

Richards Bay Minerals
Environmental Water Quality in Streams: Smelting and
Processing Site



2015-2016 Monitoring Cycle

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Executive summary

This document reports on a programme monitoring the environmental water quality of surface waters in the vicinity of the Smelting and Processing Site of Richards Bay Minerals. Data reported on were largely collected during February and August 2016, with minor collections from one site during December 2015 and May 2016. Aquatic ecological health indices were calculated for each site based on water quality data, macroinvertebrate and diatom taxa sampled.

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

Site	ASPT	IHAS	Water Quality	Diatoms	Overall
1	Poor	60	Fair	Moderate	Fair
7	Poor	50	Good	Moderate	Fair
10	Poor	41	Fair	Moderate	Fair
11	Poor	46	Fair/Good	Good	Fair
12	Poor	50	Fair	Good	Fair
13	Good/Natural	50	Good	Moderate	Good
14	Fair	58	Fair	Bad	Poor/Fair
19	Poor	32	Fair	Good	Fair

In general, the results from the current sampling cycle reflect a continuation of the deteriorating ecological health of rivers in the monitored area that was noted in the report of 2015. The lowered overall sites scores were driven in particular by deteriorating macroinvertebrate biomonitoring scores. This general trend to lowered ecological health has in the past been associated with the drought that has affected the area, and the results from this monitoring cycle reveal that, despite some rainfall before the final samples were collected, no immediate recovery was noted. Some trends noted, such as increased salinization, are easily explained by lowered rainfall levels. Others, such as spatially and temporally variable acidification, are not easily explained.

There was little variation across sites in overall ecological health, with the majority of sites being classed as Fair. Exceptions include site 13, midway along the Mdibi River, which had an improved ecological health as a result of improved macroinvertebrate biomonitoring results, and site 14, lower on the Mdibi River, which had a lower ecological health in 2016. The latter can be compared to previous years, which reveal the site to be in the worst ecological state since monitoring began in 2010. In general though, the data from 2016 show a slight decrease in ecological health compared to 2015, but a large deterioration compared with 2014.

A worrying trend noted in 2015 of acidification at some sites, as well as high nitrogen levels at all sites noted in one sampling trip, was partially continued in 2016. Acidification of some sites, and salinization at many sites, was noted in 2016. High nitrogen levels were only present at one site in 2016. The salinization that started in 2015 and continued in 2016 can easily be explained by the drought as salinization of water resources is common during dry periods. However, the acidification, which in 2016 was spatially and temporally variable, cannot simply be attributed to low rainfall levels. Nevertheless, the data from 2016 show a statistically

significant relation between acidification and salinization. As the pH levels encountered during 2016 are far below natural levels, and also far below what has been found in the region in the past, this trend needs ongoing monitoring, and, if a cause is found, this needs to be urgently addressed.

Previous reports identified a decrease in water quality and diatom biomonitoring scores along the Mpisini River between sites 1 and 7 that may be an impact of runoff or effluent from the RBM Smelting and Processing Site. Since the 2015-2016 drought began, this trend has not been observed. During the drought, site 1 was frequently found to have no water. Despite this, flow at site 7 downstream never ceased flowing, and it appears that this is due to water input from the Smelting and Processing Site. In previous years, when water flowed past site 1, the site was found to have relatively good ecological health. During the drought samples collected when the site had water revealed a poor ecological health which was relatively low relative to the ecological health of site 7 downstream. It appears that during this period of stress water input from the Smelting and Processing Site has supported ecological health at site 7 relative to site 1. However, in surveys undertaken before the drought, the ecological health at site 7 has at times been better than in 2016 (particularly as reflected in diatom community structure), and it seems that this water input may improve the ecological health at site 7 when seen relative to that at site 1, but that the site is not maintained in an optimal state.

The number of macroinvertebrate taxa found at site 11 per visit ranged from 1 in February 2016 to 6 in December 2015. The average number of taxa per sample was 3.8, and the total number of taxa collected through the year was 11. This is a decrease when compared with data from the previous year.

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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 Smelting and Processing Site from 2015 to 2016.

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 Smelting and Processing Site is adjacent to the KwaBonambi State Forest and is situated within a larger afforested area. The area around the Smelting and Processing 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 Smelting and Processing Site may impact the ecological health of the surrounding rivers. Contaminants from the RBM Smelting and Processing Site 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 or deposition of airborne material. The natural drainage from the Smelting and Processing Site is towards the Mpisini and Manzanmyana 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) or orthophosphate), chlorophyll *a* analysis (of phytoplankton and periphyton), five day biological oxygen demand (BOD₅), turbidity, electrical conductivity as a salinity 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 Manzanmyana 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 a salinity proxy, dissolved oxygen, water temperature and pH at Site 11.

1 Methods and materials

1.1 Sampling sites

Comprehensive biomonitoring and water quality sampling was undertaken at the following eight sites (Figure 1): Mpisini upstream of Smelter (site 1), Mpisini downstream of Lake Evans (site 7), Manzamnyana upstream of Smelter (site 10), Confluence (Mpisini-Manzamnyana) (site 11), Upper Mdibi River (site 12), Middle Mdibi River (site 13), Lower Mdibi River (site 14), and Mpisini upstream dam (site 19). The monitoring programme consisted of macroinvertebrate and diatom biomonitoring, IHAS assessments and a water quality analysis covering field-measured parameters (such as pH and electrical conductivity) and laboratory-analyzed parameters (such as orthophosphate and BOD₅). This was undertaken during summer (February 2016) and winter (August 2016). Additionally limited biomonitoring was undertaken at Confluence (Mpisini-Manzamnyana) (site 11) during spring (December 2015) and autumn (May 2016), 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).

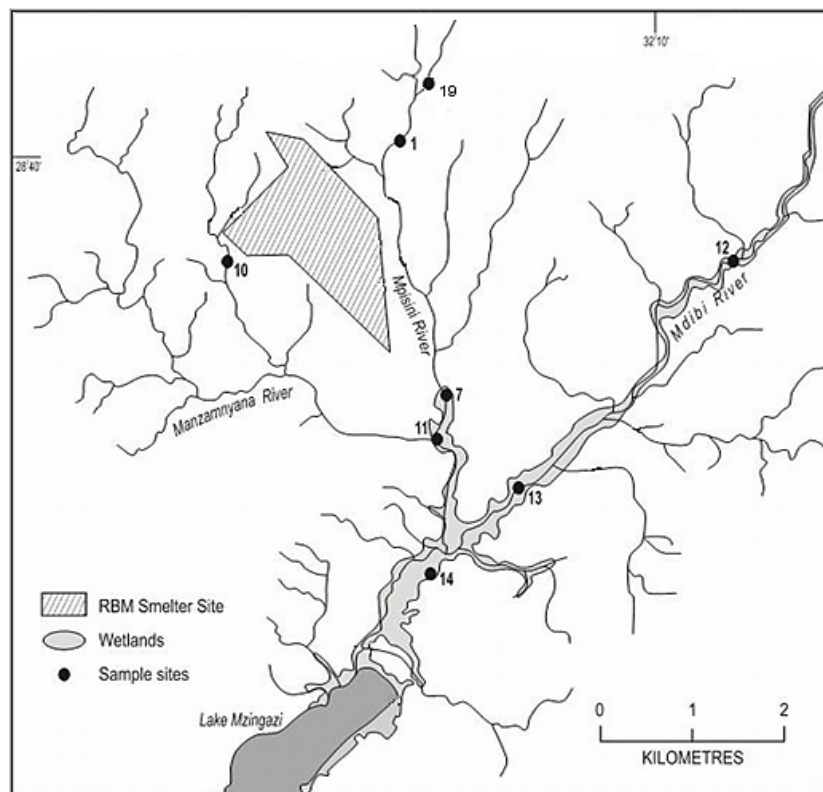


Figure 1 Monitoring points along rivers around the RBM Smelting and Processing Site area.

1.2 Water quality assessment

Water samples were collected during the February and August 2016 surveys at each of the biomonitoring sites for analysis at Mhlatuze Water Scientific Services in their accredited laboratory. The following parameters were measured: nitrite nitrogen (NO₂-N), nitrate nitrogen (NO₃-N), ammonium nitrogen (NH₄-N) and

orthophosphate phosphorous or soluble reactive phosphorous (SRP) ($\text{PO}_4\text{-P}$). The nitrogen data were combined to obtain total inorganic nitrogen (TIN) concentrations.

Assessing only dissolved nutrient status (TIN and SRP) may lead to incorrect conclusions regarding the nutrient enrichment of the water body. Dissolved nutrients are directly available for uptake by plants, and, consequently, during active plant growth periods the concentrations of these nutrients may be a poor indicator of nutrient enrichment. The estimation of algal biomass (periphyton and phytoplankton) by means of chlorophyll *a* measurements provides additional information when assessing the level of nutrient enrichment (Palmer *et al.* 2004). Periphyton and phytoplankton samples were collected following methods described by Holm-Hansen and Riemann (1978). Analysis of chlorophyll levels was undertaken at Rhodes University and followed Arar and Collins (1997).

Additional water samples were collected to assess biological 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 five day test (BOD_5) 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).

1.3 Biomonitoring

1.3.1 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.

1.3.2 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).

1.3.3 Diatom assessment

Diatom data reported on here are from diatom samples that 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, Griffin 2014, Griffin 2015) 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 conditions. (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, BDI-2006 and expert opinion indices using weight of evidence to derive an overall sample classification.

1.4 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 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).

2 Results

The results of all tests and analyses undertaken over the 2015-2016 monitoring cycle are presented below.

2.1 Water quality assessment

Water temperature at the sampled sites is presented in Figure 2 below. There is no consistent trend in water temperatures between sites. Seasonal temperature changes account for the difference in temperature between February and August samples.

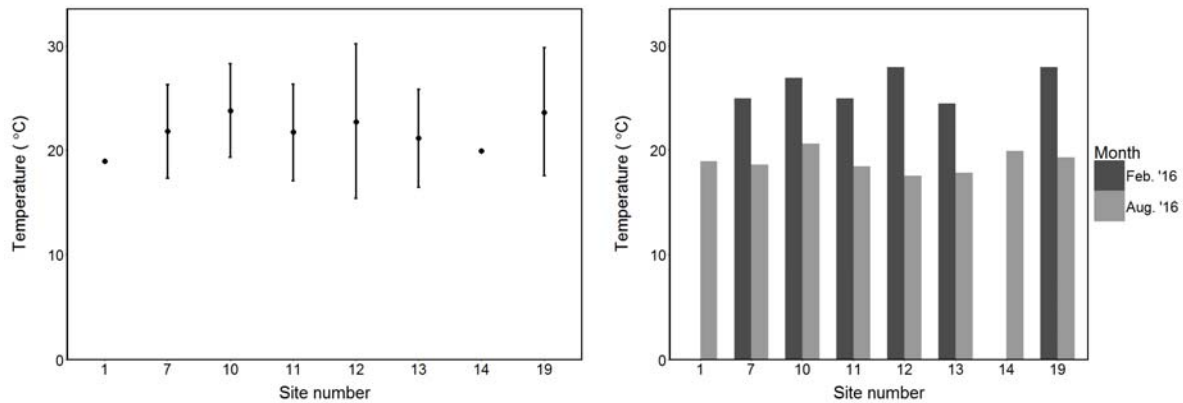


Figure 2 Mean \pm standard deviation in water temperature at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure.

Variation and temporal change in pH levels at the eight sampling sites are presented in Figure 3. The trend of acidification at certain sites noted as problematic in Griffin (2015) can still be seen to be apparent. While the mean pH at sites 7, 10, 11, 12 and 13 could be classified as Good or Natural, site 19 remained acidified, and low pH's were found during August at sites 1 and 14. In addition, site 12 and 13 showed sharp drops in pH from February to August, while site 11 showed an increase. Overall, pH levels measured in August commonly showed acidification. Only sites 7 and 10 showed no acidification over the period monitored.

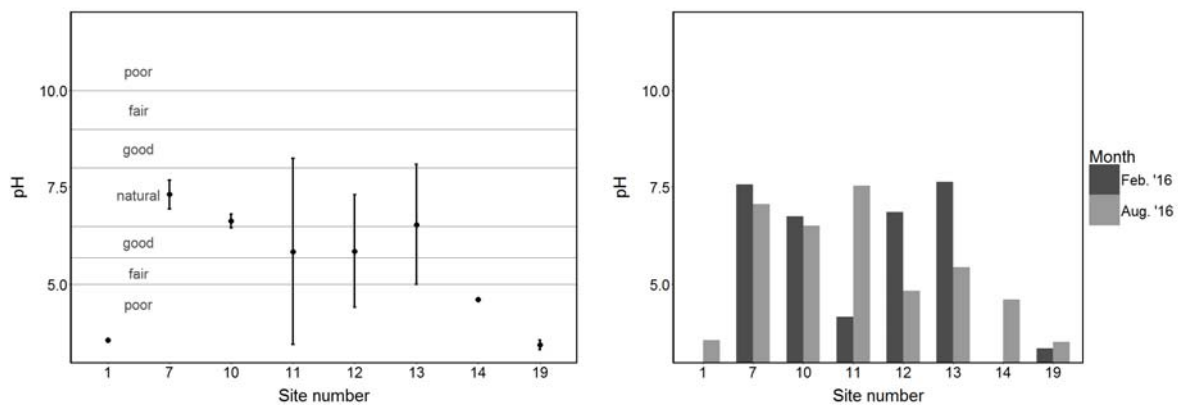


Figure 3 Mean \pm standard deviation in pH at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the left hand figure.

Electrical conductivity levels at the sample sites are presented in Figure 4. Overall, the results show severe salinization of surface water in streams surrounding the RBM Smelting and Processing Site. No sites could be classed as Natural, and only site 10 could be classed as Good. The majority of the remaining sites would be classed as Poor, with sites in the middle to upper Mpisini River performing worst. Sites along the Mdibi River are all, on average, also classed as Poor. The better sites in the catchment are those with known water inputs: site 10 is groundwater-fed, and site 7 receives some input from Lake Evans. These trends follow ongoing salinization noted during previous years, and are likely an effect of the ongoing drought. Limited rains between February and August may have led to reductions in salinity at five sites. Nevertheless, sites 1 and 14, which had no water in February, and had filled to some extent in August, had poor levels of conductivity after refilling.

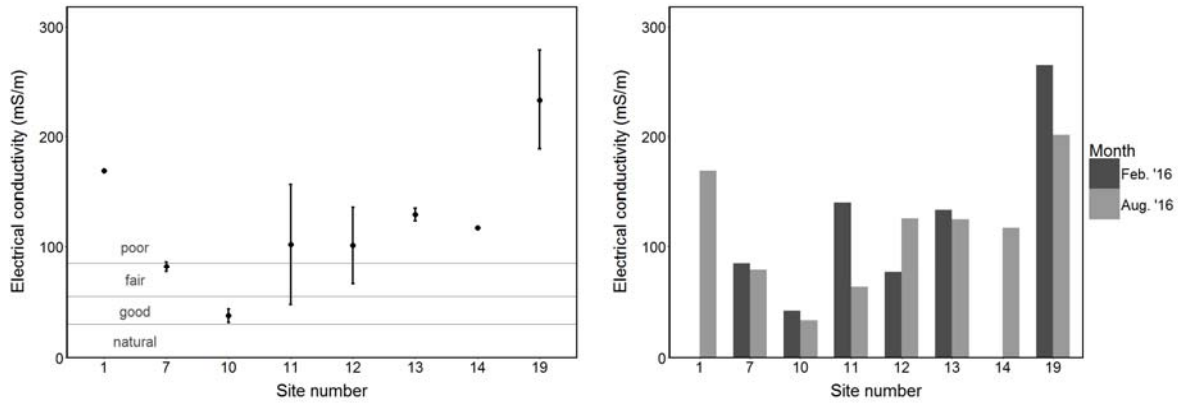


Figure 4 Mean \pm standard deviation in electrical conductivity levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the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

Dissolved oxygen levels in the various sampling sites are presented in Figure 5. Levels of oxygen ranged from Poor to Good. Sites 1 and 14, which were dry in February, had Poor to Fair levels of oxygen after refilling. Site 10, which is groundwater-fed and typically has low dissolved oxygen levels, had Good levels of oxygen in February, which declined to Poor in August. Site 13 also experienced a large decline in oxygen levels from February to August. No clear reasons for these trends at various sites are apparent. While some sites experienced large changes during the sampling cycle, others changed less, and no clear seasonal or spatial trends were found.

