P WMA 12/T30/00/5212/7

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

DIRECTORATE: OPTIONS ANALYSIS

FEASIBILITY STUDY FOR THE MZIMVUBU WATER PROJECT

RESERVE DETERMINATION
VOLUME 3:
ESTUARY: APPENDICES

OCTOBER 2014

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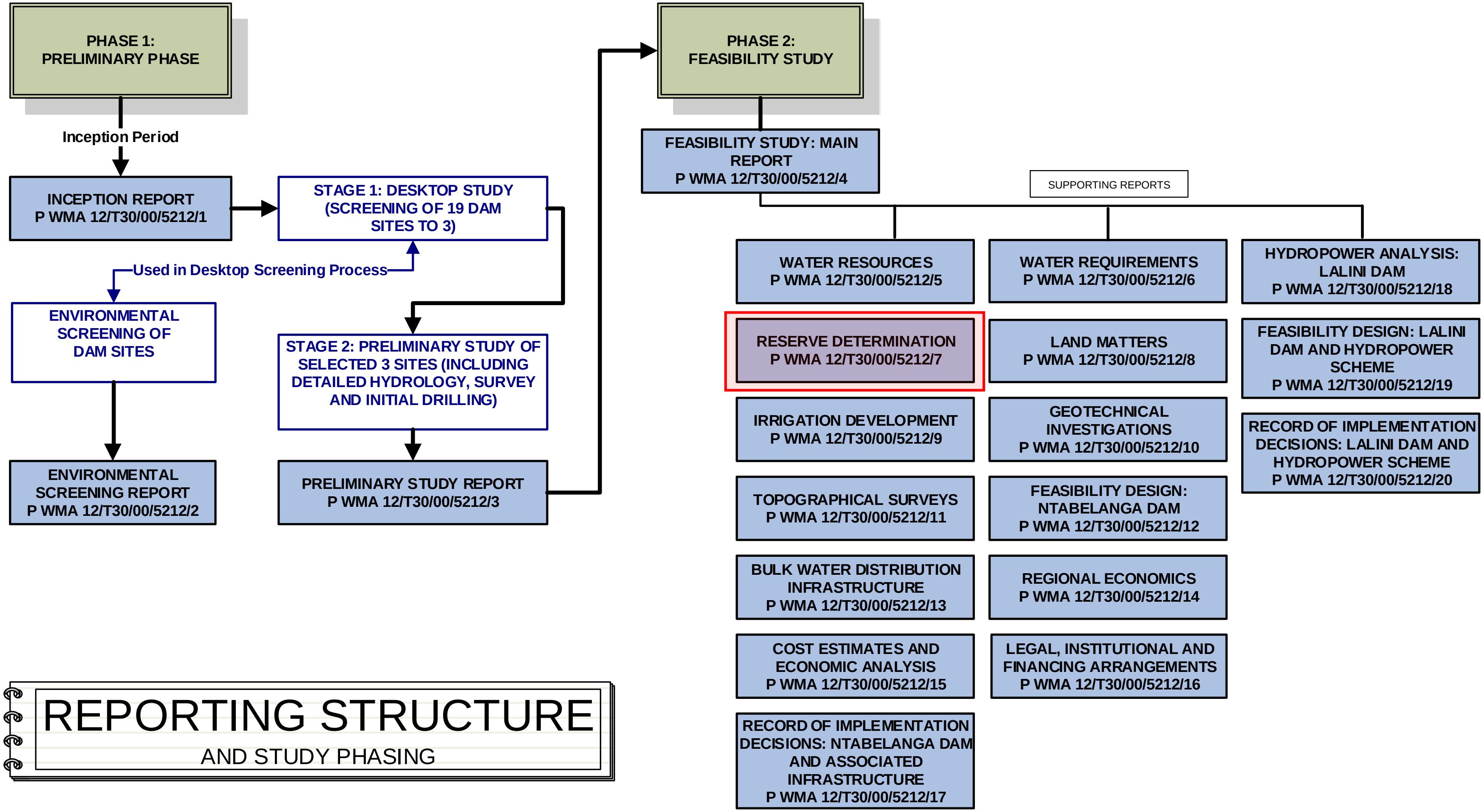
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REFERENCE

This report is to be referred to in bibliographies as:

Department of Water and Sanitation, South Africa (2014). ***Feasibility Study for the Mzimvubu Water Project: Reserve Determination: Volume 3: Estuary Appendices***

DWS Report No: P WMA 12/T30/00/5212/7

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Note on Departmental Name Change:

In 2014, the Department of Water Affairs changed its name to the Department of Water and Sanitation, which happened during the course of this study. In some cases this was after some of the study reports had been finalized. The reader should therefore kindly note that references to the Department of Water Affairs and the Department of Water and Sanitation herein should be considered to be one and the same.

Note on Spelling of Laleni:

The settlement named Laleni on maps issued by the Surveyor General is locally known as Lalini and both names therefore refer to the same settlement.

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ECOLOGICAL WATER REQUIREMENTS STUDY
MZIMVUBU ESTUARY

SPECIALIST REPORT:
PHYSICAL DYNAMICS AND WATER QUALITY

6 JULY 2013

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our future through science

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RESERVE DETERMINATION: VOLUME 2: ESTUARY: APPENDIX B: ABIOTIC SPECIALIST REPORT
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FEASIBILITY STUDY FOR THE MZIMVUBU WATER PROJECT RESERVE DETERMINATION: ESTUARY

1. INTRODUCTION

The CSIR was contracted by MER to provide specialist input on the physical dynamics and water quality for the determination of estuarine ecological water requirements (EWR) on the Mzimvubu Estuary.

The Ecological Water requirement studies on the estuaries will follow the methods as described in Resource Directed Measures for Protection of Water Resources: Methodologies for the determination of ecological water requirements for estuaries Version 2 (DWAF, 2008). The assessment is based on field data collected on two occasions during August 2012 (winter) and January 2013 (summer).

This report contains the results from the abiotic specialist study (physical dynamics and water quality).

2. ASSUMPTION AND LIMITATIONS

The brief was undertaken based on the following assumptions:

- It is assumed that the simulated run-off scenarios, representative of river inflow at the head of the uMmzimvubu Estuary provided to the CSIR are correct. These scenarios included the reference condition, the present state and a range of additional scenarios as agreed between the CSIR, MER and DWA;

- The accuracy and confidence of an Estuarine Ecological Water Requirements study is strongly dependant on the quality of the hydrology. The overall confidence in the hydrology supplied to the estuarine study team was considered to be low as there are no measured flow data records available on his systems – at least not close to the head of the estuary.

3. AVAILABLE DATA

The following data were available for the abiotic components in the Mzimvubu Estuary:

Data Required	Availability	Reference
Simulated monthly runoff data (at the head of the estuary) for present state, reference condition and the selected future runoff scenarios over a 50 to 70 year period	Not available	
Simulated flood hydrographs for present state, reference condition and future runoff scenarios: 1:1, 1:2, 1:5 floods (influencing aspects such as floodplain inundation) 1:20, 1:50, 1:100, 1:200 year floods (long-term sediment dynamics, equilibrium, budget)	Not available	

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Data Required	Availability	Reference
Aerial photographs of estuary (earliest available year as well as most recent)	Available	July 1938, August 1952, June 1969, May 1972, October 1974, April 1977, July and December 1982 and January 1993
Continuous water level recordings near mouth of estuary	Available	T3T018
Mouth observations	N/A	-
Longitudinal salinity and temperature profiles (in situ) collected over a spring and neap tide during high and low tide at: end of low flow season peak of high flow season	August 1996 August 2012 January 2013	Taljaard et al (1997) This study
Water quality measurements (i.e. system variables, and nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at: end of low flow season peak of high flow season	August 1996 (Dissolved oxygen & inorganic nutrients) August 2012 (pH, turbidity, SS, dissolved oxygen & nutrients) January 2013 (pH, turbidity, SS, dissolved oxygen & nutrients)	Taljaard et al (1997) This study
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary	Trace metals (2013)	Songca et al. (2013)
Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary	Mar 2009 to Oct 2012 (31 data points)	DWA WQ monitoring programme (T3H020Q01)
Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater	Available data	DWAF (1995)
Sediment data	Grain size analysis (Jan 2013)	This study

4. ZONING AND TYPICAL ABIOTIC STATES

For the purposes of this study, the Mzimvubu Estuary is sub-divided into three distinct zones primarily based on bathymetry (Figure 4.1):

Lower Zone: From mouth to 4 km upstream (34% of volume)
Middle Zone: From 4 - 10 km upstream (33% of volume)
Upper Zone: From 10 - 14 km upstream (33 % of volume).

