

ENVIRONMENTAL WATER QUALITY MONITORING
FOR RICHARDS BAY MINERALS:
SMELTER SITE AREA



Report for 2012/2013

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Executive summary

This document reports on a programme monitoring environmental water quality of surface waters in the vicinity of the Smelter Site of Richards Bay Minerals. Data reported on were largely collected during September 2012 and March 2013, with minor collections from one site during November 2012 and June 2013. Aquatic ecological health indices were calculated for each site based on water quality data, habitat quality, macroinvertebrate and diatom taxa sampled.

Indices for each site are presented below, where a provisional overall aquatic ecological health assessment for each of the sites assessed is included. (Note: there is no health index for the habitat score (IHAS) as it was designed to interpret the South African Scoring System (SASS) results and it is included here for that reason). It must be noted that the methods used to provide the subsequent categories are largely based on expert opinion and assessment of the available data. In addition, the boundary values for the categories are based on the default values provided by the ecological Reserve method and require site-specific refinement.

Site	ASPT	IHAS	Water Quality	Diatoms	Overall
1	Poor	49	Good/Fair	Good	Good/Fair
7	Poor/Fair	65	Good	Good	Good/Fair
10	Poor	47	Fair	Good/Fair	Fair
11	Fair	38	Good	Good	Good
12	Fair	64	Good/Fair	Good/Fair	Good/Fair
13	Good	55	Good	Good	Good
14	Poor/Fair	54	Good/Fair	Fair	Fair

The uppermost sites in the three rivers sampled are in a good to fair condition. Along all three rivers, the ecological health improves to good, before degrading again to fair at the most downstream site. A decrease in upstream site ecological health over time is largely driven by decreasing diatom index scores which have been accompanied by the occurrence or appearance of a red bacterial film covering submerged surface at these sites. This film or floc may be a natural occurrence; however, its spread, together with shifts in diatom index results, may indicate changes in ecological health, particularly at Sites 1 and 12.

Changes in trends compared to previous years include the failure to detect a decrease in diatom indices between Sites 1 and 7, a trend that has been consistent for several years. The cause is not known, though it is possible that a decrease of drainage from the Smelter Site (or other smelter-related stresses) led to this year's improved results. Another change is a decrease in ecological health between Sites 13 and 14, on a stretch where previous monitoring has found the river condition remain the same or decrease only slightly. The long term significance of this is not known at this point.

The low habitat (IHAS) scores are indicative of relatively poor habitat for macroinvertebrates throughout, and go some way to explaining low ASPT scores (especially where diatom scores lead to a different site classification).

The total number of macroinvertebrate taxa collected at Site 11 per season ranged between 5 and 9, with the most taxa being collected in autumn and the least in summer (Table 2). The average number of taxa collected during the year of assessment year was 7 and the overall total number of taxa collected was 11. The number of taxa collected during the year of assessment is considerably less than in previous years. A list of taxa collected at Site 11 during four sampling trips in different seasons is supplied in Appendix E.

Recommendations for ongoing monitoring are presented.

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1 Introduction

The Unilever Centre for Environmental Water Quality, based within the Institute for Water Research at Rhodes University, was appointed by Richards Bay Minerals (RBM) to undertake environmental water quality monitoring of the surface waters in the vicinity of the RBM Smelter Site during winter 2012 and summer 2013.

Richards Bay Minerals is situated in northern KwaZulu-Natal, producing titania slag, pig iron, rutile and zircon through processes of dune mining, mineral separation, smelting and beneficiation. The RBM Smelter Site is adjacent to the KwaBonambi State Forest and is situated within a larger afforested area. The area around the Smelter Site and the Tisand Mineral Lease area is drained by several small streams which flow into the Mdibi River and ultimately into Lake Mzingazi (Figure 1).

There is concern that RBM activities at the Smelter Site may impact the ecological health of the surrounding rivers. Contaminants from the RBM Smelter premises can reach the rivers either directly, via surface water run-off to the rivers (e.g. from pollution incidents, via effluent pipes or rainfall run-off), or indirectly, via groundwater contamination. The natural drainage from the RBM Smelter Site is towards the Mpisini and Manzamnyana Rivers, which drain into the Mdibi River, which subsequently flows into Lake Mzingazi.

For comprehensive biomonitoring in winter 2012 and summer 2013 the following tasks were identified:

1. Undertake aquatic macroinvertebrate biomonitoring at the 7 identified sites.
2. Undertake diatom biomonitoring at the 7 identified sites.
3. Undertake a habitat assessment (IHAS) at the 7 identified sites.
4. Undertake water quality monitoring of the following parameters: nutrients (specifically, total inorganic nitrogen (TIN) and soluble reactive phosphorus (SRP)) and chlorophyll-a analysis (of phytoplankton and periphyton), turbidity, electrical conductivity, dissolved oxygen (DO), biological oxygen demand (BOD), water temperature and pH at each of the 7 identified sampling sites.

In addition to the comprehensive biomonitoring at 7 identified sites, limited biomonitoring (SASS only) and basic on-site water quality analysis at Site 11 (confluence of the Mpisini and Manzamnyana Rivers) was undertaken during spring 2012 and autumn 2013.

The specific tasks identified were:

1. Undertake on-site SASS biomonitoring at Site 11.
2. Undertake a habitat assessment (IHAS) at Site 11.
3. Measure turbidity, electrical conductivity, dissolved oxygen, water temperature and pH at Site 11.

2 Methods and materials

2.1 Sampling sites

Comprehensive biomonitoring and water quality sampling was undertaken at seven sites: 1, 7, 10, 11, 12, 13, 14 (Figure 1) and consisted of macroinvertebrate and diatom biomonitoring, IHAS assessments and a water quality analysis covering field-measured parameters (such as pH and EC) and laboratory-analyzed parameters (such as SRP and BOD).

This was undertaken during winter (September 2012) and summer (March 2013). Additionally limited biomonitoring was undertaken at Site 11 during spring (November 2012) and autumn (June 2013), and consisted of SASS biomonitoring only, together with collection of field-measured water quality parameters. The biotopes sampled at each site are depicted in the individual site summaries section, along with a description of each site (Table 3-9).

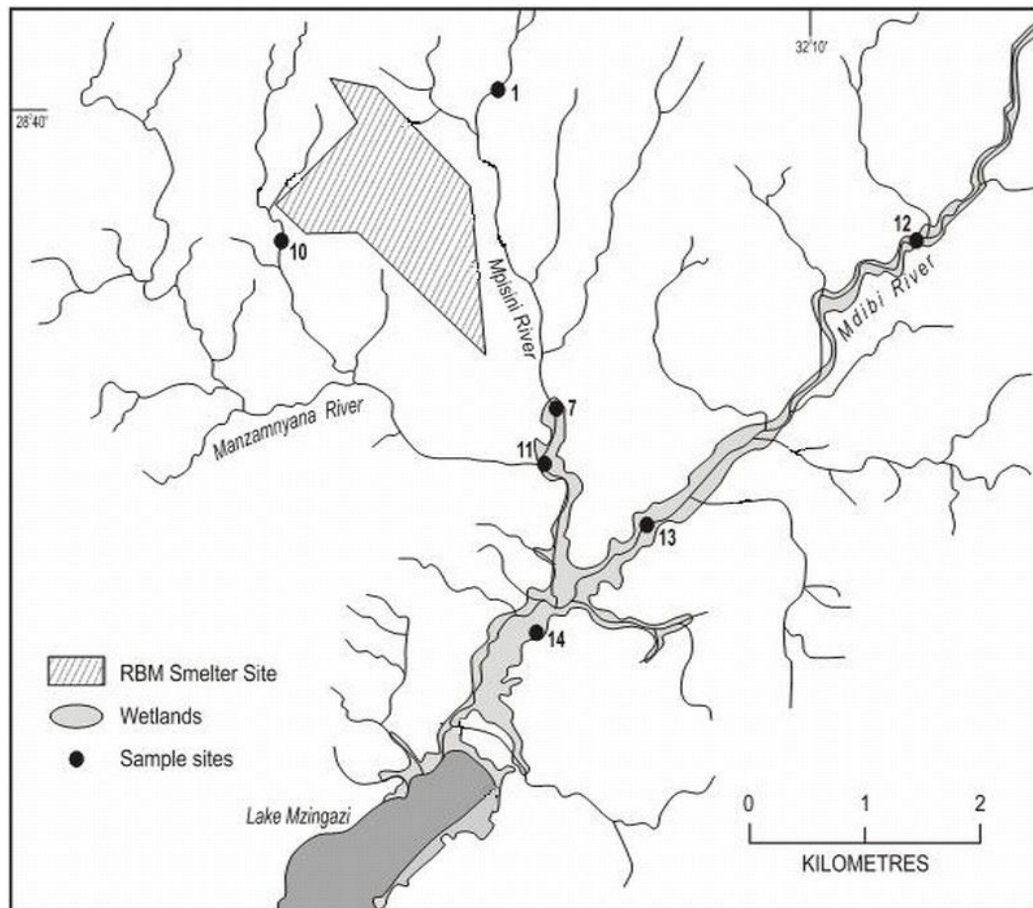


Figure 1 Monitoring points sampled in the Smelter Site area.

2.2 Water quality assessment

Water samples were collected during the winter (September 2012) and summer (March 2013) surveys at each of the biomonitoring sites and kept at 4°C for analysis at the Institute for Water Research, Rhodes University, Grahamstown. The following parameters were measured: $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$ (soluble reactive phosphorus-SRP). The nitrogen data were combined to obtain total inorganic nitrogen (TIN) concentrations.

Assessing only dissolved nutrient status (TIN and SRP) may lead to incorrect conclusions regarding the nutrient enrichment of the water body. Dissolved nutrients are directly available for uptake by plants, and, consequently, during active plant growth periods the concentrations of these nutrients may be a poor indicator of nutrient enrichment. The estimation of algal biomass (periphyton and phytoplankton) by means of chlorophyll-*a* measurements provides additional information when assessing the level of nutrient enrichment (Palmer *et al.* 2004). Periphyton and phytoplankton samples were collected following methods described by Holm-Hansen and Riemann (1978).

Additional water samples were collected to assess biochemical oxygen demand (BOD). This test determines the amount of dissolved oxygen used by the aerobic microorganisms that decompose organic waste matter in the water. It is therefore used as a measurement of the presence of certain types of organic pollutants in water. In addition, the greater the BOD the smaller the amount of dissolved oxygen available in the river to other organisms. The standard method for a 5-day test (BOD₅) was used (APHA 1992).

In addition to the parameters described above, on-site measures of dissolved oxygen (DO), electrical conductivity (EC), temperature and pH (using appropriate hand-held meters) were recorded during all biomonitoring occasions.

Where appropriate, water quality data were interpreted using the default benchmark boundary values for ecological health as provided for in Palmer *et al.* (2004). Electrical conductivity default benchmark boundary values were determined from DWA (2008).

2.3 Biomonitoring

2.3.1 Habitat assessment

A habitat assessment was undertaken at each site, using the Integrated Habitat Assessment System (IHAS; McMillan 1998). IHAS was initially developed for use with SASS4 (i.e. to interpret the SASS4 score). It provides a useful assessment of the habitat available at a site as the diversity of macroinvertebrates can be influenced by availability of biotopes and physical characteristics of the river, and surrounding land-use impacts.

2.3.2 Macroinvertebrate sampling

At each of the sites, SASS5 samples were taken from available biotopes and scored according to Dickens and Graham (2002). During the comprehensive biomonitoring a further two samples from each of the biotopes were collected using the SASS sampling method (replicate samples) with all samples preserved in 80% ethanol. In the laboratory, all samples were enumerated providing accurate counts for each of the taxa for further data analysis (macroinvertebrate community assessment, see below). For each site the SASS score was divided by the total number of families sampled in order to obtain the Average Score per Taxon (ASPT) (Dickens and Graham 2002). ASPT scores were classified according to default boundary values for ecological Reserve categories as an estimation of ecological health (DWA 2008).

2.3.3 Diatom assessment

Diatom data reported on here are from samples collected from sample sites during September 2012 (winter) and March 2013 (summer). Diatom samples were collected from hard substrates (vegetation, wood, brick or rock) on site and fixed in 20% ethanol for transport. Samples were prepared for examination using the potassium permanganate and hot hydrochloric acid method recommended by Taylor *et al.* (2007a). Cleaned frustules were mounted in Pleurax on microscope slides and examined at 1000× magnification using bright field and phase contrast optics. Only whole frustules in valve view were used for identification. One hundred frustules per slide were identified.

Where possible, diatoms were identified to species level or below. Morphospecies were assigned where identification to species level was not possible and these were maintained throughout the analysis. All diatom counts were converted to proportional abundance before analysis. Abundances were used to calculate IPS (Coste in Cemagref 1982), a diatom-based index of general water quality that has been tested for use in South Africa (Taylor *et al.* 2007b, 2007c) and has been successfully applied in KwaZulu-Natal (Taylor, pers. comm.).

The revised Biological Diatom Index (BDI-2006, Coste *et al.* 2009), a general pollution index, was also calculated. The older BDI index on which the new version is based has also been tested and used in South Africa (Taylor *et al.* 2007b, 2007c). Both indices use a large number of taxa in inferring water quality. IPS and BDI-2006 scores were rescaled to give a maximum of 20 as per common convention. Water quality classes were assigned to IPS index data after Eloranta and Soininen (2002) and to BDI-2006 index data after Prygiel and Coste (2000) (Table 1).