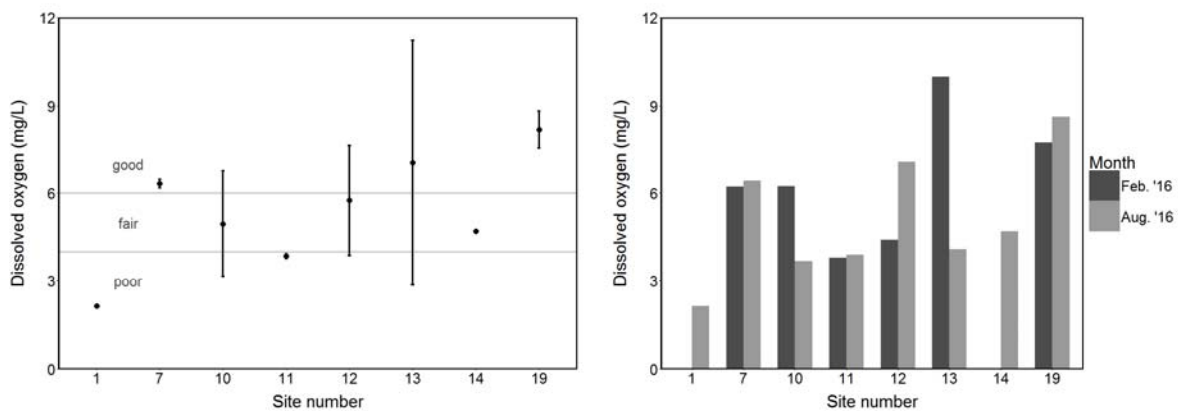


Figure 5 Mean \pm standard deviation in dissolved oxygen levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the left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

The 5-day biological oxygen demand (BOD_5) of water samples from the various sample sites are presented below in Figure 6. Overall, BOD_5 levels were higher in February, indicating a higher microbial demand for oxygen. Levels at site 19 were unusually high in February, reaching levels several times higher than have been found in the area before. At this time the dam at the site was nearly dry, and conductivity levels at the site were likewise high (and conductivity levels at this site were higher than recorded in the area before). The reason for the high BOD_5 is not known. However, the low water levels and associated decreased water quality is likely to contribute. This site experienced a fish kill event during the previous monitoring cycle. Overall, BOD_5 levels often improved from February to August.

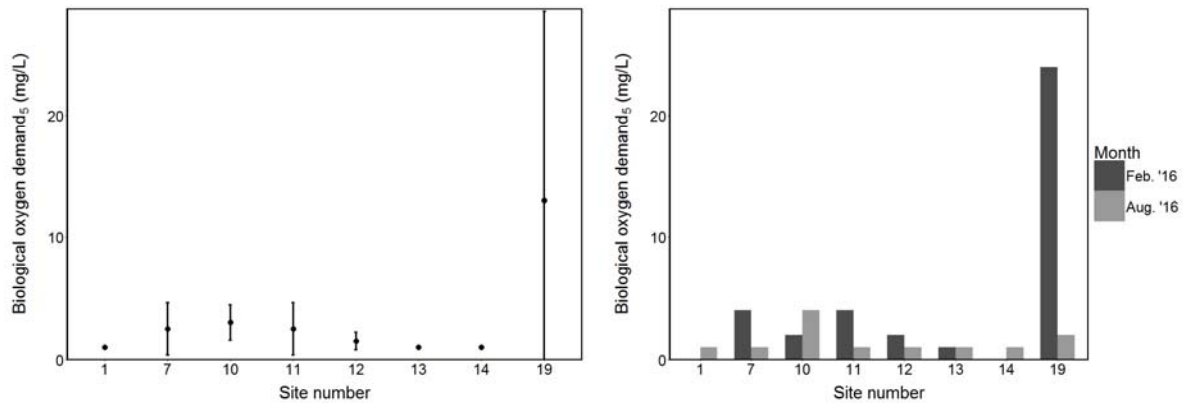


Figure 6 Mean \pm standard deviation in 5-day biological oxygen demand (BOD₅) levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure.

Changes in turbidity levels across the various sampling sites are presented in Figure 7. Overall, turbidity levels were low in comparison with previous years. Turbidity levels at site 10 have usually been far higher than at other sites. This been attributed to regular disturbance of the site by cows, combined with the presence of red bacterial floc covering submerged surfaces. While levels are lower in this sampling cycle, site 10 has one of the higher turbidities of sites surveyed. Site 19 also has higher turbidities, and the reason for this is not known. Turbidity along the Mdibi River increased from February to August. It must be stressed though that the levels of turbidity recorded during this sample cycle are very low, and as a result the sitewise changes are minor in comparison with past trends.

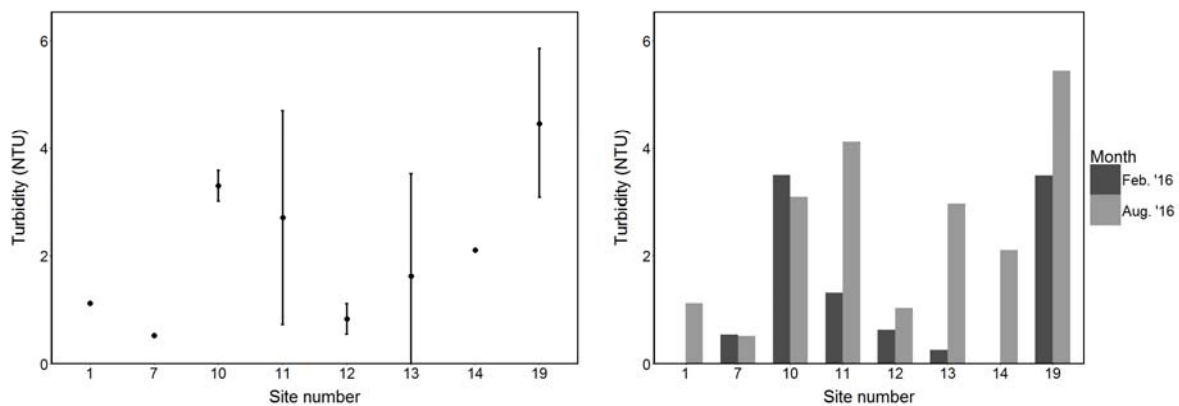


Figure 7 Mean \pm standard deviation in turbidity levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure.

Data on total inorganic nitrogen (TIN) levels at sampling sites are presented in Figure 8 below. With the exception of site 19 during February, sites are nearly all classed as having TIN levels that are either Good or Fair. The very levels of TIN noted at site 19 in February are higher than recorded before, and may mirror the increase in TIN noted at the end of the previous sampling cycle. This increase was found at the majority of sites, including site 19, and raised TIN levels at these sites to 5-6 mg/L. February levels in the current sampling cycle are significantly higher, but by August have reduced to a level classed as Fair. The source of this TIN is not known, though it may be associated with input in surface runoff followed by retention and concentration. The significant reduction in water volume noted since the previous sampling cycle may also have concentrated TIN in the reservoir (provided it is not removed from the water column by biological nutrient cycling). The

increased conductivity levels noted support the concentration scenario. Regardless of the potential of concentration to increase TIN levels as water evaporates, TIN levels decreased sharply to August. Whether this reduction follows dilution following rainfall, biological nutrient cycling, deposition, or another mechanism is not known. TIN levels at other sites decreased from the end of the previous sampling cycle. No other clear spatial or temporal trends are apparent.

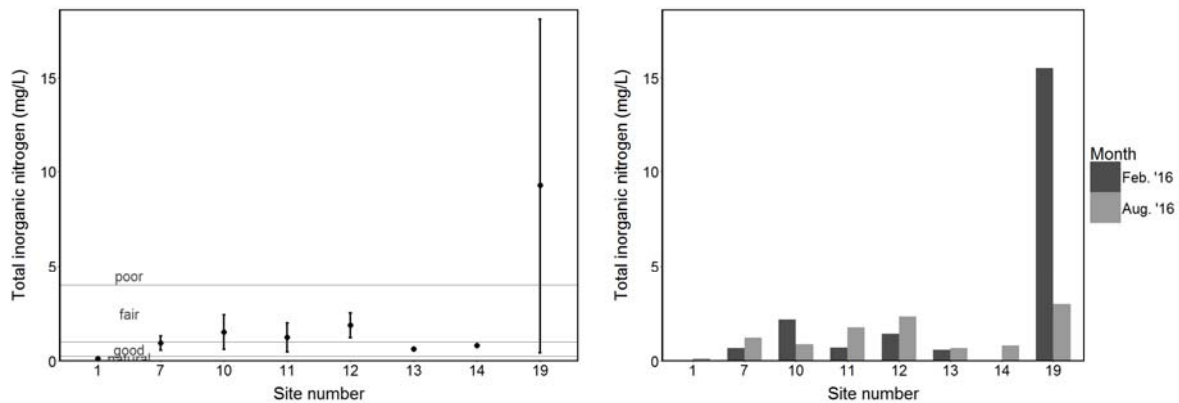


Figure 8 Mean \pm standard deviation in total inorganic nitrogen (TIN) levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the left hand figure.

Data on orthophosphate or soluble reactive phosphorus are presented in Figure 9. On average, most sites would be classified as Good, with sites 1, 10, and 12 being classed as Fair. The reason for the changed classification relates to increased orthophosphate in February (sites 10 and 12) or August (site 13 and possibly 7). The reason for these seasonal changes is not known. Sites 10 and 12 are upstream on the Manzamnyana and Mdibi Rivers respectively, and there are no known orthophosphate sources above these traditionally clean sites. In addition, downstream sites show no sign of increased levels of orthophosphate being introduced from upstream. It is unclear what process may have led to the reduction, though biological nutrient cycling is a possibility. Another possibility is that orthophosphate increases may be short-term and episodic. If so, no process is easily identified as being responsible.

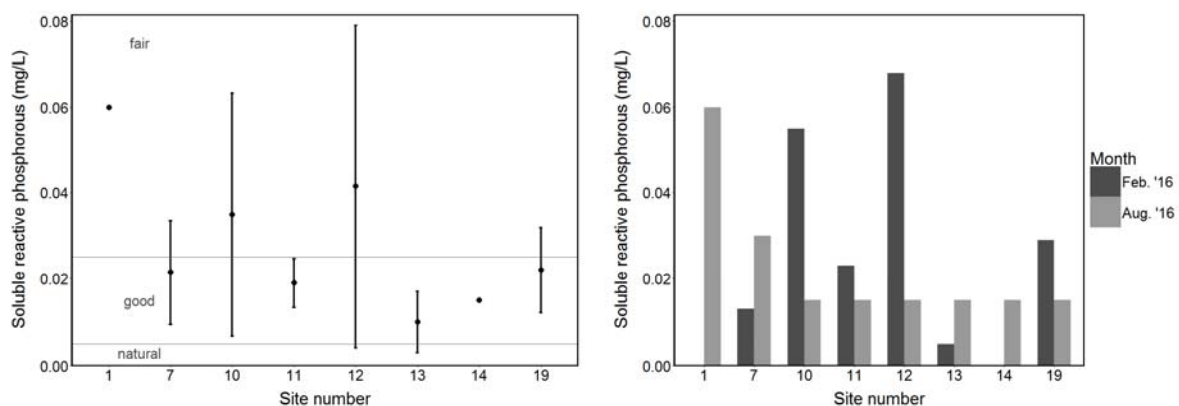


Figure 9 Mean \pm standard deviation in soluble reactive phosphorus (SRP) or orthophosphate levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figure. Default ecological categories based on ecological Reserve determination methodologies 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 below in Figure 10. No data are available from February owing to a field-based equipment malfunction. Phytoplankton chlorophyll *a* levels from August would all be classed as Natural, with the exception of site 10 where levels were classed as Poor. Periphyton chlorophyll *a* levels have a less favourable classification, with no sites classified as Natural, sites 10, 12 and 7 classified as Good, sites 10 and 19 classified as Fair, and sites 1, 13 and 14 classified as Poor. With the exception of site 10, phytoplankton chlorophyll *a* levels were fairly stable across sites, but periphyton levels varied widely.

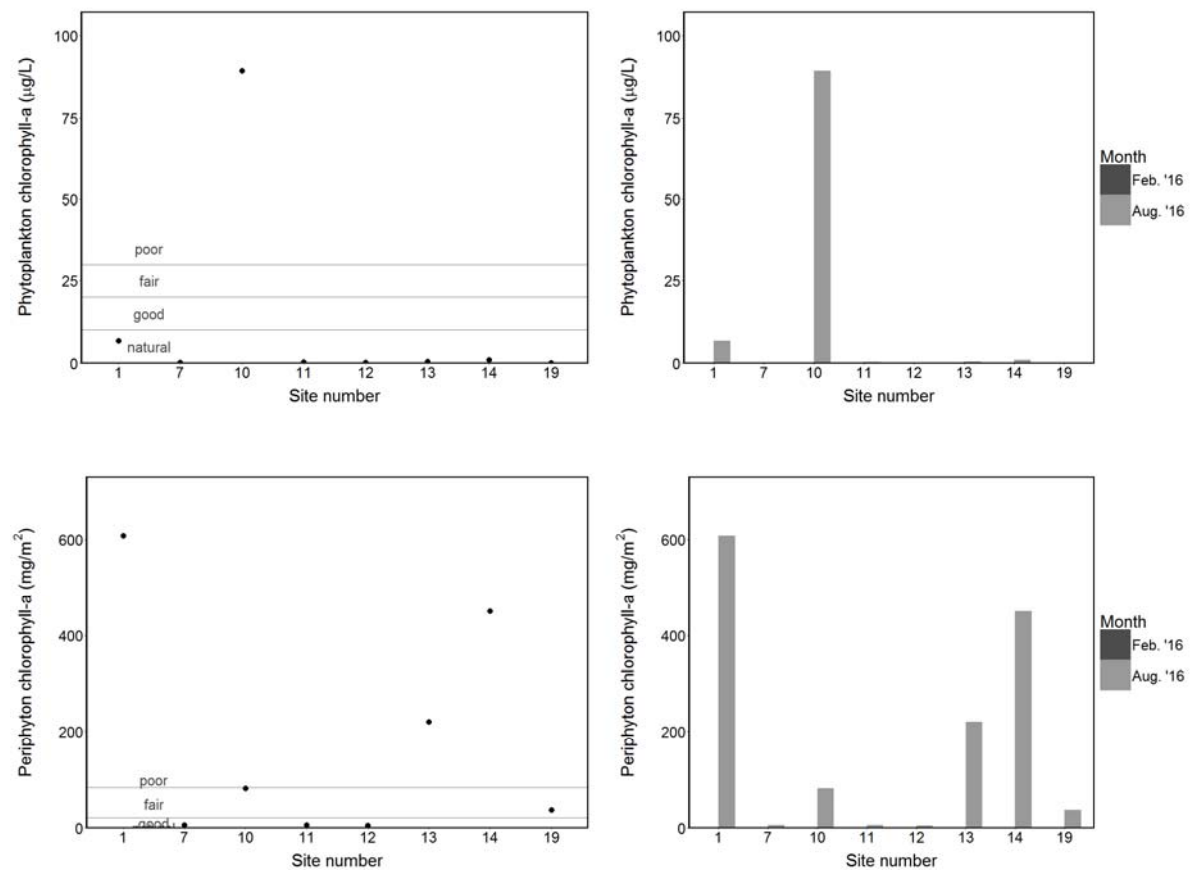


Figure 10 Mean ± standard deviation in phytoplankton (top) and periphyton (bottom) chlorophyll *a* levels at sampling sites are presented to the left of this figure, while temporal changes are presented in the right hand figures. No data are available from February owing to equipment malfunction. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the left hand figure.

