Richards Bay Minerals

Environmental Water Quality in Streams: Smelter Site

2013-2014 Monitoring Cycle

Prepared by NJ Griffin Pr.Sci.Nat.
Unilever Centre for Environmental Water Quality
Institute for Water Research
Rhodes University
PO Box 94
Grahamstown
South Africa

September 2014

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 March and July 2014, with minor collections from one site during December 2013 and June 2014. 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	Fair	45	Good	Good	Good
7	Fair/Poor	70	Good	Good	Fair/Good
10	Poor	52	Good	Good	Fair/Good
11	Fair/Poor	47	Good	Good	Fair/Good
12	Fair/Poor	59	Good	Good	Good
13	Good	52	Good	Good	Good
14	Good	53	Good	Good	Good
19	Fair/Poor	48	Good	Good/Natural	Good

Sites higher in the catchment in general had worse overall classification than sites lower in the catchment. This classification is in general driven by macroinvertebrate scores, as diatom and water quality classifications varied little between sites. While variation in several water quality parameters was observed, unusually low nutrient levels across the catchment elevated the water quality scores.

Overall site classifications were in general an improvement on those from the previous year, driven by better diatom and water quality scores.

The decrease in water quality and ecological health of the Mpisini River as it passes the RBM Smelter complex that has commonly been noted in previous years is apparent in data from this reporting cycle. The change is marked by lowered diatom scores, together with elevated pH, salinity and oxygen levels. Despite this apparent change, the ecological health at site 11, which drains the entire catchment around the Smelter complex, is generally good (the low macroinvertebrate score can be attributed to the highly limited habitat at the site).

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).

A new sampling site, site 19, was introduced this reporting cycle as an upstream control in the Mpisini River following the appearance of red bacterial floc at site 1, previously the upstream site in this river. The site, being in standing water, is not appropriate for SASS5. However, diatom scores indicate that the site has the best ecological health of all in this survey. It seems therefore likely that some degradation occurs along the Mpisini River even as far upstream as site 1.

The number of macroinvertebrate taxa collected at site 11 per visit ranged from 9 in July 2014 to 14 in March 2014. The average number of taxa per sample was 11.8, and the total number of taxa collected through the year was 24. This is an increase over the previous year, when an unusually low number of taxa were found.

Table of Contents

Tables

Figures

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 from 2013 to 2014.

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.

There is concern that 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.

The specific tasks to successfully undertake comprehensive biomonitoring during at all identified sites during summer and winter are as follows:

1. Undertake aquatic macroinvertebrate biomonitoring at 8 identified sites (includes on-site SASS biomonitoring and collection of two subsequent replicate samples using SASS protocol at each site for enumeration in the laboratory and statistical/community analysis).
2. Undertake diatom biomonitoring at the same sites and undertake statistical and community analysis on diatom counts and indices.
3. Undertake a habitat assessment (IHAS) at the 8 identified sites.
4. Undertake water quality monitoring of the following parameters: nutrients (specifically, Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP)), chlorophyll-a analysis (of phytoplankton and periphyton), biological oxygen demand (BOD), turbidity, electrical conductivity as TDS proxy, dissolved oxygen, water temperature and pH at each of the 8 identified sites.

In addition to the comprehensive biomonitoring at 8 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 and autumn. The tasks to successfully undertake the limited biomonitoring are:

1. Undertake on-site SASS biomonitoring at Site 11.
2. Undertake a habitat assessment (IHAS) at Site 11.
3. Measure turbidity, electrical conductivity as TDS proxy, 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 eight sites: 1, 7, 10, 11, 12, 13, 14, and 19 (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 summer (March 2014) and winter (July 2014). Additionally limited biomonitoring was undertaken at Site 11 during spring (December 2013) and autumn (June 2014), and consisted of SASS biomonitoring only, and the 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 2-Table 9).

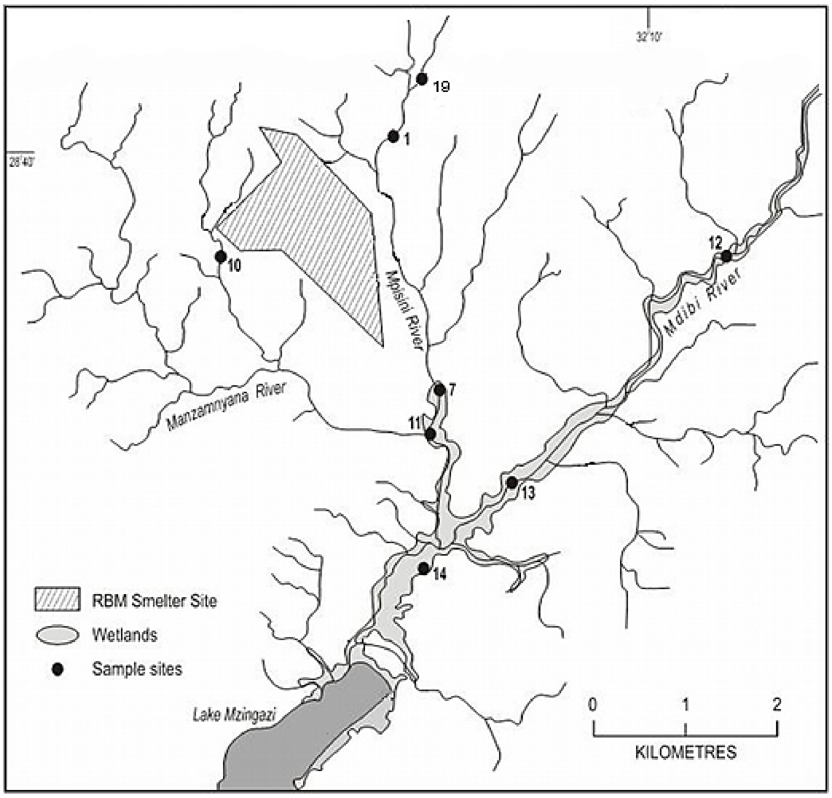

Figure 1 Monitoring points along rivers in the Smelter Site area.

2.2 Water quality assessment

Water samples were collected during the March 2014 survey 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: NO_2-N, NO_3-N, NH_4-N and PO_4-P (soluble reactive phosphorus-SRP). The nitrogen data were combined to obtain total inorganic nitrogen (TIN) concentrations. During the July 2014 survey, water samples were collected and delivered to Mhlatuze Water Scientific Services for nutrient analysis in their accredited laboratory.

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 5-day test (BOD5) was used and analyses undertaken by Mhlatuze Water Scientific Services.

In addition to the parameters described above, on-site measures of dissolved oxygen (DO), electrical conductivity (EC), temperature, pH and turbidity were assessed using appropriate field meters 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 March (summer) and July (winter) 2014. 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≥17
Good	15-17	17>BDI≥13
Moderate	12-15	13>BDI≥9
Poor	9-12	9>BDI≥5
Bad	<9	BDI<5

Previous reports (Muller *et al*. 2007, Gordon *et al*. 2008, 2010, Gordon and Griffin 2012, Holland *et al*. 2011, Griffin and Holland 2013) 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 IPS and BDI-2006 using weight of evidence to derive an overall sample classification.

2.4 Statistical analysis

Analysis of variance and post-hoc testing of macroinvertebrate and diatom scores was undertaken using R 3.0.2 (R Development Core Team, 2013).

Calculation of alpha diversities and ordination of diatom and macroinvertebrate community data was undertaken using non-metric multidimensional scaling using the package vegan (Oksanen *et al*., 2013). Multivariate community analysis employed ordination using non-metric multidimensional scaling of distance matrices produced using the Bray-Curtis index applied to untransformed abundance data (after Minchin 1987). The diatom ordination used a dataset without rare taxa, where rare is defined as taxa occurring in two or fewer samples The use of beta diversity as a potential indicator of stress follows Warwick and Clarke (1993). 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

The results of all tests and analyses undertaken over the 2013-2014 monitoring cycle are presented below.

3.1 Water quality assessment

Variation in water temperature at the sampled sites is presented in Figure 2 below. There is little notable change in temperature along the river system. Water temperatures were several degrees warmer in March than in Jul 2014 owing to seasonal changes.

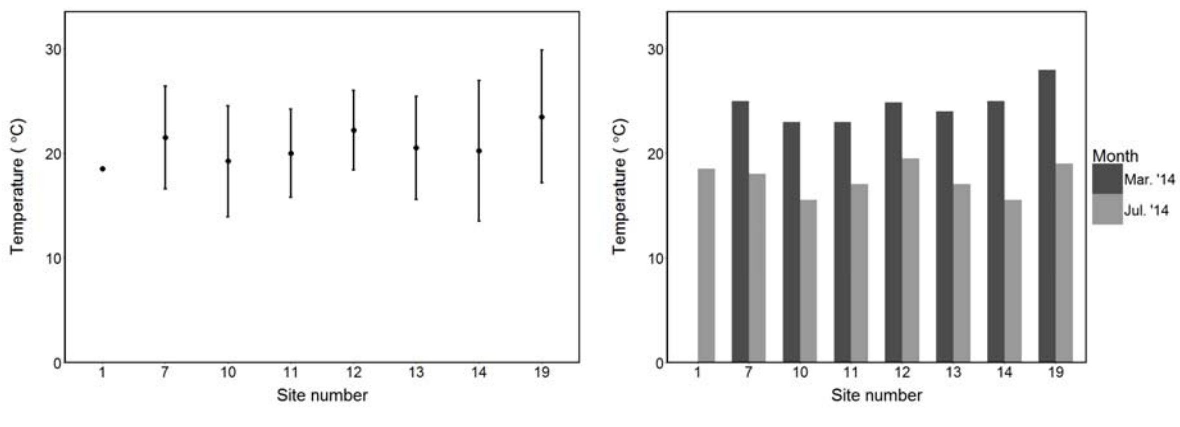

Figure 2 Mean ± standard deviation in water temperature at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure.

Variation and temporal change in pH levels at the eight sampling sites are presented in Figure 3. Annual mean pH levels over the sampled period would be classed as good or natural, although the March results at site 12 would be classed as fair. In general, pH levels were higher during July than they were in March. However, in sites in the Mpisini River (sites 1 and 19), the reverse was found to be true, although the difference between data from the two sampling times was minor. Overall, pH levels were slightly higher than the previous year.

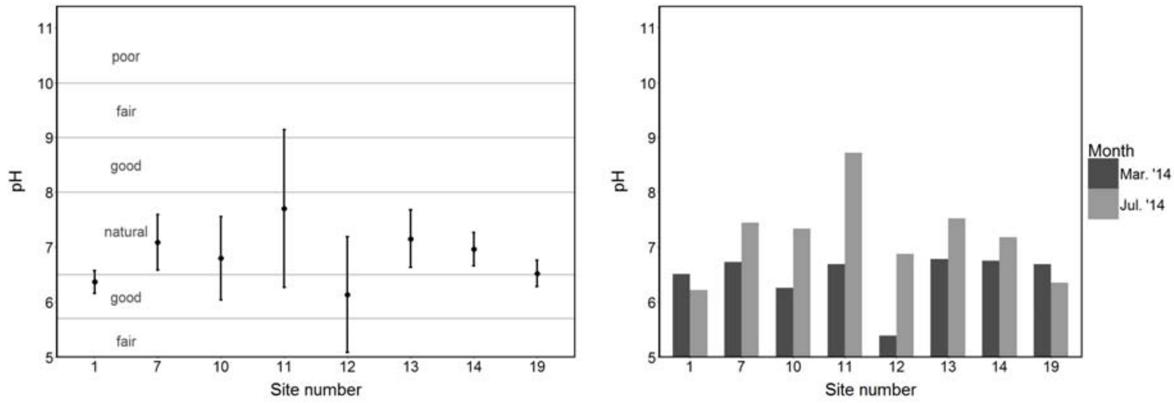

Figure 3 Mean ± standard deviation in pH at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the left hand figure.

Electrical conductivity levels are generally lower at upstream sites 10, 12 and 19 than they are at sites further downstream (Figure 4). Electrical conductivity levels do not change significantly between upstream site 19 and midstream site 1 on the Mpisini River, but increase sharply between site 1 and downstream site 7. This increase has been noted at this site before and appears to be related to proximity to/and or drainage from the RBM Smelter site. Site 11 at the confluence of the Mpisini and Manzamnyama Rivers and downstream of site 7 had comparable conductivity levels. As site 10 upstream on the Manzamyama River has relatively low conductivity, it seems likely that conductivity levels at site 11 are a function of input of water from the lower Mpisini River (although the Mazamnyama River also flows past the RBM Smelter site to the west and some level of consequent impact cannot be ruled out). Conductivity levels at all sample sites in the Mdibi River are higher than upstream sites in the Mpisini and Mazamnyama systems, and increase steadily with distance downstream.

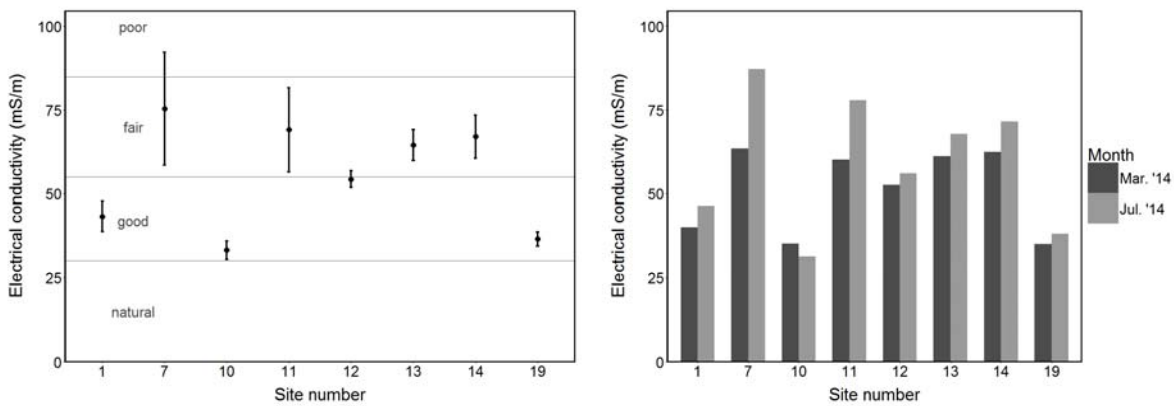

Figure 4 Mean ± standard deviation in electrical conductivity levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the left hand figure.

