial in their use as indicators of health of river ecosystems. The present study revealed that...
deteriorating water quality did not impact greatly on metrics in the abundance category, since most of these were not able to distinguished between Site 1 and impacted sites, whereas metrics in the composition (or relative abundance), richness and diversity categories, as well as the two biotic indices, SASS5 score and ASPT value, were severely affected, and these were significantly correlated with the water chemistry variables. For example, EPT
Figure 3: Medians (small squares) and quartiles (boxes) for nine non-sensitive metrics (see Table 1 for details of metrics) measured seasonally at four sites in the Swartkops River between August 2009 and July 2010. Range bars = maximum and minimum non-outlier numbers, circles = outliers, asterisks = extremes.

Table 3: Pearson’s correlation coefficients between water quality variables and mean metric values. Peri = periphyton, Phyto = phytoplankton, Turb = turbidity

<table>
<thead>
<tr>
<th>Metric</th>
<th>BOD₅</th>
<th>TIN</th>
<th>PO₄-P</th>
<th>Peri</th>
<th>Phyto</th>
<th>EC</th>
<th>DO</th>
<th>Turb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichoptera abundance</td>
<td>-0.630**</td>
<td>-0.538*</td>
<td>-0.615*</td>
<td>-0.520*</td>
<td>-0.624**</td>
<td>-0.885**</td>
<td>0.252</td>
<td>-0.023</td>
</tr>
<tr>
<td>%Chironomidae + Oligochaeta</td>
<td>0.697**</td>
<td>0.855**</td>
<td>0.807**</td>
<td>0.620*</td>
<td>0.349</td>
<td>0.466</td>
<td>-0.779**</td>
<td>0.405</td>
</tr>
<tr>
<td>%Trichoptera</td>
<td>-0.635**</td>
<td>-0.565*</td>
<td>-0.657**</td>
<td>-0.565*</td>
<td>-0.640**</td>
<td>-0.901**</td>
<td>0.278</td>
<td>-0.068</td>
</tr>
<tr>
<td>%ETOC</td>
<td>-0.839**</td>
<td>-0.912**</td>
<td>-0.909**</td>
<td>-0.595*</td>
<td>-0.218</td>
<td>-0.549*</td>
<td>0.809**</td>
<td>-0.367</td>
</tr>
<tr>
<td>ETOC richness</td>
<td>-0.812**</td>
<td>-0.805**</td>
<td>-0.764**</td>
<td>-0.610*</td>
<td>-0.343</td>
<td>-0.608*</td>
<td>0.616*</td>
<td>-0.444</td>
</tr>
<tr>
<td>EPT richness</td>
<td>-0.843**</td>
<td>-0.840**</td>
<td>-0.784**</td>
<td>-0.687**</td>
<td>-0.507*</td>
<td>-0.793**</td>
<td>0.568*</td>
<td>-0.264</td>
</tr>
<tr>
<td>SHannon index</td>
<td>-0.698*</td>
<td>-0.853**</td>
<td>-0.818**</td>
<td>-0.579*</td>
<td>-0.329</td>
<td>-0.475</td>
<td>0.689**</td>
<td>-0.531*</td>
</tr>
<tr>
<td>Simpson index</td>
<td>-0.649**</td>
<td>-0.833**</td>
<td>-0.844**</td>
<td>-0.698**</td>
<td>-0.425</td>
<td>-0.557*</td>
<td>0.712**</td>
<td>-0.471</td>
</tr>
<tr>
<td>Margalef index</td>
<td>-0.792**</td>
<td>-0.893**</td>
<td>-0.904**</td>
<td>-0.734**</td>
<td>-0.369</td>
<td>-0.633**</td>
<td>0.756**</td>
<td>-0.448</td>
</tr>
<tr>
<td>Equitability</td>
<td>-0.702**</td>
<td>-0.860**</td>
<td>-0.841**</td>
<td>-0.628**</td>
<td>-0.360</td>
<td>-0.513*</td>
<td>0.713**</td>
<td>-0.503*</td>
</tr>
<tr>
<td>SASSS score</td>
<td>-0.812**</td>
<td>-0.886**</td>
<td>-0.872**</td>
<td>-0.693**</td>
<td>-0.367</td>
<td>-0.668**</td>
<td>0.695**</td>
<td>-0.331</td>
</tr>
<tr>
<td>ASPT value</td>
<td>-0.817**</td>
<td>-0.836**</td>
<td>-0.800**</td>
<td>-0.742**</td>
<td>-0.451</td>
<td>-0.732**</td>
<td>0.507*</td>
<td>-0.467</td>
</tr>
</tbody>
</table>

* = significant at p < 0.05; ** = significant at p < 0.01
richness was significantly correlated with all water quality variables except turbidity. Evidence of such interactions or correlations between water quality and specific metrics could easily be masked if their relationships to water chemistry in a specific system are not explored. Overall, the results suggest that the 10 metrics, as well as the two biotic indices, SASS5 score and ASPT value, which proved to be sensitive in this study, could be useful in elucidating the effects of water quality impairment on the Swartkops River macroinvertebrate communities.