High levels of phytoplankton chlorophyll *a* at site 10 are a result frequently observed at this site over time. These results have been attributed in the past to ongoing disturbance of the substrate at or near the time of sampling by the regular passage through the site of herd of cows. Cows were found at the site during sampling and it seems that this is the reason for the high phytoplankton chlorophyll *a* levels in this sampling cycle. Nevertheless, in the previous sampling cycle phytoplankton chlorophyll *a* levels at site 10 were higher than elsewhere, but were still classed as Natural, in contrast with the Poor classification from the current sampling cycle. Temporal variation at this site has been found before and may relate to the level of disturbance encountered immediately prior to sampling.

There is considerable spatial variation between sites in periphyton chlorophyll *a* levels during the current sampling cycle. Results from previous years also show considerable temporal and spatial variation in this

parameter. Results ranging from Good to Poor across sites are common for this parameter, and no consistent trend at particular sites has been found. Results from the previous sampling cycle were in general better than the results presented here with most sites on average being classed as Fair. The previous year found many sites classed as Poor.

2.2 Habitat assessment

2.2.1 IHAS score

The Integrated Habitat Assessment System scores for the sampling cycle are presented below in Figure 11. Scores in general range from 40 to 60, with the exception of scores from site 19, which are lower. Site 19 is a sandy bottomed dam and as such not a suitable site for biomonitoring using SASS, and a low score from this site is to be expected.

As in previous years, the index levels from site 7 were generally better, owing to the presence of a rocky riffle at the site that offers greater habitat diversity than at other sites. Scores from site 19, which is in a sandy-bottomed dam and which is not suitable for SASS, are the lowest. Site 7, which is the only monitoring point with a significant stone biotope, usually has the best IHAS scores. In the data presented below, the score from site 7 is among the better scores, but not the best. A clear temporal change is apparent in the current sampling cycle, with IHAS scores higher in August than in February. As the score is based on habitat quality, which should change little at any site in the absence of major disturbance, it seems this change is related to limited rainfall leading to improved water availability and flow. As an example, site 1, historically one of the better sites, showed a considerable decrease in IHAS scores in recent years, a trend largely driven by a cessation of flow at the site. No data from the current sampling cycle could be collected in February, when no water was found at the site. However, the August sample returned scores that are considerably improved over previous years.

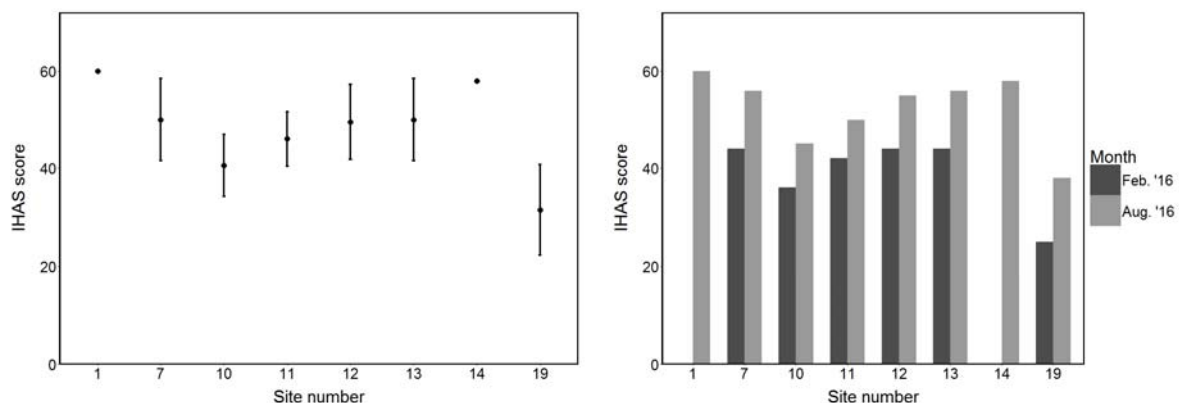


Figure 11 Integrated Habitat Assessment System (IHAS) scores at each sample site. The left plot shows the mean score \pm standard deviation, and the right plot shows temporal change in this index.

2.2.2 Site 14 impacts

The monitoring point at site 14 was severely impacted by the construction of a road along its banks (Figure 12), noted during August 2016, that cut the link between the river and an adjacent wetland (Figure 13). No such changes were visible when sampling in February 2016. It was reported that local residents involved in small-scale forestry and stock farming had expressed discontent about the wetland noting that they believed high water levels in the wetland was harming trees planted around it. They also reported that cattle that had drunk

from the wetland had died. As a result of this they intended to fill the wetland in. The effects of their activities can be seen in Figure 12 and Figure 13, and include, at the time of sampling, severing the link between the wetland and the river and some infilling of the river banks.



Figure 12 Impacts noted at site 14: view along the river.



Figure 13 Impacts noted at site 14: view across the wetland.

2.3 Macroinvertebrate assessment

2.3.1 Macroinvertebrate indices

The results of macroinvertebrate biomonitoring at the sample sites are shown in Figure 14. The sample sites that were assessed would on average be classed as Poor, with only site 13 being classed on the boundary between Poor and Fair. These results show a continued downward trend in ecological health in sites in the region as reflected in the aquatic macroinvertebrate community structure. The results will be addressed in detail below, but note that the report on the previous sampling cycle associated the decreasing trend in macroinvertebrate biomonitoring scores with the ongoing drought. This report indicates that increased rainfall between February and August seems to have increased water availability in the area, but that the aquatic macroinvertebrate community has not recovered. Water quality changes noted over recent years are likely to be at least partially responsible for the low aquatic macroinvertebrate biomonitoring scores. Relations between rainfall patterns, water quality and biomonitoring scores will be addressed in the discussion.

Site 19 is located in a dam high on the Mpisini River above any known potential impacts on water quality. The site was selected as a reference site on the Mpisini River following ongoing degradation at site 1, the previous reference site. The location of site 19 means the site can easily be accessed, though its placement in a dam means the use of riverine monitoring methods, like SASS5, is inappropriate. Since monitoring began, results from the site indicated a lack of impact. However, a site visit in July 2015 revealed low water levels together with an algal bloom and concomitant fish kills (Griffin 2015). Water levels remained low through 2016, though no further algal blooms were observed. Macroinvertebrate biomonitoring results for the site reveal it to be in a Poor condition, and, after sites 1 and 11, the worst-performing site of those surveyed. Nevertheless, results from the site are only slightly worse than several other riverine sites. The lack of flowing water and related habitat will account for some of this. However, the site remained salinized and acidified throughout the year, and the resultant poor quality will have impacted on macroinvertebrate scores.

Site 10 scored relatively highly in relation to other sites during this sampling cycle, a trend that was consistent across season. This is unusual as site 10 normally returns low scores in relation to other sites, which has generally been attributed to low oxygen levels at the site. In the current sampling cycle, site 10 recorded Fair oxygen levels, comparable to other sites. In comparison, several other sites have lower oxygen levels than experienced before, and these are matched by poor biomonitoring scores. However, variation in oxygen levels aside, inspection of previous data show that the macroinvertebrate biomonitoring score for site 10 has not changed with time. The reason site 10 results are comparable to other sites is that macroinvertebrate biomonitoring scores from other sites are lower than in previous years.

Two sites with notably decreased average biomonitoring scores were sites 1 and 11. Site 1 was chosen as a reference site on the Mpisini River and has historically returned Fair to Good biomonitoring scores. Site 11 is the point where the Manzanynana and Mpisini Rivers, which drain the region around the RBM Smelting and Processing Site, converge. Site 11 has generally had lower macroinvertebrate biomonitoring scores, though this appears to largely be a function of the paucity of habitat at the site, as the diatom biomonitoring scores at this point have generally been good. Nevertheless, average site 11 scores are lower for the current year than is usual. Inspection of February and August results show the decrease at site 11 is driven by particularly bad results from February. Inspection of quarterly results for site 11 (Section 2.5) show that the lowered February biomonitoring scores were matched by lowered pH and increased conductivity that was uncharacteristic for that year. It appears that the lowered macroinvertebrate biomonitoring score for the site was driven by unusual results from February and appears not to be representative for the whole sampling cycle. Likewise,

lowered macroinvertebrate biomonitoring results from site 1 appear to be a result of high conductivity and low pH during August (no water was present during February).

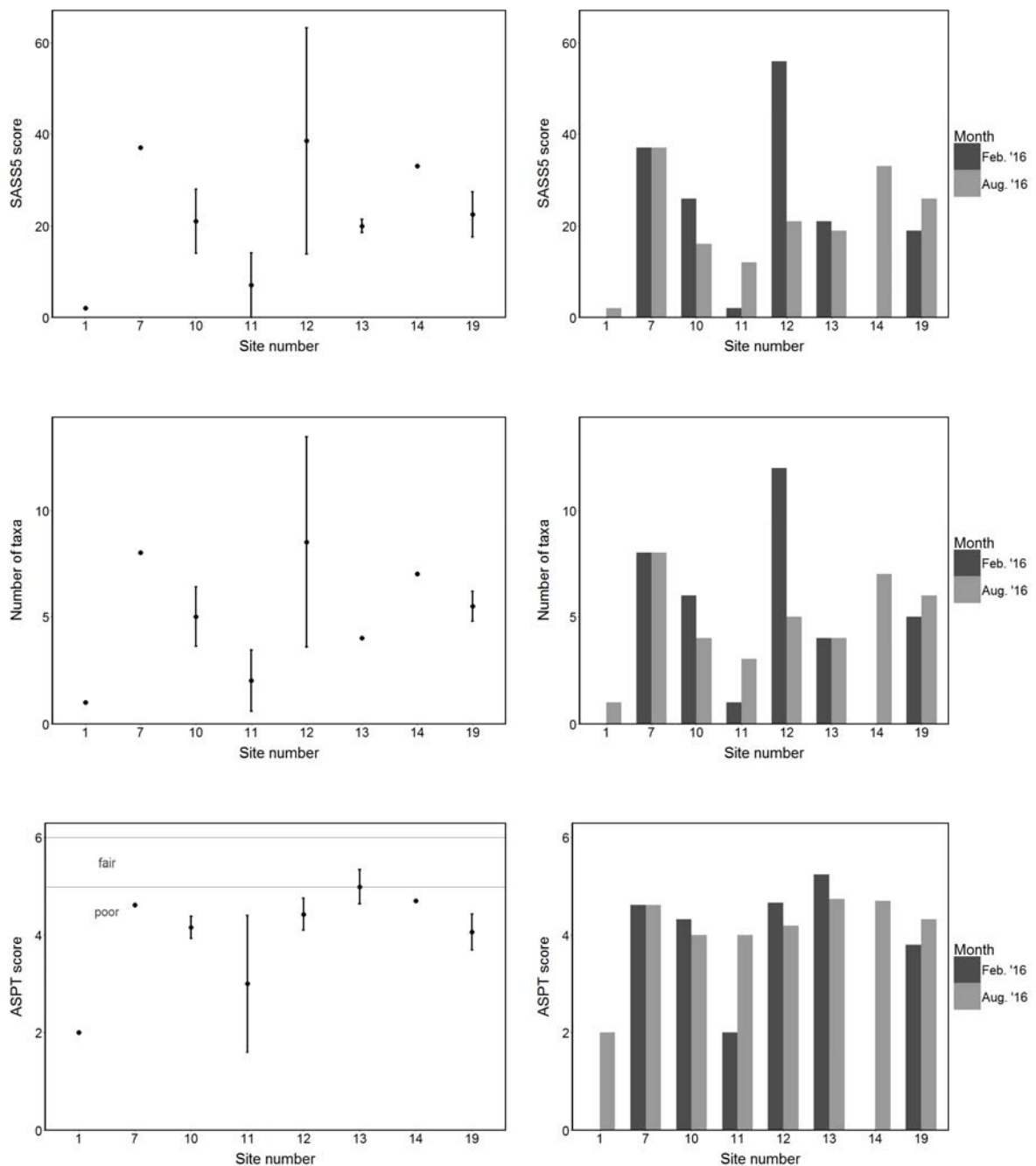


Figure 14 Macroinvertebrate biomonitoring scores, as SASS score, number of taxa, and ASPT score at the various sample sites. Plots to the left show mean \pm standard deviation, while plots to the right show temporal changes in the indices. Default ecological categories for ASPT scores based on ecological Reserve determination methodologies are shown.

Site 7 was the second-best site overall, though it was still classed as Poor. Site 7 has the best habitat of all the sites as it has the only significant in-current stone biotope. Previous work at the site has found that the added biotope may act to inflate scores at this site despite other stresses that lowered diatom biomonitoring scores. Results from the current year show the site to perform well relative to other sites, but to return a macroinvertebrate biomonitoring score that is nevertheless classed as Poor. In comparison, the site has been

classed mostly as Fair in prior reports. The relative good performance of the site in the current report reflects a drop in the scoring at site 7, and a larger drop in the performance of other sites that have been classed as Fair to Good in the past.

Site 12 is the uppermost site on the Mdibi River. Known impacts upstream include forestry (left bank) and mixed smallholdings with forestry or small scale agriculture. The site was scored as Poor in the current sampling cycle, and a lack of temporal variation suggests this to be valid. The site has scored as Fair to Poor in recent surveys, a decrease from Fair to Good as found in earlier work.

Site 13 lies midway along the Mdibi River in the sampled region. Upstream impacts include those noted for site 12, with greater density of residences as one moves downstream from site 12. This site returned the best score in the current biomonitoring cycle, and continues a trend noted in previous surveys. The current overall score resulted in the site being classed as Fair/Poor, which is notably low for a site that has frequently been classed as Good in previous surveys.

Site 14 is on the lower Mdibi River, and downstream of all sites surveyed. The site was scored as Poor in the current year, which shows no change from the previous year, though in earlier years the site was more often classed as Fair or Good. The decrease in biomonitoring scores has coincided with the recent drought, and it seems likely that this is the cause. It is important to note that the overall annual score is only based on data from August, as a lack of water in the river in February precluded sampling at that time. Water quality in August indicated increased salinization and acidification that impacted macroinvertebrate scores along the river.

A trend noted across all sites is a decrease in the number of taxa found at sites in the area. This is particularly so in the current sampling cycle, when the mean number of taxa at a site was found to be 5.3, down from 8.7 the previous year, and 11.4 the year before that. The decrease in diversity is matched by a decrease in ASPT scores, though the change is less pronounced (2016: 4.1; 2015 4.8; 2014 5.3). This indicates that despite the decreased diversity, some sensitive taxa are still present.

2.3.2 Macroinvertebrate community analysis

The ordination biplot produced in the NMDS ordination of invertebrate family-level community structure is presented in Figure 15. Differences in community structure between sites and months were found to be statistically significant (site $p < 0.001$; month $p < 0.001$).

Limited water levels encountered during sampling restricted collection of a full set of replicate samples from several sites during the February sampling trip. Increased water availability by August ensured that the full set of replicate samples were collected on the August trip.

Changes in the number of families and Shannon diversity between sites and month were examined to determine whether alpha diversity had shown consistent trends during the study cycle. The number of families varied significantly between sites ($p = 0.002$), though it did not change with time of sampling. Significant changes were largely driven by the low number of families at site 1 and site 11. Shannon diversity likewise varied significantly between sites ($p < 0.001$) but not with time of sampling. These changes were also mostly driven by low diversity at sites 1 and 11. Beta diversity varied between sites to a marginally significant level ($p = 0.055$), while differences between months was not significant at all.

Inspection of Figure 15 reveals considerable grouping of sites that indicates low relative changes in community structure between sites. Nevertheless, some trends are clear. Perhaps the major trend can be seen in the

relative lack of overlap of samples from February and samples from August. Samples from February cluster in general to the left of Figure 15, while those from August cluster to the right. This supports the conclusion that taxa changed to some extent between February and August 2016. These changes may have been driven by changes in water quality between samples (for example, August samples were often more acidic, less saline and more turbid) or by other seasonal factors. For the most part, differences between months overpowered the tendency of sites to stay the same, despite relatively unchanged habitat etc.

