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

Draft Final Report for 2007 Biomonitoring

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EXECUTIVE SUMMARY

A summary of the indices measured is provided in Table I. A provisional overall ecological health assessment for each of the sites assessed is provided. (Note: there is no health index for 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 due to insufficient data for ASPT and water quality, the methods used to provide the subsequent categories could not be followed accurately and are therefore 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 method and require site-specific refinement. Both of these issues can only be resolved through further collection of data to allow a more accurate assessment of the true environmental water quality conditions. The method used to derive the diatom categories is based on expert opinion and will require validation through further data collection and analysis.

TABLE I A summary of main index score results to provide an overall assessment for each of the sites.

Site	ASPT	IHAS	Water Quality	Diatoms	Overall ecological health assessment
1	6.1 Good	58	Good	Good	Good (may be natural)
7	6.3 Good	64	Good	Fair / Poor	Fair
10	4.4 Poor	49	Good / Fair	Fair / Poor	Fair / Poor
11	5.6 Fair	48	Good	Poor	Fair
12	6.4 Good	58	Good	Good	Good
13	6.1 Good	56	Good	Fair / Poor	Good / Fair
14	6.0 Good	58	Good	Fair / Poor	Good / Fair

The overall water quality categories is generally not reflected in the measured biological indices (macroinvertebrates and diatoms) which suggests that water quality parameters not measured during the biomonitoring may be driving the impaired water quality conditions reflected by the macroinvertebrates and diatoms. An examination of more recent water quality data collected by the routine and on-going RBM chemical sampling programme at these sites is warranted. The biological data collected so far will go towards establishing better site-specific reference conditions, and may be useful in assessing the validity of recalibrating the benchmark boundary values for water quality parameters to yield site-specific boundary values.

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1. INTRODUCTION

The increasing demands on aquatic ecosystems urgently requires the need for science-based decision making. Monitoring data which are obtained through scientifically tested methods and based on sound ecological indicators can provide the scientific basis for water resource management decisions to achieve a balance between human health, ecosystem protection and integrity and economic sustainability (Barbour *et al.*, 2004). It is essential that monitoring takes place over various spatial and temporal scales, at key points and throughout the water resource management cycle. The resultant increasing understanding of the interaction between physical, chemical and biological processes in aquatic ecosystems will culminate in a more integrated and holistic approach to water resource management.

Ecological assessments allow for the assessment of prevailing conditions and trends using field measurements, and can therefore direct management strategies that are required to deal with existing and emerging water resources problems (Barbour *et al.*, 2004); good monitoring programmes are therefore the backbone of a process that promotes effective water resource management. A well-designed monitoring programme will allow identification of impairments, determination of cause and effect, monitor changes over time and confirm management initiatives (Barbour *et al.*, 2004). Therefore, the planning of monitoring programmes is as essential as the implementation and evaluation of the monitoring programme to allow for optimum data collection and yield the information necessary for integrated water resource management.

Richards Bay Minerals (RBM) is situated in northern KwaZulu-Natal, producing titania slag, pig iron, rutlie and zircon through processes of dune mining, mineral separation, smelting and beneficiation. The RBM smelter site is adjacent to the KwaBonambi State Forest and is situated within a larger afforested area. The area around the smelter site and the Tisand Mineral Lease area is drained by several small streams which flow into the Mdibi River and ultimately into Lake Mzingazi (Figure 1). There is known contamination of the groundwater in the area of the RBM smelter (Fischer, pers. comm.) and there is concern that the RBM activities at the smelter site may be compromising the ecological health of the rivers near the smelter site. Contaminants from the RBM smelter premises can reach the rivers either directly, via surface water run-off to the rivers (e.g. from pollution incidents, via effluent pipes or rainfall run-off), or indirectly, via the groundwater contamination. The natural drainage from the RBM smelter site is towards the Mpisini and Manzamnyana Rivers, which drain into the Mdibi River, and this river subsequently flows into Lake Mzingazi.

Based on the results of Phases I and II, a comprehensive environmental water quality monitoring programme was developed. The aim of this project was to undertake on-going biomonitoring required as part of the proposed integrated environmental water quality monitoring programme.

The specific tasks identified to successfully complete the project are therefore to:

1. Undertake aquatic macroinvertebrate biomonitoring at the identified sites in Smelter Site area.
2. Undertake diatom biomonitoring at the identified sites.
3. Undertake additional water quality sampling, namely nutrient analysis (specifically, Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP)) and chlorophyll-*a* analysis at the identified biomonitoring sites.

2. METHODS AND MATERIALS

Eight sites were identified for continued biomonitoring: 1, 7, 10, 11, 12, 13 and 14 (Figure 1). The selected biomonitoring sites are depicted in Figures 2-9, showing general habitat availability and condition.

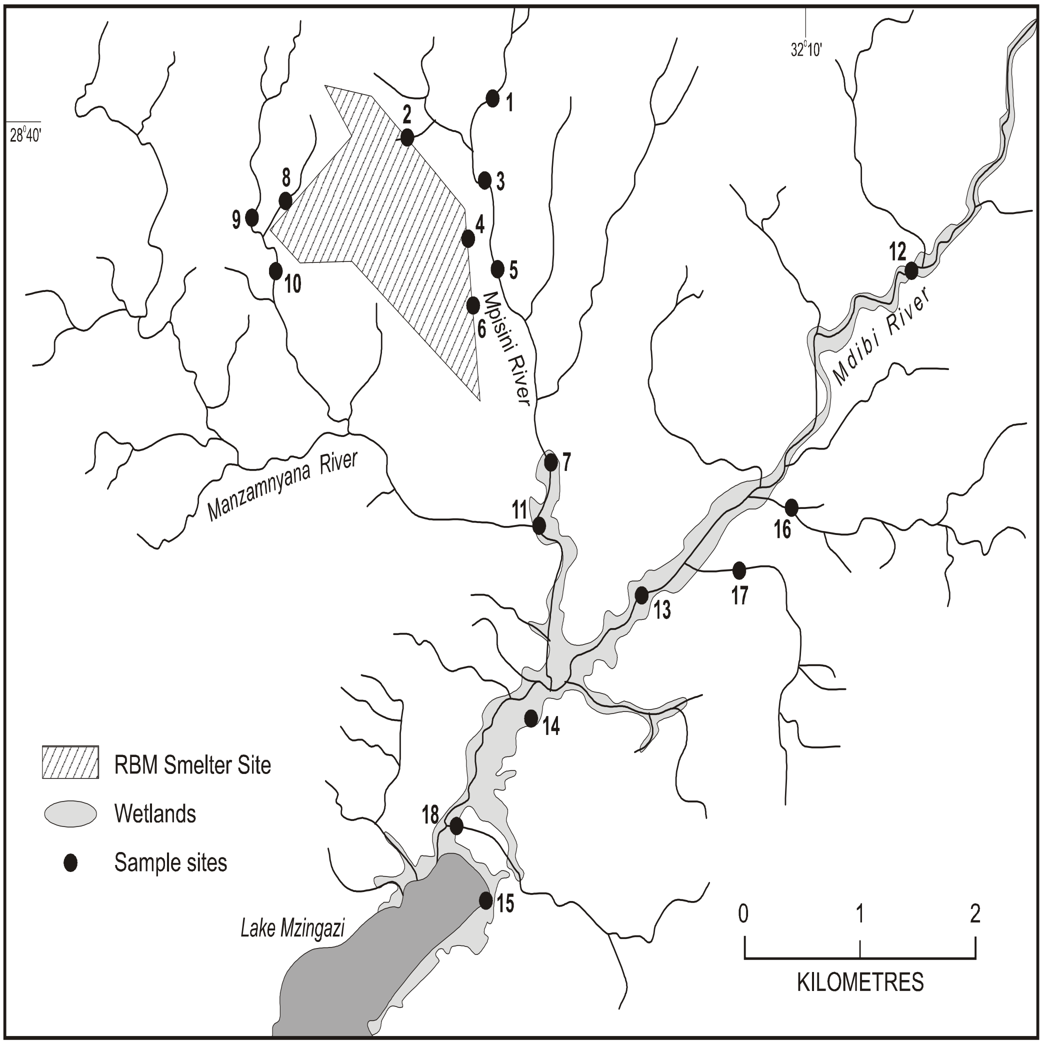

FIGURE 1 **Monitoring points in the Smelter Site area: Mpisini River (Sites 1 and 7), Manzamnyana River (Site 10), confluence of Mpisini and Manzamnyana Rivers (Site 11) and Mdibi River (Sites 12 to 14).**

FIGURE 2 Site 1, upper Mpisini River (Summer 2007; the land-use surrounding this site changed dramatically from 2006 to the first sampling event in Winter, with the harvesting of the pine trees on the right hand bank).