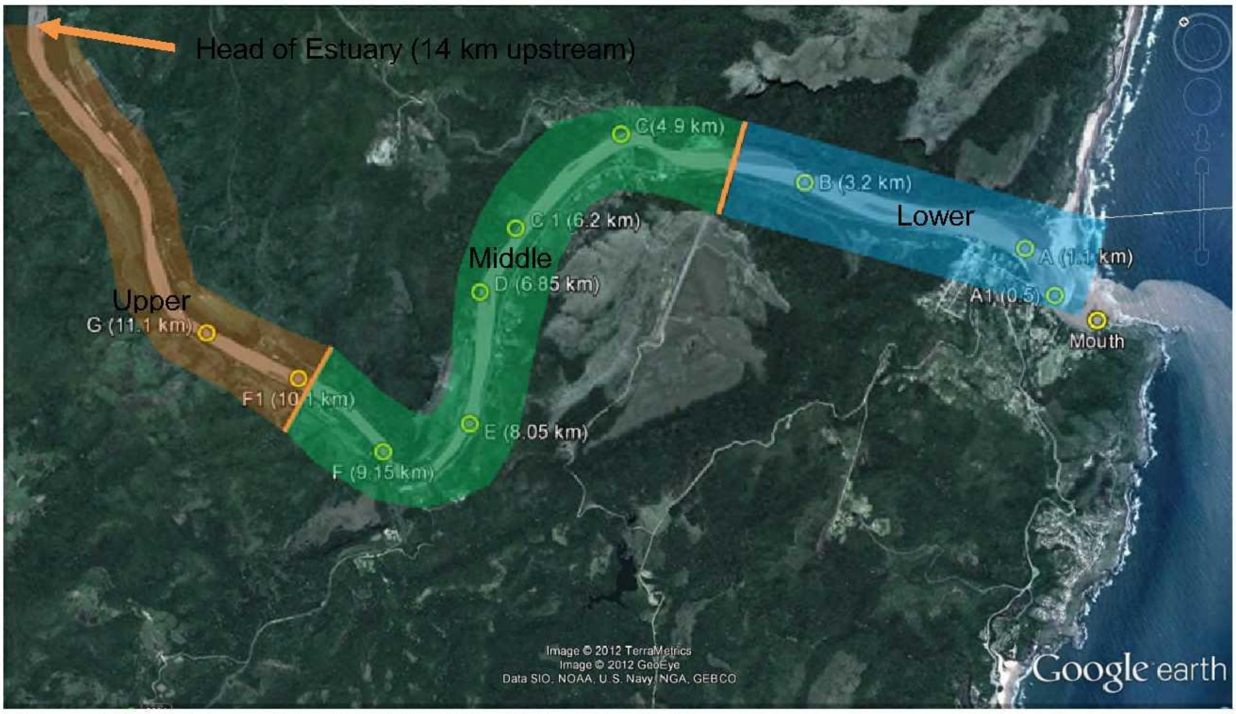

Figure 4.1: Zones identified for the uMzimvubu Estuary

For this assessment four abiotic states are proposed for the uMzimvubu Estuary (Table 4.1).

Table 4.1: Typical Abiotic States in the Mzimvubu Estuary

State	Flow Range (m3/s)
State 1: Significant saline penetration into Lower, Middle and Upper Zones	1-31
State 2: Intermediate saline penetration, into Lower and Middles Zones	3-10
State 3: Limited saline penetration, only in Lower Zone	10-30
State 4: Freshwater dominates, all zones fresh	>30

5. PHYSICAL PROCESSES

This section provides a brief overview of the available information on the physical process of the Mzimkulu River Estuary.

5.1 Depth

Skead (1864) recorded that about one mile (1.6 km) of the estuary was sounded (from the mouth inland). The average depth of water found was 15 feet (~4.6 m) at low water, and the width averaged 300 yards (~ 274 m). In May 1857, not less than 8 feet (~2.4 m) of water was found at low tide over the bar in the channel into the estuary. The small vessels which entered this river were guided over the bar. A local trader, Mr White, reported a depth of not less than

[1] This estuary is classified as a permanently open system, but under extended periods of very low base flows this system can close. The actual cut-off flows for closure is unknown due to a lack of data, but for the purposes of this study it is assumed to be base flows less than 1 m3/s. Based on the scenarios provided such a severe reduction in base flows are not expected in future and for this reason the close state has not been included as a typical Abiotic State for this permanently open estuary, at least not at this stage.

12 feet (~3.7 m) was to be found as far as his trading station, a distance of nine miles (~14,5 km) from the river's mouth. No information is available on the methods used or the accuracy of this data. Although valuable because of the long historic perspective the data provides, it can at best be used to give a very rough indication of the conditions at the time.

In August 1996 during a low river flow period, tidal influence was experienced 11 km upstream in the estuary (see Figures 5.1a and b). The estuary had a width of about 200 to 300 m at the mouth and becomes progressively narrower moving upstream. In 1996 the narrowest section of about 80 m was located some 10 km upstream of the mouth (Taljaard et al, 1997). During average to low river flow periods, a depth of about -2 to -4 m (to MSL) is usually found at the mouth. The deepest section that was found in the estuary in 1996 was about -5 m to MSL located some 5 km upstream of the mouth. Thereafter the estuary was generally shallower, with a deep hole of about -7 m (to MSL) located 8 km upstream of the mouth (Taljaard et al, 1997). Another very deep hole is apparently located about 300 m downstream of the Pondoland Bridge adjacent to the cliffed northern bank (according to the proprietor of the Spotted Grunter Lodge). The head reaches of the estuary are quite shallow with meandering sandbanks and narrow channels less than 1 m deep. According to residents, these sand banks are of fairly recent origin, having been deposited during the previous major floods. (The sand banks were also observed during the CSIR 1997 survey (Van Niekerk, CSIR pers. comm., 2005).

5.2 Mouth State

The Mzimvubu River Estuary is by far the largest system in the Wild Coast (formerly Transkei) area. The mouth of the Mzimvubu River Estuary is permanently open to the sea. River flow is critical to the maintenance of an open mouth. This is assisted by the outlet forming in the lee of the Cape Hermes headland, where wave energy (from the prevailing south-westerly waves) is reduced. The estuary probably has an insufficient tidal prism to maintain an open mouth against sediment accumulation by nearshore wave and tidal action, partially due to the constraint of the narrow bedrock valley. Riverine (fluvial) sediment extends to the sand banks near the mouth.