Conductivity levels were greater at all sites bar site 10 in July as opposed to March. In general, conductivity levels recorded during 2014 were greater than those from the previous 2012-2013 sampling cycle.

Dissolved oxygen levels in the various sampling sites during the 2013-2014 sampling cycle are presented in Figure 5. Owing to an instrument malfunction, data are only available from the March sampling trip. The majority of sites assessed have fair to good oxygen levels, with no major spatial trends. The major exception to this generality is the low, poor level of oxygen observed at site 10 upstream on the Manzamnyama River. Low oxygen levels at this site have been consistent over recent years and can be attributed to the site being groundwater-fed with limited surface flow.

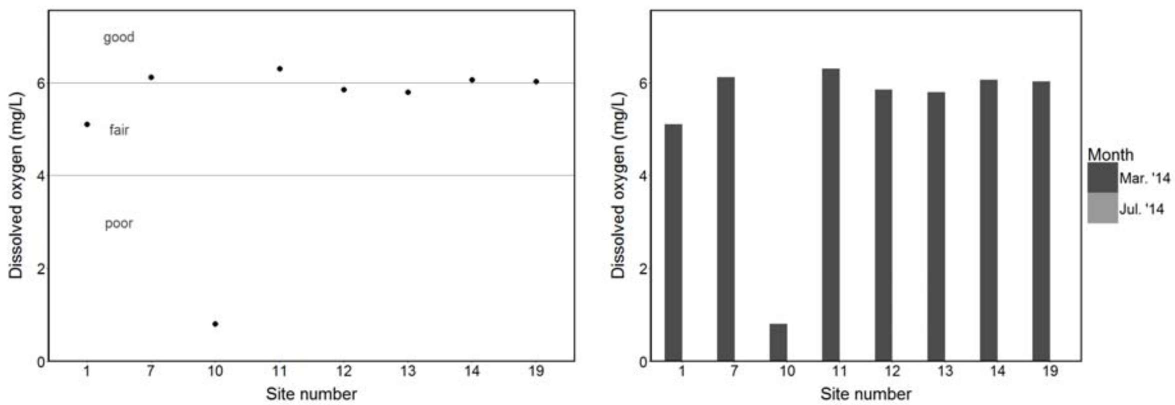

Figure 5 Mean ± standard deviation in dissolved oxygen levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the left hand figure.

The 5-day biological oxygen demand (BOD_5) of water samples from the various sample sites are presented below in Figure 6. BOD_5 levels varied little across sites, and shifted from 2 to 3 mg/L. Given the resolution of the test method, no clear spatial or temporal trend in this parameter can be identified. Levels of BOD_5 at site 10 are consistently 3 mg/L, and, alone, are not able to fully account for the low oxygen levels at this site.

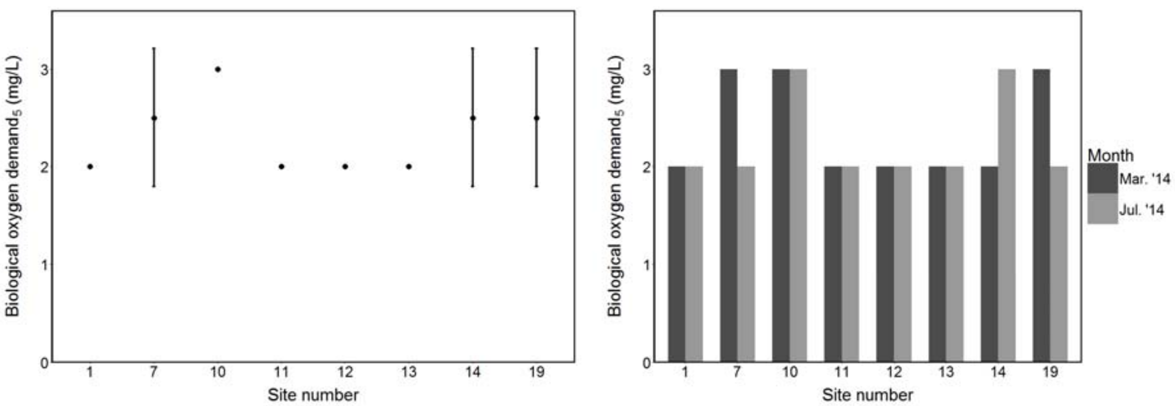

Figure 6 Mean ± standard deviation in 5-day biological oxygen demand (BOD_5) levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure.

Changes in turbidity levels across the various sampling sites are presented in Figure 7. Site 10 stands out from the other sites assessed here because of elevated and consistent turbidity at this site. The levels at site 10 are likely a function of the quantity of easily disturbed organic material and biofilm found on submerged surfaces at this site, and, in the absence of any disturbance, turbidity at this site would likely be lower. Beyond the elevated levels at site 10, and somewhat low levels at site 19, the latter probably because of the lack of bacterial biofilm in standing water, elevated levels of turbidity at sites 1, 7, and 11 in the Mpisini River were noted in March as opposed to July 2014.

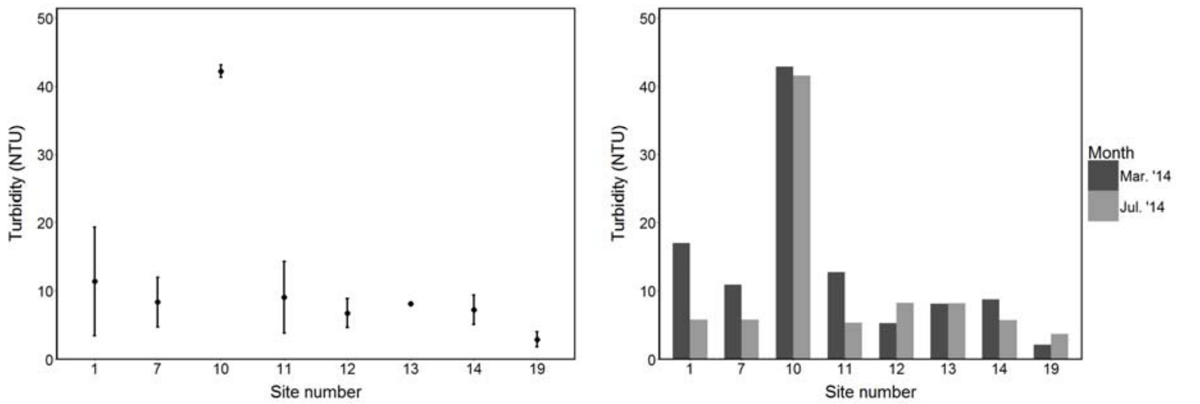

Figure 7 Mean ± standard deviation in turbidity levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure.

Data on total inorganic nitrogen (TIN) levels at sampling sites are presented in Figure 8 below. Analyses of nitrogen levels in March 2014 produced levels that were unrealistically low and deemed unreliable. TIN levels varied between sites but were overall low and classed as natural. In general, TIN levels increased as samples were collected lower in the catchment. Levels were lower than the previous year.

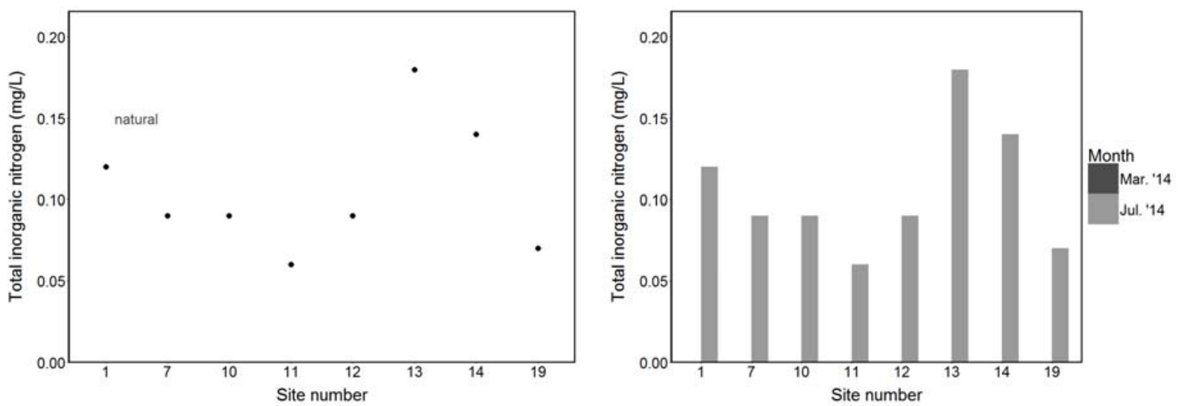

Figure 8 Mean ± standard deviation in total inorganic nitrogen (TIN) levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure. No data were available for March 2014. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the left hand figure.

Data on orthophosphate or soluble reactive phosphorus are presented in Figure 9. Analyses of orthophosphate levels in March 2014 produced levels that were unrealistically high and deemed unreliable. Samples from July 2014 contained levels of orthophosphate that were identical (being below the detection limit of the test) and values of half the detection limit were substituted. As a result, sites cannot be distinguished on the basis of orthophosphate levels and all sites are classed as natural/good. Levels were lower than the previous monitoring cycle.

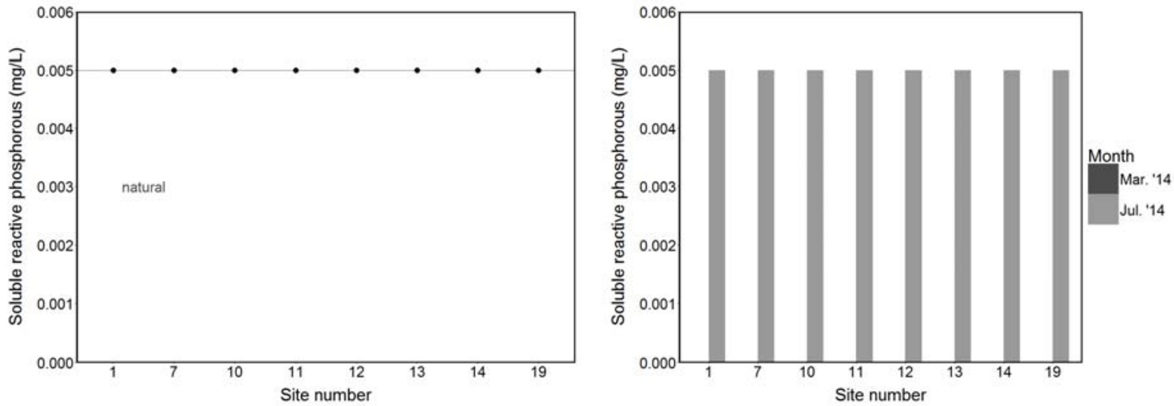

Figure 9 Mean ± standard deviation in soluble reactive phosphorus (SRP) or orthophosphate levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure. No data were available for March 2014. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the left hand figure.

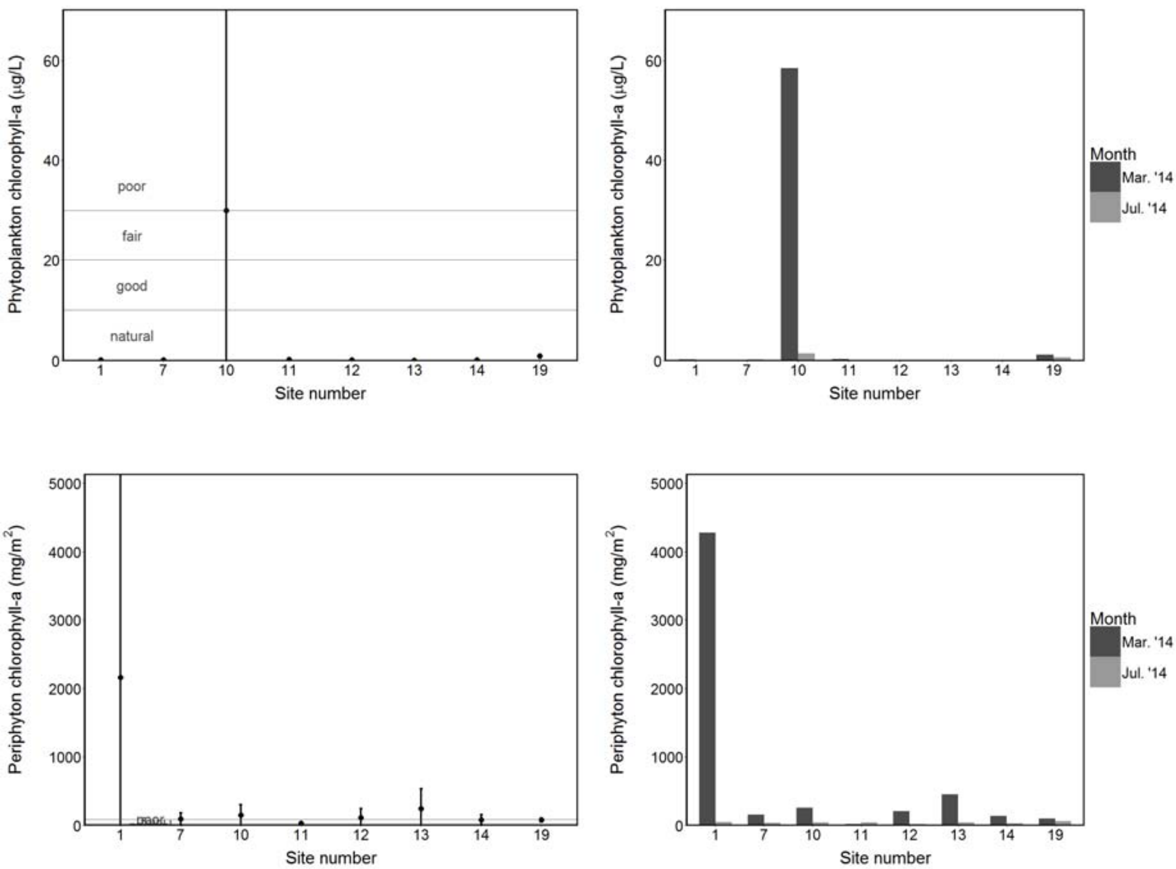

Figure 10 Mean ± standard deviation in phytoplankton (top) and periphyton (bottom) chlorophyll *a* levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figures. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the left hand figure.