FIGURE 3 Site 7, lower Mpisini River (Spring 2007).

FIGURE 4 Site 10, upper Manzamnyana River (Spring 2007).

FIGURE 5 Site 11, Confluence of the Mpisini and Manzamnyana Rivers (Summer 2007)

FIGURE 6	**Site 12, upper Mdibi River (Winter 2007).**

FIGURE 7	**Site 13, middle Mdibi River (Summer 2007)**

FIGURE 8 **Site 14, lower Mdibi River (Summer 2007).**

2.1 Water quality assessment

Water samples were collected at each of the biomonitoring sites and frozen for further analysis at the Institute for Water Research, Rhodes University, Grahamstown. The following parameters were measured: NO_2-N, NO_3-N, NH_4-N and PO_4 (SRP). The nitrogen data were combined to obtain Total Inorganic Nitrogen (TIN) concentrations. Periphyton and phytoplankton samples were collected following methods described by Holm-Hansen and Riemann (1978) and analysed for chlorophyll-*a* concentrations, as an additional indication of nutrient status of the surface waters.

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

2.2 Biomonitoring

2.2.1 Habitat assessment

A habitat assessment was undertaken at each site, using the Integrated Habitat Assessment System (IHAS; McMillan, 1998). Although IHAS was initially developed for use with SASS4 (i.e. to adjust the SASS4 score), it provides a useful assessment of the habitat being assessed as the diversity of macroinvertebrates can be influenced by the availability of biotopes and physical characteristics of the river and surrounding land-use impacts. In this case, IHAS was used to assess and aid interpretation of the final SASS and ASPT results.

2.2.2 Macroinvertebrate sampling

At each of the sites, South African Scoring System Version 5 (SASS5) samples were taken from available biotopes and scored accordingly (Dickens and Graham, 2002). Once the SASS evaluation was complete, the samples were preserved and a further 2 samples from each of the biotopes were collected and preserved. The standard SASS protocol (described in Dickens and Graham (2002) as well as the standard data sheet) was utilised to collect the SASS samples as well as the replicate samples. All samples were further enumerated at the UCEWQ-IWR laboratories, providing accurate counts for each of the taxa for data analysis (Family level assessment). The SASS scores and total number of families were used to obtain the Average Score per Taxon (ASPT) for each of the sites (Dickens and Graham, 2002).

2.2.3 Diatom assessment

Diatom samples were collected from hard substrates (vegetation 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. Slides were examined until five minutes observation revealed no new taxa.

Where possible, diatoms were identified to species level. Environmental preferences of common species as presented by Taylor *et al*. (2007b) were used to derive information on the ecological health of the site. Water quality indices based on diatoms, such as the Specific Pollution sensitivity Index (SPI) have been successfully applied in South Africa (de la Rey *et al*., 2004). However, current indices, including the SPI, were not developed for South African conditions and are not always applicable when too many tropical species are found. They may also be misled when marine influences are pronounced. For both these reasons, this analysis will not calculate SPI. For the purpose of summarizing the results of this analysis, samples are classified into one of three classes as follows:

- Good: These are representative of clean water quality conditions. Samples where all or most species found are characteristic of unpolluted oligotrophic to mesotrophic water with low to moderate levels of electrolytes. The dominant species must be typical of these conditions.
- Fair: These are representative of intermediate water quality conditions. Dominant taxon is not indicative of clean conditions, and the sample has species typical of clean and stressed condition.
- Poor: These are representative of stressed water quality conditions. All species present are tolerant of at least moderate levels of pollution, or typical of eutrophic or osmotically stressed conditions.

3. RESULTS

3.1 Water quality

A summary of the water quality is provided in Table 1.

There was no significant difference between the sites in temperature although there were, as expected, seasonal differences. Similarly, pH showed no difference between sites and nor were any seasonal trends observed. Dissolved oxygen (DO) varied significantly between the sites, with Site 10 having significantly lower DO concentrations than the other sites (Figure 9). Site 10 is characterised by a large pool with a wetland immediately adjacent to it (both upstream and alongside the sampling point) with very slow flowing water (biotic samples are taken from both the deep and shallow parts of the site). The large variation seen at Sites 11 and 12 are due to seasonal differences, although there was no consistency between the seasons in terms of the lowered DO concentrations. Although there no significant differences between the sites for electrical conductivity (EC), there is an observable pattern (Figure 10). All the upstream sites had lower mean EC values than the downstream sites on the same river. The lack of signficant differences may be accounted for by the large seasonal variability, as the EC values recorded in Summer were lower than in Winter and Spring. Further monitoring would be required to establish whether the seasonal pattern and differences between sites are persistent and indicative of water quality impairment (especially at Sites 7, 13 and 14, as these are downstream of the Smelter Site and human settlement). Nutrient concentrations were low (total inorganic nitrogen (TIN) and soluble reactive phosphorous (SRP)), and mostly below the detection limits of the analytical methods (as a consequence, a water quality category cannot be provided for TIN and SRP as the boundary values are below the detection limits). The low nutrient concentrations are reflected in the low Chlorophyll-*a* concentrations, and are indicative of oligotrophic conditions. Although not significant, Site 7 had higher phytoplankton chlorophyll-*a* concentrations while the large variability exhibited in the periphyton chlorophyll-*a* concentrations allowed no observable patterns to be detected.

TABLE 1 **Means of selected water quality parameters measured during the Winter, Spring and Summer 2007 biomonitoring fieldtrips (DO: dissolved oxygen; EC: electrical conductivity; TIN: total inorganic nitrogen; SRP: soluble reactive phosphorous; Chlorophyll-*a* mg/m^3: phytoplankton chlorophyll-*a*; Chlorophyll-*a* mg/cm^2: periphyton chlorophyll-*a*). (water quality categories based on the ecological Reserve methodologies for water quality are provided below the values where relevant).**

Site	TºC	pH	DO (mg/L)	EC (mS/m)	TIN (mg/L)	SRP (mg/L)	Chlorophyll-*a*	
							(phytoplankton) mg/m^3	(periphyton) mg/cm^2
1	21.7	6.1 Good	6.4 Good	33.1 Good	5.2 -	0.14 -	0.32 Natural	38.6 Natural
7	21.4	6.2 Good	6.4 Good	45.6 Good	5.2 -	0.05 -	0.57 Natural	25.1 Natural
10	20.3	5.9 Good	1.8 Poor	32.4 Good	5.2 -	0.05 -	0.24 Natural	35.7 Natural
11	20.4	5.9 Good	5.4 Fair	44.1 Good	5.2 -	0.05 -	0.37 Natural	62.3 Natural
12	19.9	6.0 Good	5.9 Fair	29.5 Natural	5.4 -	0.05 -	0.34 Natural	32.7 Natural
13	19.1	6.6 Good	6.0 Good	39.0 Good	5.2 -	0.05 -	0.36 Natural	19.0 Natural
14	19.7	5.9 Good	5.9 Fair	41.5 Good	5.2 -	0.05 -	0.35 Natural	23.1 Natural