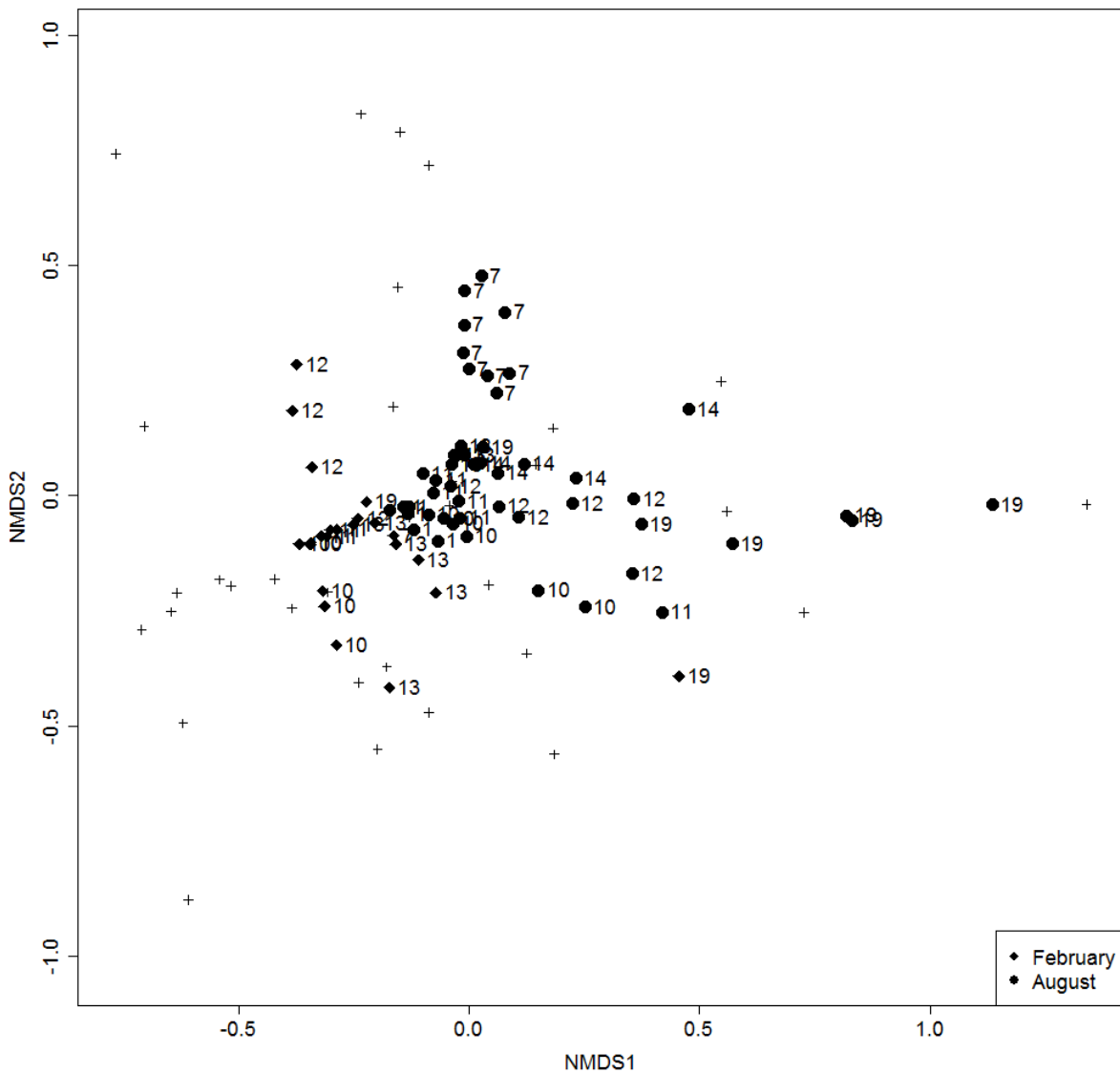


Figure 15 NMDS ordination plot of Bray-Curtis distances between all samples assessed based on untransformed invertebrate family-level abundances (stress: 8.7%). Sites are labelled and species indicated by +.

Samples from some sites and months were found to have a distinctly different community structure to other samples that were collected. A particular example would be the community sampled at site 7 in August. These samples showed very little variation despite having been collected from different habitats at the site. This seems to be driven by the large numbers of Atyidae and the relative lack of Baetidae in August samples from that site. Samples collected at site 7 in February were limited as little water was present, but no Atyidae and

few Baetidae were present. Despite the relatively high dispersion (an indicator of beta diversity) in August samples from site 19, these are also largely distinct from other samples collected, and this trend seems to be a function of the high numbers of Chironomidae and Coenogrionidae in these samples. February samples from this site were also limited by low water levels, and fewer Chironomidae and Coenogrionidae were present.

February and August samples from site 10 tended to be placed to the bottom of Figure 15. No clear dominance of any particular taxon could be found to explain this, and it is therefore reflective of a multivariate relationship. Despite this trend, there are clear distinctions between samples collected in February and August. Nevertheless, it reflects on a trend in community structure that distinguishes most samples from site 10 from other samples.

Perhaps the most notable outcome of the results presented in Figure 15 is the absence of trends in the data that were observed during previous years. In the past it was commonly observed that trends were visible from upstream sites to downstream sites. The clustering of samples with few outliers demonstrates that this trend has disappeared during the current sampling cycle, and therefore that the distinction between upstream and downstream samples has decreased. While a clear reason for this is not known, the presence of the ongoing drought during this sampling cycle coupled with changes in water quality are likely to have influenced community structure and may have largely over-ridden changes with distance downstream along the rivers assessed.

2.4 Diatom assessment

2.4.1 Diatom indices

The changes in three indices based on diatom communities present at the sites during February and August 2016 are presented in Figure 16. There was wide variation in scores returned, with scores ranging from High to Bad being returned for a range of sites. These results are worse than previous years, when high scores were more common and bad scores rare. Macroinvertebrate biomonitoring results for this sampling cycle were also poor. Levels of variation encountered resulted in no statistically significant differences being found in either index as a result of changes between sites or month sampled, although changes with site in the BDI-2006 index were marginally significant ($p=0.058$).

Discrepancies between the score based on expert opinion and the other diatom indices used commonly relate to inclusion of local taxa in index calculations. In 2016, differences are often due to the inclusion (or not) of *Actinella* species (and to some extent on *Eunotia* species) that were found to be more common in samples from this sampling cycle than before. Both genera are associated with acidic water, and, in compiling the score based on expert opinion, acidic water was treated as abnormal, based on previous results from the region. This is in spite of the fact that acidic water may be natural, and that the acidic water where many *Actinella* species have been described from generally is acidic although not impacted (Melo et al. 2010). The IPS scoring did not use *Actinella* in index generation, although some species may be used for index generation and these, if used, are treated as sensitive species. The BDI-2006 index does not use *Actinella* in index generation at all.

Despite the lack of clear statistically significant trends, some trends are apparent in Figure 16. Sites around the RBM Smelting and Processing Site generally returned lower scores than most other sites in the catchment. Some seasonal variation was noted, particularly in the score based on expert opinion. Nevertheless, on average, samples from sites 10 (west of the Smelter), 1 (east of the Smelter), and 7 (downstream of the Smelter) commonly scored lower than most other sites. Several of these sites experienced water stress during the monitored period, and several water quality issues related to acidification, salinization, oxygen levels, and

phosphate levels were encountered. No water quality trend provided a simple and clear explanation for the changed diatom results. Site 11 receives water from these sites via the Mpisini and Manzamnyana Rivers, and in general scores better than the upstream sites. The reason for this is not known. Site 19 is upstream in the Mpisini River, and results from this site (when water was present) are better than those from the sites around the RBM Smelting and Processing Site. This was despite unacceptably high salt and acidity levels at the site (results from both lie far outside DWS tolerable bounds (DWA 2011)).

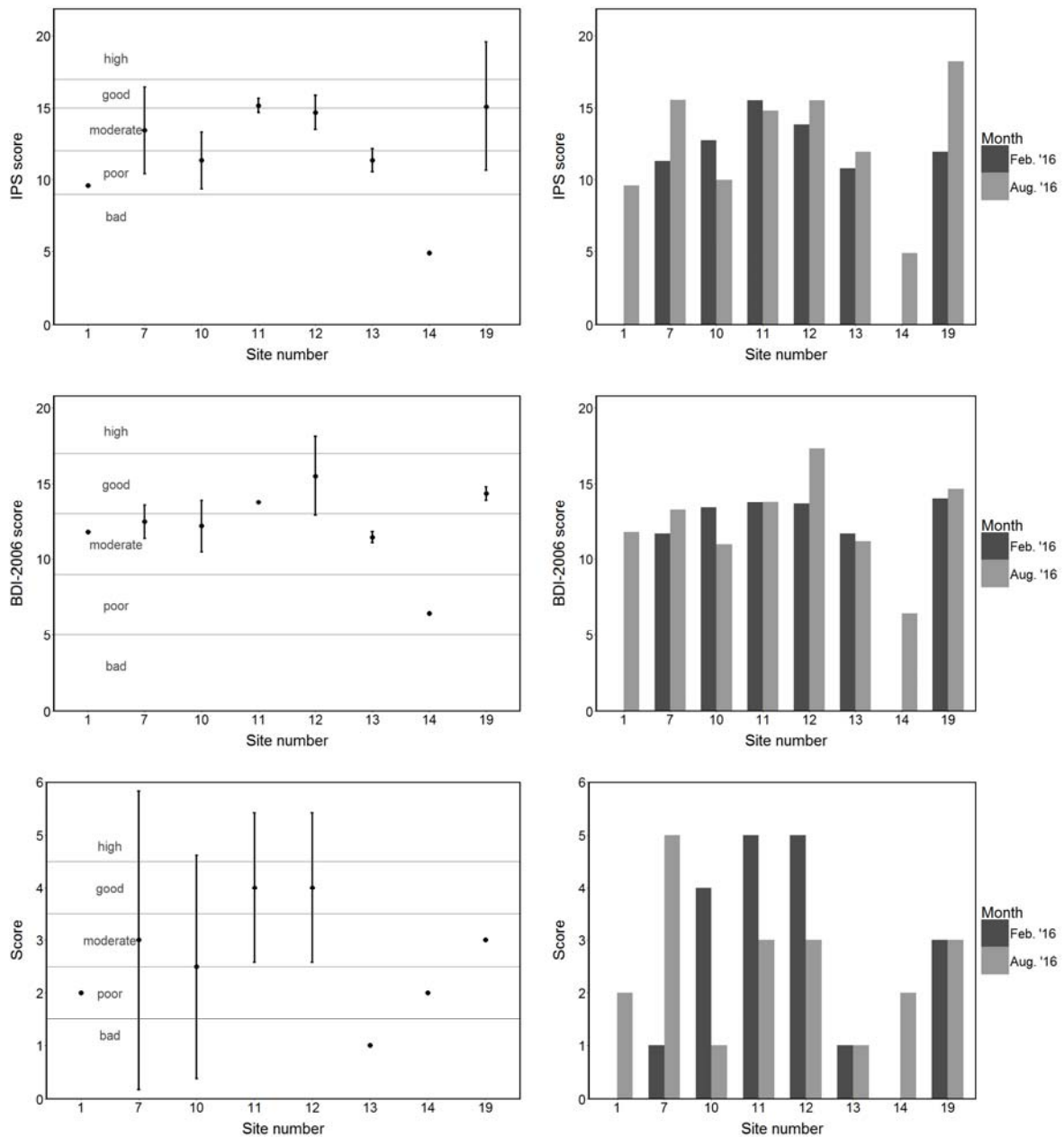


Figure 16 Diatom biomonitoring scores, as IPS score, BDI-2006 score, and the score based on expert opinion at the various sample sites. Plots to the left show mean \pm standard deviation, while plots to the right show temporal changes in the indices. Ecological categories for the various scores are shown.

While some indices differ, the results of diatom biomonitoring show a progressive decrease in water quality with distance downstream along the Mpisini and Manzamnyana Rivers. Sites upstream in each river are classified as Good (or nearly Good) by most indices. The major discrepancy is at site 19, where the index based

on expert opinion indicated a Moderate score. This was as a result of using the dominant *Actinella* species as an acidity indicator for this index. The high scores from site 19 are somewhat of a surprise as the site was extremely acidic and saline, and water levels were very low. Macroinvertebrate biomonitoring results classified it as Poor overall (although the site is not suitable for SASS5 biomonitoring and this may have affected results from the site). A decrease in water quality is normal along the course of a river. However, the decrease in water quality found here is more pronounced than would normally be expected and worse than in previous sampling cycles. The decrease in water quality in the overall area is supported by results from chemical monitoring and biomonitoring using macroinvertebrates and diatoms.

In a similar vein, the results from site 10 are lower than previous years. Site 10 is immediately below a groundwater-fed wetland. Macroinvertebrate biomonitoring has typically returned low scores from this site, which has been attributed to low oxygen levels in the source water and the wetland itself. In contrast, the diatom population has generally indicated good water quality. In contrast, the diatom results from this sampling cycle reflect results that are Moderate to Poor overall. The reason for this drop is not known. The chemical data from this site give the best water quality of all sites overall, and the severe acidification and salinization apparent at other sites does not occur at site 10. Given that water at this site derives largely from groundwater, changes here should reflect changes to the groundwater quality.

Overall, diatom indices indicate good water quality at site 11, at the confluence of the rivers that drain the RBM Smelting and Processing Site. This is despite Poor scores upstream at sites 1 and 10, and a Moderate score at site 7. Another site with a Good score was site 12, upstream on the Mdibi River. This site has historically returned good scores, although in recent years scores from this site have dropped somewhat.

2.4.2 Diatom community analysis

The results of the diatom community ordination are presented in Figure 17. Difference between results from different sites and different months were not statistically significant.

Alpha diversity in the samples was assessed by measuring the number of species present and the Shannon diversity. Neither measure showed statistically significant changes between sites or between months. Beta diversity changes were likewise compared, and, while changes across months was marginally statistically significant ($p=0.079$), changes with site were highly statistically significant ($p<0.001$). Beta diversity changes have been proposed as a measure of stress at the sites. The results suggest that certain sites were more stressed than others during the sampling cycle.

A trend apparent in previous reports, where some similarity between sites over time was found, is entirely absent in Figure 17. Variation between sites is massive, inconsistent, and largely eclipses the effect of site-specific drivers. This suggests that temporal changes affecting the diatom community have been significant and that changes have not been consistent across sites. All sites have been affected by the drought in the region, and while low water levels have been recorded across all sites recently, the impacts have varied from site to site. The extent of the drought is illustrated by a lack of water at sites 1 and 14 in February, with very low levels at other sites. By August, some rain had fallen and the situation had improved slightly. However, diatom community responses varied from site to site.

Samples plotted on Figure 17 do group somewhat by dominant diatom species ecological preference's. Samples in the top left of the plot all have an unknown species of *Actinella* dominant or common, and all contained relatively acidic water. However, these sites were not the only ones with acidic water as some sites, in particular sites 1 and 14 in August, had more acidic water at the time of sampling. However, this species of

Actinella was rare at site 14 and absent from site 1. The taxa at the former were mostly indicative of organic or nutrient enrichment, while most of the taxa at the latter were indicative of electrolyte enrichment. One can argue that, for sites in the left top corner, the acidity overrode other factors such as electrolyte levels. But the sites in the top left corner had some of the highest electrolyte levels recorded in this sampling cycle.