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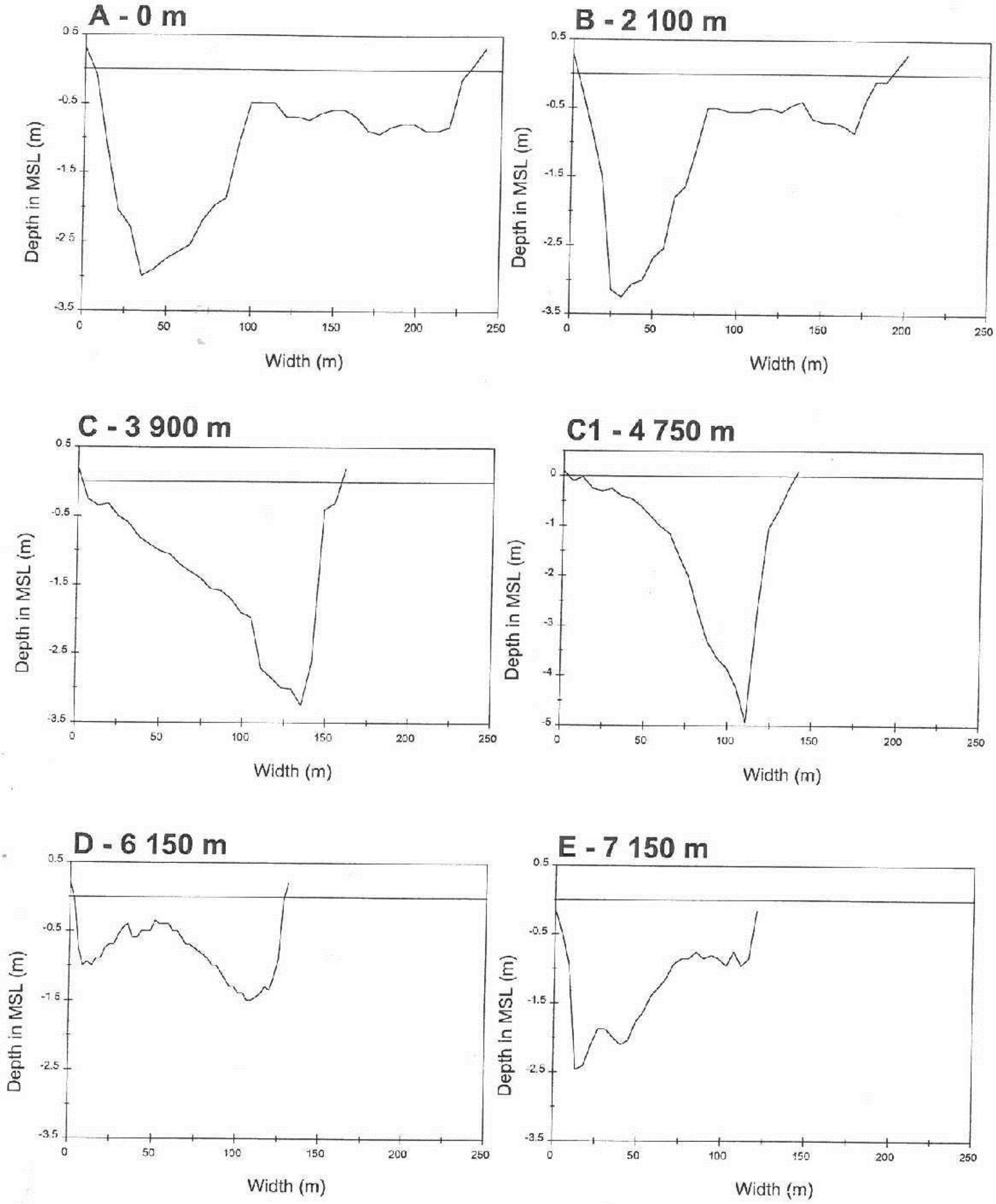


Figure 5.1a: Cross-sectional profiles of the Mzimvubu taken on 14 August 1996

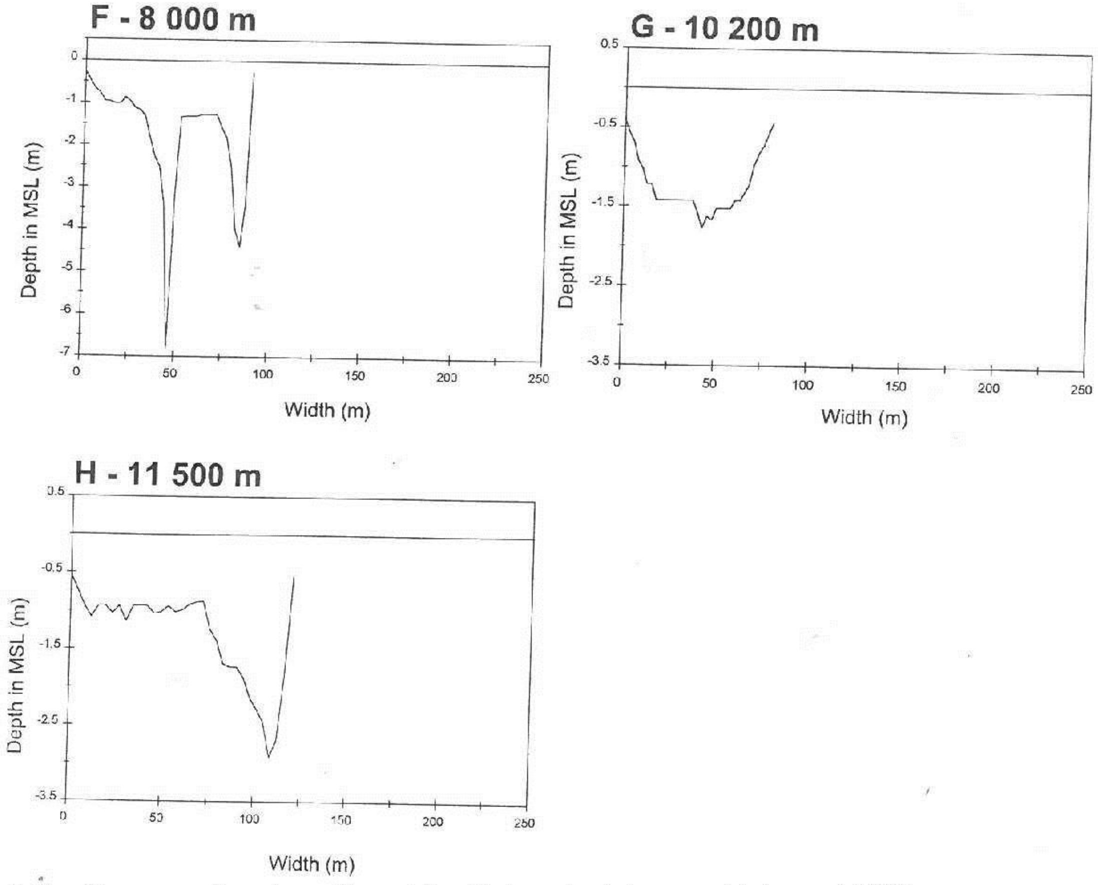


Figure 5.1b: Cross-sectional profiles of the Mzimvubu taken on 14 August 1996

5.3 Sediment processes

5.3.1 Erosion in the Mzimvubu catchment and river

Grazing pressures in the Mzimvubu catchment appear to have been very high for most of the 20th century. However, it appears that there may have been a decline in grazing pressure during recent years (CSIR, 2005). There is widespread evidence of erosion and degradation in the catchment of the Mzimvubu River, affecting almost 11% of the area of the catchment. (This is possibly an underestimate, due to the coarseness of the data.) The information source used to determine the extent of erosion and degradation in the catchment was the South Africa Land-Cover Database, 2000. Many authors feel that soil erosion is excessive when the rate of soil loss exceeds the rate of soil formation. In South Africa, soil formation is as little as 0.25 to 0.38 tonnes/ha/yr (Snyman 1999), and Scotney and McPhee (1991) have suggested that a rate of soil loss for uncultivated land as 0.5 tonnes / ha /year would be acceptable. In South Africa, water-driven erosion, largely induced by agricultural practices, is extensive, and often leads the these rates being exceeded. The formation of dongas (which are common in parts of the Mzimvubu catchment) are considered as evidence of very severe soil loss (CSIR, 2005). There are no data in which trends in sediment transport in rivers are monitored. There is therefore no basis on which to speculate that this may have increased or decreased over time. However, erosion and degradation of vegetation cover in the catchment suggest that sediment transport levels are higher than those that existed prior to degradation in the 20th century (CSIR, 2005).

5.3.2 Sediment dynamics and morphological processes in the Mzimvubu Estuary

The Mzimvubu River has cut a deep valley through the tablelands of the coastal belt and the estuary meanders through a deep gorge (> 300 m) of Table Mountain sandstone vegetated with indigenous forest (Day, 1981). The town of Port St Johns has been built on a Pleistocene flood-plain on the south bank of the estuary (Figure 5.2).

Riverine (fluvial) sediment extends to the mud/silt banks near the mouth. (Sediment samples taken during a site inspection in May 2005 ranged from 94% mud/silt near the Pondoland Bridge, to 93% mud/silt and very fine sand near the mouth.) The estuary channel bottom is muddy as a result of suspension-settling during low flow periods (Harrison et al 1998). A turbid plume is often observed seaward of the mouth, especially during November to April (e.g. Figure 5.2). The role of floods is important in eroding accumulated sediment and temporarily deepening the estuary channel (Cooper et al, 1989). Erosion during extreme floods appears to be distributed throughout the channel and even cohesive sediments may be eroded.