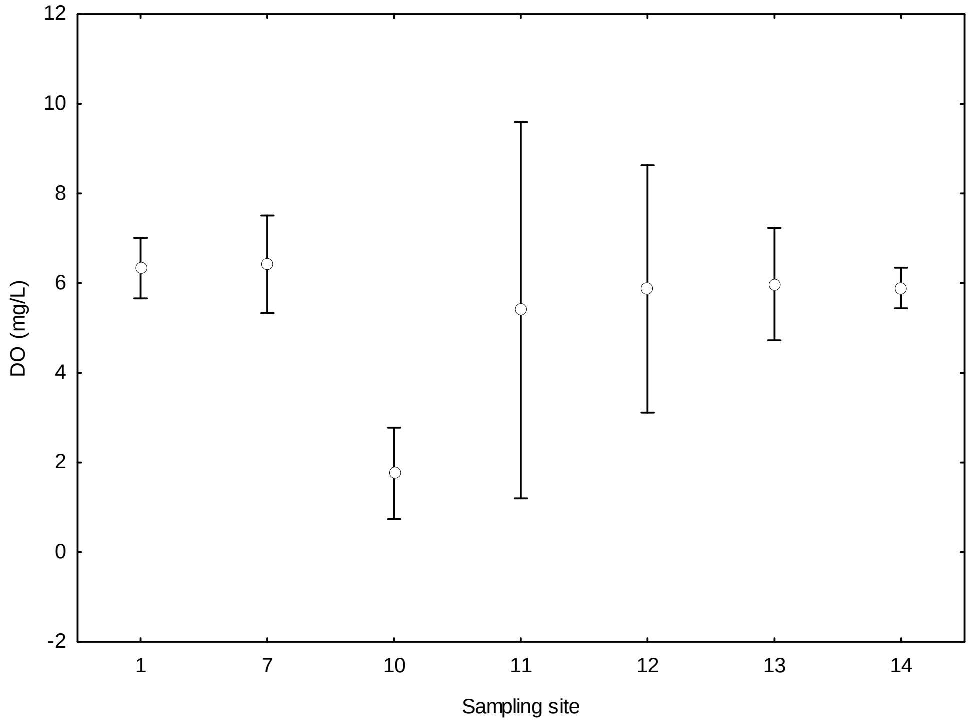

FIGURE 9 Mean Dissolved oxgyen (DO) (mg/L) at the different sampling sites over sampling seasons. Bars represent 95% confidence intervals. DO at Site 10 was significantly lower than the remained of the sites.

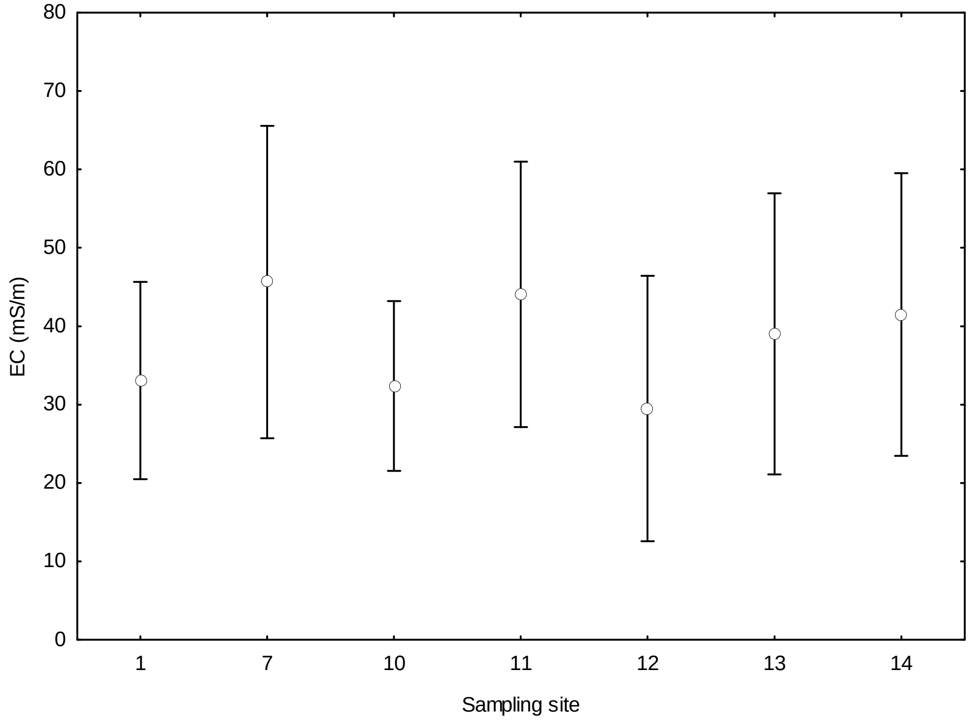

FIGURE 10 Mean Electrical conductivity (EC) (mS/m) at the different sampling sites over sampling seasons. Bars represent 95% confidence intervals. No significant differences could be established.

3.2 Integrated Habitat Assessment System (IHAS) results

The Integrated Habitat Assessment System results are presented per season and site in Figures 11 and 12.

Overall, the IHAS scores are low due to the absence of the stones biotope at all the sampling sites, but generally, Sites 1 and 7 (Mpisini River) tended to have higher scores than the sites on the Manzamyana or Mdibi Rivers. Sites 10 and 11 have significantly lower IHAS scores than the remainder of the sites, despite the large variability seen, and is observable in all seasons. Site 10 is in the upper reaches of the Manzamyana River, and is characterised by a pool with slow flowing water. There is also a cattle crossing which results in a reduced scores (disturbance of the site), although this appears to have no influence on the water quality at this site (Table 1). in Site 11 is at the confluence of the Mpisini and Manzamyana Rivers, and the availability of biotopes is strongly influenced by flows: low flows result in significantly reduced habitat availability, thus affecting the IHAS score.