Table 1: Water quality classes for the IPS index (Eloranta and Soininen 2002) and the BDI-2006 index (Prygiel and Coste 2000).

Class	IPS value	BDI-2006 value
High	>17	BDI \geq 17
Good	15-17	17>BDI \geq 13
Moderate	12-15	13>BDI \geq 9
Poor	9-12	9>BDI \geq 5
Bad	<9	BDI<5

Previous reports (Muller *et al.* 2007, Gordon *et al.* 2008, 2010, Gordon and Griffin 2012, Holland *et al.* 2011) used an index based on expert opinion as doubt existed as to the applicability of indices derived in Europe in a region where tropical taxa might be encountered. As the IPS index has been successfully applied in the region (Taylor, pers. comm.) and the BDI-2006 index contains a number of tropical taxa (Coste *et al.* 2009), and as the majority of taxa encountered in previous surveys are included in the two diatom indices, these indices will be used for sample classification, and, for continuity with previous reports, sample classifications based on expert opinion are also derived for each sample.

Sample classifications based on expert opinion are derived as follows.

Environmental preferences of common taxa as presented by Taylor *et al.* (2007d), Van Dam *et al.* (1994) and Spaulding *et al.* (2010) were used to derive information on the ecological health of the site. Using this information, samples are scored according to the following scheme.

- High: Samples where all or most taxa found are characteristic of unpolluted oligotrophic to mesotrophic water with low to moderate levels of electrolytes. Dominant taxa must be typical of these conditions. (Score 5)
- Moderate: Dominant taxa not consistently indicative of clean conditions, and the sample has taxa typical of clean and stressed condition. (Score 3)
- Bad: Most taxa present are tolerant of at least moderate levels of pollution, or typical of eutrophic or osmotically stressed conditions. (Score 1)

Sites are ranked according to scores assigned according to the above scheme. Where sites fall between classes, intermediate scores are assigned e.g. 4 represents a classification of Good, and 2 represents a classification of Poor.

Only taxa that were well represented in each sample were used to infer water quality class, as these will best indicate the prevailing and recent water quality. For the purposes of this analysis, dominant taxa are the one taxon with the greatest abundance in the sample. Where other taxa have abundances not less than 10% less than the dominant taxon, they are classed as co-dominant. Other taxa that are less common than the dominant taxa and

that make up 10% or more of the sample are classed as subdominant and are used to infer water quality. Taxa present in lower quantities are only used in this analysis where information from dominant and subdominant taxa is insufficient for site classification.

Overall classification of sites combined the expert opinion classification described above with IPS and BDI-2006 using weight of evidence to derive an overall sample classification.

2.3.4 Statistical analysis

Analysis of variance and post-hoc testing of diatom scores was undertaken using R 2.15.1 with base and stats packages (R Development Core Team, 2012).

Calculation of alpha diversities and ordination of diatom and macroinvertebrate community data was undertaken using non-metric multidimensional scaling using the package *vegan* 2.0.4 (Oksanen *et al.*, 2012). Hypotheses relating to the differences in community structure between sites and seasons were explored using the function *adonis*, which undertakes non-parametric multivariate analyses of variance (after Anderson, 2001).

3 Results

3.1 Water quality assessment

Water temperatures recorded showed little variation between sites (temperatures at sites 10 and 11 represent the summer sample only) (Figure 2), with summer being the warmer season at all sites.

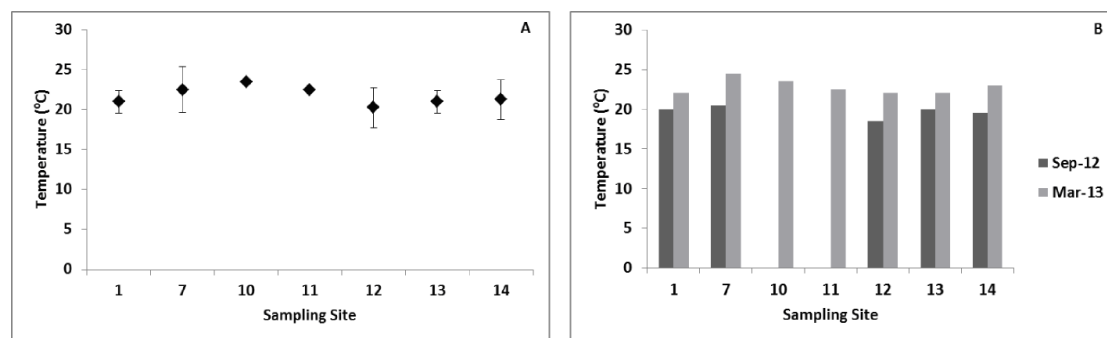


Figure 2 A: Mean (\pm standard deviation) temperature values measured at sampling sites over two seasons. B: Seasonal temperatures measured at each site.

Differences in measured pH were small, with the uppermost sites on each river being slightly more acidic with the exception of the Manzamnyana River, where Site 11 downstream was more acidic than the upstream site (Figure 3). Summer values are not available for Sites 7, 13 and 14 owing to equipment malfunction. Acidity is not usually a problem in this area; therefore winter values are expected to be representative. All sites were classed either natural or good.

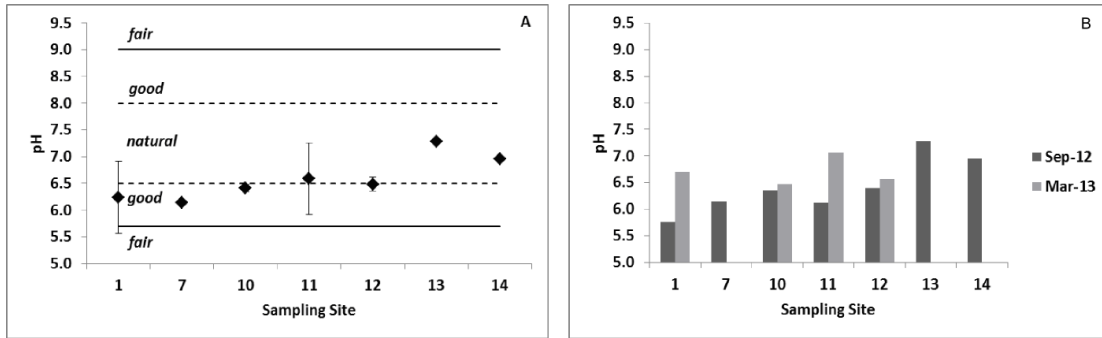


Figure 3 A: Mean (\pm standard deviation) pH measured at sampling sites over two seasons. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the graph. B: Seasonal values measured at each site.

Electrical conductivity (EC) levels at the uppermost sites of the Mpisini and Mdibi Rivers (Sites 1 and 12 respectively) as well as Site 13 (the middle site of the Mdibi River) were classified as being good or fair/good (Figure 4). Sites 7 and 11, downstream on the Mpisini river to the confluence with the Manzamnyana river, were classified as good/fair. The extremely high conductivity values at Sites 10 and 14 measured during the September 2012 trip (winter) caused Site 10 to be categorized as fair and Site 14 as poor for the current annual report. EC levels were highest in March 2013 (summer) at all sites except Sites 10 and 14. The cause of Site 10 and 14's matched high September 2012 EC values is not known. Rains prior to sampling had washed a large amount of sand into the river at Site 10, and Site 14 was noted as having unusually turbid and discoloured water during the sampling trip. The increase in EC levels from Site 1 to Site 7 noted in previous reports is still present, and this change appears to be related to proximity to and/or drainage from the RBM smelter plant. Remaining sites downstream of the smelter are surrounded by human settlements and thus it is difficult to determine relative contributions of these two land uses to increased EC.

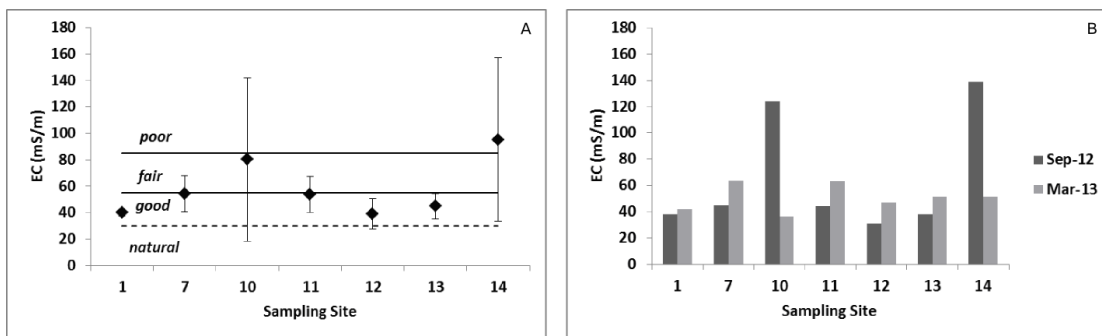


Figure 4 A: Mean (\pm standard deviation) electrical conductivity (EC) measured at sampling sites over two seasons. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the graph. B: Seasonal values measured at each site.

Mean dissolved oxygen (DO) levels were notably low at Site 10, falling within the poor ecological category (Figure 5). Remaining sites were classified as fair, with the exception of Site 7, which was classed as fair/good, and Site 11, which was classed good). Seasonal differences in DO levels were in general negligible except at Site 10 where levels were higher in the winter sample. The low DO measured at Site 10 could possibly be attributed to the large proportion of ground water feeding the wetland lake immediately upstream and

limited surface flow. Low DO at Site 10 has been consistently observed over recent years.

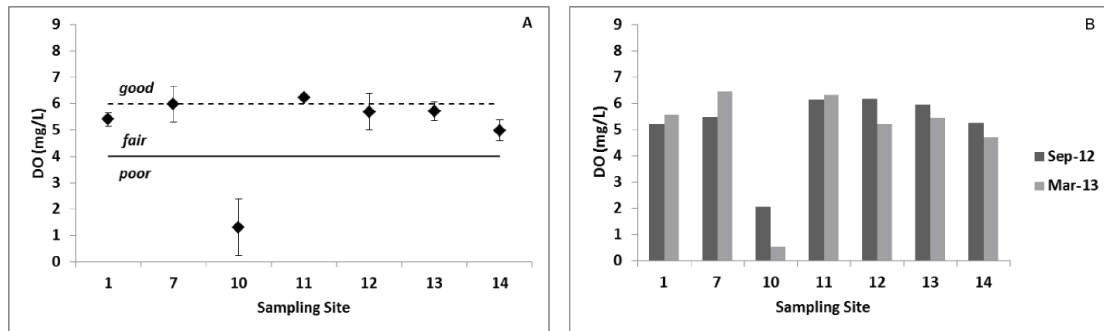


Figure 5 A: Mean (\pm standard deviation) dissolved oxygen (DO) levels measured at sampling sites over two seasons. Default ecological categories for DO based on ecological Reserve determination methodologies are superimposed on graph A. B: Seasonal values measured at each site.

The average values for the 5-day biological oxygen demand (BOD_5) test ranged between 1 and 3mg/L (Figure 6). No clear spatial pattern in BOD_5 values is apparent. Most sites had higher BOD_5 levels in winter, although Site 10 had higher summer BOD_5 , and Site 11 showed no seasonal change.

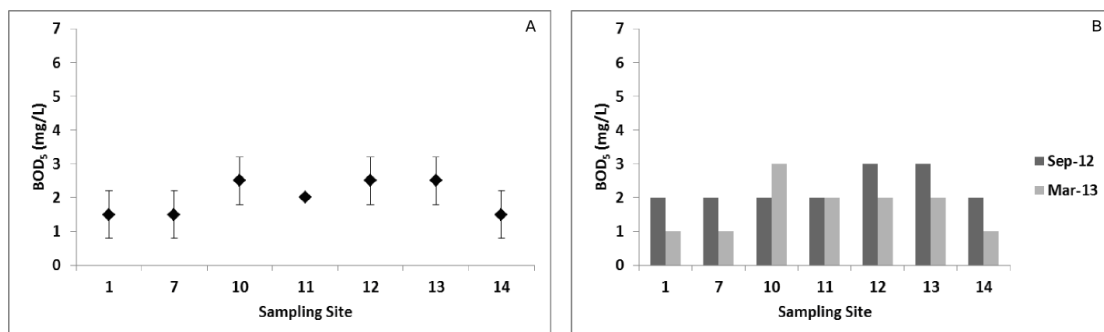


Figure 6 A: Mean (\pm standard deviation) 5-day biological oxygen demand (BOD_5) levels measured at sampling sites over two seasons. B: Seasonal values measured at each site.

Average turbidities were highest overall at Sites 7 and 12, though seasonal variation leads to high intra-annual variation (Figure 7). With the exception of Site 10, summer samples had higher turbidity than winter samples. As summer sampling following a rainfall event, the higher summer turbidities are liable to be caused by sediment-containing surface runoff or possibly groundwater entering the streams in question.