Figure 5.2: The Mzimvubu Estuary showing where the estuary enters the Indian Ocean, location of Port St Johns and First Beach, as well as river transects sampled in May 2005

The condition of the Mzimvubu Estuary results from the combined effects of numerous processes. Some of these processes act on the estuary directly, while others do so indirectly, through influencing the condition of the catchment. It can be said that the important processes that drive change in the Mzimvubu Estuary, with regard to the sediment dynamics are as follows:

- Sediment transport and deposition (sedimentation) through river flows and marine processes (mainly tidal inflows and wave action at the mouth);
- Erosion, sediment scouring and flushing (out to sea) through river flows and marine processes (mainly tidal outflows);
- Inflow of freshwater, including the changes over seasons and between years; and changes to inflows brought about by human modification of flow regimes, through dams or other impoundments, or other forms of abstraction, or even water addition (e.g. through outflows from sewerage plants or inter-basin transfers); and
- Erosion in the catchment, which will impact on sediment loads in the river and estuary.

5.3.3 Available background information and data

Schoonees (1988) roughly estimated the critical erosive shear stress of sediment in the estuary (at Banana Point) to be about 0,2 to 0,4 Pa. This range of critical erosive shear stresses corresponds to mean flow velocities in the estuary of only about 0,15 to 0,25 m/s. Of significance, is that these velocities are easily exceeded during spring tidal flows or periods of higher river outflow, which means that this fine sediment is easily eroded and transported during conditions that often occur in the estuary.

Flemming (1981) estimated the annual suspended sediment load of the Mzimvubu River to be as much as 4.2 million m^3 and the bedload as about 210 000 m3. Hay (1984) estimated total load as 3.51 million m^3/yr including bedload of 176 000 m^3/yr and biogenic bed load of 26 000 m3/yr. Lenhoff, et al (1989) found six depocentres off the Wild Coast (a depocentre is an area of sediment accumulation on the continental shelf.) The second largest of these depocentres was found off Port St. Johns. Most of this sediment originates from the Mzimvubu River. The Port St. Johns depocentre has a very large volume (about 1 200 x106 m3). Also significant is that the sediments in this depocentre comprise up to 75% mud; and that this mudbank, and those off the Tugela River, form the only two major mud depocentres on the east coast (Marten and Flemming, 1986). Evidence of massive Holocene mud deposits off Port St. Johns indicate that high loads of muddy material have occurred for a very long time.

Previous observations made during the 1970s and 1980s (Wallace and Van der Elst, 1974; Town and Regional Planners, 1979; Day, 1981; Marten and Flemming, 1986; and Emmerson, 1988), appear to correspond in terms of the heavy silt load of the Mzimvubu River. The data available on turbidity in the Mzimvubu Estuary were that collected by Harrison (unpublished data) in 1992 during a high flow period. At the time, turbidity levels were considered to be high, averaging around 250 NTU.

These data provide limited means of assessing the condition of the Mzimvubu in fairly recent times. Some of the above datasets address the processes that drive change in the estuary, while the others provide indirect means of assessing the processes. Importantly, no indication is given of what the system resembled in its historical reference condition (i.e. totally, or nearly, undisturbed conditions for hydromorphological aspects, general physical and chemical elements, European Commission, 2000). Also, to date, there have been no directed studies of the hydrodynamics, sediment-dynamics or morphology of the Mzimvubu Estuary. Also, no detailed ecological work with specific reference to high sediment loads has been conducted on the Mzimvubu estuary. However, a spatially extensive study in the Mzimvubu catchment above the estuary has been reported on by Madikizela et al. (2001) and Madikizela and Dye (2003). Relevant findings of this study were considered in the assessment of the condition of the estuary. All in all, the available information on the Mzimvubu Estuary is at best considered to be poor.

Extensive and shallow muddy/silty banks were observed within the estuary right up to the mouth. According to the proprietor of the Spotted Grunter Lodge the mud bank built out by about 20 m into the river over the 2004/05 summer season (this is on the western side of the estuary about 0.5 km below the bridge) (Figure 5.3).

Figure 5.3: (a) Site inspection May 2005: 94% mud/silt near bridge; (b) Site inspection Jan 2013: mostly silt/fine sand at mouth

Table 5.1 Sediment grading in the Mzimvubu Estuary (Port St Johns) measured von 30 January 2013

	Ntaba Lodge - Right upper bank	Beach - North of mouth	Mouth of right bank	Right bank - Start of town	Right bank at slip - Town	Left bank Opposite slip - Town	Ntaba lodge - Right bank
% Gravel	0	0	0	0	0	0	0
% Sand	87	100	99	64	20	11	20
% Silt/clay	13	0	1	36	80	89	80
D50/Median mm	0.127	0.320	0.162				
% <2.0mm	100.000	100.000	100.000	100.000	100.000	100.000	100.000
% <1.4mm	100.000	100.000	100.000	100.000	100.000	100.000	100.000
% <1.0mm	100.000	100.000	100.000	100.000	100.000	100.000	100.000
% <0.71mm	100.000	99.839	100.000	100.000	100.000	100.000	100.000
% <0.5mm	100.000	99.034	100.000	99.661	100.488	100.000	100.000
% <0.3mm	99.278	65.539	99.721	98.983	100.000	99.174	99.505
% <0.25mm	93.141	12.560	96.234	98.305	99.024	98.347	99.010
% <0.212mm	86.282	5.636	89.679	97.966	98.537	98.347	98.515
% <0.18mm	77.978	2.415	73.780	96.949	97.073	98.347	98.020
% <0.15mm	63.177	0.644	31.381	93.559	95.122	97.521	96.040
% <0.125mm	48.736	0.322	11.576	86.102	92.195	95.868	94.059
% <0.09mm	27.798	0.161	2.929	60.678	87.805	94.215	89.109
% <0.063mm	13.357	0.000	0.837	35.932	80.000	89.256	80.198

5.3.4 Perceived silting up of the Mzimvubu Estuary

All in all, no significant local sources of sediment input into the estuary could be found during the site inspection of 10-12 May 2005. It appears that the sediment load must virtually all come from the catchment, whether "natural" or increased due to anthropogenic activities such as farming. Accelerated erosion refers to levels of erosion that exceed normal rates of natural erosion, usually as a result of human activities. Accelerated erosion has now become the dominant type of erosion over much of South Africa (Snyman 1999). However, evidence of massive Holocene mud deposits off Port St. Johns indicate that high loads of muddy material have occurred for a very long time. More than 30 years ago (1974 aerial photographs), mud/silt banks were already visible downstream of the Pondoland Bridge (i.e. in the lower reaches, Figure 5.2).

From the account given by Skead in 1864 (Section 6.4.1), it may appear that the estuary was somewhat shallower during the CSIR survey in 1986 (Taljaard et al, 1997; Section 6.1), and as it appeared during the site inspection of 10-12 May 2005. However, at any given time, the bathymetry of the estuary is highly dependent on the preceding flow regime and the nature of previous floods. It is not known what the conditions were preceding the soundings conducted by Skead. In any case, the mud/silt/sand banks and channels are highly dynamic and simple observations are very subjective and potentially misleading. All the available information indicates that sediment loads in the Mzimvubu are naturally high and have been so for a long time. There is no hard evidence to prove or disprove that the estuary is silting up in the long-term, but if it is indeed doing so, the nett rate of overall sediment build-up is likely to be quite low.

All the available information indicates that sediment loads in the Mzimvubu are naturally high and that very large volumes of fine sediment are deposited in the mouth and nearshore areas. However, it appears that this sediment is mostly muddy, with some silt and fine sand, but relatively little medium to coarse sand (of which material KZN beaches normally consist).

5.4 Peak Discharges and Flood Levels

As an unregulated river, the Mzimvubu is subject to floods from time to time, driven by rainfall in the catchment. However, these have never been severe, and there is no discernable trend in flooding. Floods within the Mzimvubu catchment between 1848 and 1989 never reached the one in 50 year level. By definition, a one in 50 year level flood is a flood which is statistically expected to happen once in 50 years, based on the known variation in flow levels in the river. Van Bladeren (1992) has documented information on the floods that have occurred within the Mzimvubu catchment (Table 5.2). These floods are all under the one to 50 years level and have never occurred in the entire catchment at the same time (i.e. one in 50 year floods have occurred in tributaries from time to time, but never in all tributaries at the same time). If this was to happen, then it would probably have a large scouring effect on the estuary.