The samples grouped on the lower left hand side of Figure 17 are united by several factors. Both samples were collected in August from sites that had no water in February. Both samples scored relatively poorly using diatom biomonitoring. Both sites were dominated by *Nitzschia capitellata*, a taxon indicative of high electrolyte levels that was present at site 1 in significant numbers in recent years (Griffin 2014, 2015), but has not otherwise been dominant in the area. Finally, both sites have low pH and high salinity, and dissolved oxygen levels were Poor to Fair.

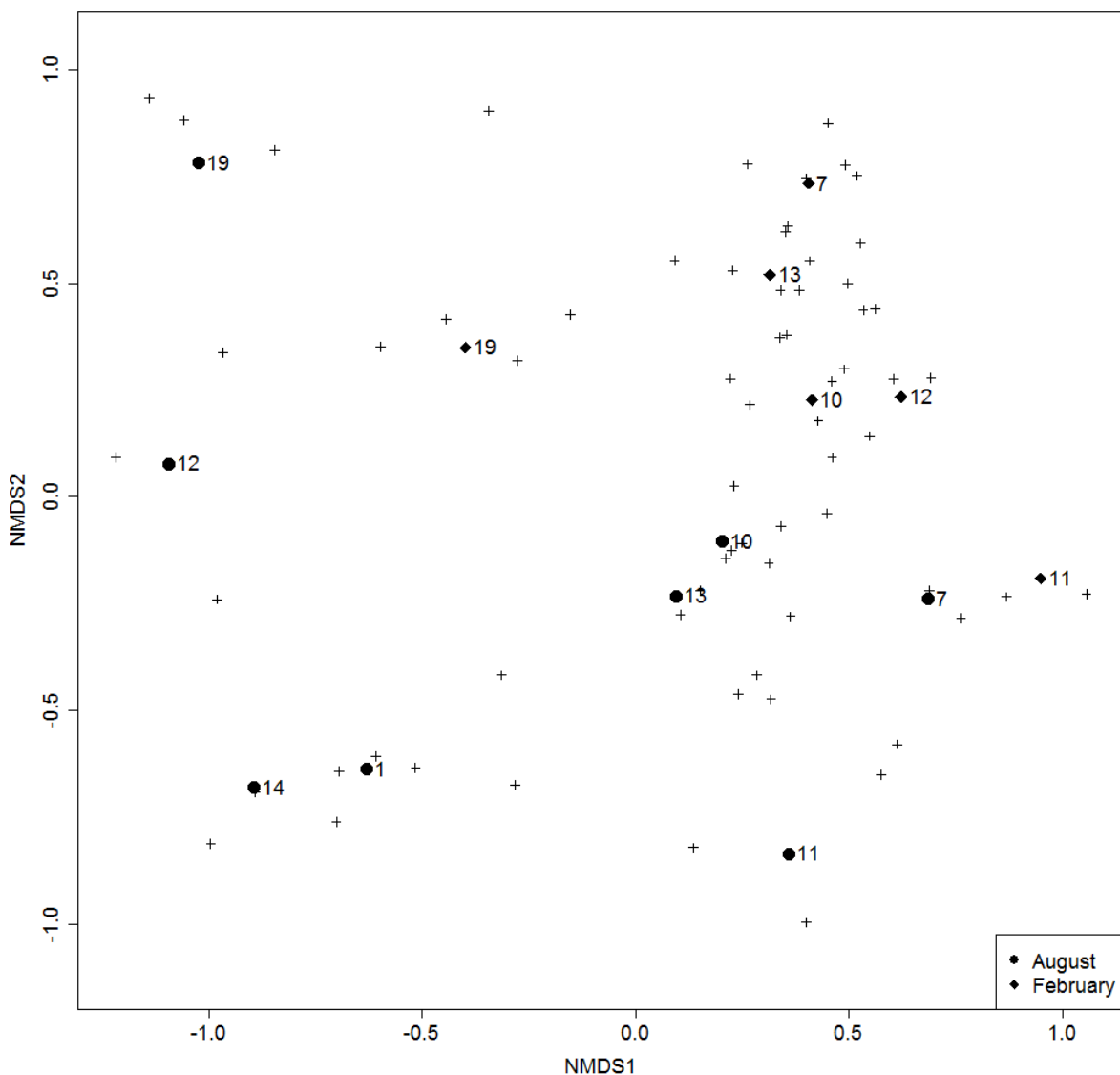


Figure 17 NMDS ordination plot of Bray-Curtis distances between all samples assessed based on untransformed diatom species-level abundances (stress: 14.9%). Sites are labelled and species indicated by +.

In contrast, samples towards the centre-right hand side of the plot had generally good diatom scores. It is worth repeating that temporal variation led to few of these (bar at site 11) being repeat samples from one site. Beyond site 11 samples, February samples from sites 10 and 12, and the August sample from site 7 scored highly and were clustered in this group. These samples were not grouped owing to the presence of one or a few dominant taxa but rather shared many of the same taxa in varying quantities.

The remaining samples, lying between the group with good scores and the group dominated by *Actinella*, are all dominated by taxa associated with organic or nutrient enrichment. As with the group with good scores, the sites in this group changed (bar site 13) with time, and the group has samples from several sites that also appear in the group with good scores. This group shares several taxa between samples and is not held together by one dominant taxon. Species from the genera *Nitzschia*, *Navicula*, *Luticola* and *Sellaphora* are more common in these samples. No obvious physicochemical parameters define these samples, and, despite containing taxa associated with nutrient enrichment, levels of nutrients at these sites are relatively low.

In summary the major trends revealed that the main changes found, were changes themselves. Few sites had temporally stable results, with site 10 showing the least change with time (although the diatom scores from this site varied more), and many sites showed large changes with time. Trends were not consistent across time, however. Some sites showed signs of trends being driven by acidification and salinization at many sites. The samples were collected in February, when the drought in the region was ongoing, and in August, after some rains had fallen although rainfall levels had not returned to normal. The limited rainfall had not reversed acidification and salinization at all sites, and some sites showed signs that the water quality had worsened.

2.5 Extended biomonitoring at Confluence (Mpisini-Manzamnyana) (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 Manzamnyana Rivers. The data presented here were collected during sampling trips during December 2015, and February, May, and August 2016.

2.5.1 Water quality assessment

Water quality data from the extended monitoring programme at site 11 are presented in Figure 18 below. Conductivity in the catchment ranged from Fair to Poor. Poor conductivity was recorded in February 2016, when the drought was at its height, and the Fair conductivity was recorded before in December and later, after limited rainfall had raised water levels in the area. The pH was largely Natural, except in February, when acidic conditions led the sample to be classified as Poor. February's sampling trip also found that site 19 was acidified, though the cause of this was not clear. Temperatures were, unsurprisingly, warmer in the spring and summer samples. Finally, dissolved oxygen levels were generally Poor, except in the May sample. Fair to Poor oxygen levels are not unusual at this site.

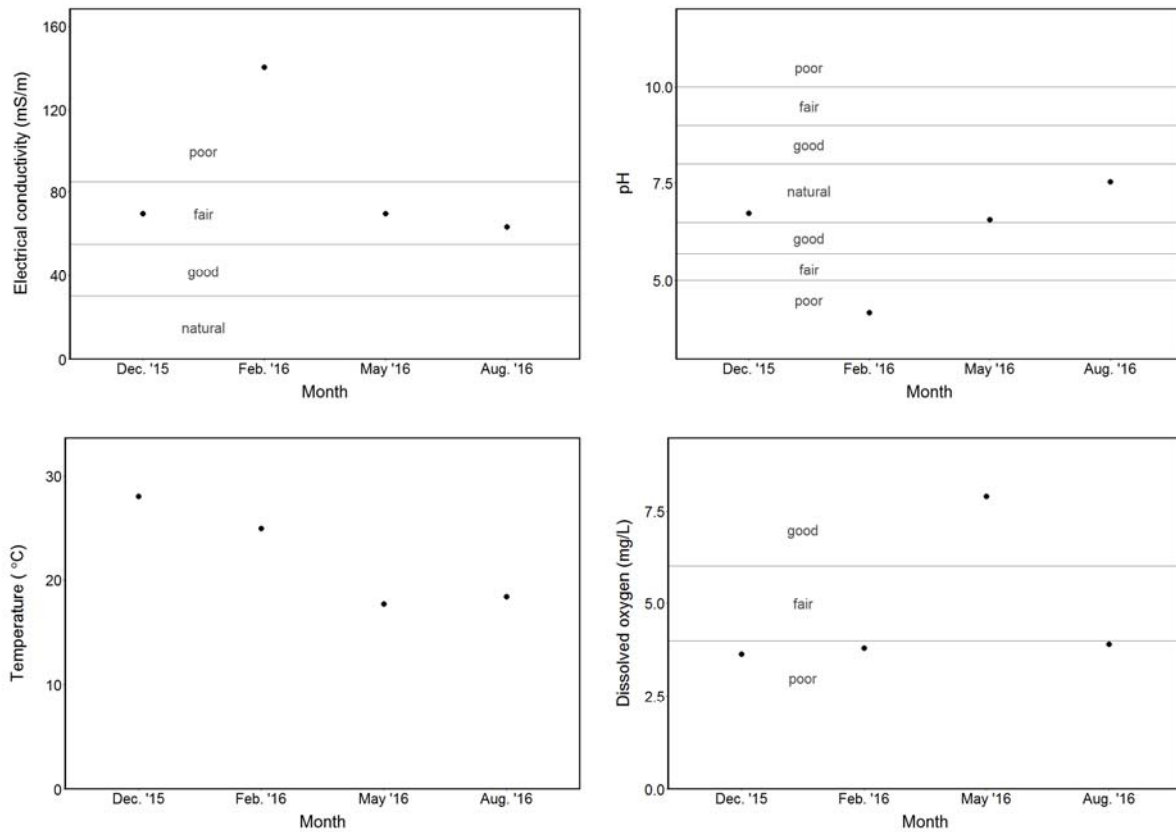


Figure 18 Electrical conductivity, pH, temperature and dissolved oxygen levels at Confluence (Mpisini-Manzamyana) (site 11) between December 2015 and August 2016. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the plots where appropriate.

2.5.2 Macroinvertebrate biomonitoring (SASS) and habitat assessment

The results of extended macroinvertebrate biomonitoring at site 11 are presented in Figure 19 below. IHAS results fall into the range of 40 to 60, which shows no change from previous years. The highest IHAS score was encountered in December 2015, which corresponds with the best biomonitoring scores. Thereafter habitat quality was found to decrease, a change roughly followed by biomonitoring scores. Biomonitoring results from this sampling cycle show the site to be classed as Poor on a year-round basis. These results are somewhat worse than preceding years, when the site was often but not exclusively classified as Fair to Good.

The poor biomonitoring scores from the current sampling cycle might reflect the impact of the ongoing drought with some evidence for slight recovery following the onset of limited rains.

In the same way as at sample sites throughout the catchment, the number of taxa recorded during the current sampling cycle is less than in previous years. This reached its worst in February, when only one taxon was found. Although the ASPT scores are also lower at this site during the current sampling cycle, the extent of the decrease does match that of the number of taxa. The cause of the recent reduction in diversity is not known, although the long drought may have contributed to this.

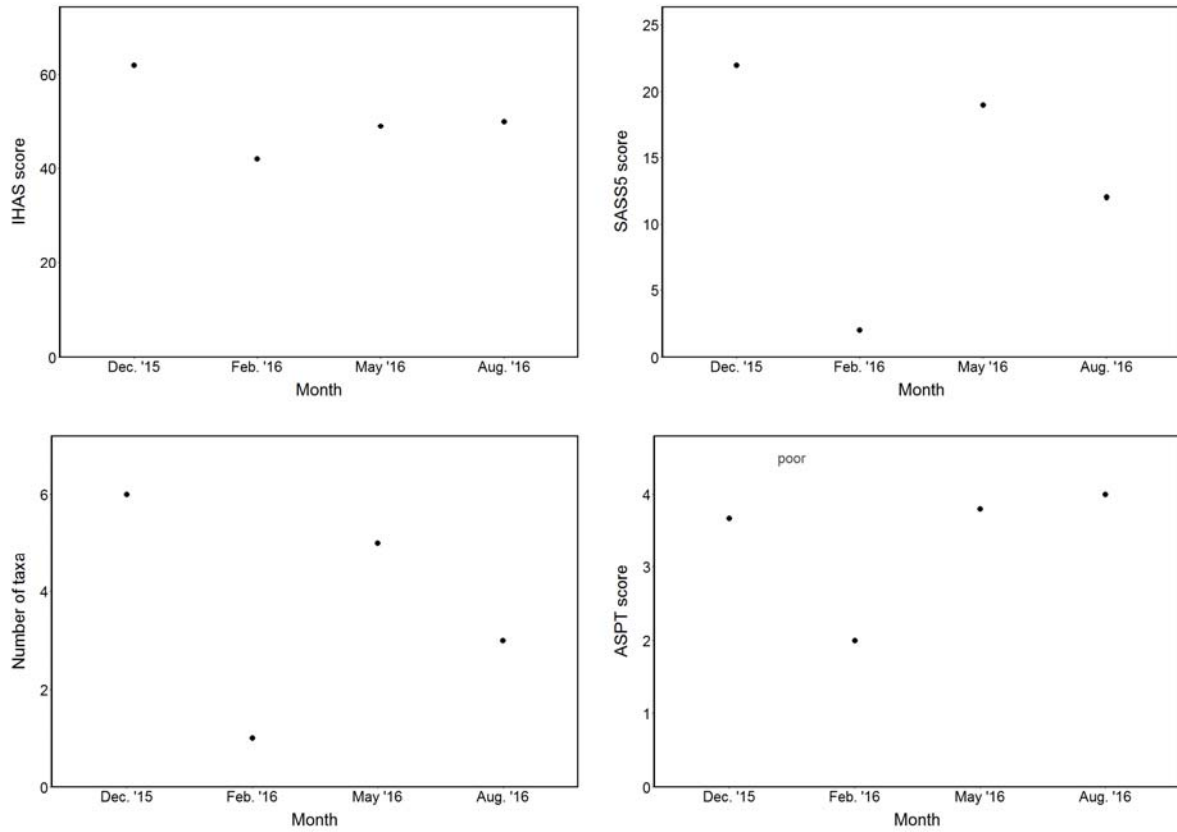


Figure 19 Integrated habitat assessment system (IHAS) score, SASS score, the number of taxa, and the ASPT score at Confluence (Mpisini-Manzamnyana) (site 11) between December 2015 and August 2016. Default ecological categories based on ecological Reserve determination methodologies are superimposed on the plots where appropriate.

3 Site summary and overall classification

Table 2 Summary of Mpisini upstream of Smelter (site 1) midstream on the Mpisini River.


									
<p>Site description: This site is slightly upstream of the Smelting and Processing 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 site is dominated by mud with limited sand, usually covered with leaf litter. Both marginal and aquatic vegetation are present. The site was dry during February 2016.</p>									
<p>Water quality parameters: T: temperature; DO: dissolved oxygen; EC: electrical conductivity; TIN: total inorganic nitrogen; SRP: soluble reactive phosphorous. Water quality categories based on the ecological Reserve methodologies for water quality are provided below the values where relevant.</p>									
T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
18.9	3.6	2.1	168.9	0.13	0.060	1.0	1.11	6.8	608.0
	Poor	Poor	Poor	Natural	Fair			Natural	Poor
<p>Biological and water quality indices: Summary of the main index scores. ASPT: average score per taxon; IHAS: integrated habitat assessment system; diatoms; and composite water quality. Ecological health categories are largely based on those used for ecological Reserve determinations.</p>									
ASPT		IHAS (%)			Diatoms		Water quality		
2.0		60			2.7		Fair		
Poor					Moderate				
<p>Overall ecological assessment: Fair</p>									

Table 3 Summary of Mpisini downstream of Lake Evans (site 7) on the Mpisini River.