Levels of chlorophyll *a* in phytoplankton (suspended algae) and periphyton (attached algae) over two sampling periods are presented above in Figure 10. When compared with standards, phytoplankton chlorophyll *a* levels were low and most samples were classified as natural, but periphyton chlorophyll *a* levels were higher and many samples were fair at best, or poor. Considerable variation between samples with space and time in both measures were present.

The March sample from site 10 had notably higher phytoplankton chlorophyll a levels than any other sample. This is likely a function of disturbance of the site owing to cattle that entered the sampled area while sampling was underway and before a collection of water could be made. The impact of cattle at this site has been noted before. The remainder of the sites have low phytoplankton chlorophyll *a* and all are classed as natural. No clear spatial or temporal patterns in this parameter are apparent. Levels of this parameter were similar to those recorded during the previous monitoring cycle.

At all sites bar site 11, periphyton chlorophyll *a* levels were significantly higher in samples collected in March compared with those collected during July. No other obvious spatial trends were apparent. Periphyton chlorophyll *a* levels are significantly higher than the previous monitoring cycle.

3.2 Habitat assessment

With the exception of site 7, IHAS scores were generally low at all sample sites (Figure 11). Site 7 is the only sample site with a stones biotope and this is the primary reason for the elevated IHAS score. All sites had gravel-sand-mud and vegetation biotopes. The score for site 12 was slightly higher than those of the remaining sites. Temporal variation in IHAS scores was relatively low, and no trends with time were apparent in the data collected.

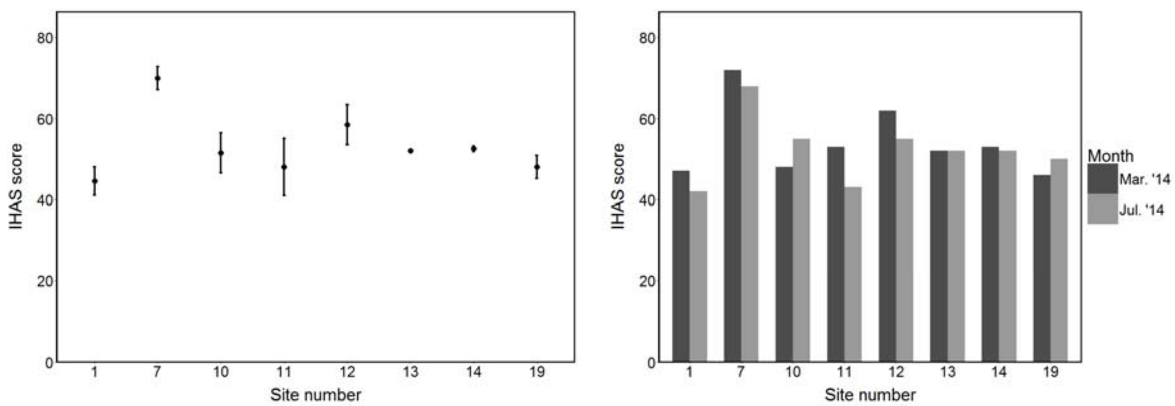

Figure 11 Integrated Habitat Assessment System (IHAS) scores at each sample site. The left plot shows the mean score ± standard deviation, and the right plot shows temporal change in this index.

3.3 Macroinvertebrate assessment

3.3.1 Macroinvertebrate indices

The results of macroinvertebrate biomonitoring at the sample sites are shown in Figure 12. Sample sites reported on here would be classed as poor, fair or good, with none falling into a natural class. In general, upstream sites returned lower scores that downstream ones.

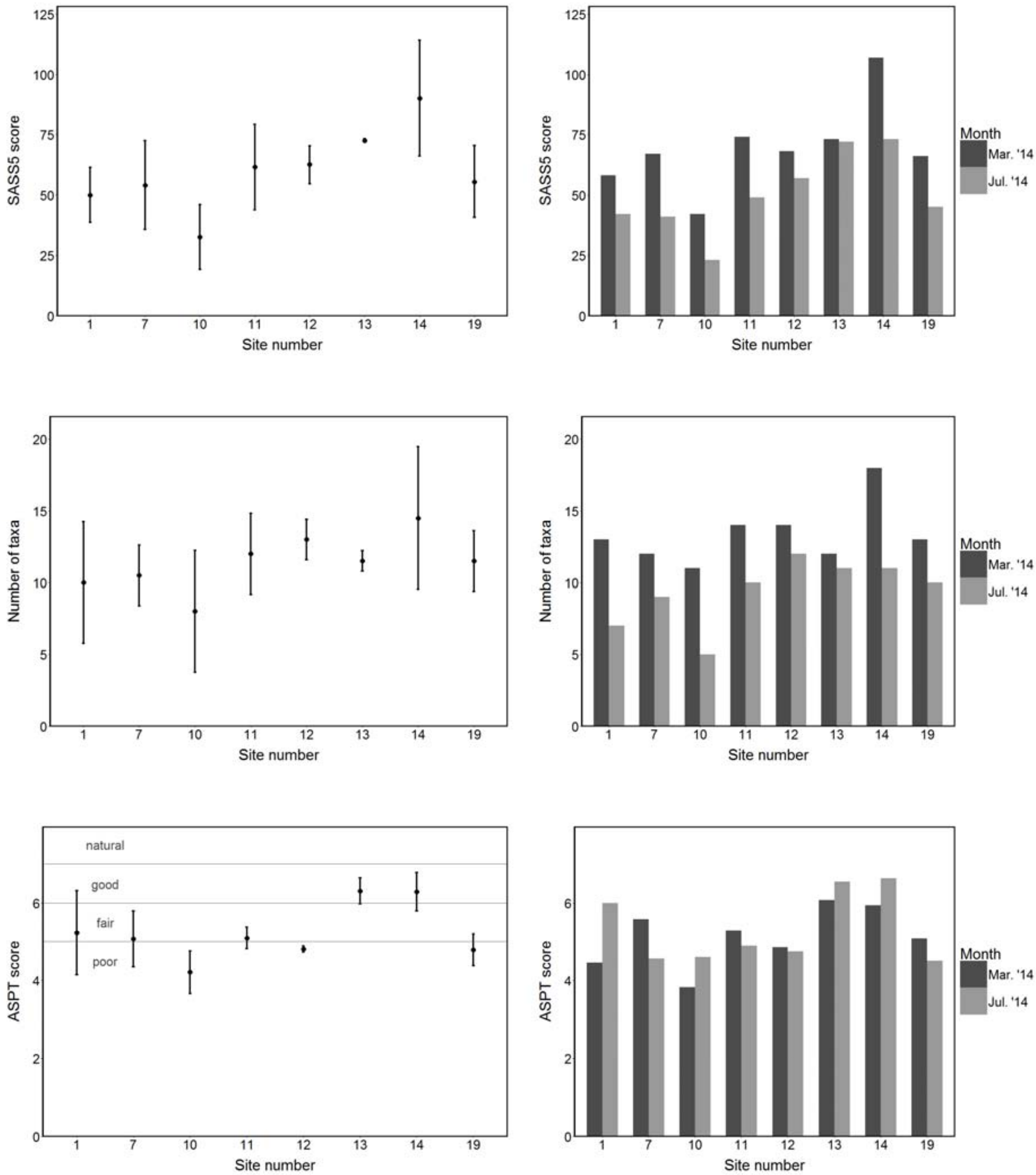

Figure 12 Macroinvertebrate biomonitoring scores, as SASS score, number of taxa, and ASPT score at the various sample sites. Plots to the left show mean ± standard deviation, while plots to the right show temporal changes in the indices. Default ecological categories for ASPT scores based on ecological Reserve determination methodologies are shown.

Sites 10, 12 and 19 all would be classed as poor over the monitored period. Each of these is upstream on the Manzamnyama, Mdibi, and Mpisini Rivers, and might be expected to be above impacts on the ecological health of the rivers. Site 10 commonly returns low scores, as the site is located under a wetland with slow flow, overgrowth by red bacterial floc, and consistently low oxygen levels. Site 19 is a new site, upstream of site 1, that was assessed as a control site for the assessment of apparent degradation of site 1. The site was selected as it is accessible and further upstream in the system and further removed from RBM Smelter operations. The site is in a small dammed stretch of the river, and as a consequence is in standing water. The

SASS5 methodology was designed for use in low to moderate flows and is specifically contraindicated for application in standing water. This, combined with limited habitat at the site, may explain the low scores encountered at this site. Site 12 is a site where, despite an apparently clean environment, red bacterial floc has been noted at times, and low macroinvertebrate biomonitoring scores have been the norm for several years.

There was very little change in macroinvertebrate biomonitoring scores across sites in the Mpisini/Manzamnyama system, as the scores from sites 1, 7 and 11 were indistinguishable and were all classed as fair. These scores were an improvement on upstream sites 10 and 19. A decrease in the biomonitoring scores at site 7 has been made before, and the data presented here confirm the trend. Despite better and more varied habitat at this site, the biomonitoring scores were not distinguishable from those at sites 1 and 11, where worse habitat might have been expected to lead to lower scores.

Biomonitoring scores along the Mdibi River improved considerably with distance downstream, shifting from poor at site 12 to good at sites 13 and 14. These results are similar to those from previous years, where, despite the impact of flowing through a settled area, the biomonitoring results at the downstream sites were as good as or better than upstream sites.

Both SASS and NOT scores were consistently higher in samples collected in March compared to those from July. ASPT scores on the other hand showed no clear temporal pattern.

3.3.2 Macroinvertebrate community analysis

A biplot showing the results of a NMDS ordination of a Bray-Curtis distance matrix based on differences in macroinvertebrate family-level community composition between samples is presented in Figure 13. Statistically significant differences were found between the various sample sites ($p<0.001$) and times of sampling ($p<0.001$).

A major trend apparent in Figure 13 is a clear distinction between the community composition of samples collected in March and in July, with July samples being placed to the top right of the plot, and March samples being found on the bottom left of the plot. Considerably more variation between samples was found in the March samples ($p=0.009$), which show major changes in community composition from sites 10 and 11 on the bottom right of Figure 13 to sites 12, 13 and 14 on the upper left. In March, the results for site 1 reveal this to be somewhat distinct from other sites sampled at this time.

Samples from July show far less inter-sample variation than those collected in March. Despite this, the broad trend of a gradient in community composition from site 10 to sites 12, 13 and 14 is maintained. A change in community composition from site 10, an upstream, groundwater-fed site to sites 13 and 14, the lowest sites in the catchment, is to be expected. However, it is somewhat surprising that samples from site 12, highest in the Mdibi catchment, and those from site 19, highest in the Mpisini catchment, are not more clearly separated from downstream sites.

Site 19 was newly introduced in the 2014 biomonitoring cycle in an attempt to introduce a better control site on the upstream Mpisini River. Site 19 is situated in standing water behind a small dam, and flow changes between this and other sites could be expected to affect invertebrate community structure. In this light, it is notable that samples from this site are not easily distinguished from those in several other sites, most notably site 7.