Table 5.2: Maximum flood peaks measured in the Mzimvubu catchment (Data show return period and the year of the flood, note the lack of occurrence of 1:50 year flood)

River within Mzimvubu catchment	Return Period (yrs)	Date of flood peak
Mooi	10 – 20	20 February 1972
Tsitsa	20 – 50	Pre-1899
Tina	50 – 100	Pre-1899
Kinira	20 – 50	21 March 1976

River within Mzimvubu catchment	Return Period (yrs)	Date of flood peak
Mzimvubu	20 – 50	29 September 1987
Mzimvubu	20– 50	Pre – 1897
Umzintlava	20 – 50	29 September 1987
Umzintlava	20- 50	Pre 1944
Umzintlava	20 – 50	18 May 1959
Mzimvubu	20 - 50	29 September 1987

5.5 Water levels

Water levels have been recorded at the Pondoland Bridge by the DWA since November 2003 (T3T018). An extract of the water levels recorded here in 2013 is shown in Figure 5.4. The raised water levels resulting from high river flow events in January 2013 can clearly be seen. While in 1 to 20 January 2013 river inflow was lower and sea tidal influence was dominant. At the bridge, the maximum tidal difference during this period was about 1.5 m, while the maximum tidal difference. Thus, it would appear that the mouth constriction at the time was sufficient to dampen the tide in the estuary by about 20%. After 20 January the water level at the bridge was clearly affected by both the tide and relatively strong river inflow.

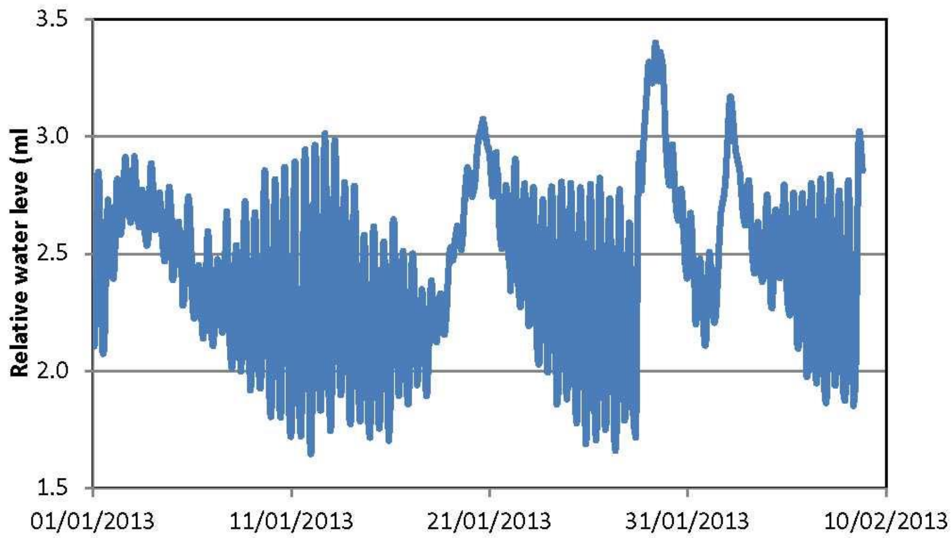


Figure 5.4: Relative water level variation in the Mzimvubu Estuary recorded at the Pondoland bridge (T3T018)

6. WATER QUALITY CHARACTERISTICS

The water quality assessment considered the following variables:

- System variables - salinity, temperature, pH, dissolved oxygen and suspended solids/turbidity (and secchi depth);
- Dissolved inorganic nutrients - dissolved inorganic nitrogen, dissolved inorganic phosphate and dissolved reactive silicate
- Organic matter as represented by Total phosphorus; Kjeldahl nitrogen and Particulate organic carbon (limited data only).

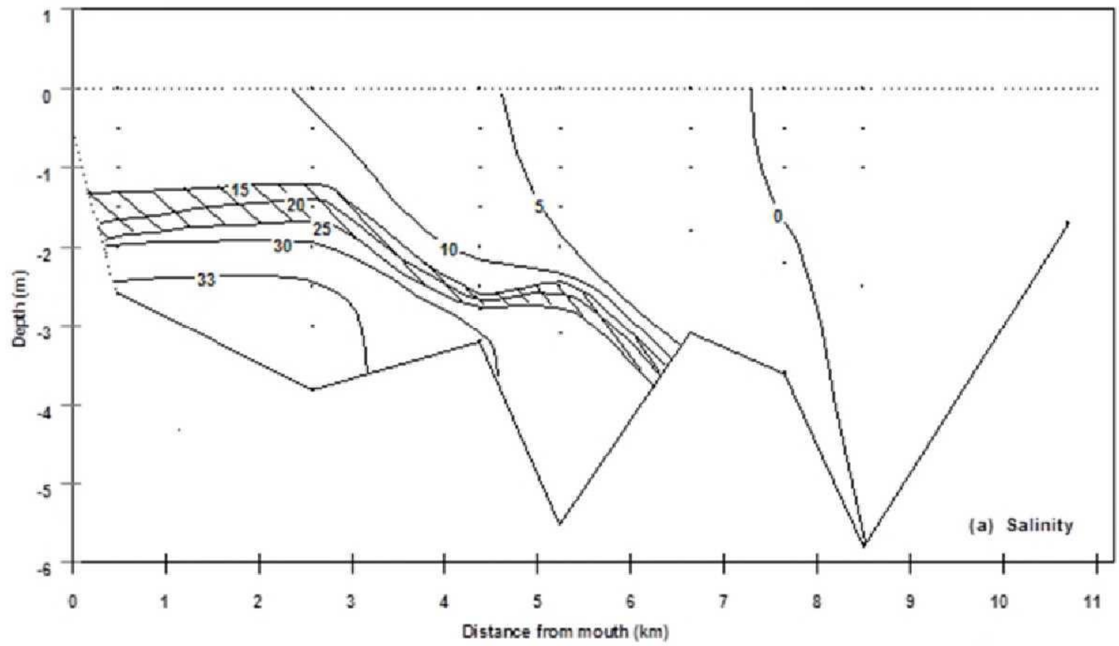
No data were collected for toxic substances, but these were not considered a serious issue in this catchment. Available literature was assessed in this instance.

Sampling station for the 2012/13 surveys are indicated in Figure 6.1. During these surveys the estuary was completely fresh further upstream.

Figure 6.1: Location of sampling station during August 2012 (top) and January 2013 (bottom) surveys

6.1 Salinity

In August 1996, during the ebb tide, riverine influence in the estuary was particularly strong with water of salinity less than 5 ppt extending to within 5 km of the mouth at the surface and salinities less than 15 ppt present in the surface waters of the mouth (Figure 6.2a).



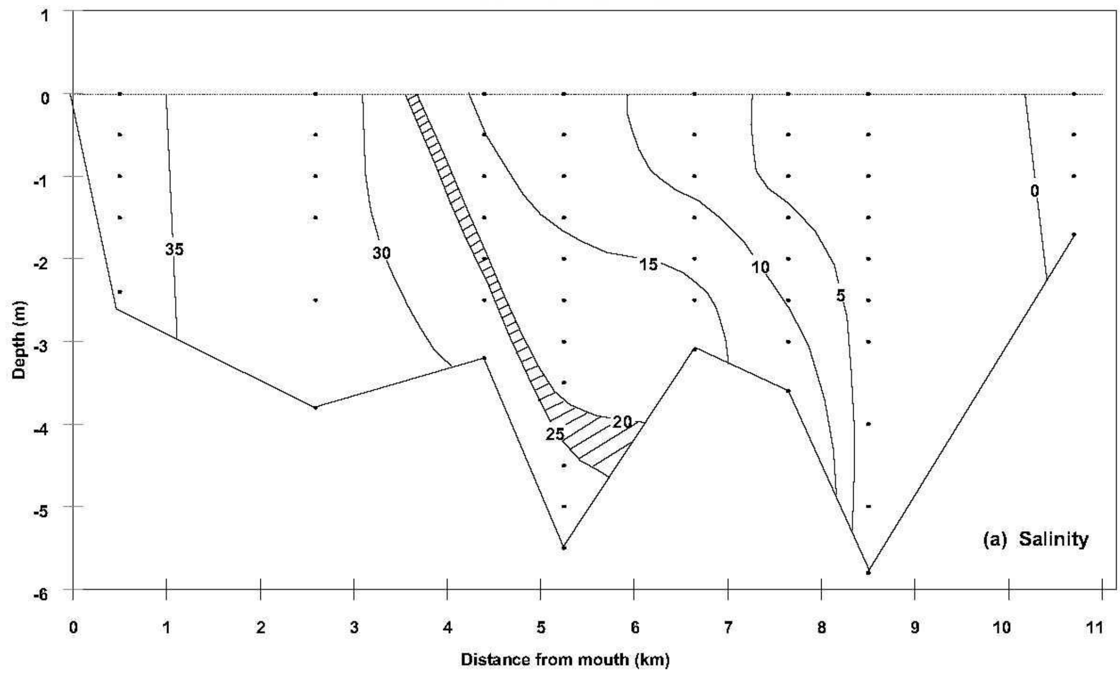


Figure 6.2 **Longitudinal salinity profiles in the Mzimvubu River Estuary during the ebb and flood tide of 14 August 1996 (shaded area indicate intense salinity gradients)**