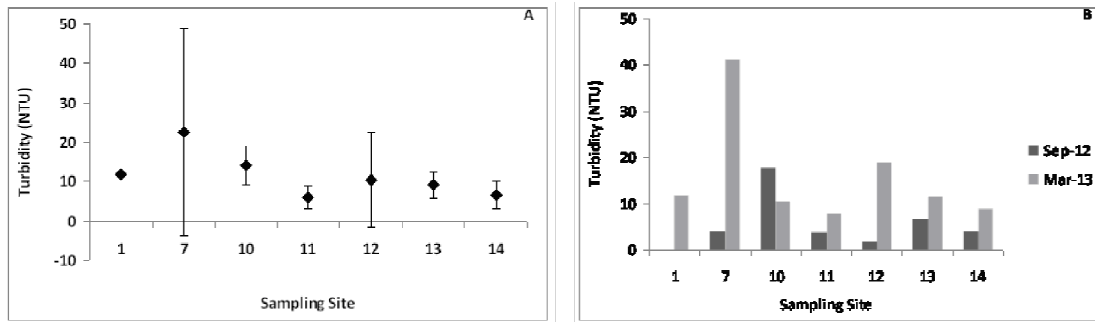


Figure 7 A: Mean (\pm standard deviation) turbidity levels measured at sampling sites over two seasons. B: Seasonal values measured at each site.

Average total inorganic nitrogen (TIN) levels were higher at the uppermost sites on all rivers (Sites 1, 10 and 12) than at downstream sites (Figure 8). Upstream sites were all classified as fair, and Site 7 was good/fair, Site 13 fair/good, and Site 14 fair. Notably higher values were recorded in the summer samples from all sites, although TIN levels were relatively high in the winter samples from Site 10.

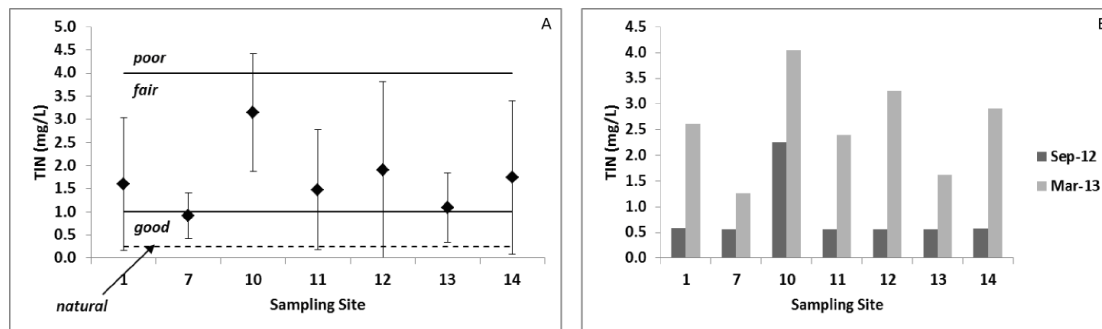


Figure 8 A: Mean (\pm standard deviation) total inorganic nitrogen (TIN) levels measured at sampling sites over two seasons. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the graphs. B: Seasonal values measured at each site.

Overall soluble reactive phosphorus (SRP) concentrations were mostly classed as fair except at Site 11 (Figure 9). SRP levels were below the resolution of the test undertaken in the majority of samples, and the true class could range from natural to fair. Site 11 was classified as poor overall, owing to a very high SRP level recorded in the sample from March 2013. The reason for this high level of SRP at this point is not known; the sites upstream along the Mpisini and Manzamnyama rivers had good levels of SRP at the time.

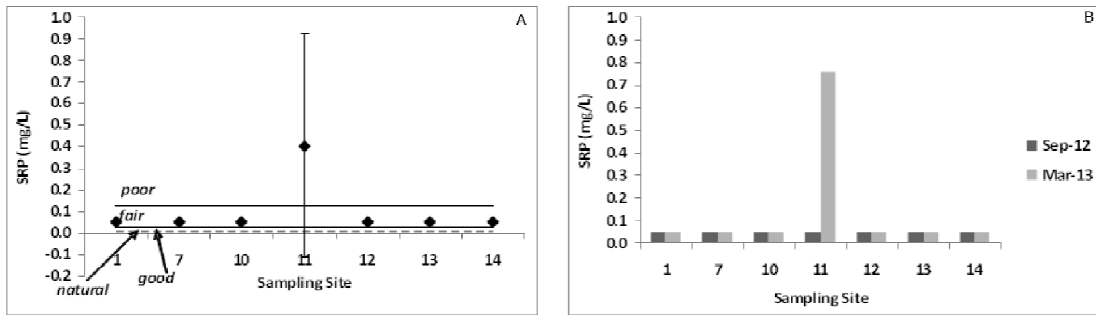


Figure 9 A: Mean (\pm standard deviation) soluble reactive phosphorus (SRP) levels measured at sampling sites over two seasons. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the graphs. B: Seasonal values measured at each site.

Phytoplankton chlorophyll *a* concentrations at all sites were classed as Natural (Figure 10), with a slightly higher value recorded at Site 10 during the winter sampling trip. No other significant seasonal variation was recorded. Periphyton chlorophyll *a* concentrations ranges from good/natural to fair. Large seasonal variations were observed at most sites with values being higher during the winter months. The low periphyton chlorophyll *a* levels at Site 11 are likely a function of this being the most shaded of all sites; Site 13, although it has relatively low periphyton chlorophyll *a* levels, is not shaded and light levels cannot account for the low chlorophyll *a* found. Site 10 was heavily impacted by cows over the year of study, and fouling of the water by cows may account for the often high chlorophyll *a* levels recorded there.

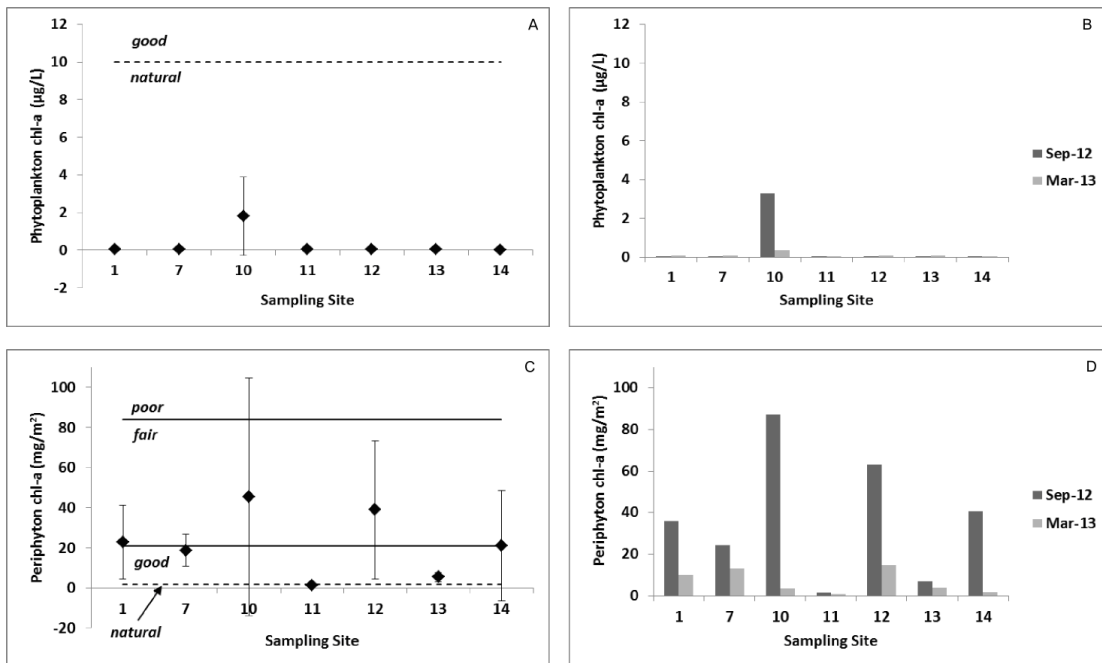


Figure 10 A, C : Mean (\pm standard deviation) phytoplankton and periphyton chlorophyll *a* values measured at sampling sites over two seasons. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the graphs. B, D: Seasonal values measured at each site.

3.2 Habitat assessment

IHAS scores were generally low at all sampling sites (Figure 11). The slightly higher IHAS score at Site 7 is due to the presence of a stones biotope, which is missing at all other sampling sites. Seasonal variability was largely negligible, although sites on the Mdibi river (Sites 12, 13, and 14) have a higher score in the winter sample. Reasons for low IHAS scores include: Site 10 being characterized by a pool with slow moving water which is regularly disturbed by cattle, Site 1 consisting of a pool with slow flow; Site 11 having low flow with little to no vegetation biotope; and Site 13 having reduced GSM biotope.

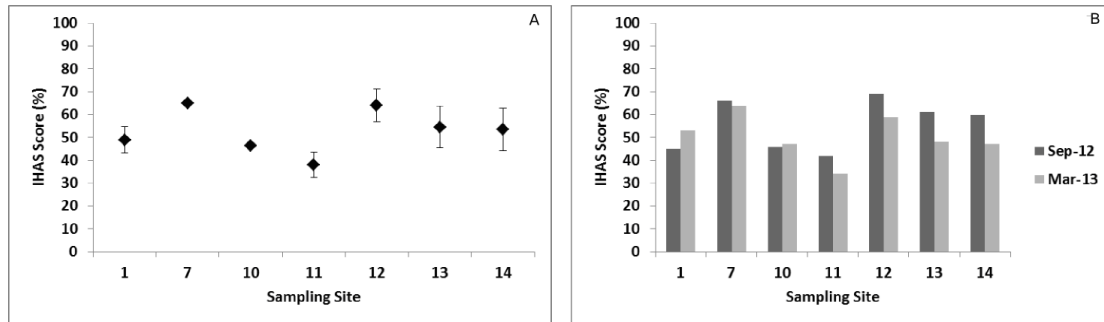


Figure 11 A: Mean Integrated Habitat Assessment System (IHAS) score (\pm standard deviation) per sampling site. B: Seasonal differences in IHAS recorded at each site.

3.3 Macroinvertebrate assessment

At each site, results from vegetation and GSM biotopes were combined to provide overall SASS scores, number of families and ASPT values (Figure 12). SASS scores and number of taxa were usually lower at upstream sites compared to downstream sites. The SASS score and number of taxa found at Site 7 are much lower than in previous years. SASS scores and number of taxa varied during different seasons with no clear seasonal pattern.

ASPT scores were, however, more consistent seasonally, being higher in winter than in summer with the exception of Site 13, where seasonal variation was negligible, and Site 1, where the summer score was greater. The ASPT score is generally considered to be the least variable of the SASS assessment scores and thus preferred when assessing river health. ASPT scores were classed as poor at Site 1 and Site 10, poor/fair at Site 7 and Site 14, fair at Site 11 and Site 12, and good at Site 13.

Poor habitat owing to red bacterial floc overgrowth may be the cause for the low SASS and ASPT scores at Sites 1 and 10. Site 10 has in addition very low DO values, together with high EC and TIN levels, which impact on organisms at this site. Along the length of the Mdibi ASPT values increased from fair at Site 12 (reference site) to good at Site 13. However, after input of the combined waters of the Manzanynana and Mpisini rivers, together with a third, smaller and unmonitored tributary, the ASPT class drops to a fair class at Site 14. The potential impact of water from the Manzanynana and Mpisini rivers cannot be separated from the potential effects caused by dense human settlements upstream of Site 14. Despite the decreased SASS scores and numbers of taxa at Site 7, the ASPT score does not change significantly compared to recent years.