Among the metrics in the abundance category, only Trichoptera abundance enabled the discrimination of Site 1 from Sites 2, 3 and 4. Although Trichoptera are known to be indicators of relatively clean water, there are some species which are tolerant of pollution, and thus the low level of taxonomic resolution employed in this study would mask such effects. The inability of EPT, ETOC abundances and EPT:Chironomidae ratio to discriminate Site 1 from Sites 2, 3 and 4 was probably due to the high abundances of Baetidae and coleopterans at Site 2. In addition, families in the order Plecoptera are mostly temperate-water invertebrates and very few species are known to exist in South African waters (de Moor et al. 2003). Thus, throughout the sampling seasons, not a single individual in this order was caught. Consequently, in this study, the metric EPT refers to individuals in Ephemeroptera–Trichoptera. Those reasons probably explain why EPT abundance, ETOC abundance and EPT:Chironomidae ratio could not distinguish between Site 1 and the downstream Sites 2, 3 and 4.

Three metrics in the richness category, Ephemeroptera–Plecoptera–Trichoptera EPT richness, Ephemeroptera–Trichoptera–Odonata–Coleoptera ETOC richness, and Margalef’s family richness index, discriminated Site 1 from Sites 2, 3 and 4, and were also strongly correlated with physico-chemical variables across the four sites. Metrics in this category are widely used in biomonitoring programmes because they are presumed to respond to man-induced changes in a predictable fashion, usually decreasing in values with increased level of pollution (Klemm et al. 2002, Suriano et al. 2011). Based on the discriminatory evaluation of the three metrics in the richness category with satisfactory discriminatory ability, EPT richness and Margalef’s family richness index were able to discriminate between Sites 2, 3 and 4 (Figure 2), which seems to suggest that these two metrics could detect subtle differences between polluted sites. The Margalef’s family richness index, and the Shannon and Simpson diversity indices, discriminated Site 1 from Sites 2, 3 and 4, and also exhibited strong correlations with measured water quality variables. These indices were lowest at Site 3, which is indicative of the impaired water quality there having impacted greatly on macroinvertebrate assemblages at this site. The findings of this study are consistent with those of Camargo et al. (2004), who reported that Simpson diversity was among the indices that exhibited strong negative correlations with nutrient values. Ofenböck et al. (2004) also reported that Margalef’s index could be suitable for the assessment of the impacts of organic pollution, channel modification and impoundments. The evenness of macroinvertebrate samples from an undisturbed environment is often greater than that from a disturbed or impacted environment, where opportunistic and tolerant taxa dominate the species abundance (Ogbeibu 2005). At the downstream sites, particularly at Sites 3 and 4, the abundances of families were skewed toward the most pollution-tolerant taxa such as the Chironomidae, Oligochaeta and Hirudinae. Thus, equitability was found to be reduced at these sites. The biotic indices, SASS5 score and ASPT value, investigated in this study revealed evidence of impaired water quality at the three downstream sites, and were able to discriminate between the sampling sites. The generally low SASS5 and ASPT scores at the three downstream sites, particularly at Sites 3 and 4, were not unexpected, because of the range of impacts at these sites.

Generally, the strong correlations of all 12 sensitive metrics with DO and BOD5 levels suggested that these metrics could be good indicators of organic pollution associated with low dissolved oxygen and high biochemical oxygen demand, which may be indicative of nutrient enrichment. Specifically, increased values of %Chironomidae + Oligochaeta indicated depleted oxygen and increased nutrient levels. Conversely, increased values of EPT richness, %ETOC, %Trichoptera, Trichoptera abundance, Shannon and Simpson indices, equitability, SASS5 score and ASPT indicated improved DO level.

Although a multimetric approach may help to provide a greater understanding of ecological relationships, the results presented here suggest that, where analytical resources are limited, the biotic indices SASS5 and ASPT provide a very acceptable summary of environmental conditions.

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