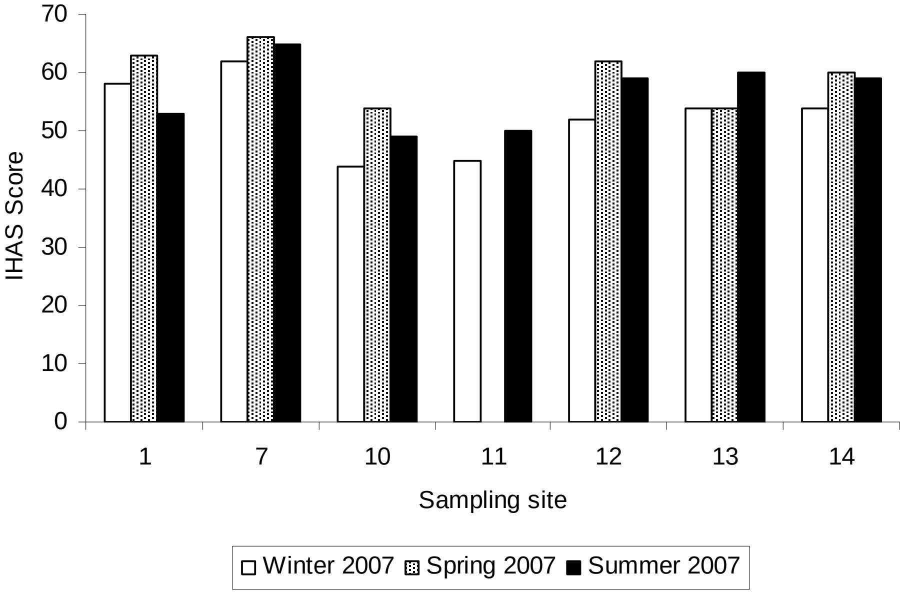

FIGURE 11 **Integrated Habitat Assessment System (IHAS) per site and season.**

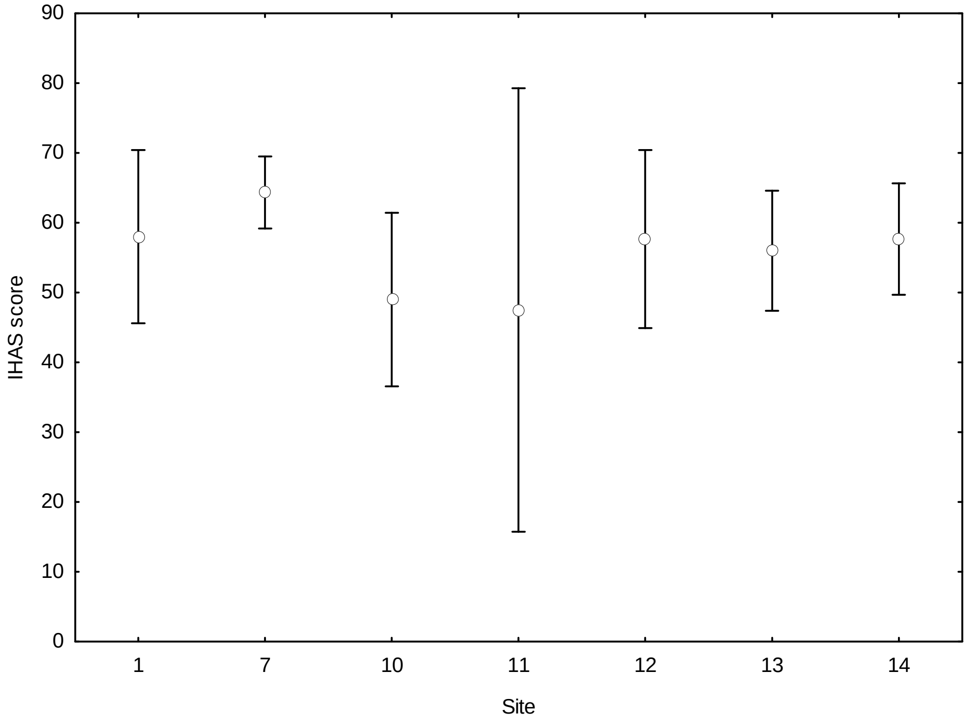

FIGURE 12 Mean Integrated Habitat Assessment System (IHAS) score per site in the Smelter Site area. The bars represent 95% confidence intervals. Sites 10 and 11 had significantly lower IHAS scores.

3.3 Macroinvertebrate assessment

3.3.1 SASS assessment

The same biotopes were available at all the sampling sites, namely vegetation and the gravel, sand and mud biotope, and results from the different biotopes were therefore combined to provide total site scores. The total site SASS scores, number of families and average score per taxon (ASPT) obtained for each of the sites during each of the seasons are shown in Figure 13. Generally, there appears to be no seasonal pattern observable within each site, with scores varying over both site and season. Site 10 had significantly lower mean SASS scores, fewer families and ASPT scores than any of the other sites. However, there was an improvement in these scores by Site 11, although this is likely a consequence of input from the Mpisini River. There was no obvious difference between sites 1 (reference site) and 7 (smelter activity impacted site) on the Mpisini River, but the Mdibi River showed a different pattern, where there was a slight decrease in ASPT scores along the length of the river, possibly a consequence of the land-use activity (dense rural settlements and consequent run-off to the river).

There was a significant difference between the biotopes in SASS scores, number of families and ASPT scores in sites, with the vegetation biotope scoring higher in all three measures.

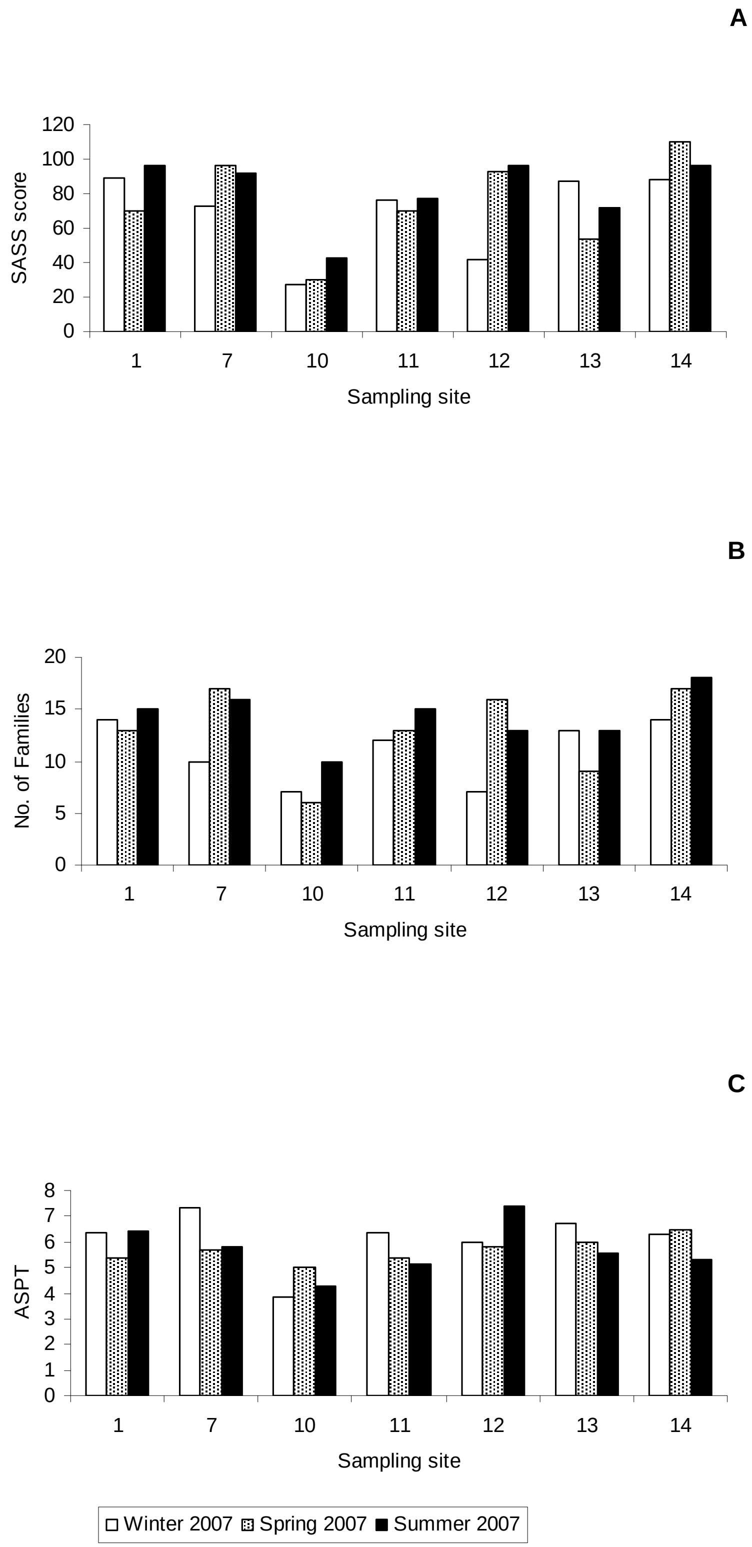

FIGURE 13 **SASS scores (A), number of families (B) and average score per taxon (ASPT)(C) for each of the sites over the three sampling periods.**

All the ASPT scores obtained indicate some impairment (of water quality or habitat) when compared to the Reserve water quality benchmark boundary values (Table 2), as none of the sites scored a natural category, not even Site 1. There was, however, a considerable change in land-use on the righthand bank at Site 1, with the logging of trees having taken place. This may have affected the macroinvertebrates through run-off to the river, through water quality parameters that were not measured. The site on the upper Manzamyana River was in a poor category, likely a combination of reduced habitat and possible water quality impairment (though not through any of the water quality parameters measured as part of this study). A further examination of more recent water quality results from the on-going RBM water quality monitoring programme is warranted.

TABLE 2 Mean ASPT values and resultant ecological category.

Site	Mean ASPT	Category
1	6.1	Good
7	6.3	Good
10	4.4	Poor
11	5.6	Fair
12	6.4	Good
13	6.1	Good
14	6.0	Good

3.3.2 Invertebrate diversity and richness assessment

Measures of diversity and richness (at the taxon level of family) were calculated using a number of different indices. Richness was assessed using N, S and Margalef's index, while the Shannon diversity index, Pielou's index and Simpson's index contributed to an assessment of diversity. The diversity indices measure various components of sample diversity to varying and different degrees and they are therefore used together to provide a more integrated assessment of the samples from different sites. Once the sample data had been converted to a relevant index, results were analysed using ANOVA. Summaries of these analyses are presented in Table 3 and Figures 14 – 21.