No measured river inflow data were available for the Mzimvubu Estuary near the head of the estuary. Flows into the estuary were therefore estimated by aggregating flows for upstream gauging stations (T3H007, T3H006 and T3H005) as a rough estimate of inflows during this period. The average inflow for the period 15 July 1996 to 14 August 1996 was ~ 8m^3/s, ranging between 15 and 6 m^3/s.

During August 1996 saline water was not expelled from the system, but was trapped in deeper portions of the lower and middle estuary (up to 6 km from the mouth). An area of intense salinity gradients (15 ppt to 25 ppt over about 0,5 m marked the interface between the saline bottom water and the ebbing surface water. The intrusion of seawater on the flood tide, resulted in a strong longitudinal salinity gradient between 4 and 6 km upstream of the mouth and reduced vertical stratification in comparison with conditions during the ebb tide. The more mixed nature of the water column is ascribed to more intense tidally-induced mixing on the spring flood tide. At the time, the estuary exhibited both strong tidal and riverine influences.

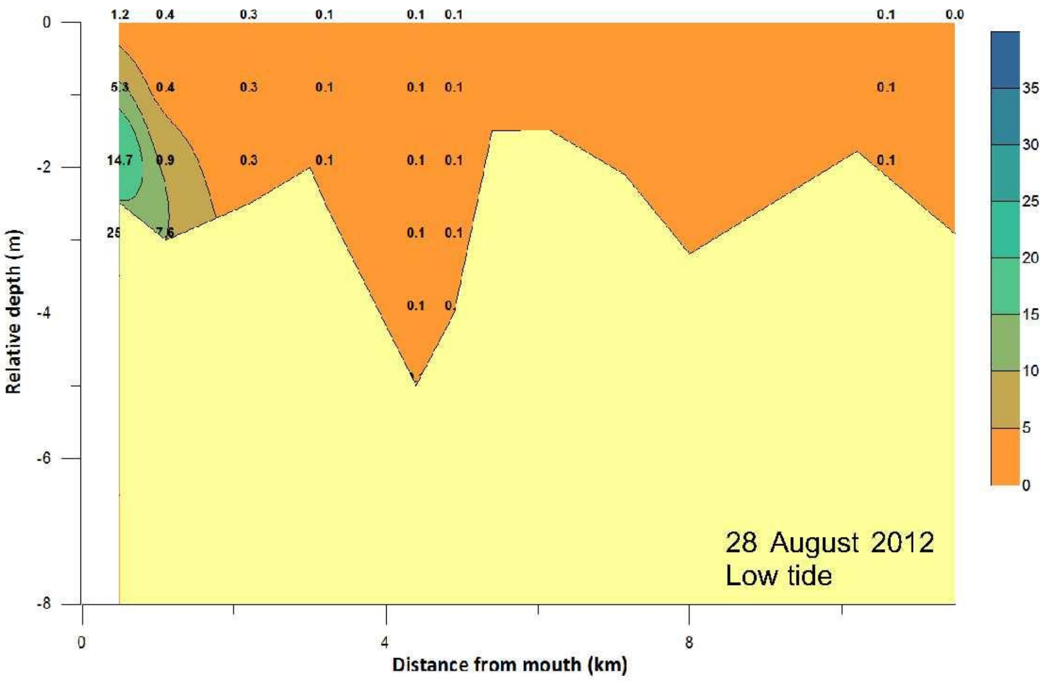


Figure 6.3a: Longitudinal salinity profiles in the Mzimvubu River Estuary - August 2012

On the low tide of 28 August 2012 traces of saline waters were only observed 2.0 – 3.0 km upstream from the mouth (Figure 6.3a). Saline water of ~ 25 was just recorded in the mouth at ~ 0.5 km at depth of 1.5 m.

While, during the 29 August 2012 survey saline waters were observed 4.5 km upstream from the mouth on the high tide (Figure 6.3b). Marine water was recorded in the lower 1.5 km at depths below 2.0 m. During this survey strong stratification were observed. River inflows were estimated from the aggregation of upstream gauging stations (T3H019, T3H006 and T3H005) for this period. The average inflow during 30 July 2012 and 29 August 2012 was between 20 – 30 m^3/s, ranging between 7 and 582 m^3/s. Flows closer to the measuring period were similar to the average flow conditions.

No saline water penetrated the estuary on the low tide of 29 January 2013 (Figure 6.4a). During the 30 January 2013 survey saline waters were only observed in the lower 3 km of the system on the high tide(Figure 6.4b). Marine water (> 30) was only recorded in the lower 1.0 km at depths below 2.0 m. During this survey strong stratification occurred, with the surface layer (~ 1.0 m deep) nearly fresh. River inflows were again estimated from the aggregation for this period from upstream gauging stations (T3H019, T3H006 and T3H005).

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MZIMVUBU WATER PROJECT

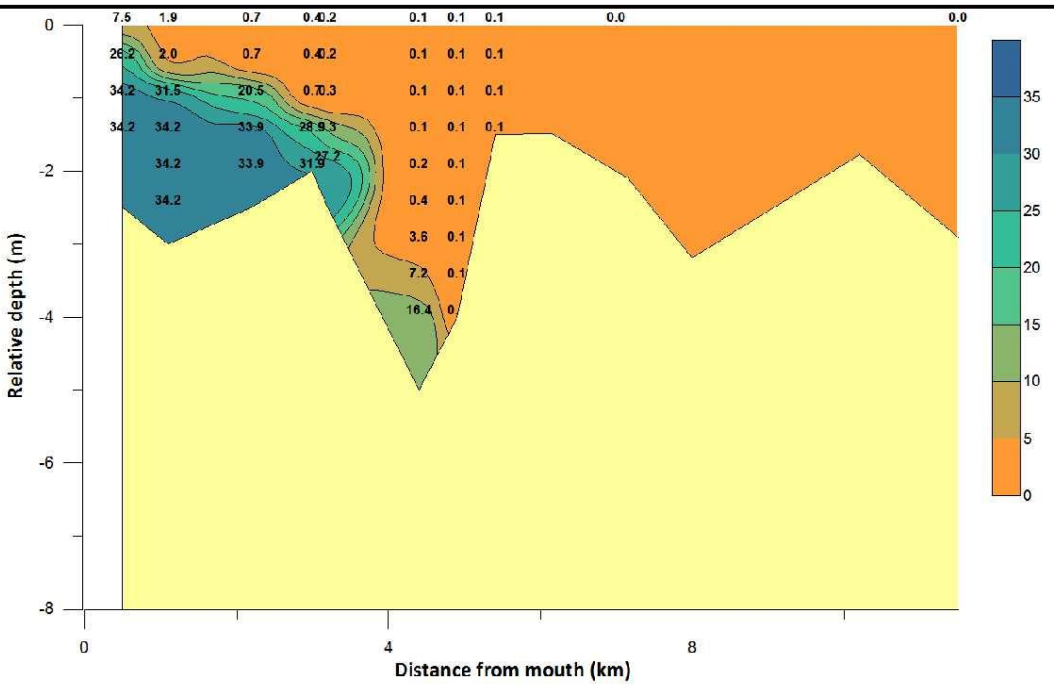

Figure 6.3b: Longitudinal salinity profiles in the Mzimvubu River Estuary - August 2012

The average inflow during 30 July 2012 and 29 August 2012 was between 20 – 30 m^3/s, ranging between 7 and 582 m^3/s. Flows closer to the measuring period were similar to the average flow conditions. River inflows were estimated from the aggregation inflows from upstream gauging stations (T3H019, T3H006 and T3H005) for this period. The average inflow during 31 December 2012 and 30 January 2013 was ~110 m^3/s, ranging between 43 and 323.69 m^3/s.