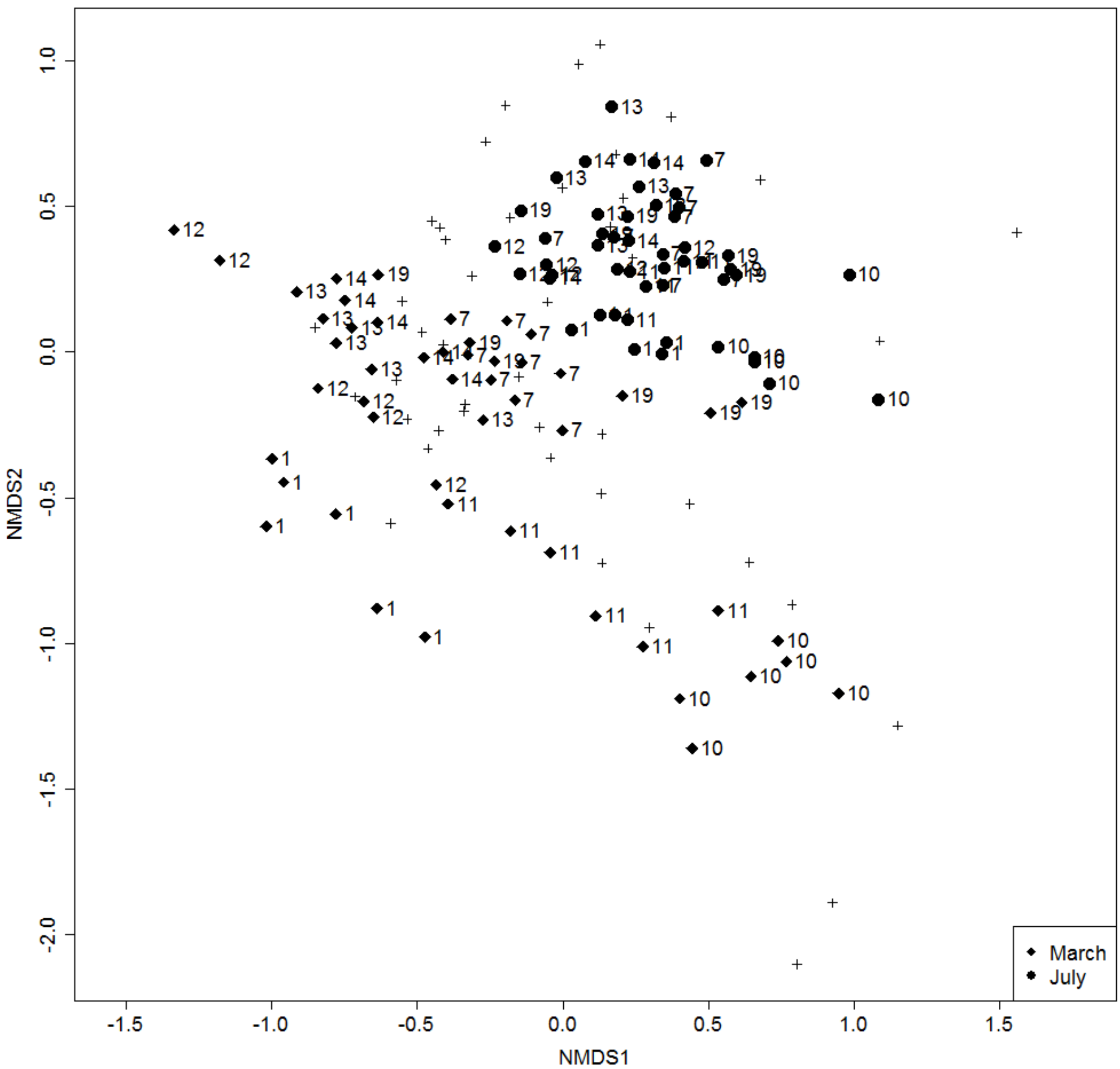

Figure 13 NMDS ordination plot of Bray-Curtis distances between all samples assessed based on untransformed invertebrate family-level abundances (stress: 14.6%). Sites are labelled and species indicated by +.

Increased sample to sample variation within any particular site (or beta diversity) has been used as an indication of habitat structure and diversity (Anderson et al. 2006) as well as a potential measure of stress (Warwick and Clarke 1993). No significant differences between sites in beta diversity were detected (p=0.071).

Alpha diversity as number of taxa per sample varied between sites (p<0.001), with sites 1 and 19 having in general fewer taxa, and site 13 in particular having more taxa overall. Alpha diversity as Shannon diversity found differences between sites (p<0.001) and sampling time (p=0.002). The trends across sites in this parameter were the same as when the number of taxa were assessed. Samples from March had higher diversity than those from July.

3.4 Diatom assessment

3.4.1 Diatom indices

The results of diatom biomonitoring using three indices are presented in Figure 14. Scores returned from the various sites ranged from the classes moderate to high. While the results vary depending on the index adapted, there is a general agreement that sites 1, 11 and 19 returned better scores than other sites, and that sites 7, 13 and 14 returned lower scores. Both the IPS and the score based on expert opinion found statistically significant differences between the sites (p=0.050 and p=0.047 respectively). No index could be linked to statistically significant changes in scores with time of sampling.

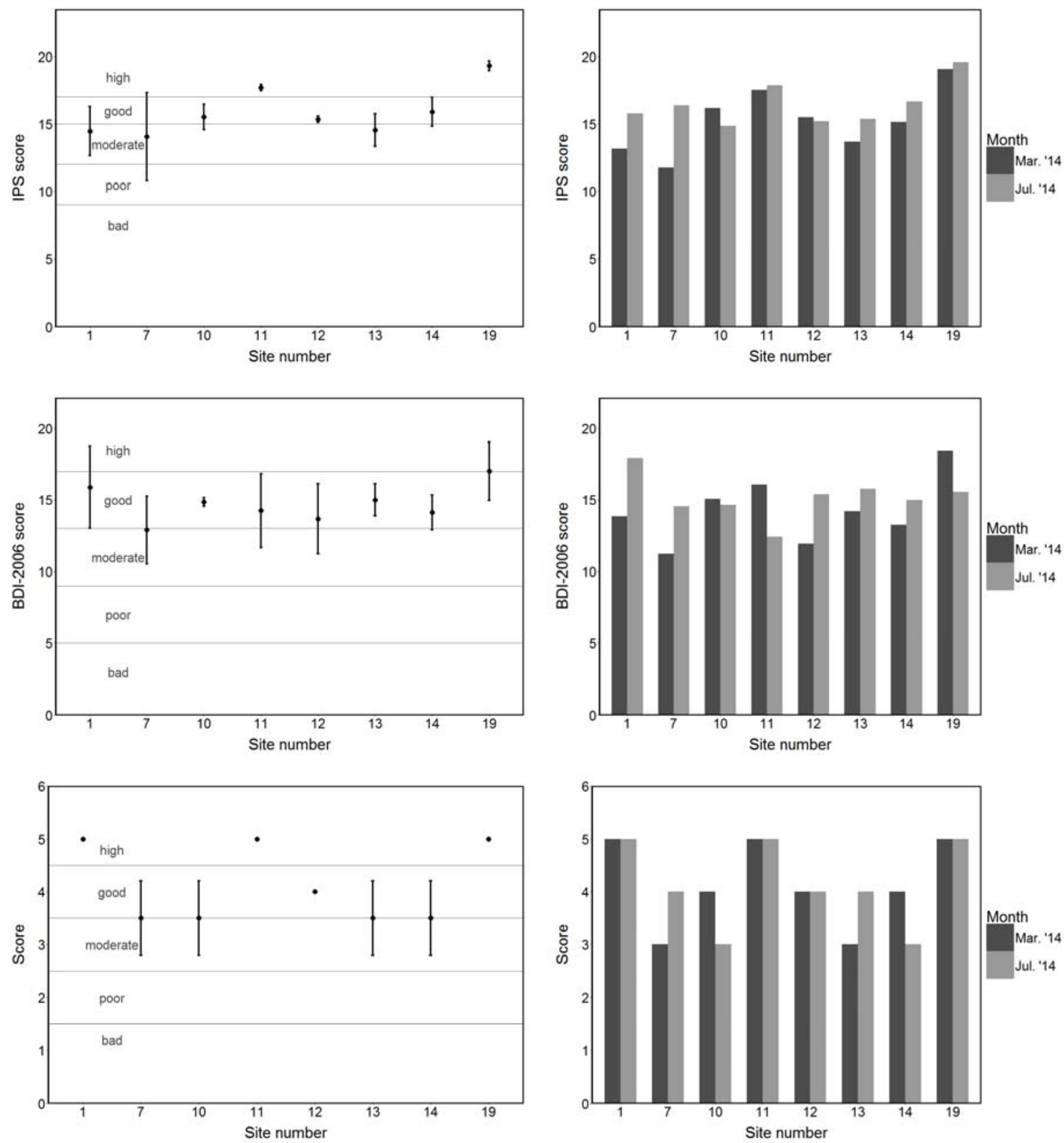

Figure 14 Diatom biomonitoring scores, as IPS score, BDI-2006 score, and the score based on expert opinion at the various sample sites. Plots to the left show mean ± standard deviation, while plots to the right show temporal changes in the indices. Ecological categories for the various scores are shown.

The diatom scores at site 19, upstream on the Mpisini River are consistently the best of the sites sampled, and samples from this site are generally classed as being of high quality. Site 1 is approximately 1.6 km downstream, and at this point the index scores have dropped such that samples from this site would be classed as moderate to good by all bar the index based on expert opinion. Site 7 is approximately 3.1 km further downstream, and in this stretch the river flows past the RBM Smelter complex. All indices record a decrease in index score along this stretch, and scores from site 7 range from moderate to good. This decrease in water quality along this stretch has been recorded and noted for several years (Gordon *et al*. 2008, 2010, Gordon and Griffin 2012, Holland *et al*. 2011).

Site 10 is the uppermost site on the Manzamnyama River, and is located below a groundwater-fed wetland with slow flow, overgrowth by red bacterial floc, and consistently low oxygen levels. Scores from this site during this reporting cycle were for the most part good. Although the results from diatom biomonitoring at this site are generally better than those from invertebrate monitoring, it is of interest that the scores reported from this site are generally lower than those from other upstream sites in the broader Mdibi catchment. The cause of this is not known. The site has been noted to have a somewhat differing diatom presence (e.g. *Stauroneis heinii* is typical at this site, but rare elsewhere). Several possible causes may be proposed, though no hard evidence is available to firmly support any of them: it is possible that the chemical composition of the water feeding this site may underlie this; regular disturbance of the site by cows may contribute; the RBM Smelter complex is close and it is possible that some impact may be attributed to this; bacterial floc overgrowth of surfaces may alter the suitability of the site to particular diatoms.

Site 11 is at the confluence of the Mpisini and Manzamnyama rivers, and the diatom scores at this point are often better than scores from upstream sites 7 and 10. This trend continued through the 2013-2014 sampling cycle, with the site being classed as high by two indices, while according to the BDI-2006 index the site was good quality. The reason for the improvement is not known, but it has been noted in the past.

The uppermost site on the Mdibi River is site 12, which would be classed overall as good according to all indices, and as having a similar score to site 10 upstream on the Manzamnyama River. Score from this site used to commonly be the best in the entire Mdibi catchment, but in roughly 2012 lower scores were encountered and these seem to have become the norm. The cause of this is not known, but may relate to impacts from scattered human settlements that abut the river upstream. Site 13 is approximately 3.8 km downstream, and in this stretch the river passes scattered and denser human settlements. Depending on the index used, the scores at site 13 roughly approximate those or are slightly lower than those at site 12. Site 14 is a further 1.5 km downstream, and in this stretch receives input from the combined Mpisini-Manzamnyama catchments as well as a small stream draining a settled area. Index scores at site 14 are similar to those at site 13.

The differences in scores between the IPS and the BDI-2006 index are largely a function of the species used to derive the scores. For example, *Achnanthes oblongella* is common and occasionally dominant in samples from this area, and this is used in calculating the IPS index, but not the BDI-2006 index. Another difference between the two is that, where species cannot be identified beyond genus level, a generic score for that genus may be used in deriving the IPS index, but not the BDI-2006 score. A difference between the calculated IPS and BDI-2006 scores and the score based on expert opinion is that the latter incorporates taxa that have been found to be typical of clean sites in this region in the past but are not used by the IPS and BDI-2006 indices.

3.4.2 Diatom community analysis

The ordination biplot of samples ordinated on the basis of diatom community differences is presented below in Figure 15. Stress levels in the plot are high, indicating the distance between sites in Figure 15 may misrepresent the ecological distance. Changes in diatom community structure between sites was statistically highly significant ($p<0.001$). Changes with time of sampling were also significant ($p=0.008$).

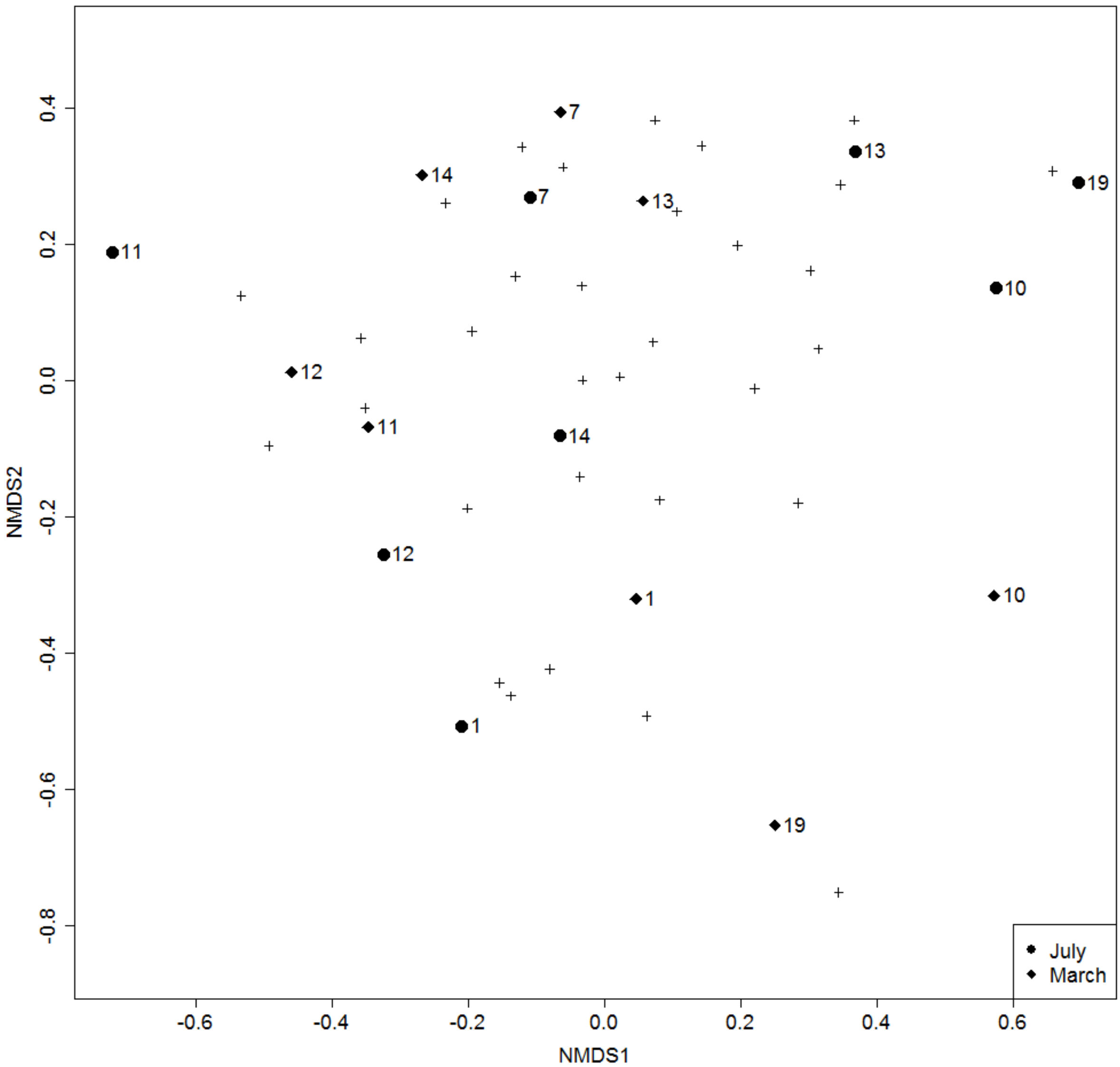

Figure 15 NMDS ordination plot of Bray-Curtis distances between all samples assessed based on untransformed diatom species-level abundances (stress: 21.1%). Sites are labeled and species indicated by +.