There were significant differences within sampled sites between biotopes sampled depending on the measure of diversity and richness used for the analysis. This warrants further investigation (using both previously collected data and data to be collected during 2008), especially as differences were not consistent for the indices or biotopes.

There was little seasonal difference, with only the Summer sample displaying any difference for the species richness index N. Site 10 most frequently displayed any difference to the other sites, with Sites 1 and 7 only being different for the species richness index N. There were no significant interactions between sites and season. These data warrant further exploration with the previously collected data as well as data to be collected during 2008 (i.e. a 3 year data record).

TABLE 3 **A summary of the species richness and diversity indices, indicating differences between site samples at season and site levels, as well as interactions between season and site.**

Index	Season	Site	Interaction between Season and Site
Species richness (N)	The summer sample was significantly different to the winter and spring samples.	Sites 1 and 7 were significantly different, while Sites 10, 11 and 12 grouped together (Figure 14).	No significant interaction exists between season and site (Figure 15).
Species richness (S)	There were no significant seasonal differences.	Site 10 was significantly different from the remainder of the sites.	No significant interaction exists between season and site (Figure 16).
Species richness (Margalef's index; d)	There were no significant seasonal differences.	There were no signficant differences between the sites.	No significant interaction exists between season and site (Figure 17).
Pielou's evenness index (J')	The winter sample was significantly different to the summer sample.	There were significant differences between sites, with Site 10 being significantly different from all sites except Site 12 (Figure 18).	No significant interaction exists between season and site (Figure 19).
Shannon diversity index (H'log$_e$)	There were no significant seasonal differences.	There were no signficant differences between the sites.	No significant interaction exists between season and site (Figure 20)..
Simpson index (1-Lambda')	There were no significant seasonal differences.	There were no signficant differences between the sites.	No significant interaction exists between season and site (Figure 21)..

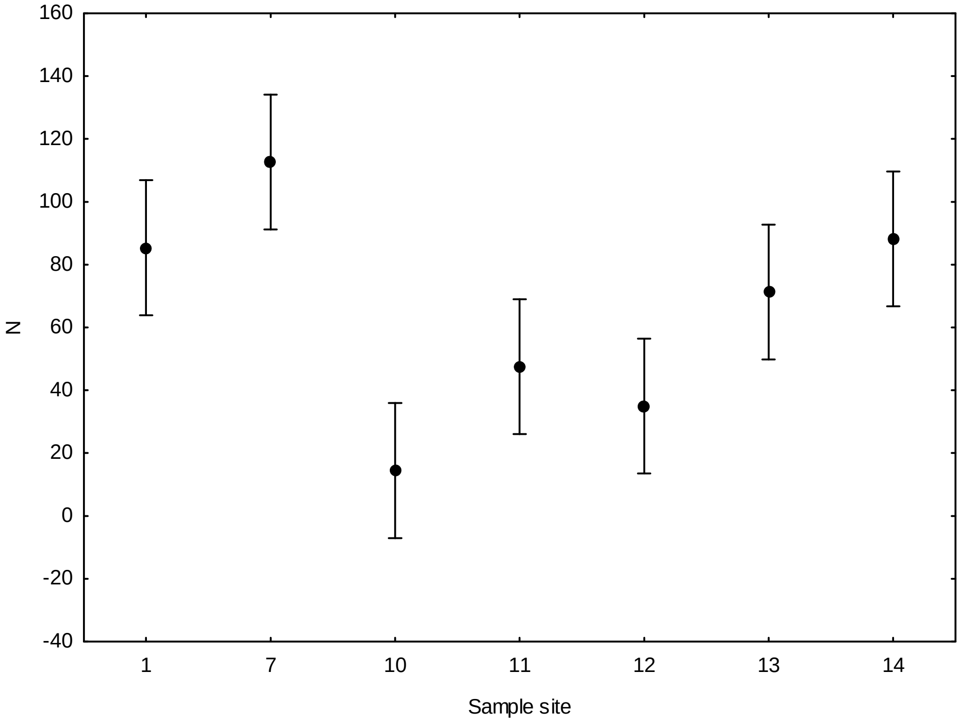

FIGURE 14 Mean N, with 95% confidence limits, per sample site. There is a significant difference.

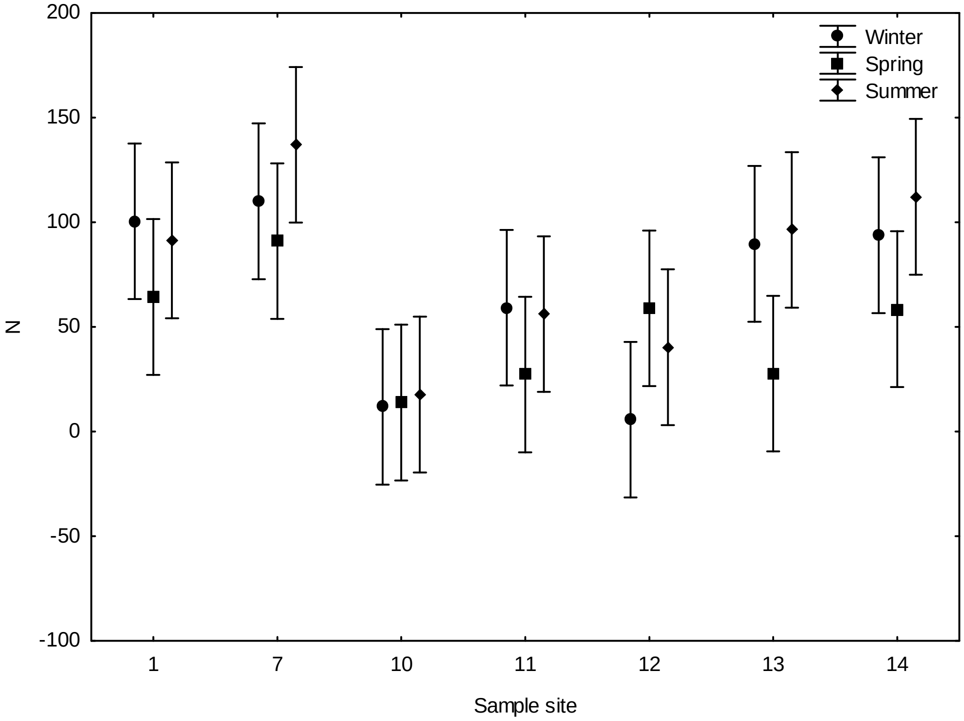

FIGURE 15 Mean N, with 95% confidence limits, per sample site per season. There is no significant interaction.

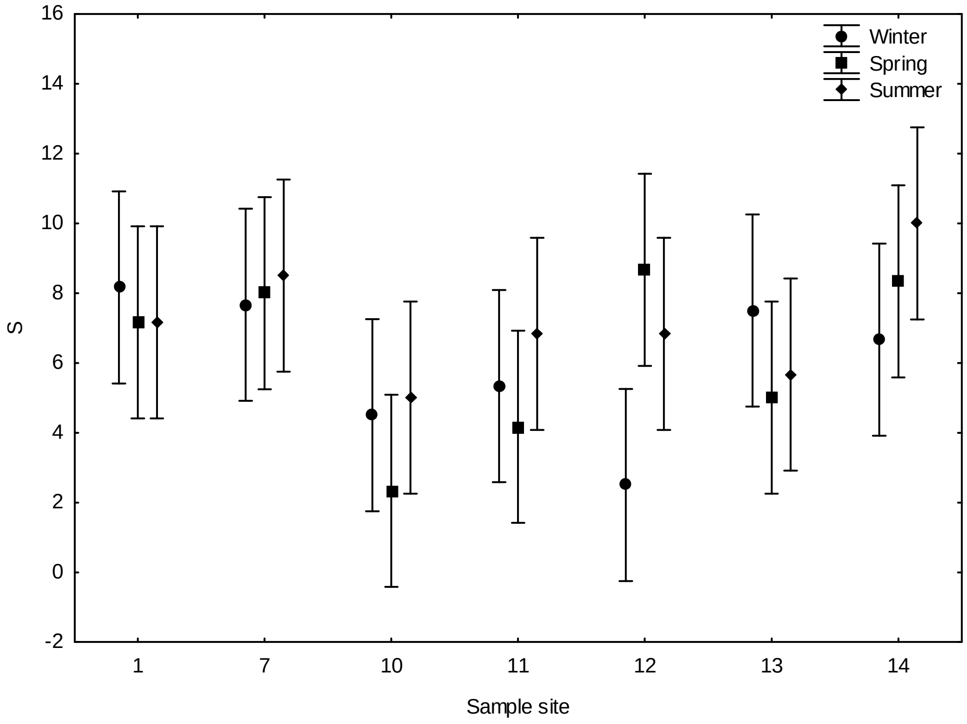

FIGURE 16 Mean S, and 95% confidence limits, per sample site per season. There is no significant interaction.