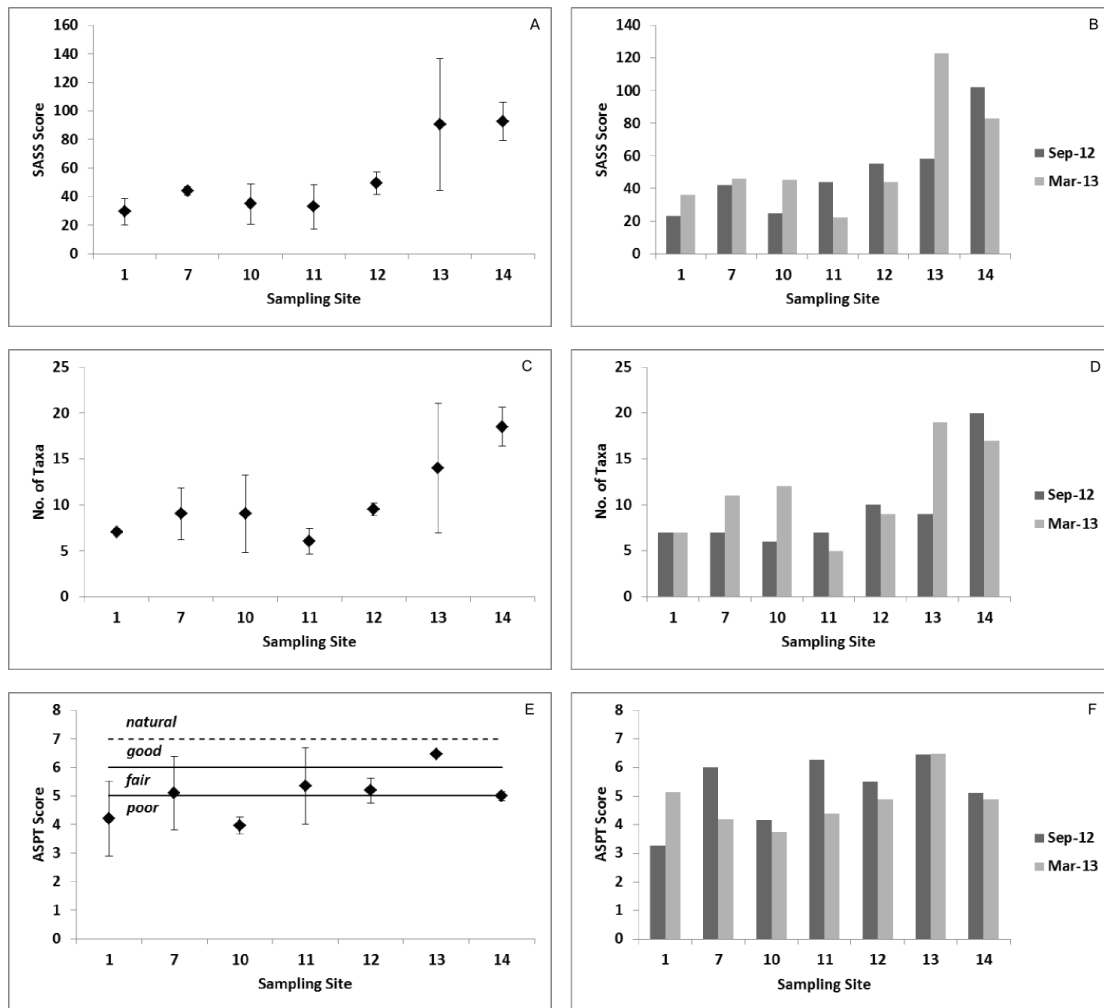


Figure 12 A, C, E: Mean (\pm standard deviation) South African Scoring System (SASS) scores, number of families/taxa sampled and average score per taxon (ASPT) values determined for sites over two seasons. Default ecological categories for ASPT scores based on ecological Reserve determination methodologies are superimposed on graph E. D, F: Seasonal variation in SASS score, number of taxa and ASPT values at each site.

3.4 Macroinvertebrate community analysis

Results of an NMDS ordination of Bray-Curtis differences based on invertebrate communities in samples collected are presented below in Figure 13. Differences between different sites were highly significant ($p < 0.001$), as were seasonal changes ($p < 0.001$). Seasonal patterns are clear in Figure 13, with summer samples being found on the top right of the plot, and winter samples on the lower left. Sites 1 and 7, central in the plot, showed relatively little seasonal variation in contrast to other samples from other sites. No clear match between community structure and ASPT scores is apparent on the plot, as high ASPT scores were obtained from Sites 13, together with winter samples from Sites 7 and 11, and these are widely dispersed in Figure 13. This indicates that changes in the invertebrate community structure are not necessarily matched with changing biomonitoring scores, and therefore that stability in biomonitoring scores does not imply an underlying stability of community structure.

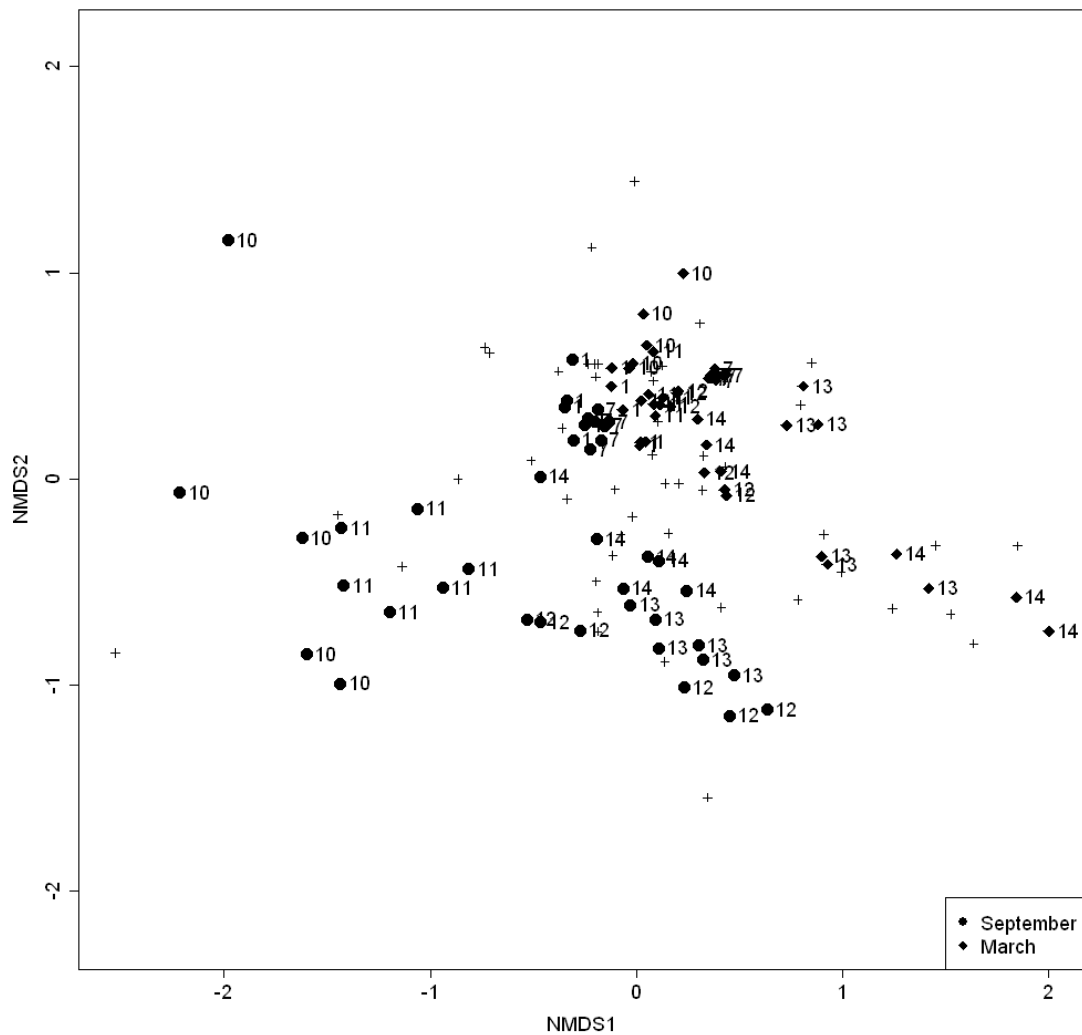


Figure 13 NMDS ordination plot of Bray-Curtis distances between all samples assessed based on untransformed invertebrate family-level abundances (stress: 12.1). Sites are labeled and species indicated by +.

Dispersion between samples, which has been proposed as an indicator of stress, changes significantly between sites ($p=0.001$) and seasons ($p=0.002$). These changes in beta diversity are matched by significant changes in the alpha diversity of sites, most apparent in the lower diversity of Site 7.

3.5 Extended biomonitoring at Site 11

In the sections below, water quality, habitat and biological monitoring data collected at Site 11 are reported. Data from the limited sampling undertaken during autumn 2012 and spring 2013 are presented and data from the comprehensive sampling undertaken during winter 2012 and summer 2013 are included for comparative purposes.

3.5.1 Water quality assessment

Water quality data for Site 11 throughout the year are presented in Figure 14 below. Water temperatures recorded at Site 11 showed variation of about 5°C, with spring and summer being the warmer seasons (no value is available for winter owing to a broken thermometer).

The pH increased slightly from winter to summer, passing from a good to a natural class (no datum is available for autumn owing to a faulty pH meter). Electrical conductivity was classified as good during winter and spring and as fair during summer and autumn. Dissolved oxygen concentrations ranged from good in winter and summer to fair in autumn and poor/fair in spring.

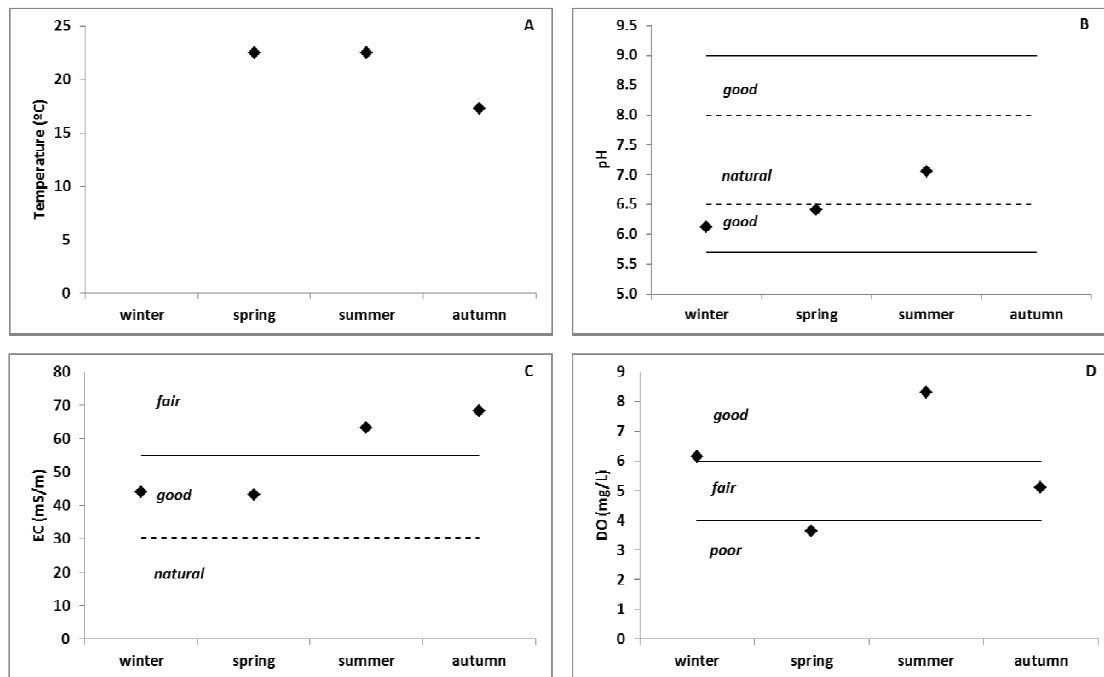


Figure 14 Temperature (A), pH (B), electrical conductivity (EC) (C), and dissolved oxygen (DO) (D) values measured at Site 11 over four seasons. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the graphs.

3.5.2 Macroinvertebrate biomonitoring (SASS) and habitat assessment

SASS scores and numbers of taxa were lower in summer than during all remaining seasons (Figure 15). The ASPT score bordered on the good/fair boundary during winter, while in spring ASPT was classified as fair and in summer and autumn as poor, with an overall pattern of ASPT scores decreasing throughout the year. IHAS scores were low overall due to the absence of the stones biotope and very little vegetation biotope. IHAS scores were highest in spring and lowest in summer. Changes in the IHAS score do not explain the decrease in ASPT scores over the year. Matching changes in pH and EC over the same period may partially explain changes in ASPT values. Evidence of cow activity and fouling around the site was noted over the year under study; the potential impact of this on in-stream biota is unknown. All raw data for the water quality and SASS assessments are supplied in Appendix D.

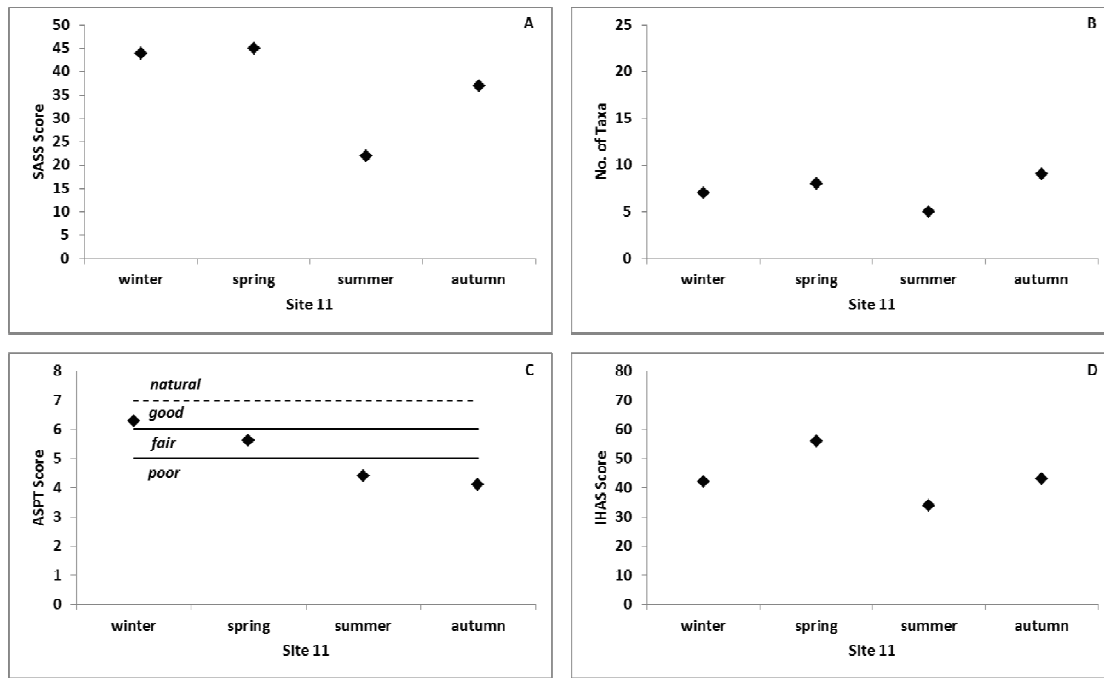


Figure 15 South African Scoring System (SASS) score (A), number of families/taxa sampled (B) and average score per taxon (ASPT) scores (C), and Integrated Habitat Assessment System (IHAS) score (D) determined for Site 11 over four seasons. Default ecological categories for ASPT based on ecological Reserve determination methodologies are superimposed on graph C.