Sites that had lower diatom index score are to be found to the upper central area of the plot, with + marks in this region indicating the species characteristic of these sites. Upstream sites can be seen to vary widely from site to site. Samples from site 19, furthest upstream on the Mpisini River, are separated from other sites to the upper and lower right of Figure 15, and show considerable change between sampling trips. Samples from site 10, upstream on the Manzamnyama River, are to the middle right of the plot separate from other plots though not distinct from those at site 19, indicating an overlapping diatom community structure. In contrast, samples from site 12, upstream on the Mdibi River are towards the left centre of the plot, loosely associated with samples from sites with lower index scores, and distinct from samples from sites 10 and 19. It is clear from Figure 15 that diatom communities at upstream, apparently undisturbed sites in the Mdibi River vary significantly from site to site.

Samples from site 11 are located close to those from site 12, although diatom index scores were generally better at site 11. Both sites had diatom communities with *Achnanthes oblongella* dominant or subdominant. Samples from Site 1, which lies downstream of site 19 and generally recorded fairly good index scores, are found to the lower centre of the plot. Despite the short distance and lack of obvious disturbance between site 1 and 19, a change in diatom community structure between the sites is apparent, most particularly in samples from July.

The change in index scores between site 1 and 7, the next site downstream, is commented on above. The change in community structure between the two sites is evident in Figure 15 as samples from the two sites are located on opposite sides of the plot, indicating a large ecological distance between the two.

In terms of diatom community structure, sites with lower diatom index scores lower on rivers in the catchment generally show considerable overlap in community structure. This is in sharp contrast to the distinctive communities found at upstream sites.

The appearance of several new taxa over recent years has been noted in previous reports. Many of these are present in samples from the period reported on. Examples include *Stauroneis heinii* at site 10, unknown small species of *Cocconeis* at sites 13 and 14, and an unusual and unknown species of *Gomphonema* at several sites.

3.5 Extended biomonitoring at Site 11

This section covers data collected as part of the extended monitoring programme undertaken at site 11 at the confluence of the Mpisini and Manzamnyama Rivers. The data presented here were collected during sampling trips during December 2013, and March, June, and late July 2014.

The site showed evidence of cow trampling and fouling of banks and shallow water throughout the monitored year.

3.5.1 Water quality assessment

Water quality data from the extended monitoring programme at site 11 are presented in Figure 16 below. Electrical conductivities are fair throughout, and slightly lower in the wetter months of December and March than in drier June and July. pH levels were good to natural throughout. Between December 2013 and June 2014, pH levels were on the lower boundary of the natural class; however, in the July 2014 sample, pH levels climbed significantly to pass beyond the upper bound of the natural class and as a result being classed as good. The July 2014 pH levels were the highest of all sample sites assessed at the time. It is not known what caused this increase, particularly as upstream sites in the Mpisini and Manzamnyama Rivers do not show a matching increase. Water temperatures at site 11 ranged around 20°C, and were not surprisingly warmer in the warmer summer months that they were in the cooler autumn and winter months. Dissolved oxygen levels were good throughout, though no data are available from July 2014 owing to a malfunctioning probe. Levels were higher in June 2014 than at other times, possibly because oxygen dissolves more readily in cooler water.

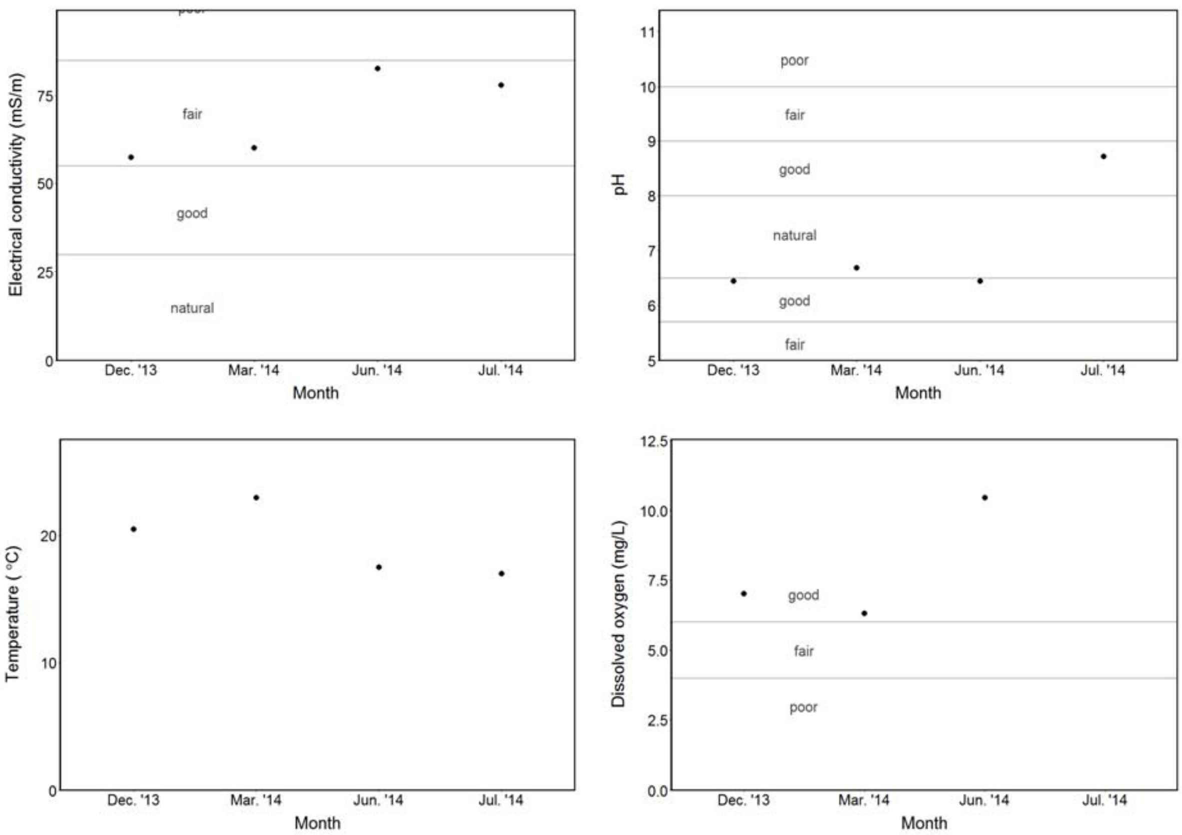

Figure 16 Electrical conductivity, pH, temperature and dissolved oxygen levels at site 11 between December 2013 and late July 2014. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the plots where appropriate.

3.5.2 Macroinvertebrate biomonitoring (SASS) and habitat assessment

The results of extended macroinvertebrate biomonitoring at site 11 are presented in Figure 17 below. Habitat quality as rated using IHAS decreased somewhat from the warmer, wetter months to the cooler, drier ones. Site 11 habitat quality is generally rated as fairly low when compared with other monitored sites. The SASS score changed relatively little from December 2013 to June 2014, but fell significantly thereafter in late July 2014. The number of taxa present in samples was greater in the warmer and wetter months of summer than in during the cooler and drier parts of the year. The consequence of the changes in the SASS score and the number of taxa is an increase in the score during June 2014, when the ongoing score that had hovered around the boundary between fair and poor increased to good. By July 2014 though the ASPT score had returned to the boundary between fair and poor. Data from recent years scores this site as fair or fair to poor, and in comparison to other sites the results from site 11 have weakened in recent years. The reason for the disappointing ASPT scores is likely linked to the relative scarcity of habitat at this site, where stones are effectively missing and vegetation is scarce.

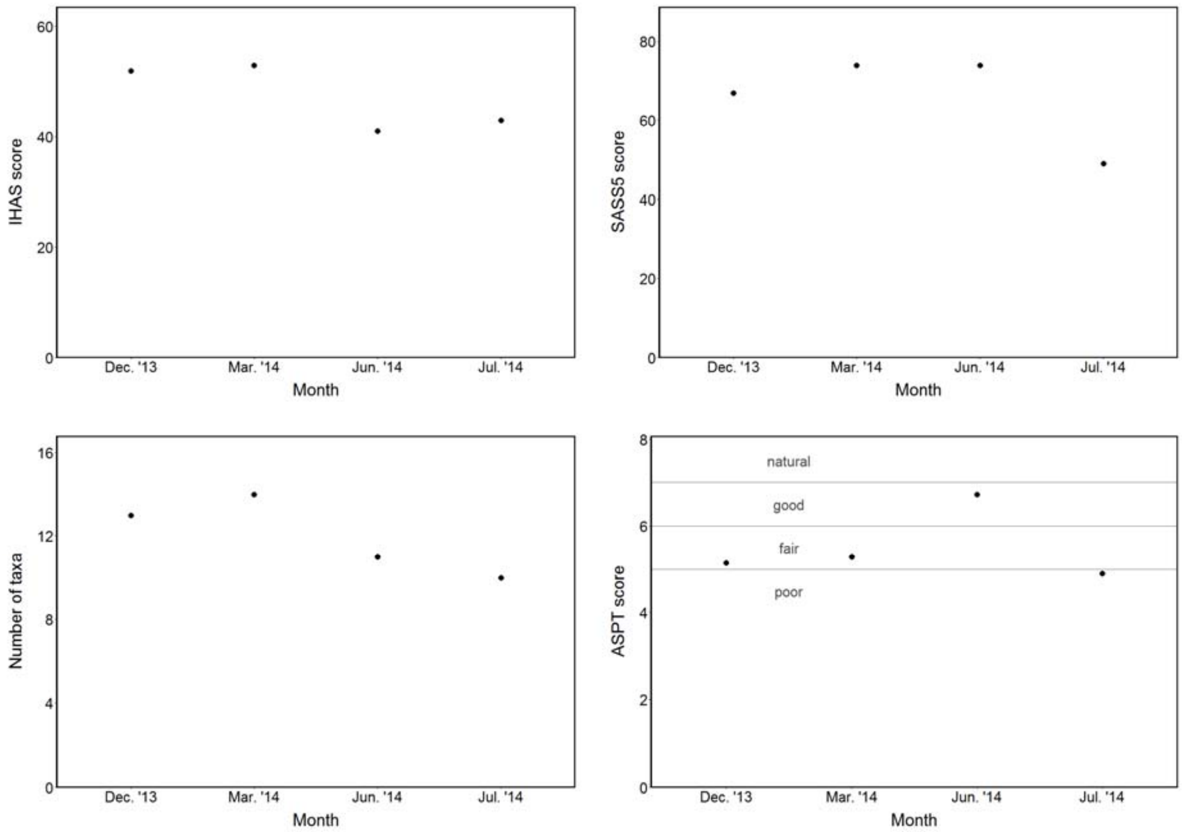

Figure 17 Integrated habitat assessment system (IHAS) score, SASS score, the number of taxa, and the ASPT score at site 11 between December 2013 and late July 2014. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the plots where appropriate.

4 Site summary and overall classification

Table 2 Summary of site 1 midstream on the Mpisini River.

Site description: This site is slightly upstream of the Smelter Site and was originally chosen as a possible reference site. In recent assessments, increased cover of red bacterial floc was noted. The first red floc appearance was recorded during winter 2011 and has been observed ever since. The GSM biotope is dominated by mud with limited sand, usually covered with leaf litter. Both marginal and aquatic vegetation biotopes are present.

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 *a*	
								Phytoplankton (µg/L)	Periphyton (mg/m^2)
18.5	6.4	5.1	43.2	0.12	0.005	2.0	11.4	0.15	2163
	Good/ Natural	Fair	Good	Natural	Good/ Natural			Natural	Poor

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.

ASPT	IHAS (%)	Diatoms	Water quality
5.2	44.5	3.8	Good
Fair		Good	

Overall ecological assessment: Good

Table 3 Summary of site 7 downstream on the Mpisini River.

Site description: The Mpisini river flows past the Smelter immediately upstream of this site. The surrounding land use is forestry, and 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, with some in a riffle. This is a cattle drinking site. Red bacterial floc levels have increased at this site.

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 *a*	
								Phytoplankton (µg/L)	Periphyton (mg/m^2)
21.5	7.1	6.1	75.4	0.09	0.005	2.5	8.3	0.17	93
	Natural	Fair/ Good	Fair	Natural	Good/ Natural			Natural	Poor

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.

ASPT	IHAS (%)	Diatoms	Water quality
5.1	70.0	3.4	Good
Fair/Poor		Moderate/Good	

Overall ecological assessment: Fair/Good

Table 4 Summary of site 10 upstream on the Manzamnyama River.

Site description: This site consists of a deep wetland lake which gradually becomes shallower 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.