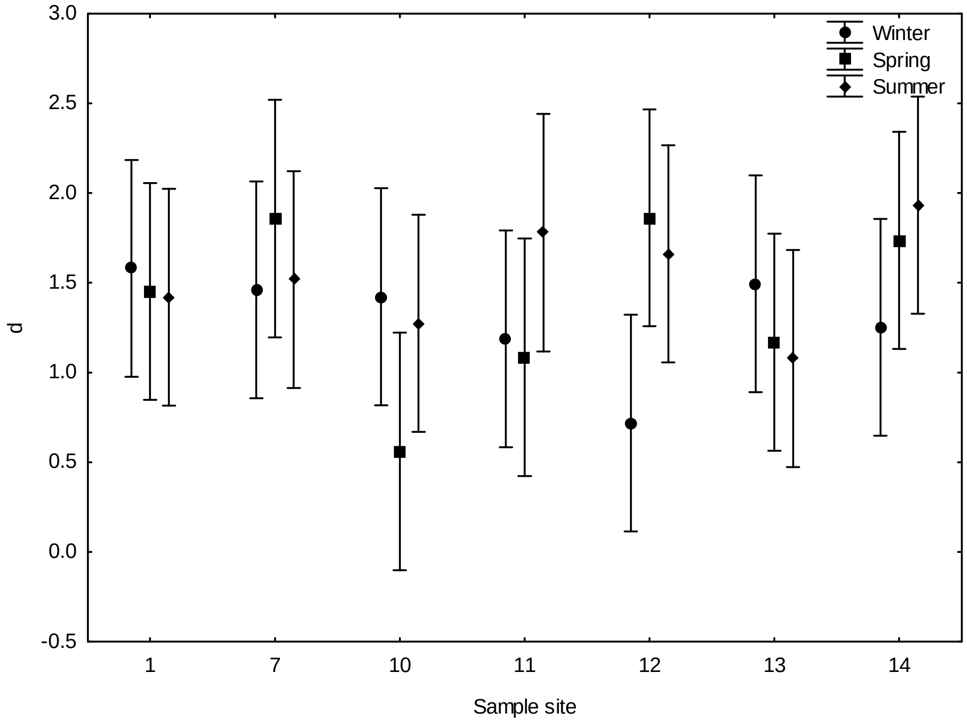

FIGURE 17 Mean d, and 95% confidence limits, per sample site per season. There is no significant interaction.

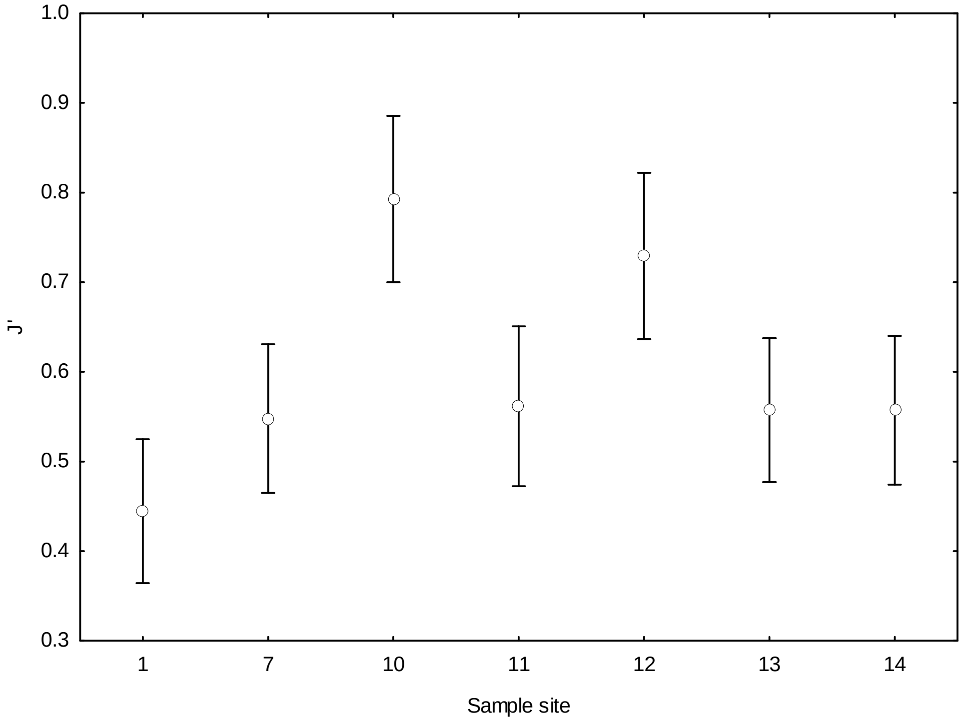

FIGURE 18 Mean J', and 95% confidence limits, per sample site. Site 10 is significantly different to all sites except Site 12.

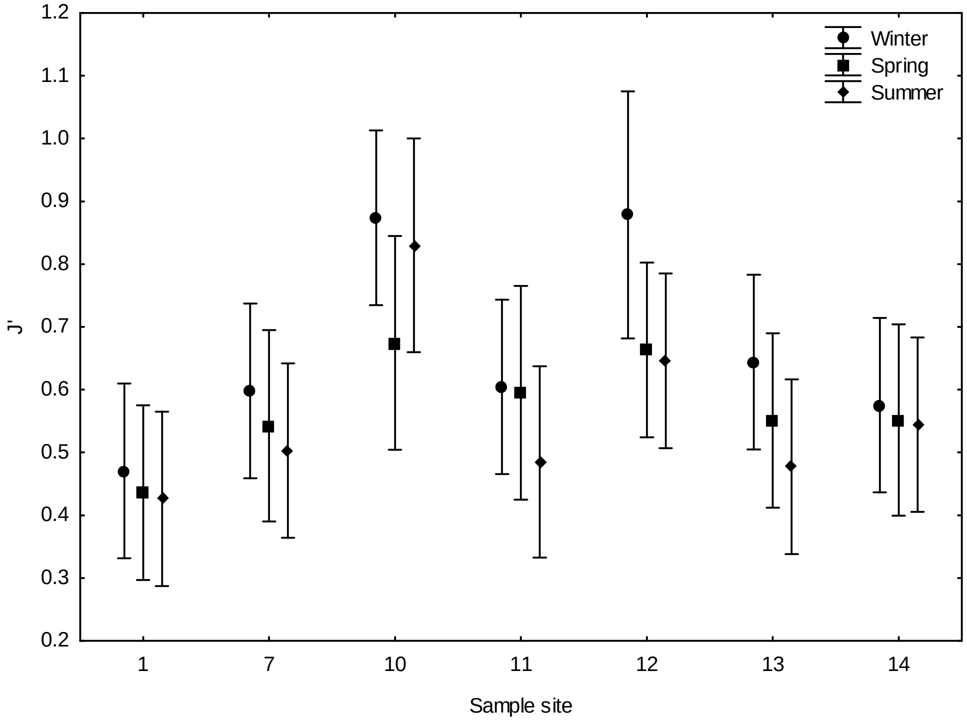

FIGURE 19 Mean J', and 95% confidence limits, per sample site per season. There is no sifnificant interaction.