The total number of taxa collected at Site 11 per season ranged between 5 and 9, with autumn yielding the most taxa and summer the least (Table 2). The average number of taxa collected over the year of assessment was 7 and the overall total number of taxa per year was 11. A list of taxa collected at Site 11 during four sampling trips in different seasons is supplied in Appendix E.

Table 2 Number of taxa collected at Site 11 per season and per year.

Year Month Season	2012 September winter	2012 November spring	2013 March summer	2013 June autumn
Total taxa per season	7	8	5	9
Average number of taxa	7			
Total taxa per year	11			

3.6 Diatom assessment

3.6.1 Diatom indices

Mean index values for each site are presented in Figure 16. Raw data underlying these plots are presented in Appendix G and brief descriptions used to derive the index based on expert opinion are presented in Appendix F. General trends between sites are broadly the same across all indices, although inter-site variation and the range across scores are greater for the score based on expert opinion. Differences between indices are largely a function of whether taxa in samples, and in particular dominant taxa, contribute to the indices in question.

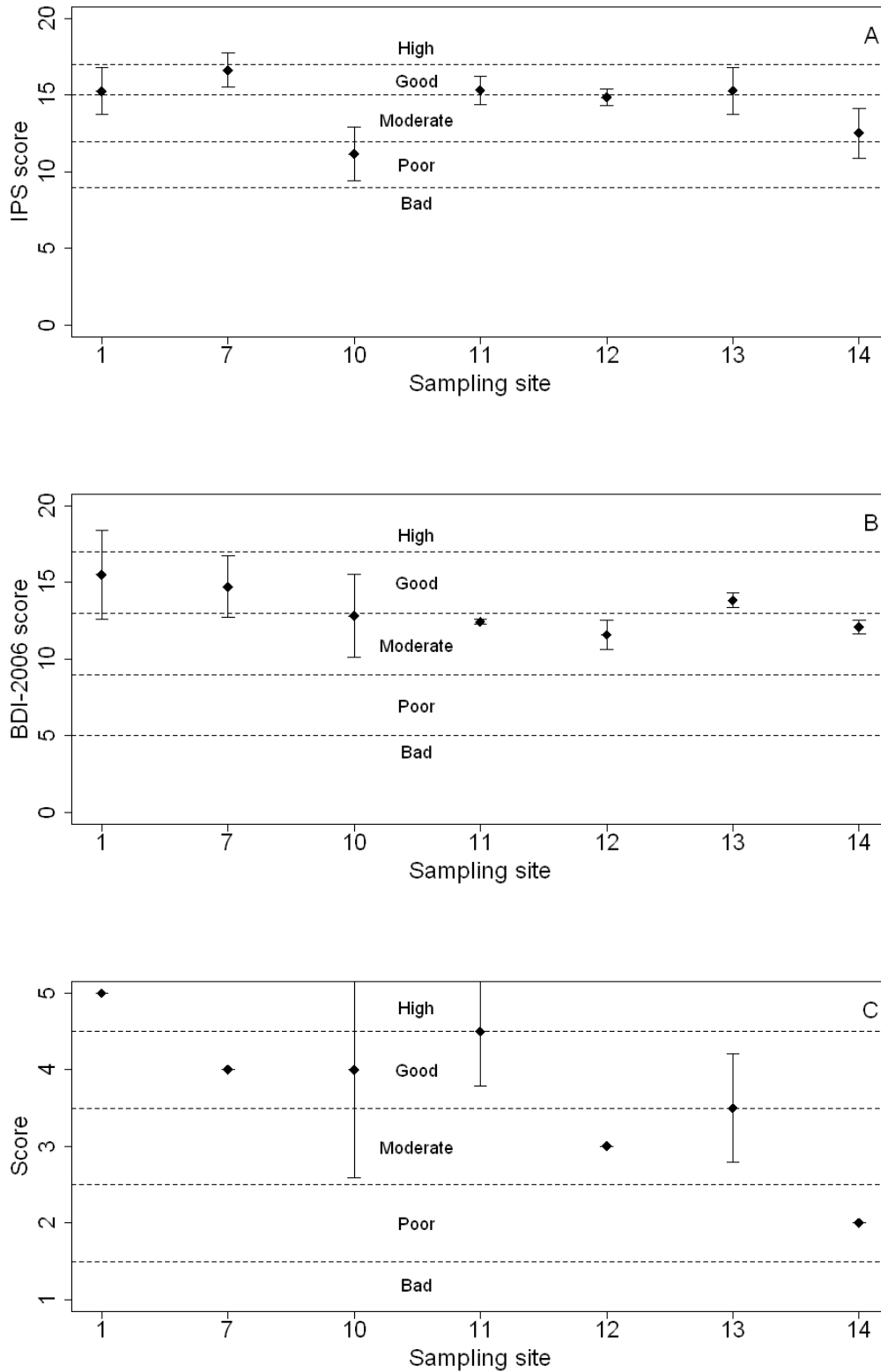


Figure 16: Mean scores (\pm standard deviation) of the three diatom indices used in this study. A: IPS index; B: BDI-2006 index; C: Score based on expert opinion.

Site 1 is classed as high overall, and is the only site that overall is in this class. This is an improvement on the results from the previous year (Gordon and Griffin, 2012). The dominant taxa at this site did not change overall, and changes in rarer taxa influenced the reclassification of this site (particularly as the IPS and BDI-2006 indices do not use information on the dominant taxa). The finding that water quality, as reflected in diatom community structure, was good was surprising in the light of the continued presence of a red bacterial floc covering submerged surfaces at the site.

Site 7 is classed as good overall. This is an improvement on the classification of moderate over the previous three years. This change has been accompanied by a change in dominant diatom taxa, from a situation in 2010-2011 where *Gomphonema* and *Nitzscha* species (amongst others) were dominant to the current study where species of *Achnanthes* and *Achnantheidium* typical of clean water were dominant. Previous reports noted a significant drop in water quality from Site 1 to Site 7 along a short stretch of the Mpisini river where it runs past the RBM smelter. This decrease in water quality is still present, but it is much reduced in comparison with previous years. As in Site 1, a red biofilm is present that was not present at the site in 2010, but appeared afterwards.

Site 10 is classified as moderate overall according to the various diatom indices. This is the same classification as the previous three years. There is considerable disagreement between indices and sampling dates as to the site's classification (Figure 16). Community dominants vary between samples, but all contain an unidentified species of *Brachysira* typical of upstream sites in this region.

Site 11 is classified as good overall, with little disagreement between indices. This is the same as the previous year, and an improvement on the years before that. The improvement in scores from this site can largely be linked with the increasing dominance of *Achnanthes oblongella* in samples. The increasing impact of cattle and their urination/defecation at this site over the last few years seems to have had little impact on the water quality.

Site 12 is classified as moderate overall. The overall score for this site is considerably decreased from the previous year, which in turn is lower than the two previous years. The change seems to be largely a result of significant numbers of *Nitzschia inconspicua* in the samples assessed here. This is a taxon associated with slightly basic water with moderate-high electrolyte levels and high nutrient levels. Another change is the reduction in the number of the clean water indicator *Achnanthes oblongella*, previously highly dominant at this site.

Site 13 is classified as good overall. This is a higher classification than in the previous two years, but the change in overall score is relatively low. The community structure at this site may vary with time, but the set of dominant taxa remains fairly stable over time.

Site 14 is classified as poor overall, and the inferred water quality at this site has shown a consistent decrease with time over the previous four years. In the past four years, this site has scored the same or better than Site 13, immediately upstream along the Mdibi river; over the past year the site is consistently worse. The community structure has varied over time at this site, suggesting changes in driving variables.

The effects of changes in index values between sites and over time was not found to be statistically significant at $p \leq 0.05$ regardless of which index was tested.

3.6.2 Diatom community analysis

The ordination based on diatom species abundance over the period reported on is presented in Figure 17. Underlying diatom abundance data are presented in Appendix H. The effects of site on diatom community structure were highly significant ($p < 0.001$), while changes with time were not ($p = 0.108$). In general, sites with higher water quality appear on the lower left of the plot, with water quality decreasing towards the right of the plot.

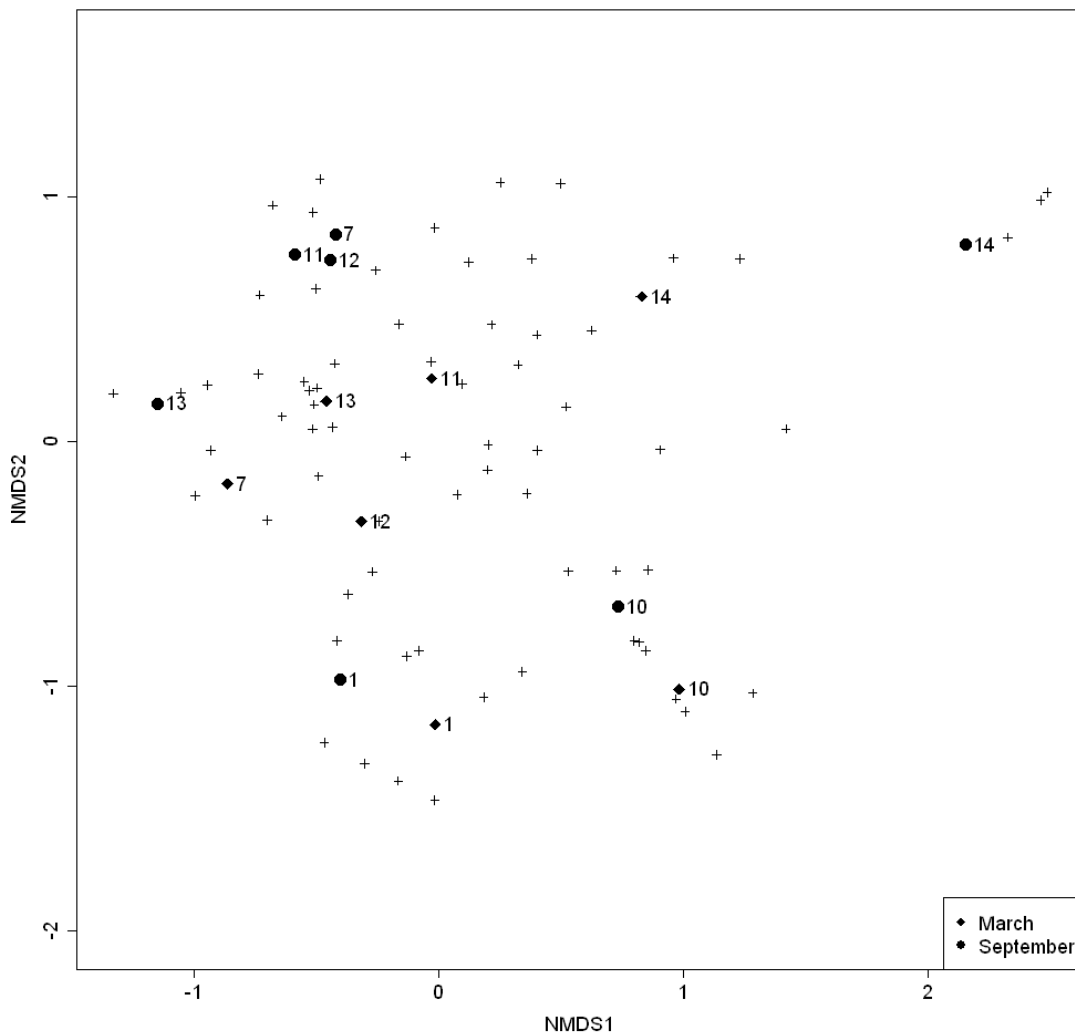


Figure 17 NMDS ordination plot of Bray-Curtis distances between all samples assessed based on untransformed diatom abundances (stress: 13.5). Sites are labeled and species indicated by +.

It is apparent on the plot that communities at certain sites remained fairly stable over time (e.g. Site 1), while others, in particular at Site 14, were less so. This change in dispersion between sites is statistically significant ($p = 0.001$). Increased dispersion at a site over time suggests changing conditions or some other form of disturbance. Reference sites 1 and 10 have the most stable communities over the period assessed (this despite regular cow herds crossing through the stream at Site 10). Over previous years, Site 1 has been consistently stable over time. The other upstream reference sites 10 and 12 have been less consistently stable, and, despite the stability of the community at Site 10 in the current study, the community at Site 12 varied considerably. This was accompanied by lowered index scores

for this site.