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 *a*	
								Phytoplankton (µg/L)	Periphyton (mg/m^2)
19.3	6.8	0.8	33.2	0.09	0.005	3.0	42.3	29.98	148
	Natural	Poor	Good/ Natural	Natural	Good/ Natural			Fair/ Poor	Poor

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.

ASPT	IHAS (%)	Diatoms	Water quality
4.2	51.5	3.8	Good
Poor		Good	

Overall ecological assessment: Fair/Good

Table 5 Summary of Site 11 at confluence of the Mpisini and Manzamnyama Rivers.

Site description: The site is within a natural forest at the confluence of the Mpisini and Manzamnyama 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 in recent years.

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 *a*	
								Phytoplankton (µg/L)	Periphyton (mg/m^2)
19.5	7.1	7.9	69.6	0.06	0.005	2.0	8.4	0.19	28
	Natural	Good	Fair	Natural	Good/ Natural			Natural	Fair

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.

ASPT	IHAS (%)	Diatoms	Water quality
5.5	47.3	4.0	Good
Fair/Poor		Good	

Overall ecological assessment: Fair/Good

Table 6 Summary of site 12 upstream on the Mdibi River.

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. The vegetation biotope consists of aquatic plants and marginal grass. Red floc was recorded at this side for the first time during the summer 2013 sampling trip.

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 *a*	
								Phytoplankton (µg/L)	Periphyton (mg/m^2)
22.2	6.1	5.9	54.3	0.09	0.005	2.0	6.7	0.10	108
	Good	Fair/ Good	Fair/ Good	Natural	Good/ Natural			Natural	Poor

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.

ASPT	IHAS (%)	Diatoms	Water quality
4.8	58.5	3.6	Good
Fair/Poor		Moderate/good	

Overall ecological assessment: Good

Table 7 Summary of site 13 midway along the Mdibi River.

Site description: The site is located midstream on the Mdibi River downstream of a bridge culvert. Surrounding land use includes forestry and human settlements. The vegetation biotope is dominated by reed stalks and leaves, although there are some aquatic plants available. The 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 *a*	
								Phytoplankton (µg/L)	Periphyton (mg/m^2)
20.5	7.2	5.8	64.5	0.18	0.005	2.0	8.1	0.08	243
	Natural	Fair/ Good	Fair	Natural	Good/ Natural			Natural	Poor

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.

ASPT	IHAS (%)	Diatoms	Water quality
6.3	52.0	3.7	Good
Good		Good	

Overall ecological assessment: Good

Table 8 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. The 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 *a*	
								Phytoplankton (µg/L)	Periphyton (mg/m^2)
20.3	7.0	6.1	67.0	0.14	0.005	2.5	7.2	0.12	81
	Natural	Fair/ Good	Fair	Natural	Good/ Natural			Natural	Fair/ Poor

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.

ASPT	IHAS (%)	Diatoms	Water quality
6.3	52.5	3.8	Good
Good		Good	

Overall ecological assessment: Good

Table 9 Summary of site 19 upstream on the Mdibi River.

Site description: This is the uppermost site on the Mpisini River, and sampling here started following the increase in bacterial floc at Site 1 downstream. The site is located on a small reservoir in the upper river. There is substantial marginal and aquatic vegetation at the site, and the GSM biotope is represented by a sandy bottom. No upstream impacts are known, and surrounding land is dominated by forestry.

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 *a*	
								Phytoplankton (µg/L)	Periphyton (mg/m^2)
23.5	6.5	6.0	36.5	0.07	0.005	2.5	2.9	0.89	76
	Good/ Natural	Fair/ Good	Good	Natural	Good/ Natural			Natural	Fair

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.

ASPT	IHAS (%)	Diatoms	Water quality
4.8	48.0	4.5	Good
Fair/Poor		Good/High	

Overall ecological assessment: Good

5 Discussion

Nutrient levels in nearly all samples were unusually low in the year reported on and this has the effect of elevating the overall water quality score at all sites, such that all sites were classified as having good overall water quality. Nevertheless, particular site-specific issues, such as depressed oxygen levels at site 10, and increasing salinity with distance down the catchment, are still present. The cause of the lowered nutrient levels is not known; however, it must be noted that these levels are based on a single sample and more data are required to assess whether this might be a trend.

Chlorophyll levels in phytoplankton across the catchment showed little change, while there was a distinct increased in the periphyton and particularly in March. The cause of this is not known. Increased nutrient levels may be associated with increased algal growth and consequently with chlorophyll levels, but no reliable data are available from March, and the data from July show low nutrient levels. It is also not clear why periphytic chlorophyll would increase while that from phytoplankton would not change.

Macroinvertebrate scores for most sites, and particularly upstream sites, are lower than corresponding water quality scores or diatom scores. In the case of site 10, this is easily explained by low oxygen levels at this site. Site 19 is in standing, rather than flowing water, and is not appropriate for the application of SASS5, and this accounts for unusual scores at this site. Site 11 is a muddy bottomed stream with little vegetation and consequent limited habitat and as a result lowered macroinvertebrate scores from this site are understandable.

Upstream sites 1 and 12, while not having a stone biotope and therefore with restricted habitat that may limit invertebrate biodiversity, are sites that appear relatively clean, and with no clear upstream impacts or physicochemical data that might explain the lower macroinvertebrate scores. Flow is slow at both sites. Nevertheless, the previous several years' data support the conclusion that these sites are generally classified and fair to poor based on macroinvertebrate scores.

The stretch of Mpisini River between site 1 and site 7 is where the river passes the RBM Smelter complex and is a stretch of the river where degradation has previously been noted, particularly as evidenced by diatom scores. In so far as the diatom indices indicated, this decrease is once again confirmed in the current data. As in previous years, there is a matching increase in salinity, pH and dissolved oxygen levels between the sites. Interpreting the macroinvertebrate data is more complex, as the improved habitat at site 7 (as evidenced by a significantly higher IHAS score) supports the likelihood of better macroinvertebrate scores at this site. In previous years, this has largely been the case. In the current data, despite an improvement in habitat, mean ASPT scores cannot clearly be distinguished, and scores were found to increase on one sampling trip and decrease on the other.

Although site 11 was classed as Fair/Poor based on macroinvertebrate evidence, diatom evidence indicates this site is in good ecological health. This confirms observations since 2010. As noted above, the low macroinvertebrate scores can likely be attributed to the relative lack of habitat at this site. Site 11 is at the confluence of the Mpisini and Manzamnyama River which drains the RBM Smelter complex region and so should reflect the amalgamated impact of the complex on adjacent rivers. Diatom scores at this site have improved since 2010, driven by the increasing dominance of *Achnanthes oblongella* at this site. Macroinvertebrate scores have decreased slightly over this period, but have in general been classified as fair.

Sites 12, 13 and 14 are located along much of the length of the Mdibi River before it flows into Lake Mzingazi. The stretch between site 12 and site 13 sees the river passing from an area dominated by forestry to one with increasingly dense human settlements. Along this stretch the pH and conductivity levels increased. There is little change in chemical water quality between site 13 and 14. Diatom biomonitoring scores show little change along the Mdibi River, though ordinations show some change in community structure along the river. Macroinvertebrate scores improved between sites 12 and 13, and changed little thereafter. In ordinations, the macroinvertebrate communities at site 12 are slightly different to those at sites 13 and 14. In comparison with previous data, the similarity between sites 13 and 14 is in common with most recent data. However, diatom scores at site 12 have historically been higher than those further downstream, while macroinvertebrate scores have characteristically been lower.

A distinct seasonality in macroinvertebrate community structure was noted over this reporting cycle, which corresponded with seasonality in SASS Score and Number of Taxa. This corresponds with detected seasonality in community structure in recent years, and underlies the importance of sampling on a seasonal basis to best understand macroinvertebrate community changes.

The appearance of a red bacterial floc at several sites has been noted in recent years, with the speculation that this could be linked to an inflow of iron-rich groundwater. While high levels of floc were present at site 1 in March 2014, these decreased by July 2014. Floc was also present in low quantities at site 12 in March, but none was apparent by July. Floc was continually present at sites 7 and 10.

Site 19 is a site introduced during this reporting cycle to have an upstream reference site in the Mpisini River located above site 1, which, though upstream of the RBM Smelter complex, is spatially close and has seen in increase in red bacterial floc in recent times. Site 19 is placed in a dam which, firstly, makes this location inappropriate for the application of SASS5 ("The method is designed for low/moderate flow hydrology and is not applicable in wetlands, impoundments, estuaries and other lentic habitats": Dickens and Graham 2002), and secondly, makes direct comparison of data from this site with other lotic sites difficult. Sampling at the site was initiated as access to the River upstream of site 1 is limited at other points. Despite these drawbacks, data from this site, particularly the diatom scores, warrant maintaining monitoring at this point or nearby, particularly during years when red bacterial floc is prevalent at site 1.

6 Recommendations

Ongoing monitoring

- Maintain current monitoring programme. Timing of monitoring must span seasons in order that potential seasonal variation be accounted for.
- Ongoing monitoring of the presence of red bacterial floc at sampling sites. It would be advantageous to have this identified and to determine what the drivers of its appearance and maintenance are.
- Ongoing assessment of changes along the Mpisini River. Long term monitoring has established degradation along this stretch that seems to be linked to the presence of RBM Smelter complex, and that this is the river most clearly impacted by the Smelter complex.
- Ongoing assessment of water quality and ecological health at site 11 as this site should reflect all changes owing to the RBM Smelter complex.
- Maintain monitoring at site 19 or locate another more appropriate site with river access and flowing water upstream of site 1 and the RBM Smelter complex.

Other

- Assess drainage patterns around the RBM Smelter complex. In particular, storm drains to the east of the complex should be assessed, and drainage during dry period and periods of rain collected and subjected to a full chemical and toxicological analysis.
- Undertake an analysis of flow patterns, if any, from the retention dam on the south-east of the Smelter complex and above a drainage channel to the Mpisini River. As above, full chemical and toxicological analysis should be undertaken.

7 References

Anderson MJ (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology* 26: 32-46.

Anderson MJ, Ellingsen KE and McArdle BH (2006) Multivariate dispersion as a measure of beta diversity. *Ecology Letters* 9: 683-693.

Cemagref (1982) *Etude des méthodes biologiques quantitatives d'appréciation de la qualité des eaux*. Rapport Division Qualité des Eaux Lyon. Agence financiè de Bassin Rhone-Méditerarée. Corse, Pierre-Bénite. 28 pp.

Coste M, Boutry S, Tison-Rosebery J and Delmas F (2009) Improvements of the Biological Diatom Index (BDI): Description and efficiency of the new version (BDI-2006). *Ecological Indicators* 9: 621-650.

Dickens CWS and Graham PM (2002) The South African Scoring System (SASS) Version 5rapid bioassessment method for rivers. *African Journal of Aquatic Science* 27: 1-10

DWA (2008) *Methods for determining the Water Quality component of the Ecological Reserve*. Department of Water Affairs, South Africa. Second Draft. Prepared by P-A Scherman of Scherman Consulting.

Eloranta P and Soininen J (2002) Ecological status of some Finnish rivers evaluated using benthic diatom communities. *Journal of Applied Phycology* 14: 1–7.

Gordon AK and Griffin NJ (2012) *Environmental water quality monitoring for Richards Bay Minerals: Smelter site area.* Unpublished report submitted to RBM by Institute for Water Research.

Gordon AK, Griffin NJ and Muller WJ (2008) *Environmental water quality monitoring for Richards Bay Minerals: Smelter site area*. Unpublished report submitted to RBM by Institute for Water Research.

Gordon AK, Griffin NJ and Holland AJ (2010) *Environmental water quality monitoring for Richards Bay Minerals: Smelter site area.* Unpublished report submitted to RBM by Institute for Water Research.

Griffin NJ and Holland AJ (2013) *Environmental water quality monitoring for Richards Bay Minerals: Smelter site area.* Unpublished report submitted to RBM by Institute for Water Research.

Holland AJ, Griffin NJ and Gordon AK (2011) *Environmental water quality monitoring for Richards Bay Minerals: Smelter site area.* Unpublished report submitted to RBM by Institute for Water Research.

Holm-Hansen O and Riemann B (1978) Chlorophyll *a* determination: improvements in methodology. *Oikos* 30: 438-447.

McMillan PH (1998) *An integrated habitat assessment system (IHAS V2), for the rapid biological assessment of rivers and streams.* CSIR Research Project Number ENVP- I 98132 for the Water Resources Management Programme, Council for Scientific and Industrial Research, Pretoria.

Minchin PR (1987) An evaluation of relative robustness of techniques for ecological ordinations. *Vegetatio* 69: 89–107.

Muller WJ, Gordon AK and Griffin NJ (2007) *Environmental water quality monitoring for Richards Bay Minerals: Smelter site area*. Unpublished report submitted to RBM by Institute for Water Research.

Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH and Wagner H (2012). *vegan: Community Ecology Package. R package version 2.0-4.* URL http://CRAN.R-project.org/package=vegan.

Palmer CG, Muller WJ and Hughes DA (2004) Chapter 6: Water quality in the ecological reserve. IN: *SPATSIM, An Integrating Framework For Ecological Reserve Determination and Implementation.* Hughes DA (Ed.). WRC Report No. 1160/1/04, Water Research Commission, Pretoria, South Africa.

Prygiel J and Coste M (2000) *Guide méthodologique pour la mise en oeuvre de l'Indice Biologique Diatomées NF T 90–354*. Agences de l'Eau – Cemagref-Groupement de Bordeaux. Agences de l'Eau, mars 2000, 134 pp + clés de détermination (90 planches couleurs) + cédérom bilingue français-anglais(Tax'IBD).

R Development Core Team (2012). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Spaulding SA, Lubinski DJ and Potapova M (2010). *Diatoms of the United States.* URL http://westerndiatoms.colorado.edu. Accessed on 06 July 2013.