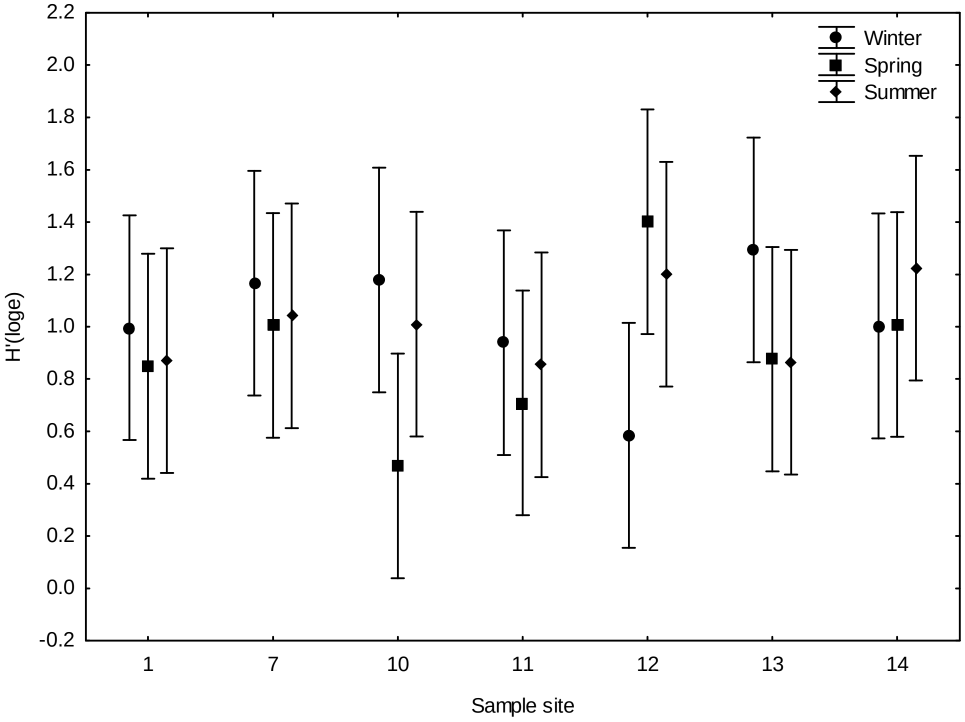

FIGURE 20 Mean H'(log_e), and 95% confidence limits, per sample site per season. There is no significant interaction.

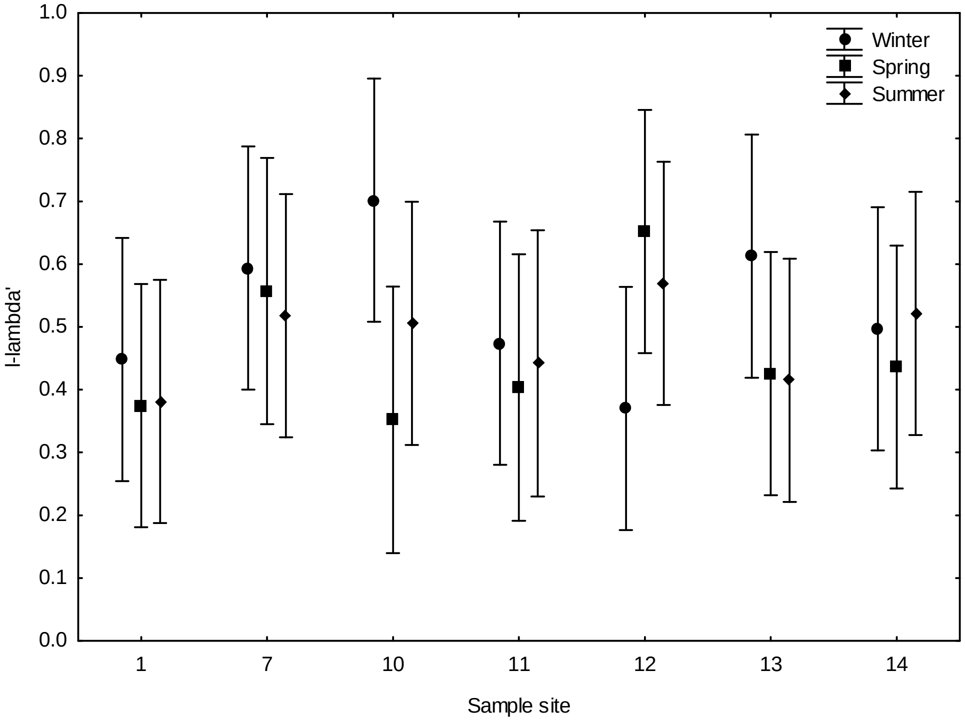

FIGURE 21 Mean I-lambda', and 95% confidence limits, per sample site per season. There is no significant interaction.

3.4 Diatom assessment

The Summer sample has not yet been analysed, due to insufficient time to process the sample collected in early December 2007. A summary of the species of diatoms found at each of the sites during the Winter and Spring sampling events is found in Table 4.

Site 1

Winter: Six species were identified in this sample. Although two species are cosmopolitan and may be found in meso-eutrophic or moderately polluted conditions, all other species for which environmental preferences were known are indicative of circumneutral, and usually oligotrophic, electrolyte poor conditions. One of these, *Achnanthes oblongella*, was dominant in the sample.

Spring: Eight species were identified in this sample. All species for which environmental preferences were known were indicative of excellent water quality. Between them, species preferred well oxygenated, circumneutral, oligotrophic, electrolyte-poor water. *Eunotia minor* was the most common species in this sample.

Site 7

Winter: Nine species were found in this sample. The ecologies of eight are known. Together, they indicate that the water quality at this site is mesotrophic with moderate levels of electrolytes. *Nitzschia filiformis*, a species typical in water of moderate to high electrolyte levels, and tolerant of moderate pollution, is dominant.

Spring: Nine species were found in this sample. The ecologies of four are known. All species indicate the the water quality at this site is at least mesotrophic, and possibly eutrophic. Electrolyte levels may be elevated. No one species was dominant in this sample.

Site 10

Winter: Fourteen species were identified in this sample. Although several species found are pollution tolerant (e.g. *Nitzschia palea*, *Stauroneis phoenicenteron*), *Frustulia crassinerva* and *Brachysira wygaschii* are normally found in oligotrophic, electrolyte poor waters.

Spring: Nine species were identified in this sample. All taxa for which environmental preferences were known were tolerant of various levels of pollution. *Achnanthidium eutrophilum*, a species usually found in well oxygenated eutrophic but not critically polluted water was dominant, and *Sellaphora pupula*, a cosmopolitan species tolerant of strongly polluted conditions was subdominant.

Site 11

Winter: Only one frustule was present in the sample collected in July. It was from a species of *Achnanthes*. No conclusions can be drawn regarding this sample.

Spring: Four species were identified in this sample. All are species tolerant of high levels of electrolytes and frequently associated with industrial pollution. The sample is dominated by *Luticola goeppertiana*.

Site 12

Winter: Seven taxa were identified in this sample. All taxa with known ecologies were characteristic of oligotrophic conditions and low electrolyte levels (*Achnanthes oblongella*, *Navicula ranomafenensis*, *Pinnularia viridiformis*). No one species was dominant in this sample.

Spring: This sample contained a large number of broken frustules that could not be used to identify species present at time of sampling. Three species were identified from entire frustule in valve view. All three prefer oligotrophic conditions, and one, *Achnanthidium minutissimum*, prefers well oxygenated conditions. *Achnanthes oblongella*, the dominant species, is characteristic of circumneutral, oligotrophic and electrolyte poor conditions.

Site 13

Winter: Seven species were identified in this sample. The ecologies of five are known, and all are tolerant of moderate to high levels of electrolytes and at least moderate levels of pollution. The sample was dominated by *Gomphonema pseudoaugur*, a species found in mesotrophic to eutrophic water but not tolerant of more than critical levels of pollution.

Spring: Eleven species were identified in this sample, and environmental preferences were known for seven of these. All are pollution tolerant species, and one, *Navicula reichardtiana*, is a good indicator of pollution. The sample was dominated by two species: *Navicula rostellata*, which is tolerant of critical levels of pollution; and *Amphora* sp.