The cluster of samples to the upper left hand side of the plot is made up samples where *Achnanthes oblongella* was either dominant or present in significant quantities. Despite this taxon being a clean water indicator, these samples do not all have very good index scores owing to the effect of other taxa in the community.

The appearance of new taxa in certain samples was noted in the previous report (Gordon and Griffin 2012). In particular, the appearance of significant levels of *Stauroneis heinii* and an unidentified *Gomphonema* species were noted. Both are still present, with the former in two samples, in particular at Site 10 in the March 2013 sample, and the latter in 4 samples and subdominant in the sample from Site 7 in the March 2013 sample. In addition, unidentified and as yet unrecorded *Cocconeis* species were found to be dominant in the March 2013 sample from Site 14. Several other new taxa were found, with the most significant (in terms of numbers) being *Achnanthidium jackii* in the September 2013 sample from Site 13.

3.7 Site summary and overall classification

Table 3 Summary of Site 1 upstream on the Mpisini river.


									
<p>Site description: This site is upstream of the Smelter Site and was originally chosen as a possible reference site. During both sampling seasons a red floc was covering stones and vegetation in the river. The first red floc appearance was recorded during winter 2011 and has been observed ever since. GSM biotope is dominated by mud with limited sand available, usually covered with leaf litter.</p>									
<p>Water quality parameters: T: temperature; DO: dissolved oxygen; EC: electrical conductivity; TIN: total inorganic nitrogen; SRP: soluble reactive phosphorous. Water quality categories based on the ecological Reserve methodologies for water quality are provided below the values where relevant.</p>									
T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll- <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
21.0	6.2	5.4	40.0	1.6	0.05	1.5	12.0	0.04	22.7
	Good	Fair	Good	Fair	Fair			Natural	Fair/Good
<p>Biological and water quality indices: Summary of the main index scores. ASPT: average score per taxon; IHAS: integrated habitat assessment system; diatoms; and composite water quality. Ecological health categories are largely based on those used for ecological Reserve determinations.</p>									
ASPT		IHAS (%)			Diatoms		Water quality		
4.2		49			4.2		Good/Fair		
Poor					Good				
<p>Overall ecological assessment: Fair</p>									

Table 4 Summary of Site 7 downstream on the Mpisini river.


									
<p>Site description: The Mpisini river flows past the Smelter immediately upstream of this site. The surrounding land use is forestry (there is no impact from human settlements). Vegetation and GSM biotopes provide good sampling opportunities. This is the only site which contains gravel and limited stones (sampling of these areas is included in the GSM biotope). This is a cattle drinking site. Red bacterial floc levels have increased at this site.</p>									
<p>Water quality parameters: T: temperature; DO: dissolved oxygen; EC: electrical conductivity; TIN: total inorganic nitrogen; SRP: soluble reactive phosphorous. Water quality categories based on the ecological Reserve methodologies for water quality are provided below the values where relevant.</p>									
T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll- <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
22.5	6.1	6.0	54.2	0.9	0.05	1.5	22.6	0.04	18.7
	Good	Good/Fair	Good/Fair	Good/Fair	Fair			Natural	Fair/Good
<p>Biological and water quality indices: Summary of the main index scores. ASPT: average score per taxon; IHAS: integrated habitat assessment system; diatoms; and water quality. Ecological health categories are largely based on those used for ecological Reserve determinations.</p>									
ASPT			IHAS (%)		Diatoms		Water quality		
5.1			65		3.9		Good		
Poor/Fair					Good				
<p>Overall ecological assessment: Fair/Good</p>									

Table 5 Summary of Site 10 upstream on the Manzamnyana river.


									
<p>Site description: This site consists of a deep wetland lake (upstream of picture) which gradually becomes shallower (pictured above) before flowing very slowly into a wetland. Surrounding land use is forestry with the Smelter Site in close proximity. There are no impacts from human settlements. Vegetation biotope is sampled in the wetland lake, consisting of marginal vegetation (reeds and grass) and aquatic vegetation. GSM biotope is sampled in the shallower part of the lake and consists of sand and anoxic mud. The GSM is regularly disturbed by cattle passing through and drinking. Red bacterial floc has been present at this site since monitoring started.</p>									
<p>Water quality parameters: T: temperature; DO: dissolved oxygen; EC: electrical conductivity; TIN: total inorganic nitrogen; SRP: soluble reactive phosphorous. Water quality categories based on the ecological Reserve methodologies for water quality are provided below the values where relevant.</p>									
T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll- <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
23.5	6.4	1.3	80.2	3.2	0.05	2.5	14.0	1.8	45.4
	Good	Poor	Fair	Fair	Fair			Natural	Fair
<p>Biological and water quality indices: Summary of the main index scores. ASPT: average score per taxon; IHAS: integrated habitat assessment system; diatoms; and water quality. Ecological health categories are largely based on those used for ecological Reserve determinations.</p>									
ASPT			IHAS (%)		Diatoms		Water quality		
4.0			47		3.2		Fair		
Poor					Good/Fair				
<p>Overall ecological assessment: Fair</p>									

Table 6 Summary of Site 11 at confluence of the Mpisini and Manzanmyana rivers.


									
<p>Site description: The site is within a natural forest at the confluence of the Mpisini and Manzanmyana rivers, downstream of the Smelter Site. Surrounding land use is forestry with no impact from human settlements. There is very limited vegetation biotope available for sampling, particularly during the lower flows. Vegetation sampled usually consists of marginal vegetation leaves that dip into the water, root wads and twig snarls. GSM biotope consists of sand and mud. The site has become impacted by cattle over the year under study.</p>									
<p>Water quality parameters: T: temperature; DO: dissolved oxygen; EC: electrical conductivity; TIN: total inorganic nitrogen; SRP: soluble reactive phosphorous. Water quality categories based on the ecological Reserve methodologies for water quality are provided below the values where relevant.</p>									
T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll- <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
22.5	6.6	7.2	53.7	1.5	0.4	2.0	6.0	0.04	1.2
	Natural /Good	Good	Good/ Fair	Fair	Poor			Natural	Natural
<p>Biological and water quality indices: Summary of the main index scores. ASPT: average score per taxon; IHAS: integrated habitat assessment system; diatoms; and water quality. Ecological health categories are largely based on those used for ecological Reserve determinations.</p>									
ASPT			IHAS		Diatoms		Water quality		
5.3			38		3.8		Good		
Fair					Good				
<p>Overall ecological assessment: Good</p>									

Table 7 Summary of Site 12 upstream on the Mdibi river.


									
<p>Site description: This is the uppermost site on the Mdibi River and tentatively proposed as a reference site for this river. Surrounding land use is forestry and some limited human settlement. The GSM biotope consists of sand, some mud and limited leaf litter. Vegetation habitat consists of aquatic plants and marginal grass. Red floc was recorded at this side for the first time during the summer 2013 sampling trip.</p>									
<p>Water quality parameters: T: temperature; DO: dissolved oxygen; EC: electrical conductivity; TIN: total inorganic nitrogen; SRP: soluble reactive phosphorous. Water quality categories based on the ecological Reserve methodologies for water quality are provided below the values where relevant.</p>									
T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll- <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
20.3	6.5	5.7	38.9	1.9	0.05	2.5	11.0	0.04	38.9
	Natural/Good	Good	Good/Fair	Fair	Fair			Natural	Fair
<p>Biological and water quality indices: Summary of the main index scores. ASPT: average score per taxon; IHAS: integrated habitat assessment system; diatoms; and water quality. Ecological health categories are largely based on those used for ecological Reserve determinations.</p>									
ASPT			IHAS			Diatoms		Water quality	
5.2			64			3.0		Good/Fair	
Fair						Fair/Good			
<p>Overall ecological assessment: Fair</p>									

Table 8 Summary of Site 13 midway along the Mdibi river.



Site description: The site is located downstream of a bridge culvert. Surrounding land use includes forestry and settlements. Vegetation biotope is dominated by reed stalks and leaves, although there are some aquatic plants available. GSM biotope is limited, usually consisting of some mud and sand which is covered by thick shredded leaf litter.

Water quality parameters: T: temperature; DO: dissolved oxygen; EC: electrical conductivity; TIN: total inorganic nitrogen; SRP: soluble reactive phosphorous. Water quality categories based on the ecological Reserve methodologies for water quality are provided below the values where relevant.

T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll- <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
21.0	7.3	5.7	44.7	1.1	0.05	2.5	9.0	0.04	5.4
	Natural	Fair	Good	Fair/Good	Fair			Natural	Good

Biological and water quality indices: Summary of the main index scores. ASPT: average score per taxon; IHAS: integrated habitat assessment system; diatoms; and water quality. Ecological health categories are largely based on those used for ecological Reserve determinations.

ASPT	IHAS	Diatoms	Water quality
6.5	55	3.5	Good
Good		Good	

Overall ecological assessment: Good

Table 9 Summary of Site 14 downstream on the Mdibi river.



Site description: This is the lowermost site on the Mdibi River, situated upstream from Lake Mzingazi. Surrounding land use is subsistence forestry and human settlements. Vegetation biotope usually consists of marginal reeds, grasses and aquatic plants. GSM consists of good sand and mud sampling biotope. Irregular disturbance by cows has been noted.

Water quality parameters: T: temperature; DO: dissolved oxygen; EC: electrical conductivity; TIN: total inorganic nitrogen; SRP: soluble reactive phosphorous. Water quality categories based on the ecological Reserve methodologies for water quality are provided below the values where relevant.

T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll- <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
21.3	7.0	5.0	95.2	1.7	0.05	1.5	7.0	0.03	21.1
	Natural	Fair	Poor	Fair	Fair			Natural	Fair/ Good

Biological and water quality indices: Summary of the main index scores. ASPT: average score per taxon; IHAS: integrated habitat assessment system; diatoms; and water quality. Ecological health categories are largely based on those used for ecological Reserve determinations.

ASPT	IHAS	Diatoms	Water quality
5.0	54	2.5	Fair/Good
Fair/Poor		Fair/Good	

Overall ecological assessment: Fair

4 Discussion

In the past it has been noted that the best water quality was found at Sites 1 and 12, the uppermost sites on the Mpisini and Mdibi rivers respectively. The same cannot be said of the year reported on here, where the best water quality was found at site intermediate along the Mpisini, Mdibi and Manzamnyama rivers (Sites 7, 13, and 11 respectively). Site 1 and 12 now have good/fair water quality, whereas in the past they have often been classified as good. No clear trend in any water quality parameter can be associated with this change, though nutrient levels may have increased slightly and oxygen levels decreased slightly. ASPT scores at these sites have not changed appreciably over recent years, while overall diatom scores indicate a slight decrease in water quality. Site visits reveal these upstream sites to have a red bacterial floc, initially only found at Site 10 upstream on the Manzamnyama river, covering surfaces at these sites. The appearance of this floc was noted in summer 2011 at Site 1 and summer 2013 at Site 12. The cause of the floc is not known, and warrants further investigation.

Site 10, upstream on the Manzamnyama river and adjacent to the smelter, has lower overall water quality than other upstream sites. This has been noted over all years that biomonitoring has been undertaken, and attributed to the site being groundwater fed with low oxygen levels. In the current year, the site was found to have generally higher TIN and phytoplankton chlorophyll *a* levels.

Previous reports have noted a distinct decrease in water quality between Sites 1 and 7 along the Mpisini river (largely based on diatom scores) and it has been suggested that drainage or run-off from the Smelter might be responsible for this. This notable decrease in diatom score between the sites was not found in the year under report.

The summer sampling trip undertaken in March 2013 followed a fairly heavy rainfall event. Probable effects of this include elevated TIN levels at all sites, most likely owing to nitrogen-containing runoff or seepage entering the river. SRP was high in summer at Site 11 only. This may be a function of the rainfall event, though as SRP is not elevated at Sites 1 and 10, upstream, or Site 14, downstream, this may also be an anomaly. Another notable change that may be associated with rainfall and increased flow is decreased periphyton levels in summer.

The ecosystem health at Site 14, the lowest site on the Mdibi river, has in the past been found to be much the same and occasionally better than that at Site 13, immediately upstream along the Mdibi River. In the year of reporting, water quality at Site 14 was notably worse than that at Site 13. The distance between the two sites is approximately 1.5km, and in this reach the combined flows of the Manzamnyama and Mpisini rivers enter the river, as well as that of another, smaller tributary draining a settled area to the south-east. Land-use patterns show no obvious change in comparison to areas immediately upstream of Site 13. As Site 11, next upstream along the Mpisini-Manzamnyama rivers, was found to be in a good condition, these flows should have no negative impact on the Mdibi river. Should a continued and clear drop in ecosystem health between these sites be noted, it would be of value to assess the quality and nature of input from the tributary.

The ASPT from Site 11 showed a continual decrease over the year surveyed. When data were compared with previous years, no overall decrease in ASPT with time was noted, though a pattern of decreasing ASPT over the period studied was noted. Should the overall ASPT score over a year decrease further, though, closer assessment and intervention may be required. The average number of taxa found per sampling trip was 7, with 11 taxa found overall throughout the year. This is a considerable reduction in comparison with previous years. Taxa found currently are largely ones that have been found before at this site. The

cause of the reduction in taxa at this site is not known, as the habitat and water quality has not changed significantly. It was noted that a sample collected during the previous year at this site after Tropical Storm Irina had highly reduced taxon numbers, something attributed to storm impact. This year's samples show taxa have not increased to previous levels since the storm despite a long period to recover.