Taylor, JC, Harding, WR and Archibald, CGM (2007a) *A methods manual for the collection, preparation and analysis of diatom samples*. Water Research Commission Report TT 281/07.

Taylor JC, Janse van Vuuren MS and Pieterse AJH (2007b) The application and testing of diatom-based indices in the Vaal and Wilge Rivers, South Africa. *Water SA* 33: 51-59.

Taylor JC, Prygiel J, Vosloo A, de la Rey PA and van Rensburg L (2007c) Can diatom-based pollution indices be used for biomonitoring in South Africa? A case study of the Crocodile West and Marico water management area. *Hydrobiologia* 592:455–464.

Taylor JC, Harding WR and Archibald CGM (2007d) *An illustrated guide to some common diatom species from South Africa*. Water Research Commission Report TT 282/07.

Van Dam H, Mertens A and Sinkeldam J (1994) A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. *Netherlands Journal of Aquatic Ecology* 28: 117-133.

Warwick RM and Clarke KR (1993) Increased variability as a symptom of stress in marine communities. *Journal of Experimental Marine Biology* 172: 215-226.

Appendix A Summary of macroinvertebrate biomonitoring scores and field-collected water chemistry results for the period December 2013 to July 2014.

Site	Month	Year	SASS Score	No. of Taxa	ASPT Score	IHAS Score	Temp. (°C)	pH	EC (mS/m)	DO (mg/L)	Turbidity (ntu)
11	December	2013	67	13	5.2	52	20.5	6.45	57.5	7.0	10.1
1	March	2014	58	13	4.5	47		6.51	40.0	5.1	17.0
7	March	2014	67	12	5.6	72	25.0	6.73	63.4	6.1	10.9
10	March	2014	42	11	3.8	48	23.0	6.26	35.1	0.8	42.9
11	March	2014	74	14	5.3	53	23.0	6.69	60.1	6.3	12.7
12	March	2014	68	14	4.9	62	24.9	5.39	52.5	5.9	5.3
13	March	2014	73	12	6.1	52	24.0	6.78	61.2	5.8	8.1
14	March	2014	107	18	5.9	53	25.0	6.75	62.4	6.1	8.8
19	March	2014	66	13	5.1	46	28.0	6.69	35.0	6.0	2.1
11	June	2014	74	11	6.7	41	17.5	6.45	82.7	10.5	5.2
1	July	2014	42	7	6.0	42	18.5	6.22	46.4		5.8
7	July	2014	41	9	4.6	68	18.0	7.45	87.3		5.8
10	July	2014	23	5	4.6	55	15.5	7.34	31.2		41.6
11	July	2014	49	10	4.9	43	17.0	8.72	78.0		5.4
12	July	2014	57	12	4.8	55	19.5	6.88	56.0		8.2
13	July	2014	72	11	6.6	52	17.0	7.53	67.8		8.2
14	July	2014	73	11	6.6	52	15.5	7.18	71.6		5.7
19	July	2014	45	10	4.5	50	19.0	6.35	38.0		3.7

Appendix B Summary of nutrient and other water quality data derived following laboratory analysis of collected samples results for the period December 2013 to July 2014.

Site	Month	Year	TIN (mg N/L)	Phosphate (mg P/L)	BOD_5 (mg O_2/L)	Phytoplankton chl *a* (µg/L)	Periphyton chl *a* (mg/m^2)
1	March	2014			2	0.22	4281.3
7	March	2014			3	0.16	153.1
10	March	2014			3	58.5	256.7
11	March	2014			2	0.26	16.3
12	March	2014			2	0.08	202.8
13	March	2014			2	0.12	447.3
14	March	2014			2	0.09	132.3
19	March	2014			3	1.16	94.9
1	July	2014	0.12	0.005	2	0.07	46.4
7	July	2014	0.09	0.005	2	0.18	33.5
10	July	2014	0.09	0.005	3	1.45	39.9
11	July	2014	0.06	0.005	2	0.11	39.6
12	July	2014	0.09	0.005	2	0.11	13.4
13	July	2014	0.18	0.005	2	0.04	38.4
14	July	2014	0.14	0.005	3	0.15	29.1
19	July	2014	0.07	0.005	2	0.62	57.4

Appendix C Summary of macroinvertebrate taxa found at each sampling site in March and July 2014.

The table below presents the percent that each taxon contributed to the total number of macroinvertebrates collected on each sampling occasion. Site data has been pooled across all replicates and all biotopes sampled.

Site	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
Year	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014
Month	Mar	Jul	Mar	Jul	Mar	Jul	Mar	Jul	Mar	Jul	Mar	Jul	Mar	Jul	Mar	Jul
Aeshnidae	0.3									1.4						0.4
Amphipoda											3.2	37.9	4.2	40.7		
Ancylidae										0.4					0.4	0.8
Atyidae	80.8	56.2	43.8	25.4	0.9		31.2	57.3	93.7	71.5	66.9	19.4	75.6	34.7	79.1	33.3
Baetidae	0.3	2.2	31.1	30.8	13.8	1.3	8.1	1.2	0.9	2.5	16.9	13.2	4.4	1.4	4.3	2.0
Belostomatidae																0.4
Blepharoceridae						10.6										
Caenidae	0.7	1.5	1.6	1.0			0.5	1.2	0.4	7.7	1.0	7.8	0.4	6.0	0.8	6.9
Calamoceratidae										1.4	0.3	0.9	0.2	7.0		
Calopterygidae				0.3			0.5				0.6	0.7	0.7	1.4		
Ceratopogonidae	0.3		0.4		31.4	26.5	5.4		0.1	0.7	0.3		0.2	0.4		
Chironomidae	14.4	23.4	11.3	22.4	42.2	49.0	40.3	19.5	2.2	2.8	2.1	2.1	1.5	3.5	5.1	27.2
Coenagrionidae	1.0	1.5	1.1	3.1	1.9	1.3	1.4	6.1	1.0	4.6	0.1	0.5	0.7	0.7	4.0	14.2
Corixidae					0.7	0.2										
Crambidae				0.3						0.4		0.2				
Culicidae		1.5			0.5	0.2										
Dytiscidae		2.2			1.4					0.4	0.1				1.2	
Ecnomidae			0.8	0.3			0.9	1.2								
Elmidae													0.2			

Site	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
Year	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**
Month	**Mar**	**Jul**	**Mar**	**Jul**	**Mar**	**Jul**	**Mar**	**Jul**	**Mar**	**Jul**	**Mar**	**Jul**	**Mar**	**Jul**	**Mar**	**Jul**
Gerridae		1.5	0.1				0.5	1.2	0.1							
Gomphidae		0.7		1.0							0.4	0.7	1.3	1.8		
Gyrinidae			0.5	0.3			0.5				1.0	0.2				
Hydracarina																1.2
Hydraenidae										0.4						0.4
Hydrophilidae			0.1		1.9	0.2				0.4		0.2		0.4		2.8
Hydropsychidae			0.8						0.1		0.3					
Hydroptilidae			1.5													
Leeches			0.1										0.2			
Libellulidae	0.3	1.5	0.1		0.9	0.4	1.4	2.4	0.2	1.1			0.2			1.2
Lymnaeidae										0.4						
Naucoridae					0.5								0.4			0.4
Nepidae									0.1						0.4	
Notonectidae					3.7										2.4	
Oligochaeta		5.8		0.5	0.2	9.9	0.9	3.7		0.4	0.3	2.7		0.4		6.1
Philopotamidae			0.3				2.3		0.5		0.1	0.2	0.2			
Planorbinae							0.9		0.2	3.2	0.1		0.2		1.2	
Pleidae																2.0
Polymitarcyidae															0.4	
Potamonautidae	1.7	1.5	4.3	0.8			1.8	1.2			3.1	1.4	1.8		0.8	
Simuliidae			2.0	13.6			3.6		0.1		1.3	4.3	0.4			0.4
Tabanidae			0.1						0.1			0.2	0.2			
Tipulidae		0.7		0.3		0.2			0.2							
Tricorythidae								4.9		0.7	1.8	7.3	7.0	1.8		

Appendix D Summary of macroinvertebrate biomonitoring and water chemistry results at Site 11 over the period December 2013 to July 2014.

Year	Month	SASS Score	No. of Taxa	ASPT Score	IHAS Score	Temp. (°C)	pH	EC (mS/m)	DO (mg/L)	Turbidity (ntu)
2013	Dec	67	13	5.2	52	20.5	6.45	57.5	7.0	10.1
2014	Mar	74	14	5.3	53	23.0	6.69	60.1	6.3	12.7
2014	Jun	74	11	6.7	41	17.5	6.45	82.7	10.5	5.2
2014	Jul	49	10	4.9	43	17.0	8.72	78.0		5.4

Appendix E Macroinvertebrate taxa collected at Site 11 over the period December 2013 to July 2014 using the SASS5 method

Abundances are scored following SASS5 convention as follows: 1 = 1, A = 2-10, B = 10-100, C = 100-1000.

Year	2013	2014	2014	2014
Month	**December**	**March**	**June**	**July**
Aeshnidae				1
Amphipoda			1	
Atyidae	B	B	B	B
Baetidae	A	A	B	1
Caenidae	1			
Ceratopogonidae	A	A		1
Chironomidae	B	B	A	B
Chlorocephidae		1		
Coenogrionidae	A			A
Dytiscidae	1	A		
Gerridae	A	A	A	A
Gomphidae	1			1
Heptageniidae			A	
Hydracarina	A	A		
Hydrometridae			1	
Hydropsychidae		A	A	A
Leptoceridae		1		
Libellulidae		A		
Physidae		A		
Pleidae	A			
Potamonautidae		A		
Simuiidae	A	A	A	
Tipulidae			1	
Veliidae	1		1	
Total taxa	13	14	11	9
Mean taxa per sample	11.75			
Total taxa per year	24			

Appendix F Diatom report for index based on expert opinion results for the period December 2013 to July 2014.

Site 1 (Upper Mpisini)

March 2014
This sample contained 15 taxa and had a Shannon diversity of 1.85. An unknown species of *Brachysira* was dominant, with another unidentified *Brachysira* species subdominant. Both 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, Griffin and Holland 2013) and are commonly dominant in upstream reference sites. In addition, *Brachysira* species typically are found in oligotrophic, electrolyte-poor water, and many prefer a somewhat acid pH. Other taxa present in proportions exceeding 1% are a mix of taxa typical of clean water, some of which are electrolyte-tolerant, and some taxa that may be found at more polluted sites.
Score: 5

July 2014
This sample contained 19 taxa and had a Shannon diversity of 1.81. The site was dominated by the same two species of *Brachysira* that were dominant in the March sample from this location. *Brachysira neoexilis*, a cosmopolitan taxon typical of clean, oligotrophic or mesotrophic water, was subdominant. All other taxa present that were present in proportions exceeding 1% were indicative of clean water.

Score: 5

Site 7 (Lower Mpisini)

March 2014
This sample contained 24 taxa and had a Shannon diversity of 2.75, making this the most diverse of the samples from this sampling trip. *Gomphonema parvulum* was dominant in this sample, with *Gomphonema angustatum* co-dominant. The former is cosmopolitan and pollution tolerant, but the latter is typical of oligotrophic conditions, though it can be found over a range of pH and electrolyte concentrations. The remaining taxa present in proportions exceeding 1% comprise some taxa typical of clean conditions, with others rather more typical of stressed or polluted conditions, and many noted as electrolyte-tolerant.
Score: 3

July 2014
This sample contained 16 taxa and had a Shannon diversity of 1.80. *Achnanthes oblongella*, typical of circumneutral, oligotrophic, electrolyte poor conditions and common at upstream sites in this area, was dominant. *Gomphonema angustatum* and *Achnantidium minutissimum* were subdominant in this sample. As noted above, the former is typical of oligotrophic conditions, and the latter is common in clean and fresh water. Of the remaining taxa making up more than 1% of the sample, most were typically associated with mesotrophic or eutrophic conditions.