Site 14

Winter: Seven species were identified in this sample. The ecologies of five of them are known. *Gomphonema clavatum*, a cosmopolitan and pollution tolerant species, is dominant. Other species present are tolerant of lower levels of pollution and electrolyte loading, and two *Eunotia* species are typical in acidic to circumneutral water with low electrolyte loads.

Spring: Eight species were identified in this sample. *Gomphonema pseudoaugur* was the most dominant species in this sample. This species is cosmopolitan, is often found in mesotrophic or eutrophic water, but is not tolerant of critical levels of pollution. The only other species with a known ecology was *Cocconeis placentula*, which is also common in mesotrophic or eutrophic water.

According to the diatoms collected, the upstream sites on the Mdibi and Mpisini Rivers had good water quality in all samples examined. However, the upstream site on the Manzamnyama River was at best fair. Water quality degrades within three kilometers down the Mpisini River leading to water quality at the lower site being classed as fair to poor. The stressed conditions recorded at the confluence of the Mpisini and Manzamnyama rivers seem likely to be a function of inflows from both rivers. The decrease in water quality along the Manzamnyama and Mpisini Rivers appears to be due to increased electrolyte levels, although there is an indication that nutrient levels may have increased along the Mpisini River in October.

Water quality also degrades along upper-to-mid stretches of the Mdibi River, apparently largely due to an increase in nutrients. Water quality remains the same or improves slightly along lower stretches of the Mdibi River.

The same general pattern of changes in water quality is apparent in samples from Winter and Spring 2007. Heavy rains prior to sampling in Winter may have changed the water quality and may have disturbed diatom communities or washed new taxa in from upstream. As a result, winter samples from another year may not completely correspond with the results presented here. Longer-term monitoring will be necessary to evaluate seasonality in diatom communities in the sample area.

TABLE 4 **Diatom species identified at the different sites in the Smelter Site area during the Winter and Spring 2007 (W: Winter; S: Spring).**

	Site 1 (Upper Mpisini)		Site 7 (Lower Mpisini)		Site 10 (Upper Manzamnyama)		Site 11 (Confluence)		Site 12 (Upper Mdibi)		Site 13 (Middle Mdibi)		Site 14 (Lower Mdibi)	
	W	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**
Achnanthes oblongella	×	×							×	×				
Achnanthes spp														
Achnanthidium eutrophilum			×			×								
Achnanthidium exiguum												×		
Achnanthidium minutissimum		×								×				
Achnanthidium spp	×			×	×		×							
Amphora spp												×		
Anomoensis sphaerophora														
Brachysira wygaschii					×									
Brachysira spp		×			×									
Caloneis bacillum					×									
Caloneis spp														
Capartogramma crucicula													×	
Cocconeis placentula														×
Cocconeis placentula var. *euglypta*			×											
Cocconeis spp									×		×			×
Craticula spp			×											
Cymbella tumida			×	×										
Diploneis puella											×			
Eunotia bilunaris													×	
Eunotia flexuosa										×				
Eunotia minor	×	×											×	
Eunotia spp	×	×										×		×
Fragillaria spp		×												
Frustulia crassinerva					×									

	Site 1 (Upper Mpisini)		Site 7 (Lower Mpisini)		Site 10 (Upper Manzamnyama)		Site 11 (Confluence)		Site 12 (Upper Mdibi)		Site 13 (Middle Mdibi)		Site 14 (Lower Mdibi)	
	W	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**
Gomphonema affine											×			
Gomphonema angustatum		×						×						
Gomphonema clavatum		×									×		×	
Gomphonema gracile					×						×			
Gomphonema lagenula											×			×
Gomphonema minutum												×		
Gomphonema parvulum						×					×			
Gomphonema pseudoaugur			×											×
Gomphonema pumilum var. *rigidum*	×												×	
Gomphonema venusta			×											
Gomponema exilissimum														×
Gomphonema spp				×									×	
Luticola goeppertiana								×					×	
Navicula ranomafenensis									×					
Navicula reichardtiana						×						×		
Navicula rostellata				×								×		
Navicula schroeteri				×										
Navicula vandamii			×									×		
Navicula veneta								×						
Navicula spp	×			×		×								×
Neidium spp					×									
Nitzschia capitellata						×								
Nitzschia clausii												×		
Nitzschia filiformis			×											
Nitzschia frustulum												×		
Nitzschia linearis					×									
Nitzschia nana			×			×								

	Site 1 (Upper Mpisini)		Site 7 (Lower Mpisini)		Site 10 (Upper Manzamnyama)		Site 11 (Confluence)		Site 12 (Upper Mdibi)		Site 13 (Middle Mdibi)		Site 14 (Lower Mdibi)	
	W	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**
Nitzschia palea				×	×							×		
Nitzschia sigma					×									
Nitzschia spp			×	×	×				×					
Pinnularia viridiformis									×					
Pinnularia spp					×	×								
Sellaphora pupula						×								×
Sellaphora seminulum												×		
Stauroneis pachycephala									×					
Stauroneis phoenicenteron					×	×								
Stenopterobia curvula					×									
Tabularia fasciculata								×						

4. DISCUSSION

A summary of the indices measured is provided in Table 5. A provisional overall ecological health assessment for each of the sites assessed is provided. (Note: there is no health index for 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 due to insufficient data for ASPT and water quality, the methods used to provide the subsequent categories could not be followed accurately and are therefore 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 method and require site-specific refinement. Both of these issues can only be resolved through further collection of data to allow a more accurate assessment of the true environmental water quality conditions. The method used to derive the diatom categories is based on expert opinion and will require validation through further data collection and analysis.

TABLE 5 A summary of main index score results to provide an overall assessment for each of the sites.

Site	ASPT	IHAS	Water Quality	Diatoms	Overall ecological health assessment
1	6.1 Good	58	Good	Good	Good (may be natural)
7	6.3 Good	64	Good	Fair / Poor	Fair
10	4.4 Poor	49	Good / Fair	Fair / Poor	Fair / Poor
11	5.6 Fair	48	Good	Poor	Fair
12	6.4 Good	58	Good	Good	Good
13	6.1 Good	56	Good	Fair / Poor	Good / Fair
14	6.0 Good	58	Good	Fair / Poor	Good / Fair

The overall water quality categories is generally not reflected in the measured biological indices (macroinvertebrates and diatoms) which suggests that water quality parameters not measured during the biomonitoring may be driving the impaired water quality conditions reflected by the macroinvertebrates and diatoms. An examination of more recent water quality data collected by the routine and on-going RBM chemical sampling programme at these sites is warranted. The biological data collected so far will go towards establishing better site-specific reference conditions, and may be useful in assessing the validity of recalibrating the benchmark boundary values for water quality parameters to yield site-specific boundary values.

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APPENDIX 1 Representative diatom samples from Smelter Site area

Figure 1: *Achanthes oblongella* (raphoid valve)

Figure 2: *Achnanthes oblongella* (rapheless valve)

Figure 3: *Achnanthidium minutissimum*

Figure 4: *Cymbella tumida*

Appendix: Representative diatoms

Figure 5: *Eunotia minor*

Figure 6: *Gomphonema clavatum*

Figure 7: *Gomphonema lagenula*

Figure 8: *Gomphonema pseudoaugur*


Figure 9: *Luticola goeppertiana*


Figure 10: *Navicula ranomafenensis*


Figure 11: *Navicula rostellata*


Figure 12: *Nitzschia filiformis*


Figure 13: *Nitzschia nana*

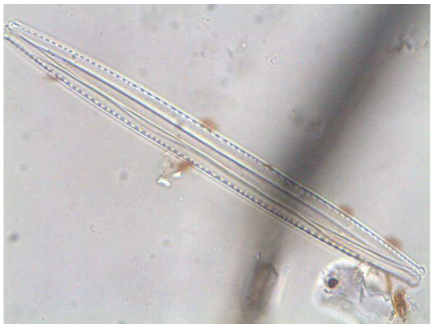
Figure 14: *Nitzschia palea*


Figure 15: *Sellaphora pupula*


Figure 16: *Stauroneis phoenicenteron*