5 Recommendations

5.1 Ongoing monitoring

- Maintain monitoring programme. Consider reducing monitoring at Site 11 to summer/winter samples to match other sites.
- Continued monitoring of changes between Sites 1 and 7 along the Mpisini river to assess negative changes along this stretch. These have commonly been found (though not in the year under study) and are best reflected in diatom index change and to a lesser extent water quality parameters. Changes in this stretch may be a function of impacts of drainage/runoff from the Smelter site.
- Continued monitoring of changes between Sites 13 and 14 to assess potential negative impacts of inflow from an unmonitored tributary that joins the Mdibi river between these sites. Significant negative change in this region was only observed recently; if it continues, assessment of the tributary and including it in a monitoring programme may be necessary.
- Ongoing monitoring of red bacterial floc. This may be a natural phenomenon; however, changes in distribution of the floc suggest there may be changing water quality (particularly oxygen, organics or iron levels) in surface or groundwater in the region.

5.2 Other

- Assess north-eastern perimeter of the smelter complex for drainage of water to the adjacent Mpisini river. Check during moderate-heavy rain to assess extent of surface water runoff and stormwater drainage.
- Assess extant biomonitoring dataset to determine:
 - Major drivers over time of biological communities. This will identify what of the monitored parameters is most important in causing changes in biological communities in the monitored water systems.
 - Potential of revision of classification scheme to reflect site-specific conditions.

6 References

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Appendix A Summary of macroinvertebrate biomonitoring scores and field-collected water chemistry results for the period September 2012 to June 2013.

Site Code	River	Month	Season	Year	Sass Score	No. of Taxa	ASPT Score	IHAS Score (%)	Temp (°C)	DO (mg/L)	pH	EC (mS/m)	Turbidity (ntu)
1	Mpisini	September	winter	2012	23	7	3.29	45	20.0	5.22	5.76	0.6	
7	Mpisini	September	winter	2012	42	7	6.00	66	20.5	5.49	6.14	0.6	4.07
10	Manzamnyama	September	winter	2012	25	6	4.17	46		2.07	6.36	0.6	17.8
11	Confluence	September	winter	2012	44	7	6.29	42		6.14	6.12	0.6	3.9
12	Mdibi	September	winter	2012	55	10	5.50	69	18.5	6.18	6.39	0.6	2.0
13	Mdibi	September	winter	2012	58	9	6.44	61	20.0	5.95	7.28	0.7	6.7
14	Mdibi	September	winter	2012	102	20	5.10	60	19.5	5.26	6.95	0.7	4.2
11	Confluence	November	spring	2012	45	8	5.63	56	22.5	3.64	6.41	0.6	13.4
1	Mpisini	March	summer	2013	36	7	5.14	53	22.0	5.57	6.71	0.7	11.8
7	Mpisini	March	summer	2013	46	11	4.18	64	24.5	6.45		0.0	41.2
10	Manzamnyama	March	summer	2013	45	12	3.75	47	23.5	0.55	6.46	0.6	10.7
11	Confluence	March	summer	2013	22	5	4.40	34	22.5	8.32	7.06	0.7	8.0
12	Mdibi	March	summer	2013	44	9	4.89	59	22.0	5.20	6.57	0.7	19.0
13	Mdibi	March	summer	2013	123	19	6.47	48	22.0	5.45		0.0	11.54
14	Mdibi	March	summer	2013	83	17	4.88	47	23.0	4.71		0.0	9.04
11	Confluence	June	autumn	2013	37	9	4.11	43	17.3	5.1		0	7.02

Appendix B Summary of nutrient and other water quality data derived following laboratory analysis of collected samples results for the period September 2012 to March 2013.

Detection limits for analyses were as follows: ammonium (NH₄⁺): 0.1mg/L; nitrites (NO₂⁻): 0.01mg/L; nitrates (NO₃⁻): 1.0mg/L; soluble reactive phosphorus (SRP): 0.1mg/L. Values below detection limit are shown as half the detection limit (NH₄⁺= 0.05mg/L; NO₂⁻=0.005mg/L; NO₃⁻=0.5mg/L; SRP=0.05mg/L).

Site Code	River	Month	Season	Year	NH ₄ (mg/L)	NO ₃ (mg/L)	NO ₂ (mg/L)	TIN (mg/L)	SRP (mg/L)	Phyto-plankton chl- <i>a</i> (µg/L)	Peri-phyton chl- <i>a</i> (µg/cm ²)	BOD ₅ (mg/L)
1	Mpisini	September	winter	2012	0.05	0.50	0.030	0.58	0.05	0.01	35.75	2
7	Mpisini	September	winter	2012	0.05	0.50	0.010	0.56	0.05	0.02	24.31	2
10	Manzamnyama	September	winter	2012	0.05	2.16	0.040	2.25	0.05	3.27	87.20	2
11	Confluence	September	winter	2012	0.05	0.50	0.005	0.56	0.05	0.02	1.59	2
12	Mdibi	September	winter	2012	0.05	0.50	0.010	0.56	0.05	0.03	63.19	3
13	Mdibi	September	winter	2012	0.05	0.50	0.010	0.56	0.05	0.03	6.95	3
14	Mdibi	September	winter	2012	0.05	0.50	0.020	0.57	0.05	0.02	40.53	2
1	Mpisini	March	summer	2013	0.05	2.52	0.035	2.61	0.05	0.06	9.79	1
7	Mpisini	March	summer	2013	0.05	1.19	0.026	1.26	0.05	0.06	13.11	1
10	Manzamnyama	March	summer	2013	0.10	3.89	0.069	4.05	0.05	0.35	3.49	3
11	Confluence	March	summer	2013	0.05	2.31	0.032	2.40		0.05	0.82	2
12	Mdibi	March	summer	2013	0.05	3.16	0.057	3.26	0.05	0.06	14.65	2
13	Mdibi	March	summer	2013	0.05	1.55	0.028	1.62	0.05	0.06	3.80	2
14	Mdibi	March	summer	2013	0.05	2.83	0.035	2.92	0.05	0.03	1.62	1

Appendix C Summary of the average number of macroinvertebrate taxa found at each sampling site in both seasons sampled (September 2012 = winter, March 2013 = summer).

Averages are shown per site and sample trip, and combine two of three biotopes with three replicates per biotope.

Site Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		
	2012 Sept	2013 Mar	2012 Sept	2013 Mar	2012 Sept	2013 Mar	2012 Sept	2013 Mar	2012 Sept	2013 Mar	2012 Sept	2013 Mar	2012 Sept	2013 Mar	
Aeshnidae										0.5		0.2		0.2	
Amphipoda				0.2								3.2	34.0	0.5	0.7
Ancylidae		0.2										0.2		0.2	
Atyidae		5.2	0.5	0.2			2.8	0.7	58.7	16.8	53.5	83.7	25.7	326.7	
Baetidae		0.2	0.2	0.1	2.0	1.8	0.8		4.7	0.8	8.3	43.0	4.3	1.7	
Belostomatidae					0.2	0.2			0.2		0.2		0.2	0.2	
Blepharoceridae														5.8	
Caenidae		5.5							0.3	0.2	3.7	3.0	7.3	3.5	
Calamoceratidae											2.0		0.8	0.3	
Calopterygidae												0.8	0.2		
Ceratopogonidae	0.3	1.2	0.2		1.6	4.5		1.0		0.7	0.5		1.3	0.2	
Chironomidae	19.5	24.7	6.2	1.1	2.2	35.5	2.5	13.5	2.8	1.7	3.8	5.2	8.3	4.0	
Coenagrionidae	0.7	0.2	1.0	0.4	0.8	4.2	1.7	1.2	0.3	1.2	0.8	3.8	1.3	2.2	
Corbiculidae												0.3	0.7	2.0	
Corixidae	0.3	0.2							0.3						
Crambidae									0.5	0.7		0.2			
Culicidae					2.6	0.3									
Dipseudopsidae												1.5			
Dytiscidae		0.3						0.3						0.2	
Ecnomidae	1.2		1.5	0.4			0.5	1.7	0.5	0.7				0.3	
Elmidae							0.3	0.3			0.3	0.2		0.2	
Empididae								0.2							

Site Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar
Gerridae	0.2	0.2		0.1		0.2	3.7	0.7	0.8		0.2		2.5	
Gomphidae											0.2	0.3	0.7	0.3
Gyrinidae	0.2		0.7	0.2			0.7	0.3	0.2		0.2		0.3	0.2
Haliplidae													0.2	
Helodidae		0.2										0.3	0.7	
Hydraenidae						0.3								
Hydrobiidae								0.3						
Hydrophilidae	0.2		0.3	0.1	0.2	0.3					0.5		0.2	
Hydroptilidae	0.3			0.1	0.4									
Leptoceridae								0.2	0.8		0.2	2.5	0.8	2.7
Libellulidae	3.2	4.3		2.1		0.5		1.5		1.5				0.7
Lymnaeidae									0.2					
Muscidae						0.2		0.2				0.2		
Naucoridae				0.1								0.2		0.5
Nepidae				0.2								0.2	0.2	
Oligochaeta	0.2	0.2	0.7	0.4	2.4	6.3	0.3	3.7	0.8	0.3	1.2	18.2	0.7	1.5
Planorbinae				0.1										0.3
Porifera				0.1										
Potamonautidae		0.5	0.2	0.1		0.2	0.2	0.5		1.3	0.3	0.5	0.2	0.7
Pyralidae										0.2				
Simuliidae							0.5		0.3		1.5	0.8	0.3	
Tabanidae	0.2		0.2											
Thiaridae			0.2	0.1										
Tipulidae			0.2			0.2	0.2	0.7	0.2	0.2		0.2		0.8
Tricorythidae									0.3		1.0	11.8	1.7	
Veliidae	0.3										0.2		0.2	

Appendix D Summary of macroinvertebrate biomonitoring and water chemistry results at Site 11 over four seasons.

			Biomonitoring				Water Chemistry			
			Sass Score	No. of Taxa	ASPT Score	IHAS Score (%)	Temp (°C)	DO (mg/L)	pH	EC (mS/m)
Year	Month	Season								
2012	September	winter	44	7	6.3	42		6.1	6.1	44.0
2012	November	spring	45	8	5.6	56	22.5	3.6	6.4	43.2
2013	March	summer	22	5	4.4	34	22.5	8.3	7.1	63.4
2013	June	autumn	37	9	4.1	43	17.3	5.1		68.2

Appendix E Macroinvertebrate taxa collected at Site 11 during the year of study over four seasons using the SASS5 method

Taxa collected between September 2012 and June 2013 at Site 11. Abundances are scored following SASS5 convention as follows: 1 = 1, A = 2-10, B = 10-100.

Year Month Season	2012 September winter	2012 November spring	2013 March summer	2013 June autumn
Potamonautidae		A	1	1
Atyidae	B	B	A	A
Baetidae	A	B		A
Coenagrionidae	A	A	1	
Gomphidae		A		
Gerridae	A	B	A	B
Veliidae		A		1
Ecnomidae	1			
Gyrinidae	A			A
Chironomidae	B	A	1	B
Culicidae				1
Total taxa per season	7	8	5	9
Average taxa per year	7			
Total taxa per year	11			

Appendix F Diatom report for index based on expert opinion results for the period September 2012 to March 2013.

Site 1 (Upper Mpisini)

September 2012

This sample contained 21 taxa and had a Shannon diversity of 2.18. *Achnanthes pulviscula* was dominant in the sample, and an unidentified species of *Brachysira* was subdominant. No knowledge on the specific ecological requirements of these taxa is available. However, these taxa have been found to be associated with good quality water in the Smelter region (Gordon *et al.* 2008, 2010, Gordon and Griffin 2012, Holland *et al.* 2011) and are commonly dominant in upstream reference sites. *Brachysira* species typically are found in oligotrophic, electrolyte-poor water, and many prefer a somewhat acid pH. The remaining taxa that make up more than 1% of the sample include representatives typical of both clean and polluted water.

Score: 5

March 2013

Sixteen taxa were identified in this sample, leading to a Shannon diversity of 2.25. Co-dominant taxa include two unidentified species of *Brachysira*, *Brachysira neoexilis* and *Achnanthes pulviscula*. As noted above, *Brachysira* species are generally found in oligotrophic, electrolyte-poor water. *Brachysira neoexilis* is commonly associated with clean, oligo- to mesotrophic waters. Nothing formal is known of the autecology of *Achnanthes pulviscula*, but it has been found to be typical of clean, typically upstream sites in the region. Of the remaining taxa present, most are considered typical of clean water.

Score 5

Site 7 (Lower Mpisini)

September 2012

This sample contained 17 taxa giving it a Shannon diversity of 1.73. *Achnanthes oblongella*, which prefers circumneutral, oligotrophic with low electrolyte loads, was heavily dominant in this sample, to the point that no other taxon made up more than 10% of the community. Of these remaining taxa, many are typical of polluted conditions.