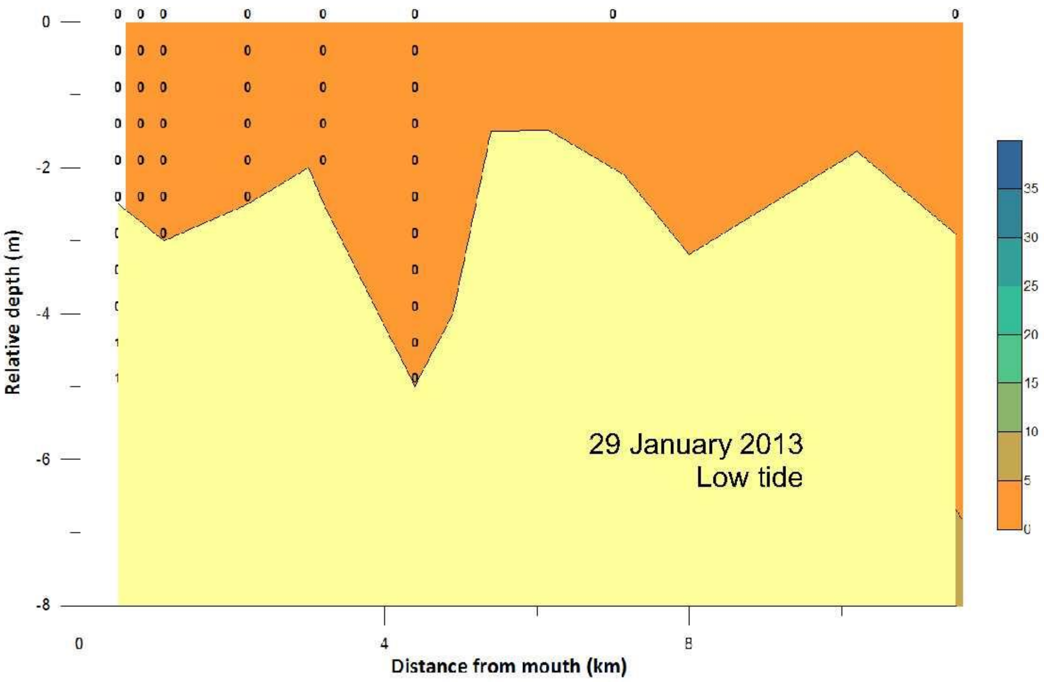

Figure 6.4a: Longitudinal salinity profiles in the Mzimvubu River Estuary - January 2013

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MZIMVUBU WATER PROJECT

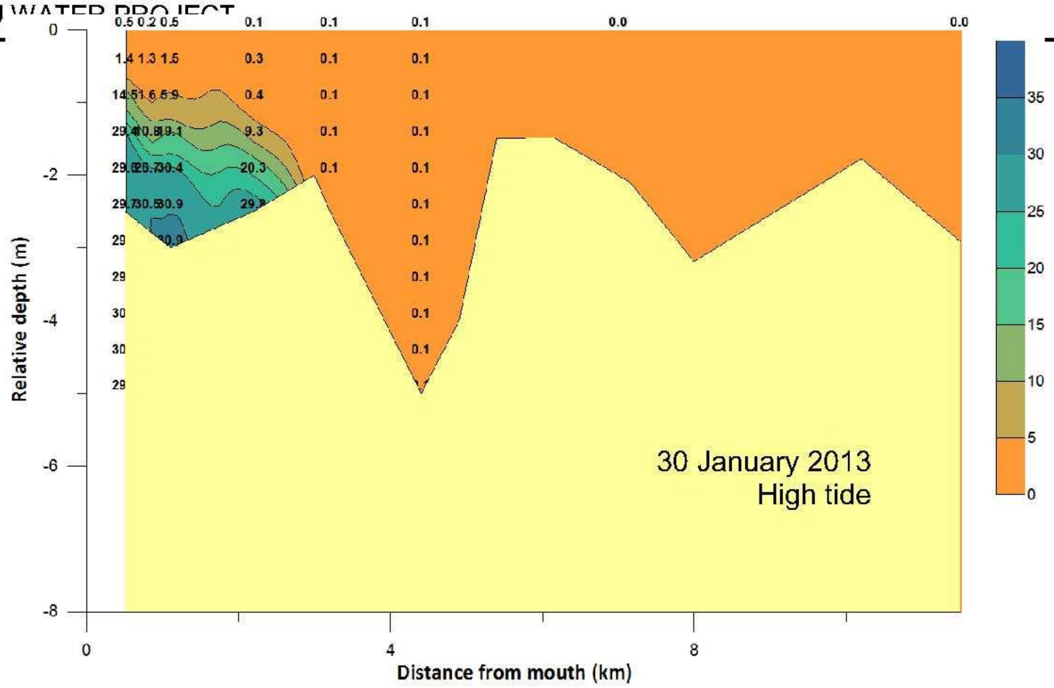

Figure 6.4b: Longitudinal salinity profiles in the Mzimvubu River Estuary - January 2013

6.2 Temperature

Available data on temperatures in the Mzimvubu Estuary (Figure 6.5) show a strong seasonal signal with summer throughout the estuary around 24°C (similar to observations by Day [1981] in January 1950) and no marked trends along the salinity gradient. During winter (August sampling), temperatures ranged between 14- 21°C, with a tendency for the fresher waters to be slightly cooler than the more saline waters near the mouth. Temperature in the estuary, therefore, is largely a function of the season.

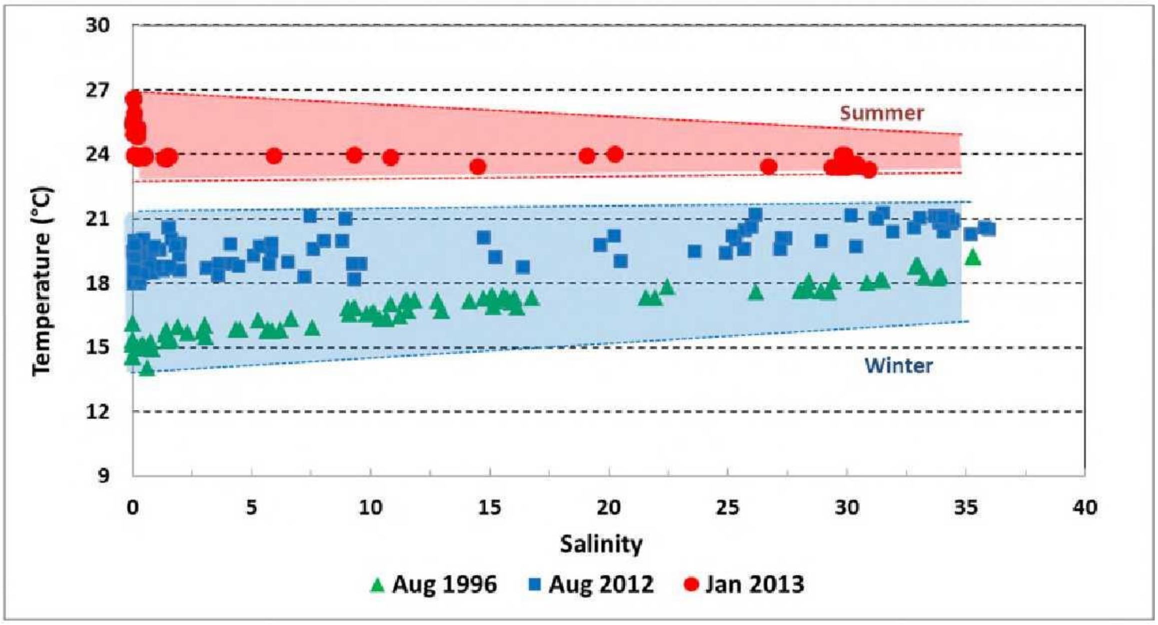

Figure 6.5: Relationship between salinity and temperature measured in the Mzimvubu Estuary during August 1996, August 2012 and January 2013

6.3 pH

Only limited data was available on pH in river inflow (31 points from Mar 2009 to Oct 2012 – DWA river water quality sampling point T36191141 on the Mzimvubu River). No marked trends were apparent with pH averaging 7.8. Measurements collected in the estuary during August 2012 and January 2013, also showed a narrow range of pH variability, ranging between 8.5 and 7.5 and no marked trends along the salinity gradient or between surveys. Therefore, average pH in all zones and during all states is estimated at 8.