Site description: The Mpisini river flows past the Smelting and Processing Site immediately upstream of this site. The surrounding land use is forestry, and there is no impact from human settlements. Vegetation and sand/mud habitats are present. This is the only site which contains gravel and limited stones, with some in a riffle. Cattle frequently drink at this 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 <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
21.8	7.3	6.3	81.7	0.940	0.022	2.5	0.5	0.19	5.4
	Natural	Good	Poor	Good	Good			Natural	Good

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

ASPT	IHAS (%)	Diatoms	Water quality
4.6	50	3.2	Good
Poor		Moderate	

Overall ecological assessment: Fair

Table 4 Summary of Manzamnyana upstream of Smelter (site 10) on the Manzamnyana 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 Smelting and Processing Site in close proximity. There are no impacts from human settlements. Vegetation in the wetland lake consists of marginal vegetation (reeds and grass) and aquatic vegetation. Gravel, sand and anoxic mud is present in the shallower part of the lake. The site 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 <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
23.8	6.6	5.0	37.6	1.520	0.045	3.0	3.3	89.49	81.4
	Natural	Fair	Good	Fair	Fair			Poor	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
4.2	40.5	2.9	Fair
Poor		Moderate	

Overall ecological assessment: Fair

Table 5 Summary of Confluence (Mpisini-Manzamyana) (site 11) at confluence of the Mpisini and Manzamyana Rivers.



Site description: The site is within a natural forest at the confluence of the Mpisini and Manzamyana Rivers, downstream of the Smelting and Processing Site. Surrounding land use is forestry with no impact from human settlements. There is very limited vegetation, particularly during the lower flows. Vegetation usually consists of marginal vegetation that dips into the water, root wads and twig snarls. Most of the site consists of sand and mud. The site is littered and 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 <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
21.7	5.9	3.9	102.1	1.235	0.019	2.5	2.7	0.34	5.7
	Good	Poor	Poor	Fair	Good			Natural	Good

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

ASPT	IHAS (%)	Diatoms	Water quality
3.0	46.0	3.6	Fair/Good
Poor		Good	

Overall ecological assessment: Fair

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


									
<p>Site description: This is the uppermost site on the Mdibi River and tentatively proposed as a reference site for this river. Surrounding land use is forestry and some limited human settlement. The channel consists of sand, some mud and limited leaf litter. Vegetation at this point consists of aquatic plants and marginal grass. Red floc was recorded at this side for the first time during the summer 2013 sampling trip, has been sporadic since.</p>									
<p>Water quality parameters: T: temperature; DO: dissolved oxygen; EC: electrical conductivity; TIN: total inorganic nitrogen; SRP: soluble reactive phosphorous. Water quality categories based on the ecological Reserve methodologies for water quality are provided below the values where relevant.</p>									
T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
22.8	5.9	5.8	101.3	1.875	0.042	1.5	0.82	0.17	5.4
	Good	Poor	Poor	Fair	Fair			Natural	Good
<p>Biological and water quality indices: Summary of the main index scores. ASPT: average score per taxon; IHAS: integrated habitat assessment system; diatoms; and composite water quality. Ecological health categories are largely based on those used for ecological Reserve determinations.</p>									
ASPT		IHAS (%)			Diatoms		Water quality		
4.4		49.5			3.8		Fair		
Poor					Good				
<p>Overall ecological assessment: Fair</p>									

Table 7 Summary of Middle Mdibi River (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. Vegetation is dominated by reed stalks and leaves, although there are some aquatic plants present. The channel consists of mud and sand which is covered by thick shredded leaf litter. Reeds have been cleared at this point over the 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 <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
21.2	6.5	7.0	129.5	0.635	0.010	1.0	1.6	0.41	220.4
	Natural	Good	Poor	Good	Good			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
5.0	50.0	2.8	Good
Good/Natural		Moderate	

Overall ecological assessment: Good

Table 8 Summary of Lower Mdibi River (site 14) downstream on the Mdibi River.



Site description: This is the lowermost site on the Mdibi River, situated upstream from Lake Mzingazi. Surrounding land use is subsistence forestry and human settlements. Vegetation usually consists of marginal reeds, grasses and aquatic plants. The channel consists of sand and mud. Irregular disturbance by cows has been noted. In February 2016 the river was dry. August 2016 found excavation and major bank modification in an apparent attempt to fill the adjacent wetland.

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

T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
19.9	4.6	4.7	117.2	0.810	0.015	1.0	2.1	0.94	450.93
	Poor	Fair	Poor	Good	Good			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
4.7	58.0	1.4	Fair
Fair		Bad	

Overall ecological assessment: Poor/Fair

Table 9 Summary of Mpisini upstream Dam (site 19) upstream on the Mpisini 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 water body has a sandy bottom. No upstream impacts are known, and surrounding land is dominated by forestry. Water levels fell during the drought and have not recovered since. The water has been somewhat acid in recent samples.

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

T (°C)	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	BOD ₅ (mg/L)	Turb. (NTU)	Chlorophyll <i>a</i>	
								Phytoplankton (µg/L)	Periphyton (mg/m ²)
23.7	3.5	8.2	233.8	9.260	0.022	13.0	4.5	0.12	37.2
	Poor	Good	Poor	Poor	Good			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
4.1	31.5	3.7	Fair
Poor		Good	

Overall ecological assessment: Fair

4 Discussion

The 2015 report on stream biomonitoring around the RBM Smelter (Griffin 2015) pointed out that 2015 overall results were worse than in previous years, and that this was driven in particular by decreasing macroinvertebrate scores. This decreasing trend continued into the 2016 sampling cycle, with decreasing overall site scores and in particular macroinvertebrate scores. Site scores dropped from 2015, when half the sites were Fair/Good, to 2016, when the majority of sites were Fair. Macroinvertebrate scores were evenly split between Poor and Fair in 2015, and now the majority are Poor. There has been less of a clear matching shift in water quality and diatom scores.

The 2015 report also noted anomalous changes in water quality at several sites, and identified issues related to low pH levels, inorganic nitrogen enrichment, and salinization. Low pH levels were recorded in particular at sites 1 and 19, while high nitrogen levels were found at most of the sites sampled. The data from this year found that clear acidification was found at sites 1, 14 and 19, and other sites showed acidification at varying times. Nitrogen levels were in general better in 2016, though site 19 in February still showed high levels of nitrogen. Finally, the trend to salinization noted in 2015, when Fair or Poor levels were recorded at all sites, was still present in 2016, when most sites recorded Poor overall salinity levels. Closer inspection of 2016 data revealed a significant linear relation ($p < 0.001$) between pH levels and salinization, where samples from sites with low pH tended to have high salt levels. The reason for this relationship is not clear but it does suggest that the same factors driving the salinization are leading to severe acidification. Some level of salinization during droughts is a well-known phenomenon as insufficient fresh water is available to dilute ions in solution, and freshwater loss is exacerbated by evaporation. 2015 salinization was attributed to the ongoing drought. The drought had not broken before sampling in February in 2016, and though some rain fell before the August sampling trip, the impacts of the drought are still apparent.

As noted above, macroinvertebrate scores have continued to decrease, but overall scores of water quality and diatom biomonitoring results do not reflect the same extent of deterioration. The 2015 report suggested that the large decrease in macroinvertebrate scores may be at least partially due to the use of SASS5 sampling in essentially standing water, an environment that SASS was not designed for. It might also result from a decreased habitat quality consequent on decreased flow.

A partial reason for the lack of a serious decrease in water quality scores is that several parameters were assessed, and an overall score for water quality was assigned using a weight-of-evidence approach. The implication of this approach is that a dramatic change in most water quality parameters would be needed to result in a dramatic change to the overall water quality score. Another reason for the relatively small change from 2015 to 2016 is that, owing to issues with water quality in 2015, the overall score had already decreased significantly compared to 2014. The small change noted in 2016 indicates that widespread problems with water quality in 2015 were still present in 2016. Nevertheless, the drop in macroinvertebrate scores in 2016 was caused by something, and, while it is possible that relatively static water contributed to changes in the macroinvertebrate score, it is possible that changes to water quality in a parameter not assessed as part of routine biomonitoring also contributed.

Diatom biomonitoring scores in 2016 showed a slight decrease in comparison with those from 2015. Nevertheless, three sites still received an overall score of Good. Two were from upstream sites on the Mdibi and Mpisini Rivers, and the last one was from the confluence of the rivers that drained the catchment around the RBM Smelting and Processing Site. The remainder of the sites scored as Moderate or Bad. While this is a slight decrease compared with 2015, it is a major decrease in comparison with 2014, when all sites scored as

Good or better. The changes in diatom scores seems to reflect the same trend that was evident in water quality scores, where many of the decreases had already started by 2015. The changes in diatom scores were accompanied by the relative disappearance of taxa that had previously dominated upstream sites in the region. Another trend noted in diatom populations was the appearance of taxa typical of acidic water. One effect of this was that, using the indices selected, these taxa (if they contributed to index calculations at all) may be seen as indicators of clean, naturally acidic water rather than acidification. Given the rapid onset of the acidification in the area, the extremes of acidity found, and the absence of any long-term naturally acidic water in the area, in the context of this survey the acidification is best considered an impact. In this regard, the results of some of the indices may be misleading if they consider acidophiles as indicators of clean, acidic water.

Sites along the mid-to-upper Mpisini River were among the most impacted in this survey. However, the trend cannot be generalized to all sites on the river. Upstream sites 1 and 19 were acidified and salinized, and often had high nutrient levels (whether nitrogen or phosphate). The trend changed dramatically in the lower Mpisini, as site 7 was not acidified and had one of the lowest and most consistent conductivities encountered during the sampling cycle. The distance between sites 1 and 7 is approximately 3 km. In this distance, two small tributaries join the river from the east, and several inflows join the river on the west bank from the RBM Smelting and Processing Site. Most of the latter are stormwater drains, and one is linked to Lake Evans within the complex's perimeter. The amount of water entering the river from either source is not known. As the tributary rises in the same forested area that the Mpisini River rises in, one would expect similar water quality. It seems likely therefore that water from the RBM Smelting and Processing Site has entered the river in this stretch and may be diluting the acidified and salinized water from upstream. This is not confirmed, but seems the most likely explanation for the dramatic change in water quality in this stretch. In this light it is worth noting that in previous reports where upstream sites were in a Good state, diatom biomonitoring results from sites 1 and 7 indicated a decrease in water quality in this stretch.

The results from site 10 on the Mazamnyana River to the west of the Smelter report a lower score from this site than before. This site is the only site on the Manzamnyana River (although site 11 samples the confluence of the Mpisini and Manzamnyana Rivers). This change is not driven by changes in macroinvertebrate populations as the results from this site have characteristically returned low macroinvertebrate scores, a result generally attributed to low oxygen levels at a site below a groundwater-fed wetland. These did not change in 2016. There was no change in the overall diatom score either (although *Stauroneis heinii*, a taxon usually characteristic of this site, was absent in 2016). However the water quality score was lower, a trend driven in particular by high phytoplankton chlorophyll *a* levels in August (which may simply be a function of disturbance of the site by cattle).

Site 11 lies at the confluence of the Mpisini and the Manzamnyana Rivers, and is the only site that receives water from all the rivers draining the Smelting and Processing Site. As such, results from this site may be expected to reflect any Smelter-induced impacts. Given that the quality of the water entering from the Mpisini and Manzamnyana Rivers is known, one can expect the results from this site to reflect a combination of these, with some local effects. To a large extent, the results from 2016 are in agreement with this. However, there are some anomalies in the more conservative water quality parameters. February pH levels at site 11 are more acidic than upstream sites suggesting some local acidification. In addition, February salinity levels are higher at site 11 than at upstream sites, indicating local salinization.

The results from sites along the Mdibi River in 2016 showed both deterioration and improvement in comparison with 2015 results. The score from site 12, upstream in the Mdibi River, decreased slightly in

comparison with 2015, while the score from site 13 was slightly improved (and was the best of all results from 2016). The decrease at site 12 was underlain by improved diatom results but declining water quality and macroinvertebrate scores. The improvement at site 13 was driven in particular by a large increase in the macroinvertebrate score from the site. The site experienced water quality much like 2015, with the exception of elevated orthophosphate levels in February.

The fairly stable results from the mid-to-upper Mdibi River can be contrasted with the results from the site lowest on the river, below the confluence with the Mpisini River. The drop in overall site score for site 14 is in particular underlain by a decrease in diatom scores. The diatom score change was based on the increasing dominance of *Nitzschia capitellata* in the August sample (there was no water in February). *Nitzschia capitellata* is pollution-tolerant and associated with high salinity levels. Although there was no change in the overall water quality score since 2015, the site in 2016 showed some acidification and is salinized, both conditions which could be observed dating from 2015. The salinization at the site can easily be explained by conditions at upstream sites. The source of the acidity is less clear. While some minor acidification can be seen at site 13 upstream, the combined pH of upstream sites 11 and 13 cannot fully explain the acidification at site 14.

The earthworks found at site 14 during the August sampling trip are a concern. Evidence from the trip suggests that attempts have started to fill in the wetland at the site and to re-engineer the banks of the river. If so, this will remove a valuable wetland from the system. Wetlands are known for high productivity and their efficiency in improving water quality. In addition, modification to the banks at site 14 is liable to increase erosion levels at the site. Wetlands have some level of protection under the National Environmental Management Act 107 of 1998, and the observed activities may be illegal. In addition, an Environmental Impact Assessment may be mandatory under Chapter 5 of NEMA published on 18 June 2010 in Government Notice No. R. 543.

The major concerns during the 2016 sampling cycle relate to a general decrease in site scores across the catchment. Notable changes to water quality include acidification and salinization of water resources. In the absence of other evidence, it seems likely that these trends are driving decreases in biomonitoring scores. These changes were already noted in 2015 and are assumed to be associated with the ongoing drought in the region. Increasing salinities across all sites was noted, and this observation can be linked to the drought as decreasing rainfall leading to salinization is a well-known phenomenon. However, drought-induced salinization is not commonly associated with acidification. However, in the surveyed region, the close relation between the two suggests that they may be ultimately driven by the same factors. However, while salinization in the current context is easily explained, acidification is not. Spatial and temporal changes in acidification do not lend themselves to easily identifying a source of the acidity. It is possible that shifting patterns in groundwater emergence into surface water may be a factor. The results from site 10, which is groundwater-fed, do not support the hypothesis that groundwater was acidified in 2016. Nevertheless, moderately acidic groundwater has been found in the Richards Bay area, which was attributed to low pH water infiltrating from wetlands (Milenkovich 2008, de Beer et al. 2014). Marcasite, which can lead to the production of acid mine drainage, was exposed when excavating the harbour at Richards Bay (Cairncross 2004), and in principle this could also contribute to acidification. Despite these observations, the extent of acidification encountered during 2016 is not easily accounted for. The source of the acidity cannot be resolved from the data presented here. The degree of acidification of surface water encountered, particularly in the mid-to-upper Mpisini River and increasingly along the Mdibi River, is unacceptable.

5 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 changes along this stretch that seems to be linked to the presence of RBM Smelting and Processing Site, and in general that this is the river most clearly impacted by the Smelting and Processing Site. Current data has the river improving along this stretch, however.
- Ongoing assessment of water quality and ecological health at site 11 as this site should reflect all changes owing to the RBM Smelting and Processing Site.
- Maintain monitoring at site 19 or locate another more appropriate site with river access and flowing water upstream of site 1 and the RBM Smelting and Processing Site.

Other

- Assess drainage patterns around the RBM Smelting and Processing Site. In particular, storm drains to the east of the complex should be assessed, and drainage during dry periods and periods of rain should be 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 Smelting and Processing Site (Lake Evans). As above, full chemical and toxicological analysis should be undertaken.
- Ongoing and more frequent monitoring of pH levels in the Mpisini and Mdibi Rivers.
- Identification of the source of acidity in the Mpisini and potentially the Mdibi Rivers.

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Appendix A Summary of macroinvertebrate biomonitoring scores and field-collected water chemistry results for the period December 2015 to August 2016.