Score: 4

Site 10 (Upper Manzamnyana)

March 2014
This sample contained 18 taxa and had a Shannon diversity of 2.36. *Nitzschia nana*, a moderately pollution-tolerant taxon that may be found in electrolyte rich conditions, was dominant. *Nitzschia archibaldii*, typical of circumneutral, and slightly to moderately polluted waters with moderate electrolyte content, was co-dominant. *Gomphonema exilissimum* and *Stauroneis heinii* were subdominant. The former is found in circumneutral, oligotrophic, electrolyte poor waters, while the latter, a taxon typical of site 10, has a fairly broad ecological range. The remaining taxa comprise a mix of pollution tolerant and more sensitive taxa, with several typical of slightly acidic conditions.
Score: 4

July 2014
This sample contained 17 taxa and had a Shannon diversity of 2.41. *Nitzschia nana* was dominant in this sample, and *Nitzschia gracilis* and *Achnanthidium minutissimum* were co-dominant. As noted above, the dominant taxon is pollution tolerant. Of the co-dominant taxa, *Nitzschia gracilis* is a moderately pollution tolerant taxon associated with elevated nutrient and electrolyte levels, and *Achnanthidium minutissimum* is associated with clean, fresh water. While remaining taxa contain several cosmopolitan and pollution tolerant taxa, many of the remaining taxa are typical of oligotrophic, electrolyte-poor conditions. *Stauroneis heinii*, previously noted as typical at this location, only made up 1% of this sample.
Score: 3

Site 11 (Confluence)

March 2014
This site contained 16 taxa and had a Shannon diversity of 1.65. The sample is heavily dominated by *Achnanthes oblongella*, a taxon typical in circumneutral, oligotrophic, electrolyte poor streams. *Eunotia bilunaris* was subdominant. The latter is found in acidic water with a low electrolyte content. The remaining taxa are a mix of sensitive and pollution tolerant taxa, with several that are typical of moderate electrolyte levels.
Score: 5

July 2014
This sample contained only 3 taxa, giving it a Shannon diversity of 0.19, by far the lowest diversity of any sample in this reporting cycle. The sample was overwhelmingly dominated by *Achnanthes oblongella*, which made up 96% of the sample and is typical of low nutrient and electrolyte levels and neutral pH. The remaining taxa included both pollution-sensitive and pollution tolerant taxa.
Score: 5

Site 12 (Upper Mdibi)

March 2014
This sample contained 12 taxa and had a Shannon diversity of 1.82. No information is available on the ecology of *Achnanthes pulviscula*, the dominant taxon, but experience with samples from around the RBM smelter associates this taxon with the cleanest of waters in the area. *Achnanthes oblongella* was co-dominant, and is typical of circumneutral, oligotrophic, electrolyte poor water. The sub-dominant taxon was *Nitzschia inconspicua*, which is tolerant of organic pollution and moderate to high electrolyte levels. The remaining taxa

consist of a range of pollution sensitive and tolerant forms.
Score: 4

July 2014
This sample contained 13 taxa, giving it a Shannon diversity of 2.12. *Achnanthes pulviscula* was dominant in this sample, with *Brachysira* aff. *steindorfiana* co-dominant. *Gomphonema* aff. *gracile* and *Achnanthes oblongella* and another species of *Brachysira* were subdominant. As noted above, little is known of the ecological requirements of the dominant taxon, but it is commonly associated with clean water in the region. Much the same applies to the co-dominant taxon. *Gomphonema* aff. *gracile* is described as extremely pollution tolerant and common in mining effluent, while *Achnanthes oblongella* is typical of water that is neither acidic nor alkaline and has low levels of nutrients and electrolytes. The ecological requirements of the subdominant *Brachysira* species are not known, though it is common in clean waters in this region and in addition many *Brachysira* species are typical of oligotrophic, slightly acidic conditions. The remaining taxa are a mix of pollution sensitive and pollution tolerant taxa.
Score: 4

Site 13 (Middle Mdibi)

March 2014
This sample contained 20 taxa and had a Shannon diversity of 2.22. In this sample, *Gomphonema angustatum* was dominant, with *Gomphonema pumilum* co-dominant. The former is cosmopolitan, but only common in oligotrophic water, and the latter is found in water with low to moderate electrolyte levels and is tolerant of a wide range of nutrient levels. *Achnanthidium saprophilum*, the subdominant, is found in organically enriched and eutrophic fresh water. Remaining taxa are a mix of pollution sensitive and pollution tolerant taxa.
Score: 3

July 2014
This sample contained 23 taxa, giving it a Shannon diversity of 2.72. No taxon was highly dominant in this sample, leading to one of the highest Shannon diversity scores. At 19% of the sample, *Achnanthidium minutissimum* was classed as dominant, and *Achnanthidium biasolettianum* was co-dominant. The former is typical of clean water, while the latter is associated with calcareous oligotrophic or mesotrophic waters with moderate to elevated electrolyte levels. Of the remaining taxa that made up more than 1% of the sample, both pollution tolerant and pollution sensitive, with rather more of the former.
Score: 4

Site 14 (Lower Mdibi)

March 2014
This sample contains 15 taxa and has a Shannon diversity of 1.93. *Gomphonema angustatum* is dominant in the sample, with *Gomphonema clavatum* sub-dominant. The former is cosmopolitan, and only common in oligotrophic water, and the latter is typical of oligotrophic waters while also tolerating high electrolyte levels. The remaining taxa are a mix of pollution tolerant and pollution sensitive taxa.
Score: 4

July 2014
This sample contained 27 taxa, the most in this reporting cycle, and had a Shannon diversity of 2.67. Only one taxon was present at levels exceeding 10% of the sample, and the ecological requirements of *Capartogramma crucicula*, the taxon in question, are not well known. As a result, classification will be based on the more

common of the remaining taxa. Of these, the most common is *Achnanthes oblongella*, associated with clean water. Of the taxa with known ecologies, the next most common is *Luticola kotschyi*, indicative of elevated electrolyte levels. The next most common is the cosmopolitan *Achnanthidium exiguum*, which prefers alkaline water with moderate to high electrolyte levels. Thereafter, *Navicula gregaria*, identified as a good indicator of moderate to severe pollution, is the next most frequent. Next most frequent is *Placoneis dicephala*, a cosmopolitan taxon that is moderately pollution tolerant. After this, the next most frequent is *Achnanthes pulviscula*, typical of clean sites in this region. Finally, *Gomphonema pseudoaugur*, a cosmopolitan taxon preferring mesotrophic or eutrophic water, is next most frequent.
Score: 3

Site 19 (High Mpisini Dam)

March 2014
This sample has 15 taxa and a Shannon diversity of 2.02. *Eunotia bilunaris*, typical of acidic waters with low electrolyte levels, was dominant, and *Eunotia incisa*, the co-dominant, is likewise typical of acidic, oligotrophic, and electrolyte-poor water. The specific ecological requirements of *Eunotia pseudoflexuosa*, which was subdominant, are not known, but *Eunotia* species are typical of acidic and oligotrophic conditions. Remaining taxa are a mix of sensitive and pollution tolerant taxa.
Score: 5

July 2014
This sample contained only 8 taxa and had a Shannon diversity of 0.86. *Achnanthidium minutissimum*, an indicator of clean water, was overwhelmingly dominant, and *Achnanthidium macrocephalum* was subdominant. The latter is found in calcareous, oligotrophic or mesotrophic water. The remaining taxa, which with one exception, comprised a single individual, include sensitive and moderately pollution tolerant taxa. Only one individual of *Eunotia minor* was found, in contrast to *Eunotia*'s dominance of the March sample.
Score: 5

Appendix G Diatom index scores and site classification for the period December 2013 to July 2014.

Diatom index scores from sample sites in the Smelter area for the period December 2013 to July 2014 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 individual indices are also presented.

			IPS		BDI-2006		Expert opinion	
Site	**Month**	**Year**	**Score**	**Class**	**Score**	**Class**	**Score**	**Class**
1	March	2014	13.2	Moderate	13.8	Good	5	High
7	March	2014	11.7	Poor	11.2	Moderate	3	Moderate
10	March	2014	16.2	Good	15.1	Good	4	Good
11	March	2014	17.5	High	16.1	Good	5	High
12	March	2014	15.5	Good	11.9	Moderate	4	Good
13	March	2014	13.7	Moderate	14.2	Good	3	Moderate
14	March	2014	15.1	Good	13.3	Good	4	Good
19	March	2014	19.1	High	18.4	High	5	Good
1	July	2014	15.8	Good	17.9	High	5	High
7	July	2014	16.4	Good	14.6	Good	4	Good
10	July	2014	14.8	Moderate	14.6	Good	3	Moderate
11	July	2014	17.9	High	12.4	Moderate	5	High
12	July	2014	15.2	Good	15.4	Good	4	Good
13	July	2014	15.4	Good	15.8	Good	4	Good
14	July	2014	16.7	Good	15.0	Good	3	Moderate
19	July	2014	19.6	High	15.6	Good	5	Good

Appendix H Diatoms at sample sites in the Smelter area for the period December 2013 to July 2014.

The table below presents the percent that each taxon contributed to the total number of diatoms identified on each sampling occasion. Where diatoms could not be identified, morphospecies were assigned and used in all analyses.

Site	**Site 1**		**Site 7**		**Site 10**		**Site 11**		**Site 12**		**Site 13**		**Site 14**		**Site 19**	
Year	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**
Month	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**
Achnanthes oblongella	2.8		38.9	8.8			96.1	57.3	12.4	28.8	1.0	2.0	7.3	6.6		
Achnanthes pulviscula	0.9	4.8	0.9				1.0		24.8	34.6	2.0	7.9	3.7	7.5		
Achnanthidium biasolettianum											13.9					
Achnanthidium crassum						1.0										
Achnanthidium eutrophilum											3.0					
Achnanthidium exiguum								1.0			5.0		4.6	0.9	1.0	2.9
Achnanthidium kranzii			2.8													
Achnanthidium macrocephalum					2.8										21.0	
Achnanthidium microcephalum																2.9
Achnanthidium minutissimum		5.8	17.6		15.0						18.8		0.9		72.4	
Achnanthidium saprophilum				1.0								9.9				1.0
Achnanthidium sp2										1.0						
Amphora copulata									1.9							
Amphora montana											6.9					
Brachysira aff. *steindorfiana*	36.8	40.4						1.9	18.1	5.8				0.9		2.0
Brachysira neoexilis	15.1				4.7				4.8							
Brachysira sp2	30.2	26.9						4.9	10.5			1.0	0.9			2.0
Brachysira styriaca					6.5											
Capartogramma crucicula			0.9					1.0		3.8	5.9	2.0	33.0			

Site	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
Year	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**
Month	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**
Cocconeis placentula													1.8	1.9		
Cocconeis sp1											3.0	1.0				
Cocconeis sp2													5.5			
Cocconeis sp3													3.7			
Cyclostephanos dubius								1.0								
Cyclotella meneghiniana					4.7											
Cymbopleura sublanceolata		1.0														
Diadesmis contenta						1.9						1.0				
Diploneis elliptica												1.0				
Diploneis oblongella				2.9												
Encyonema gracile																1.0
Encyonema mesianum						1.0										
Encyonopsis sp2	0.9															
Eolimna rutteri				1.0												
Eunotia bilunaris	1.9	4.8				1.0		14.6					1.8	2.8		28.4
Eunotia incise	0.9					2.9		1.0								25.5
Eunotia minor	0.9	1.0				1.0			1.9			1.0	1.8		1.0	
Eunotia pseudoflexuosa																16.7
Eunotia sp1														1.9		
Eunotia sp6								1.9								4.9
Fallacia monoculata		1.0														
Fragilaria biceps			3.7													
Fragilaria ulna var. *acus*												1.0				
Frustulia crassinervia					0.9											
Geissleria decussis											2.0					
Gomphonema aff. *gracile*									14.3					7.5		

Site	**Site 1**		**Site 7**		**Site 10**		**Site 11**		**Site 12**		**Site 13**		**Site 14**		**Site 19**	
Year	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**
Month	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**
Gomphonema aff. *lagenula*				3.9												
Gomphonema affine		3.8		1.0								2.0	0.9	7.5		
Gomphonema angustatum		1.9	24.1	18.6		1.9				1.9		29.7	0.9	46.2		
Gomphonema clavatum														10.4		
Gomphonema exilissimum						12.4										7.8
Gomphonema gracile		1.0	0.9	3.9	2.8										1.9	
Gomphonema lagenula											1.0	3.0				
Gomphonema parvulius					8.4										1.0	
Gomphonema parvulum			0.9	14.7	5.6	6.7		3.9				5.9				
Gomphonema parvulum f. *saprophilum*			1.9													
Gomphonema pseudoaugur													3.7	2.8	1.0	
Gomphonema pumilum			2.8								5.0	23.8				
Gomphonema sp11													0.9			
Gomphonema sp6								2.9								
Gomphonema sp9			0.9									1.0			1.0	1.0
Hanzschia distinctepunctata											1.0		0.9			
Hippodonta capitata									1.0		1.0		0.9			
Luticola goeppertiana	0.9															
Luticola kotschyi	0.9										3.0		4.6	0.9		
Mastogloia elliptica				4.9												
Mayamaea agrestis									2.9							
Mayamaea atomus	0.9												0.9			
Navicula arvensis var. *maior*	0.9								1.0							
Navicula erifuga				6.9					1.0		3.0	4.0				
Navicula gregaria			0.9				2.9						4.6			

Site	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
Year	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**
Month	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**
Navicula longicephala	0.9															
Navicula microcari	0.9												2.8			
Navicula namibica														0.9		
Navicula notha				1.0												
Navicula radiosa			0.9													
Navicula recens											2.0					
Navicula schroeteri			0.9	2.0												
Navicula sp1					0.9					4.8						
Navicula sp10													0.9			
Navicula sp6				1.0				1.0			8.9					
Navicula sp9													2.8			
Navicula subrhynchocephala										1.9		1.0				
Navicula symmetrica													1.8			
Navicula tenelloides			0.9													
Navicula vandamii											8.9					
Nitzschia archibaldii						15.2										
Nitzschia bacillum											1.0					
Nitzschia capitellata		1.0														
Nitzschia clausii	0.9			4.9								1.0				
Nitzschia dissipata								1.0								
Nitzschia filiformis		2.9		6.9												
Nitzschia fonticola	0.9			2.0				1.0								
Nitzschia frustulum										3.8						
Nitzschia gracilis					17.8						1.0					
Nitzschia hantzschiana						3.8										
Nitzschia inconspicua								3.9	5.7	11.5						

Site	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
Year	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**
Month	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**	**July**	**March**
Nitzschia microcephala	0.9	1.9														
Nitzschia nana					19.6	25.7										
Nitzschia palea		1.9		3.9	4.7								0.9			
Nitzschia paleaeformis						3.8										
Nitzschia pusilla											2.0					1.0
Nitzschia sp25					0.9											
Nitzschia tubicola						1.9										
Pinnularia mesogongyla						1.0										
Pinnularia sp6					2.8											
Pinnularia sp7						5.7										
Pinnularia viridiformis						1.9										
Pinnularia viridis					0.9											
Placoneis dicephala													4.6	0.9		1.0
Planothidium engelbrechtii				1.0							1.0					2.0
Rhopalodia gibba				1.0												
Rhopalodia operculata				2.9												
Sellaphora pupula	0.9									1.0			2.8			
Sellaphora seminulum				1.0												
Seminavis strigosa												1.0				
Stauroneis heinii					0.9	11.4										
Stauroneis pachycephala				3.9				1.9		1.0						
Ulnaria sp1				1.0												