Score: 4

March 2013

This sample has 15 taxa and a Shannon diversity of 1.87. *Achnanthidium minutissimum*, typical of well oxygenated, clean, fresh water, was dominant, with *Achnanthes oblongella* and an unidentified species of *Gomphonema* present. *Achnanthes oblongella* is described as being found in circumneutral, oligotrophic, electrolyte-poor streams. The remaining taxa include several that are typical of cleaner water, with a few that are pollution tolerant.

Score 4

Site 10 (Upper Manzamnyana)

September 2012

There were 25 taxa in this sample giving it a Shannon diversity of 2.77. No taxon was highly dominant in this sample, and an unidentified *Brachysira* and *Nitzschia palea* were co-dominant. While *Brachysiras* are often indicative of clean, acidic water, and, in samples from this region, this *Brachysira* is common in clean samples, *Nitzschia palea* is a cosmopolitan taxon tolerant of extreme levels of pollution. Of the remaining taxa making up more than 1% of the population, the majority are tolerant of polluted conditions and in particular elevated

electrolyte levels.

Score 3

March 2013

Seventeen taxa were identified in this sample, and it has a Shannon diversity of 2.2. The same unidentified *Brachysira* found in the September sample from this site is dominant, with *Navicula notha* subdominant. The *Brachysira* would seem to be indicative of clean water, and *Navicula notha* is typical of acidic or circumneutral, oligotrophic, and electrolyte-poor water. Remaining taxa are a mix of pollution tolerant and pollution sensitive species.

Score 5

Site 11 (Confluence)

September 2012

This sample contained 16 taxa and had a Shannon diversity of 1.14. The sample is heavily dominated by *Achnanthes oblongella*, to the extent that no other taxon makes up more than 10% of the population. Remaining taxa include representatives of pollution tolerant and pollution sensitive taxa.

Score 5

March 2013

This sample contained 28 taxa. The Shannon diversity was 2.49. As in the September sample from this site, *Achnanthes oblongella* is dominant, and no other single taxon makes up 10% or more of the population. The dominance of *Achnanthes oblongella* is less pronounced in this sample however, and the diversity of the sample is greater. Remaining significant taxa are a mix of clean and polluted water indicators.

Score 4

Site 12 (Upper Mdibi)

September 2012

Twelve taxa were present in this sample which had a Shannon diversity of 1.54. The dominant taxon was *Achnanthes oblongella*, with *Nitzschia inconspicua* subdominant. The former is typical of circumneutral, oligotrophic, electrolyte-poor water, while the latter is typical of slightly basic water with moderate-high electrolyte levels and high nutrient levels. Remaining significant taxa are mix of those typical of clean and polluted water.

Score 3

March 2013

The sample contained 14 taxa and had a Shannon diversity of 2.11. *Nitzschia inconspicua*, *Achnanthes oblongella*, two unidentified species of *Brachysira* and *Achnanthes pulviscula* were co-dominant in this sample. The two *Achnanthes* and two *Brachysira* species are considered indicative of clean water (although the understanding of all but *Achnanthes oblongella*'s autecology is based solely experience with samples from this region). However, *Nitzschia inconspicua* (the most common taxon) is typical of slightly basic water with moderate-high electrolyte levels and high nutrient levels.

Score 3

Site 13 (Middle Mdibi)

September 2012

This sample contains 17 taxa and has a Shannon diversity of 2.28. *Achnantheidium minutissimum* is dominant in the sample, and *Gomphonema angustatum*, *Achnanthes oblongella* and *Gomphonema pumilum* var. *rigidum* subdominant. *Achnantheidium minutissimum* is typically found in well oxygenated, clean water, and *Achnanthes oblongella*

is common in circumneutral, oligotrophic, electrolyte-poor water. *Gomphonema angustatum* is cosmopolitan, but only common in oligotrophic water. Finally, *Gomphonema pumilum* var. *rigidum* is also cosmopolitan, but most common in meso- to eutrophic water.
Score 4

March 2013

The sample contains 15 taxa and has a Shannon diversity of 1.94. *Achnanthes oblongella* and *Achnantheidium saprophilum* are co-dominant, with *Achnantheidium minutissimum* subdominant. *Achnanthes oblongella* is an indicator of clean water, as is *Achnantheidium minutissimum*. *Achnantheidium saprophilum*, on the other hand, is found in organically enriched and eutrophic water.

Score 3

Site 14 (Lower Mdibi)

September 2012

The sample contains 16 taxa and has a Shannon diversity of 1.71. *Sellaphora pupula* is dominant in the sample, with *Placoneis clementis* subdominant. The former is cosmopolitan, but typical of electrolyte-rich condition, and the latter is also typical of electrolyte-rich water. The remaining significant taxa contain a mix of pollution tolerant and pollution sensitive taxa.

Score 2

March 2013

This sample contains the greater number of taxa at 30, and has a Shannon diversity of 2.6. The dominant taxa were two small, unidentified *Cocconeis* species. The remaining taxa contained a mix of pollution tolerant and pollution sensitive taxa, with the former being predominant.

Score 2

Appendix G Diatom index scores and site classification

Diatom index scores from sample sites in the Smelter area for the period September 2012 to March 2013 are presented below. Scores range from 0-20 for IPS and BDI-2006 indices, and from 1-5 for the index based on expert opinion. Site classifications based on the indices are also presented.

Site	Date	IPS		BDI-2006		Expert opinion	
		Score	Class	Score	Class	Score	Class
1	Sept2012	14.2	Moderate	13.5	Good	5	High
7	Sept 2012	15.9	Good	13.3	Good	4	Good
10	Sept 2012	9.9	Poor	10.9	Moderate	3	Moderate
11	Sept 2012	16.0	Good	12.6	Moderate	5	High
12	Sept 2012	15.2	Good	10.9	Moderate	3	Moderate
13	Sept 2012	16.4	Good	14.2	Good	4	Good
14	Sept 2012	11.4	Poor	11.8	Moderate	2	Poor
1	March 2013	16.3	Good	17.6	High	5	High
7	March 2013	17.4	High	16.2	Good	4	Good
10	March 2013	12.4	Moderate	14.7	Good	5	High
11	March 2013	14.7	Moderate	12.3	Moderate	4	Good
12	March 2013	14.5	Moderate	12.3	Moderate	3	Moderate
13	March 2013	14.2	Moderate	13.5	Good	3	Moderate
14	March 2013	13.7	Moderate	12.4	Moderate	2	Poor

Appendix H Diatom abundances at sample sites in the Smelter area for the period September 2012 to March 2013.

Where diatoms could not be identified, morphospecies were assigned and used in all analyses.

Site Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14	
	2012 Sept	2013 Mar	2012 Sept	2013 Mar	2012 Sept	2013 Mar	2012 Sept	2013 Mar	2012 Sept	2013 Mar	2012 Sept	2013 Mar	2012 Sept	2013 Mar
	<i>Achnanthes oblongella</i>		1%	59%	17%	1%	2%	77%	41%	58%	19%	10%	31%	
<i>Achnanthes pulviscula</i>	41%	17%		10%			1%	5%	8%	14%	4%	4%		6%
<i>Achnanthes</i> sp2	7%	4%												
<i>Achnantheidium crassum</i>												2%		
<i>Achnantheidium eutrophilum</i>	5%							4%						
<i>Achnantheidium exiguum</i>					2%	1%		2%	6%				2%	1%
<i>Achnantheidium jackii</i>											8%			
<i>Achnantheidium macrocephalum</i>			1%											
<i>Achnantheidium minutissimum</i>	7%	1%	6%	43%							28%	14%		1%
<i>Achnantheidium saprophilum</i>	4%							2%			9%	28%		5%
<i>Adlafia bryophila</i>		2%												
<i>Bacillaria paradoxa</i>			2%											
<i>Brachysira</i> aff. <i>steindorfiana</i>	8%	19%	1%		6%		6%			14%				
<i>Brachysira neoexilis</i>		16%												
<i>Brachysira</i> sp2	13%	18%		3%	20%	38%	1%	3%		15%		8%		
<i>Brachysira</i> sp3	1%									1%				
<i>Caloneis bacillum</i>					2%									
<i>Caloneis hyalina</i>							1%							
<i>Capartogramma crucicula</i>										1%				3%
<i>Cocconeis</i> sp1														2%
<i>Cocconeis</i> sp2														35%
<i>Cocconeis</i> sp3														14%
<i>Craticula buderi</i>	2%													
<i>Cymbopleura naviculiformis</i>		7%												
<i>Diadlesmis confervacea</i>		1%												
<i>Diadlesmis contenta</i>			3%					3%					1%	3%
<i>Diploneis oblongella</i>				5%	1%									
<i>Eolimna minima</i>									4%					2%
<i>Eolimna subminuscula</i>								1%						
<i>Eunotia bilunaris</i>	1%		2%	1%			3%	3%		3%	2%	1%		
<i>Eunotia minor</i>	1%	2%												
<i>Eunotia paludosa</i>				1%										
<i>Eunotia</i> sp3	1%													
<i>Eunotia</i> sp4														1%
<i>Eunotia tenella</i>					2%		1%							

Site Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar
<i>Frustulia crassinervia</i>						4%		2%						
<i>Frustulia rexii</i>									1%					
<i>Gomphoneis sp1</i>	1%													
<i>Gomphonema aff. gracile</i>														
<i>Gomphonema affine</i>	1%													
<i>Gomphonema angustatum</i>		1%		1%		2%		1%	5%		2%	14%	1%	2%
<i>Gomphonema clavatum</i>												1%		1%
<i>Gomphonema exilissimum</i>				1%		2%								1%
<i>Gomphonema gracile</i>	1%													
<i>Gomphonema lagenula</i>												1%		2%
<i>Gomphonema maclaughlinii</i>												1%		
<i>Gomphonema parvulum</i>				1%		1%		4%		1%		5%		
<i>Gomphonema procerum</i>														1%
<i>Gomphonema pseudoaugur</i>												2%	1%	
<i>Gomphonema pumilum var. rigidum</i>									4%			10%	1%	
<i>Gomphonema sp6</i>														
<i>Gomphonema sp9</i>				11%					1%				2%	
<i>Kobayasiella parasubtilissima</i>														1%
<i>Luticola goeppertiana</i>														1%
<i>Luticola kotschy</i>						1%								9%
<i>Luticola mutica</i>								1%						
<i>Mayamaea agrestis</i>		3%												
<i>Mayamaea atomus</i>										4%				
<i>Mayamaea atomus var. permitis</i>	2%								1%					2%
<i>Navicula arvensis var. maior</i>	1%									2%				
<i>Navicula cari</i>				1%					1%					
<i>Navicula erifuga</i>						1%			2%				2%	3%
<i>Navicula germanii</i>														2%
<i>Navicula gregaria</i>						5%								
<i>Navicula longicephala</i>						1%								
<i>Navicula notha</i>										1%				
<i>Navicula recens</i>														1%
<i>Navicula schroeteri</i>													1%	1%
<i>Navicula sp3</i>												1%		
<i>Navicula sp6</i>										3%			1%	1%
<i>Navicula tenelloides</i>							3%							2%
<i>Navicula vandamii</i>														7%
<i>Navicula veneta</i>						1%						1%		
<i>Navicula vilaplani</i>								1%						
<i>Nitzschia acidoclinata</i>												2%		
<i>Nitzschia alpina</i>							1%							

Site Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar
<i>Nitzschia amphibia</i>		1%												
<i>Nitzschia archibaldii</i>	1%				6%									2%
<i>Nitzschia capitellata</i>	2%				2%									
<i>Nitzschia clausii</i>	1%		1%		6%		2%	3%		2%	1%			
<i>Nitzschia communis</i>							2%							
<i>Nitzschia elegantula</i>								1%						
<i>Nitzschia filiformis</i>			1%					1%						
<i>Nitzschia fonticola</i>														1%
<i>Nitzschia frustulum</i>		3%		1%			1%						1%	3%
<i>Nitzschia gandersheimensis</i>					3%									
<i>Nitzschia gracilis</i>			1%		7%	6%		1%						
<i>Nitzschia inconspicua</i>				4%				4%	12%	23%				
<i>Nitzschia microcephala</i>					5%									
<i>Nitzschia nana</i>					9%	3%	1%							
<i>Nitzschia palea</i>					11%	6%		1%				4%	3%	
<i>Nitzschia paleaeformis</i>						8%							1%	
<i>Nitzschia perminuta</i>					1%									1%
<i>Nitzschia sp24</i>							2%							
<i>Nitzschia sp4</i>								2%						
<i>Nitzschia sp9</i>														1%
<i>Nitzschia supralitorea</i>													3%	
<i>Nitzschia tubicola</i>					4%									
<i>Pinnularia obscura</i>						6%		1%						
<i>Pinnularia viridiformis</i>								1%						
<i>Placoneis clementis</i>													11%	
<i>Planothidium engelbrechtii</i>			3%										1%	
<i>Planothidium frequentissimum</i>			2%										1%	
<i>Sellaphora pupula</i>					1%								55%	
<i>Sellaphora seminulum</i>					1%					1%	1%		1%	1%
<i>Stauroneis heinii</i>						8%		1%						
<i>Stauroneis pachycephala</i>	1%	5%		1%						2%				1%
<i>Staurosirella sp1</i>														1%