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	2015	22	6	3.7	62	28.1	6.74	70.0	3.64	19.20
1	February	2016									
7	February	2016	37	8	4.6	44	25.0	7.57	84.8	6.23	0.53
10	February	2016	26	6	4.3	36	27.0	6.77	41.8	6.24	3.50
11	February	2016	2	1	2.0	42	25.0	4.17	140.6	3.80	1.3
12	February	2016	56	12	4.7	44	28.0	6.88	76.6	4.42	0.62
13	February	2016	21	4	5.3	44	24.5	7.64	133.7	10.00	0.25
14	February	2016									
19	February	2016	19	5	3.8	25	28.0	3.37	265.7	7.74	3.49
11	May	2016	19	5	3.8	49	17.7	6.58	70.0	7.90	1.18
1	August	2016	2	1	2.0	60	18.9	3.58	168.9	2.14	1.11
7	August	2016	37	8	4.6	56	18.6	7.06	78.6	6.43	0.51
10	August	2016	16	4	4.0	45	20.6	6.52	33.3	3.68	3.09
11	August	2016	12	3	4.0	50	18.4	7.54	63.6	3.91	4.12
12	August	2016	21	5	4.2	55	17.5	4.84	125.9	7.08	1.02
13	August	2016	19	4	4.8	56	17.8	5.45	125.2	4.09	2.96
14	August	2016	33	7	4.7	58	19.9	4.62	117.2	4.71	2.10
19	August	2016	26	6	4.3	38	19.3	3.54	201.9	8.64	5.45

Appendix B Summary of nutrient and other water quality data derived following laboratory analysis of collected samples results for the period February to August 2016.

Site	Month	Year	TIN (mg N/L)	Phosphate (mg P/L)	BOD ₅ (mg O ₂ /L)	Phytoplankton chl <i>a</i> (µg/L)	Periphyton chl <i>a</i> (mg/m ²)
1	February	2016					
7	February	2016	0.67	0.013	4		
10	February	2016	2.17	0.055	2		
11	February	2016	0.70	0.023	4		
12	February	2016	1.42	0.068	2		
13	February	2016	0.59	0.005	1		
14	February	2016					
19	February	2016	15.51	0.029	24		
1	August	2016	0.13	0.060	1	6.79	607.99
7	August	2016	1.21	0.030	1	0.19	5.40
10	August	2016	0.87	0.015	4	89.39	81.57
11	August	2016	1.77	0.015	1	0.34	5.74
12	August	2016	2.33	0.015	1	0.17	5.36
13	August	2016	0.68	0.015	1	0.41	220.40
14	August	2016	0.81	0.015	1	0.94	450.93
19	August	2016	3.01	0.015	2	0.12	37.15

Appendix C Summary of macroinvertebrate taxa found at each sampling site in February and August 2016.

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. Taxa not found have been omitted.

Site Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug
Aeshnidae	0%	0%	0%	0%	0%	0%	0%	0%	1%	3%	0%	0%	8%	0%	0%	0%
Ancylidae	0%	0%	0%	0%	0%	0%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Atyidae	0%	0%	0%	69%	0%	0%	0%	0%	73%	0%	5%	0%	0%	1%	0%	0%
Baetidae	0%	39%	5%	42%	3%	0%	1%	5%	0%	2%	0%	0%	0%	0%	0%	0%
Belostomatidae	0%	0%	0%	6%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Blepharoceridae	0%	0%	0%	0%	0%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Caenidae	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%
Ceratopogonidae	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Chironomidae	93%	33%	14%	30%	81%	20%	85%	12%	74%	42%	28%	52%	92%	68%	0%	0%
Coenagrionidae	0%	6%	0%	1%	3%	0%	0%	2%	17%	3%	2%	28%	1%	31%	0%	0%
Corbiculidae	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%
Corixidae	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%
Crambidae	3%	0%	0%	0%	0%	40%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Culicidae	0%	0%	0%	2%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Dytiscidae	0%	0%	0%	1%	0%	0%	0%	1%	1%	0%	0%	0%	1%	0%	0%	0%
Elmidae	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gomphidae	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	2%	2%	0%	0%	0%	0%
Helodidae	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hydrophilidae	3%	0%	0%	5%	1%	0%	0%	0%	0%	4%	2%	4%	0%	0%	0%	0%

Site Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug	Feb	Aug
Libellulidae	0%		0%	1%	3%	0%	0%	2%	3%	3%	3%	57%		5%	0%	1%
Lymnaeidae	0%		6%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
Muscidae	0%		0%	0%	0%	0%	13%	0%	0%	0%	0%	0%		0%	0%	0%
Naucoridae	0%		0%	0%	0%	0%	0%	0%	0%	0%	2%	0%		0%	0%	0%
Nepidae	0%		0%	0%	0%	0%	0%	0%	1%	0%	0%	0%		0%	0%	0%
Notonectidae	0%		0%	0%	3%	0%	0%	0%	0%	0%	1%	0%		0%	0%	0%
Notonemouridae	0%		0%	0%	0%	0%	0%	0%	1%	0%	0%	0%		0%	0%	0%
Oligochaeta	0%		17%	5%	4%	2%	7%	8%	1%	1%	33%	4%		0%	5%	0%
Philopotamidae	0%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
Physidae	0%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
Potamonautidae	0%		0%	3%	0%	0%	0%	0%	1%	0%	0%	0%		0%	1%	0%
Tabanidae	0%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
Tipulidae	0%		0%	0%	0%	1%	0%	1%	1%	0%	0%	4%		0%	0%	0%

Appendix D Summary of macroinvertebrate biomonitoring and water chemistry results at Confluence (Mpisini-Manzamyana) (site 11) over the period December 2015 to August 2016.

Year	Month	SASS Score	No. of Taxa	ASPT Score	IHAS Score	Temp. (°C)	pH	EC (mS/m)	DO (mg/L)	Turbidity (ntu)
2015	Dec	22	6	3.7	62	28.1	6.74	70.0	3.64	19.20
2016	Feb	2	1	2.0	42	25.0	4.17	140.6	3.80	1.3
2016	May	19	5	3.8	49	17.7	6.58	70.0	7.90	1.18
2016	Aug	12	3	4.0	50	18.4	7.54	63.6	3.91	4.12

Appendix E Macroinvertebrate taxa collected at Confluence (Mpisini-Manzamnyana) (site 11) over the period December 2015 to August 2016 using the SASS5 method

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

Year Month	2015 December	2016 February	2016 May	2016 August
Atyidae	A			
Baetidae				1
Chironomidae	1	A	A	A
Coenogrionidae			1	
Ecnomidae			1	
Gerridae	A			
Gomphidae				A
Libellulidae	A		A	
Oligochaeta			1	
Potamonautidae	A			
Synlestidae	1			
Total taxa	6	1	5	3
Mean taxa per sample			3.75	
Total taxa per year			11	

Appendix F Diatom report for index based on expert opinion for the period February to August 2016.

Site 1 (Mpisini upstream of Smelter)

February 2016

The site had no water at the time of sampling and so collection of diatoms was precluded.

August 2016

This sample contained 15 taxa and had a Shannon diversity of 1.96. The sample was dominated by *Nitzschia capitellata*, with *Nitzschia linearis* and *Frustulia crassinervia* subdominant. *Nitzschia capitellata* is indicative of electrolyte-rich or brackish water, and may be found in extremely polluted waters. *Nitzschia linearis* is typical in water with moderate to high levels of electrolytes, while *Frustulia crassinervia* prefers oligotrophic waters with low levels of electrolytes. Other, non-dominant taxa are also typical of electrolyte-rich water.

Score: 2

Site 7 (Mpisini downstream of Lake Evans)

February 2016

This sample contained 21 taxa and had a Shannon diversity of 2.71. The sample was dominated by *Nitzschia filiformis*, with *Sellaphora pupula* and *Luticola kotschyi* codominant. All these taxa may be found in strongly polluted conditions, and in particular where levels of electrolytes are elevated. The majority of the other taxa present, especially those that were more common in the sample, were forms typical of elevated nutrient or electrolyte levels, or both.

Score: 1

August 2016

This sample contained 21 taxa and had a Shannon diversity of 2.04. The site was heavily dominated by *Achnanthes oblongella*, with *Achnanthes pulviscula* subdominant. The former is found in circumneutral water with low salt and nutrient levels, and while the environmental preferences of the latter are not published, the taxon is typical in clean water in the Richard's Bay area. Other taxa include several typical of low salt and low nutrient levels.

Score: 5

Site 10 (Manzamnyana upstream of Smelter)

February 2016

This sample had 25 taxa, and had a Shannon diversity of 2.82, making it the most diverse of all the February samples. This site was dominated by *Sellaphora pupula*, with an unidentified species of *Brachysira* codominant. The former is a cosmopolitan taxon typical in waters with elevated levels of electrolyte. The ecology of the latter is not known but this is a taxon common in cleaner upstream waters in the Richards Bay area. *Brachysira* species are generally associated with slightly acidic, oligotrophic and electrolyte-poor waters, and so are indicators of good water quality. *Diademsis contenta* and *Gomphonema gracile* each make up more than 5% of the sample. *Diademsis contenta* is typical of oligotrophic, acidic water, while *Gomphonema gracile* may be found in water with higher salinity, but is not tolerant of more than moderate pollution. Remaining taxa

include a mix of pollution tolerant and sensitive taxa.

Score: 4

August 2016

This sample contained 29 taxa and had a Shannon diversity of 2.90, making it one of the more diverse of the August samples. The sample was dominated by *Nitzschia gracilis*, with *Nitzschia palea* codominant. Neither of these taxa comprised more than 20% of cells identified. *Nitzschia gracilis* prefers eutrophic, electrolyte-rich water (though it is only moderately pollution-tolerant). *Nitzschia palea* is a common taxon in nutrient and salt-rich waters, and can survive in high levels of pollution. Other taxa found, particularly the more common ones, in general were tolerant of high salt levels or fluctuating osmotic states.

Score: 1

Site 11 (Confluence (Mpisini-Manzamnyana))

February 2016

This sample contained 15 taxa and had a Shannon diversity of 1.25. The sample was overwhelmingly dominated by *Achnanthes oblongella*, with no other taxon being present at more than 8% of the sample. *Achnanthes oblongella* is typical of clean, circumneutral, oligotrophic, electrolyte-poor water, and has commonly been found to be dominant in clean upstream sites around Richards Bay. The two next most common taxa were an unidentified *Brachysira* and *Diademsis contenta*, both indicators of clean water. The remaining taxa include those associated with a range of water qualities.

Score: 5

August 2016

This sample contained 14 taxa, giving it a Shannon diversity of 1.83. *Cocconeis placentula* var *euglypta*, *Achnantheidium saprophilum* and *Achnantheidium minutissimum* were codominant in the sample. The first is common in water with elevated nutrient levels. The second is also typical of organically enriched or eutrophic water, and the third, in contrast, is typical of well-oxygenated and clean water. Of the remaining taxa, the more common ones are mostly typical of nutrient or salt enrichment, or both.

Score: 3

Site 12 (Upper Mdibi)

February 2016

This sample had a Shannon diversity of 2.60 and contained 22 taxa. Two unidentified species of *Brachysira* were codominant, and no other taxon was present in more than 10% of the sample. Both *Brachysiras* are typical of clean upstream sites in the Richards Bay area, and the genus as a whole is typical of slightly acidic, oligotrophic, electrolyte-poor water. *Nitzschia archibaldii*, associated with circumneutral water with up to moderate levels of electrolytes, *Gomphonema angustatum*, typical in oligotrophic water, and *Navicula caterva*, whose autecology is not known, made up more than 5% of the sample. Remaining taxa include those typical of a range of water qualities.

Score: 5

August 2016

This sample contained 10 taxa, giving it a Shannon diversity of 1.30, and making it amongst the least diverse of the samples collected during this sampling cycle. The sample was heavily dominated by an unknown species of *Actinella*. *Actinella* species are typical of humic and acidic water (Melo et al. 2010) and have not been found in significant numbers in the Richard's Bay area before. *Frustulia crassinervia*, typical of oligotrophic waters, and

especially those with low electrolyte levels, was subdominant. Other, more common taxa include several that are typical of water with high electrolyte levels or high acidity.

Score: 3

Site 13 (Middle Mdibi)

February 2016

This sample had a Shannon diversity of 2.31 and contained 18 taxa. *Nitzschia tubicola* was dominant in the sample, and *Nitzschia clausii* was subdominant. The autecology of *Nitzschia tubicola* as a whole is not known, but a subgroup in the taxon is highly tolerant of organic pollution and elevated electrolyte levels. *Nitzschia clausii* is typical of electrolyte-rich waters and is strongly pollution tolerant. *Luticola kotschyi*, *Nitzschia palea* and *Navicula rostellata* each make up at least 5% of the sample. The first is found in warm, saline water; the second is a cosmopolitan taxon that can be found in eutrophic and saline water and is extremely pollution tolerant; and the third is a cosmopolitan taxon typical of eutrophic water that tolerates critical levels of pollution. Remaining taxa include those sensitive to pollution and some that are extremely tolerant.

Score: 1

August 2016

This sample contained 30 taxa, giving it a Shannon diversity of 3.00, the highest of all the samples collected during this sampling cycle. *Gomphonema* aff. *gracile*, *Achnanthydium saprophilum*, and *Aulacoseira granulata* var. *angustissima* were (barely) codominant. No taxon made up more than 15% of the cells counted from this sample. *Gomphonema* aff. *gracile* is extremely pollution tolerant and is typical of mining effluent, *Achnanthydium saprophilum* is common in organically-enriched, eutrophic water, and *Aulacoseira granulata* var. *angustissima* is typical of eutrophic waters. Other taxa that made up more than one percent of the sample were mostly, but not exclusively, tolerant of high salt or nutrient levels.

Score: 1

Site 14 (Lower Mdibi)

February 2016

The site had no water at the time of sampling and so collection of diatoms was precluded.

August 2016

This sample contained 13 taxa and had a Shannon diversity of 0.86, and as such was one of the least diverse from this sampling cycle. The sample was overwhelmingly dominated by *Nitzschia capitellata*, which made up more than 83% of the cells identified. No other species made up more than 3% of the cells identified. *Nitzschia capitellata* is extremely pollution-tolerant and is found in water with elevated electrolyte levels. Other taxa that made up more than 1% of the sample include a range of salinity tolerant and sensitive taxa.

Score: 2

Site 19 (Mpisini upstream dam)

February 2016

This sample contained 23 taxa and had a Shannon diversity of 2.57. This sample was dominated by an unknown species of *Actinella*. *Actinella* is a genus common in humic and acidic water. No other species made up more than 10% of the sample. Of the more common remaining species, several made up nearly 10% of the sample. *Nitzschia palea* is one of these, a taxon often associated with eutrophic, saline water and which is highly pollution tolerant. *Pinnularia abaujensis* is the next most common, and the environmental preferences

of this taxon are not known, though *Pinnularia* as a whole is often associated with slightly acidic water with low electrolyte levels. *Eunotia incisa* is the next most common species, and is associated with acidic, oligotrophic, and electrolyte-poor waters. *Nitzschia capitellata* is the next most common, and is associated with electrolyte-rich water to the point that it is considered extremely pollution tolerant. Remaining taxa are a mix of pollution tolerant and pollution sensitive taxa.

Score: 3

August 2016

This sample contained 11 taxa and had a Shannon diversity of 1.69, making this sample one of the least diverse collected during this sampling cycle. *Nitzschia acidoclinata* was dominant in the sample, with *Achnanthydium affine*, an unknown species of *Actinella*, and *Pinnularia obscura* subdominant. *Nitzschia acidoclinata* is typical of oligotrophic, electrolyte-poor, but acidic water. *Achnanthydium affine* is found in oligotrophic, alkaline water, where electrolytes are moderately elevated. As a genus, *Actinella* species are common in humic and acidic water. Finally, *Pinnularia obscura* is typical of circumneutral water with moderate electrolyte levels. No other taxon made up more than 3% of the sample.

Score: 3

Appendix G Diatom index scores and site classification for the period February to August 2016.

Diatom index scores from sample sites around the Smelting and Processing Site for the period February to August 2016 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.

Site	Month	Year	IPS		BDI-2006		Expert opinion	
			Score	Class	Score	Class	Score	Class
1	February	2016						
7	February	2016	11.3	Poor	11.7	Moderate	1	Bad
10	February	2016	12.7	Moderate	13.4	Good	4	Good
11	February	2016	15.5	Good	13.8	Good	5	High
12	February	2016	13.8	Moderate	13.7	Good	5	High
13	February	2016	10.8	Poor	11.7	Moderate	1	Bad
14	February	2016						
19	February	2016	11.9	Poor	14.0	Good	3	Moderate
1	August	2016	9.6	Poor	11.8	Moderate	2	Poor
7	August	2016	15.6	Good	13.3	Good	5	High
10	August	2016	10.0	Poor	11.0	Moderate	1	Bad
11	August	2016	14.8	Moderate	13.8	Good	3	Moderate
12	August	2016	15.5	Good	17.3	High	3	Moderate
13	August	2016	11.9	Poor	11.2	Moderate	1	Bad
14	August	2016	4.9	Bad	6.4	Poor	2	Poor
19	August	2016	18.2	High	14.7	Good	3	Moderate

Appendix H Diatoms at sample sites in the area around the Smelting and Processing Site for the period February to August 2016.

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 Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.
<i>Achnanthes oblongella</i>		2%	2%	48%	0%	2%	72%	2%	2%	0%	0%	0%		0%	0%	1%
<i>Achnanthes pulviscula</i>		0%	0%	12%	0%	0%	0%	0%	0%	0%	1%	1%		0%	0%	0%
<i>Achnanthes</i> sp3		0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%		0%	0%	0%
<i>Achnantheidium affine</i>		0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	21%
<i>Achnantheidium crassum</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%		0%	0%	0%
<i>Achnantheidium eutrophilum</i>		0%	0%	2%	0%	0%	0%	2%	0%	0%	0%	0%		0%	0%	0%
<i>Achnantheidium exiguum</i>		0%	3%	1%	0%	0%	0%	0%	0%	1%	2%	0%		0%	0%	0%
<i>Achnantheidium latecephalum</i>		0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Achnantheidium minutissimum</i>		1%	1%	2%	4%	2%	0%	24%	4%	0%	2%	5%		1%	2%	0%
<i>Achnantheidium reimeri</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	3%	0%
<i>Achnantheidium saprophilum</i>		2%	0%	3%	0%	9%	3%	27%	0%	0%	5%	11%		1%	0%	3%
<i>Achnantheidium</i> sp2		1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Achnantheidium subaffinis</i>		2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Actinella</i> sp1		0%	0%	0%	0%	0%	0%	0%	0%	55%	0%	0%		1%	33%	20%
<i>Adlafia bryophila</i>		0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Amphora fontinalis</i>		0%	5%	0%	0%	0%	0%	0%	1%	0%	0%	0%		0%	0%	0%
<i>Amphora montana</i>		0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	3%		0%	0%	0%
<i>Aulacoseira granulata</i> var. <i>angustissima</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%		0%	0%	0%

Site Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.
<i>Brachysira aff. steindorfiana</i>		0%	0%	0%	3%	0%	0%	0%	18%	0%	0%	0%		0%	4%	0%
<i>Brachysira brebissonii</i>		0%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Brachysira sp2</i>		0%	0%	4%	15%	0%	8%	0%	21%	3%	0%	1%		0%	1%	0%
<i>Caloneis hyalina</i>		0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Caloneis sp2</i>		0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Capartogramma crucicula</i>		0%	1%	0%	0%	0%	0%	0%	0%	0%	1%	0%		0%	0%	0%
<i>Cocconeis placentula</i>		0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Cocconeis placentula var. euglypta</i>		0%	0%	0%	0%	0%	0%	29%	0%	0%	0%	0%		0%	0%	0%
<i>Craticula buderi</i>		0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Cymbopleura naviculiformis</i>		1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Cymbopleura sp1</i>		0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Diadsmis contenta</i>		1%	0%	0%	9%	0%	4%	2%	1%	0%	0%	2%		1%	2%	0%
<i>Eolimna minima</i>		0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Eolimna subminuscula</i>		0%	0%	0%	0%	1%	0%	4%	0%	0%	0%	0%		1%	0%	0%
<i>Eunotia bilunaris</i>		0%	0%	0%	3%	0%	0%	0%	5%	0%	0%	0%		0%	0%	0%
<i>Eunotia incisa</i>		0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%		0%	6%	0%
<i>Eunotia mesiana</i>		0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	5%		0%	0%	0%
<i>Eunotia minor</i>		0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	1%
<i>Eunotia naegelii</i>		0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Eunotia rhomboidea</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		1%	0%	0%
<i>Eunotia sp2</i>		0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%		0%	0%	0%
<i>Eunotia subarcuatoidea</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	5%	0%
<i>Eunotia tenella</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		1%	0%	0%
<i>Fallacia umpatica</i>		0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%		0%	0%	0%
<i>Fragilaria biceps</i>		0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%		0%	0%	0%
<i>Fragilaria sp1</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	1%	0%

Site Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.
<i>Frustulia crassinervia</i>		19%	0%	0%	0%	0%	0%	0%	0%	28%	1%	0%		2%	0%	1%
<i>Gomphonema aff. gracile</i>		0%	0%	3%	0%	1%	0%	0%	5%	0%	0%	14%		0%	0%	0%
<i>Gomphonema angustatum</i>		0%	0%	9%	0%	1%	0%	0%	8%	0%	0%	6%		0%	3%	0%
<i>Gomphonema gracile</i>		0%	0%	2%	7%	0%	0%	0%	0%	0%	0%	0%		0%	1%	0%
<i>Gomphonema lagenula</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%		0%	0%	0%
<i>Gomphonema minutum</i>		0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%		0%	0%	0%
<i>Gomphonema parvulum</i>		0%	0%	1%	5%	2%	0%	1%	3%	0%	0%	3%		2%	0%	0%
<i>Gomphonema pseudoaugur</i>		0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Gomphonema pumilum</i> var. <i>rigidum</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%		0%	0%	0%
<i>Gomphonema subtile</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%		0%	0%	0%
<i>Hantzschia amphioxys</i>		0%	0%	0%	0%	7%	0%	0%	0%	0%	0%	1%		0%	0%	0%
<i>Karayevia</i> sp1		0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Luticola acidoclinata</i>		0%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Luticola cohnii</i>		2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Luticola goeppertiana</i>		6%	0%	0%	0%	0%	0%	2%	0%	0%	0%	3%		0%	0%	0%
<i>Luticola kotschyi</i>		1%	12%	0%	4%	4%	0%	0%	4%	0%	10%	1%		0%	0%	0%
<i>Luticola mutica</i>		0%	0%	0%	0%	4%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Mayamaea atomus</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	1%
<i>Mayamaea atomus</i> var. <i>permitis</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%		0%	0%	0%
<i>Navicula caterva</i>		0%	0%	0%	0%	0%	0%	0%	6%	0%	5%	0%		0%	0%	0%
<i>Navicula cryptocephala</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%		0%	0%	0%
<i>Navicula erifuga</i>		0%	1%	0%	0%	0%	1%	0%	2%	0%	3%	0%		0%	0%	0%
<i>Navicula germainii</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%		0%	0%	0%
<i>Navicula gregaria</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		1%	0%	0%
<i>Navicula longicephala</i>		0%	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%		0%	0%	0%

Site	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.
<i>Navicula microcari</i>		0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Navicula notha</i>		0%	6%	0%	2%	2%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Navicula reichardtiana</i>		0%	0%	0%	1%	5%	0%	0%	3%	1%	0%	1%		0%	0%	0%
<i>Navicula rostellata</i>		0%	4%	2%	0%	0%	1%	0%	0%	0%	6%	0%		0%	0%	0%
<i>Navicula schroeteri</i>		0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Navicula sp6</i>		0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Navicula sp11</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%		0%	0%	0%
<i>Navicula staffordiae</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%		0%	0%	0%
<i>Navicula tenelloides</i>		0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Navicula vandamii</i>		0%	8%	0%	0%	0%	1%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Navicula veneta</i>		0%	2%	0%	0%	1%	0%	0%	0%	0%	0%	2%		0%	0%	0%
<i>Navicula vilaplantii</i>		0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Navicymbula pusilla</i>		0%	1%	0%	0%	1%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Nitzschia acidoclinata</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	33%
<i>Nitzschia agnewii</i>		0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Nitzschia archibaldii</i>		0%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%		0%	0%	0%
<i>Nitzschia capitellata</i>		34%	0%	0%	0%	0%	0%	0%	0%	7%	1%	1%		83%	5%	0%
<i>Nitzschia clausii</i>		0%	7%	0%	0%	1%	0%	0%	1%	0%	13%	5%		0%	0%	0%
<i>Nitzschia communis</i>		4%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Nitzschia dissipata</i>		0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%		0%	4%	0%
<i>Nitzschia elegantula</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		2%	0%	0%
<i>Nitzschia filiformis</i>		0%	14%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	4%	0%
<i>Nitzschia frustulum</i>		0%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Nitzschia gracilis</i>		0%	0%	0%	0%	19%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Nitzschia inconspicua</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	1%
<i>Nitzschia linearis</i>		20%	0%	0%	1%	0%	0%	0%	0%	2%	0%	3%		0%	0%	0%

Site Year Month	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.
<i>Nitzschia linearis</i> var. <i>subtilis</i>		0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%		0%	0%	0%
<i>Nitzschia microcephala</i>		0%	0%	2%	0%	0%	0%	0%	0%	0%	2%	1%		0%	0%	0%
<i>Nitzschia nana</i>		4%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Nitzschia palea</i>		0%	9%	0%	5%	14%	2%	0%	1%	0%	8%	5%		0%	9%	0%
<i>Nitzschia perminuta</i>		0%	0%	0%	0%	2%	0%	1%	0%	0%	0%	0%		0%	0%	0%
<i>Nitzschia recta</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%		0%	1%	0%
<i>Nitzschia sociabilis</i>		0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%		3%	0%	0%
<i>Nitzschia</i> sp1		0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Nitzschia</i> sp25		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	3%	0%
<i>Nitzschia supralitorea</i>		0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Nitzschia tubicola</i>		0%	2%	0%	0%	0%	0%	0%	0%	0%	34%	0%		0%	0%	0%
<i>Nitzschia umbonata</i>		0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Pinnularia abaujensis</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	7%	0%
<i>Pinnularia divergens</i>		0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Pinnularia gibba</i>		0%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Pinnularia intermedia</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%		0%	0%	0%
<i>Pinnularia obscura</i>		0%	0%	0%	4%	0%	0%	0%	0%	0%	0%	0%		0%	0%	17%
<i>Pinnularia subcapitata</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	1%	0%
<i>Placoneis hambergii</i>		0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Planothidium engelbrechtii</i>		0%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%		0%	3%	1%
<i>Planothidium rostratum</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	2%	0%
<i>Reimeria uniseriata</i>		0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%		0%	0%	0%
<i>Rhopalodia operculata</i>		0%	0%	3%	0%	0%	0%	2%	0%	0%	0%	0%		0%	0%	0%
<i>Sellaphora pupula</i>		0%	13%	0%	18%	5%	0%	0%	3%	1%	0%	2%		0%	2%	0%
<i>Sellaphora stroemii</i>		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		0%	1%	0%
<i>Stauroneis heinii</i>		0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%

Site	Site 1		Site 7		Site 10		Site 11		Site 12		Site 13		Site 14		Site 19	
	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.
<i>Stauroneis pachycephala</i>		0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%		0%	0%	0%
<i>Tryblionella debilis</i>		0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	0%		0%	0%	0%

Appendix I Summary of annual results from 2010-2016

This appendix contains summarized results of annual surface water monitoring in the vicinity of the Smelting and Processing Site of Richard's Bay Minerals at Richards Bay, KwaZulu-Natal. The document summarizes annual trends in monitoring results on a site-wise basis. Details of the score classification systems used are given in the Methods and materials section (above). Results cover the results reported on in documents submitted in 2010 to 2016 (Gordon *et al.* 2010, Gordon and Griffin 2012, Holland *et al.* 2011, Griffin and Holland 2013, Griffin 2014, Griffin 2015).

Mpisini Upstream of Smelter (Site 1)

Year	ASPT	IHAS	Water Quality	Diatoms	Overall
2010	Fair	56	Good	Natural	Good
2011	Poor	54	Fair/Good	Natural	Fair/Good
2012	Poor	56	Good	Good	Fair/Good
2013	Poor	49	Fair/Good	Good	Fair/Good
2014	Fair	45	Good	Good	Good
2015	Poor	38	Fair	Poor	Poor/Fair
2016	Poor	60	Fair	Moderate	Fair

Mpisini Downstream of Lake Evans (Site 7)

Year	ASPT	IHAS	Water Quality	Diatoms	Overall
2010	Fair	73	Fair/Good	Fair	Fair
2011	Fair	65	Fair/Good	Fair	Fair
2012	Poor	58	Fair/Good	Fair	Fair
2013	Poor/Fair	65	Good	Good	Fair/Good
2014	Poor/Fair	70	Good	Good	Fair/Good
2015	Fair	70	Fair	Moderate	Fair
2016	Poor	50	Good	Moderate	Fair

Manzamnyana upstream of Smelter (Site 10)

Year	ASPT	IHAS	Water Quality	Diatoms	Overall
2010	Poor	42	Fair	Good	Fair
2011	Poor	51	Fair/Good	Fair	Fair
2012	Poor	54	Fair/Good	Fair	Fair
2013	Poor	47	Fair	Fair/Good	Fair
2014	Poor	52	Good	Good	Fair/Good
2015	Poor	46	Good	Good	Fair/Good
2016	Poor	41	Fair	Moderate	Fair

Confluence (Mpisini-Manzamyana) (Site 11)

Year	ASPT	IHAS	Water Quality	Diatoms	Overall
2010	Fair	42	Good	Fair	Fair/Good
2011	Fair/Good	55	Fair/Good	Fair	Fair/Good
2012	Fair	43	Fair/Good	Good	Fair/Good
2013	Fair	38	Good	Good	Good
2014	Poor/Fair	47	Good	Good	Fair/Good
2015	Poor	51.5	Good	Good	Fair/Good
2016	Poor	46	Fair/Good	Good	Fair

Upper Mdibi River (Site 12)

Year	ASPT	IHAS	Water Quality	Diatoms	Overall
2010	Fair	48	Good	Natural	Good
2011	Fair	61	Good	Natural	Good
2012	Fair	50	Good	Good	Good
2013	Fair	64	Fair/Good	Fair/Good	Fair/Good
2014	Poor/Fair	59	Good	Good	Good
2015	Fair	38	Good	Moderate	Fair/Good
2016	Poor	50	Fair	Good	Fair

Middle Mdibi River (Site 13)

Year	ASPT	IHAS	Water Quality	Diatoms	Overall
2010	Good	53	Good	Good	Good
2011	Good	53	Fair/Good	Fair	Fair/Good
2012	Fair	50	Fair/Good	Fair	Fair/Good
2013	Good	55	Good	Good	Good
2014	Good	52	Good	Good	Good
2015	Fair	59	Fair	Good	Fair/Good
2016	Good/Natural	50	Good	Moderate	Good

Lower Mdibi River (Site 14)

Year	ASPT	IHAS	Water Quality	Diatoms	Overall
2010	Fair	53	Good	Good	Fair/Good
2011	Fair	57	Fair/Good	Fair	Fair
2012	Good	47	Fair/Good	Fair	Fair/Good
2013	Poor/Fair	54	Fair/Good	Fair	Fair
2014	Good	53	Good	Good	Good
2015	Fair	50	Fair	Moderate	Fair
2016	Fair	58	Fair	Bad	Poor/Fair

Mpisini Upstream Dam (Site 19)

Year	ASPT	IHAS	Water Quality	Diatoms	Overall
2014	Poor/Fair	48	Good	Good/Natural	Good
2015	Poor	23	Fair	Good	Fair
2016	Poor	32	Fair	Good	Fair