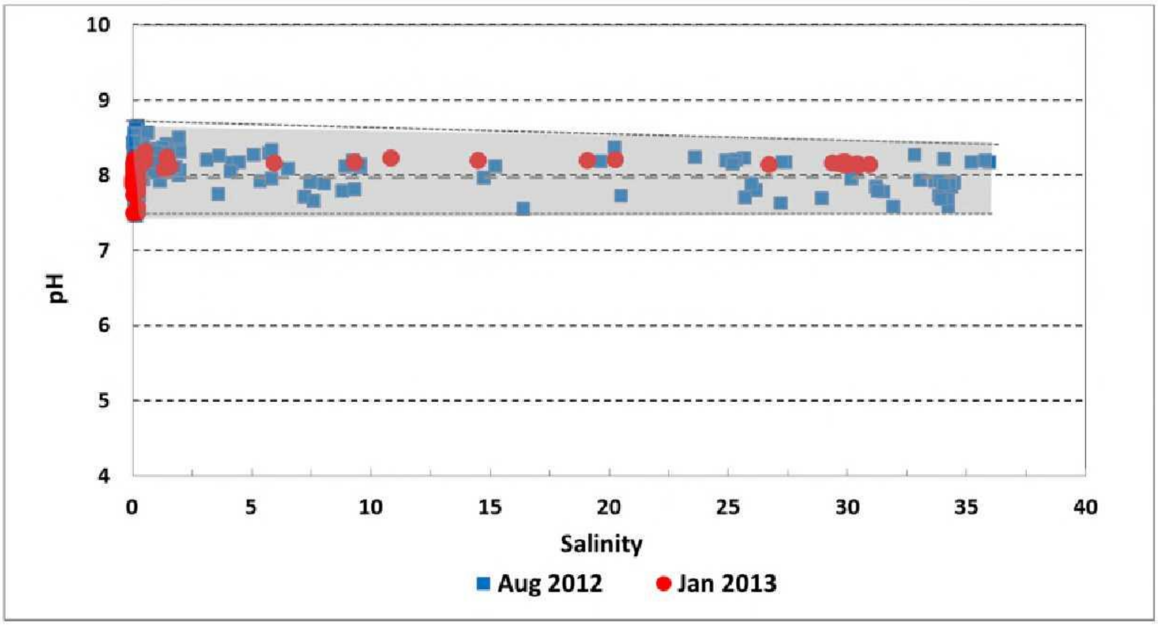

Figure 6.6: Relationship between salinity and pH measured in the Mzimvubu Estuary during August 2012 and January 2013

6.4 Dissolved Oxygen

Based on available data (Figure 6.7) the Mzimvubu Estuary remains well-oxygenated (concentrations >6 mg/ℓ).

Dissolved oxygen concentrations are dependent on the prevailing salinity and temperature regimes. Under saturation or near-saturated, dissolved oxygen concentrations are higher in fresher and/or colder waters compared with saline and/or warmer waters. This distinct relationship is clearly reflected in the DO data compared with salinity measurements from the Mzimvubu Estuary - DO decreases with increase in salinity (saturations levels were greater than 90%).

Well-oxygenated conditions are expected to occur in the estuary in all zones during all states due to either strong river inflow and/or tidal flushing. State 1 may be an exception - lower oxygen levels can develop in the deeper areas of Middle and Upper Zones when residence times of water are expected to be longer (i.e. weaker river flushing of upper reaches with strong tidal flushing limited to Lower Zone only).

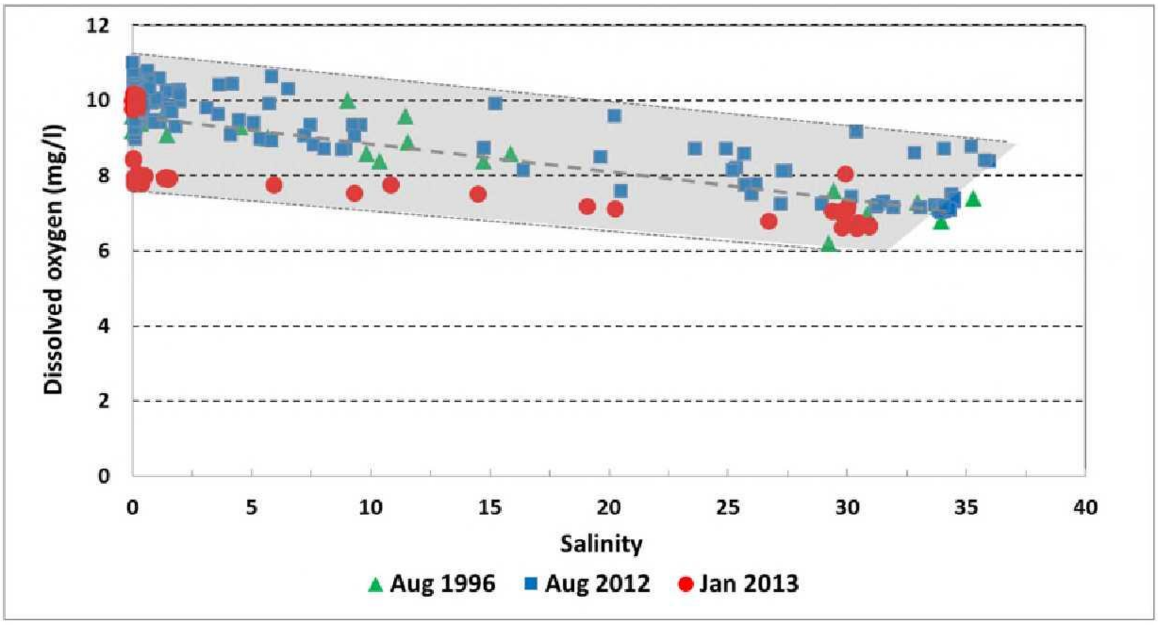

Figure 6.7: Relationship between salinity and dissolved oxygen measured in the Mzimvubu Estuary during August 1996, August 2012 and January 2013

6.5 Suspended solids (Turbidity/Transparency)

The Mzimvubu drains extensive areas of steep and undulating topography, in which the preferential sediment source areas consist of easily eroded, fine-grained shales and mudstones. In its upper reaches the Mzimvubu catchment drains the sedimentary sequence of the Drakensberg Group, which comprises the largely argillaceous sequence known as the Molteno Red Beds and the Cave Sandstones. The latter is very fine-grained sandstone with intercalated siltstone and as a result runoff from this catchment naturally comprised fine to medium sediments (Hay, 1984). High turbidity levels can therefore be expected in the estuary, particularly during periods of high river inflow, even under the Reference Condition. The extent to which anthropogenic activities in the catchment may have increased the sediment load (and thus turbidity levels) in river inflow is not certain and needs further investigation.

Tidal water level variations recorded at the Pondoland Bridge indicate that tidal flows in the estuary are not yet substantially constricted. The winter low flow period when sea tidal flows are more dominant (usually from about June to September), is the main period when “clean” marine water is likely to be found in most of the estuary (and angling for marine fish species within the estuary is likely to be best). Turbid water in the estuary for prolonged periods, especially during the summer is therefore natural, and cannot practically be changed even if so desired.

From the above it is evident that, while data are equivocal as to whether erosion in the Mzimvubu catchment, and sedimentation in the estuary are accelerating beyond natural levels or not, there is consensus that the system in naturally turbid and muddy. Perceptions that a clear estuary at the Mzimvubu river mouth in the summer months is reflective of its pristine condition are, in all likelihood, false. Some changes are probably linked to increased development pressures; anthropogenic activities in the catchment may have increased the sediment load (and thus turbidity levels) in river inflow, but there are no conclusive data and this needs further investigation.

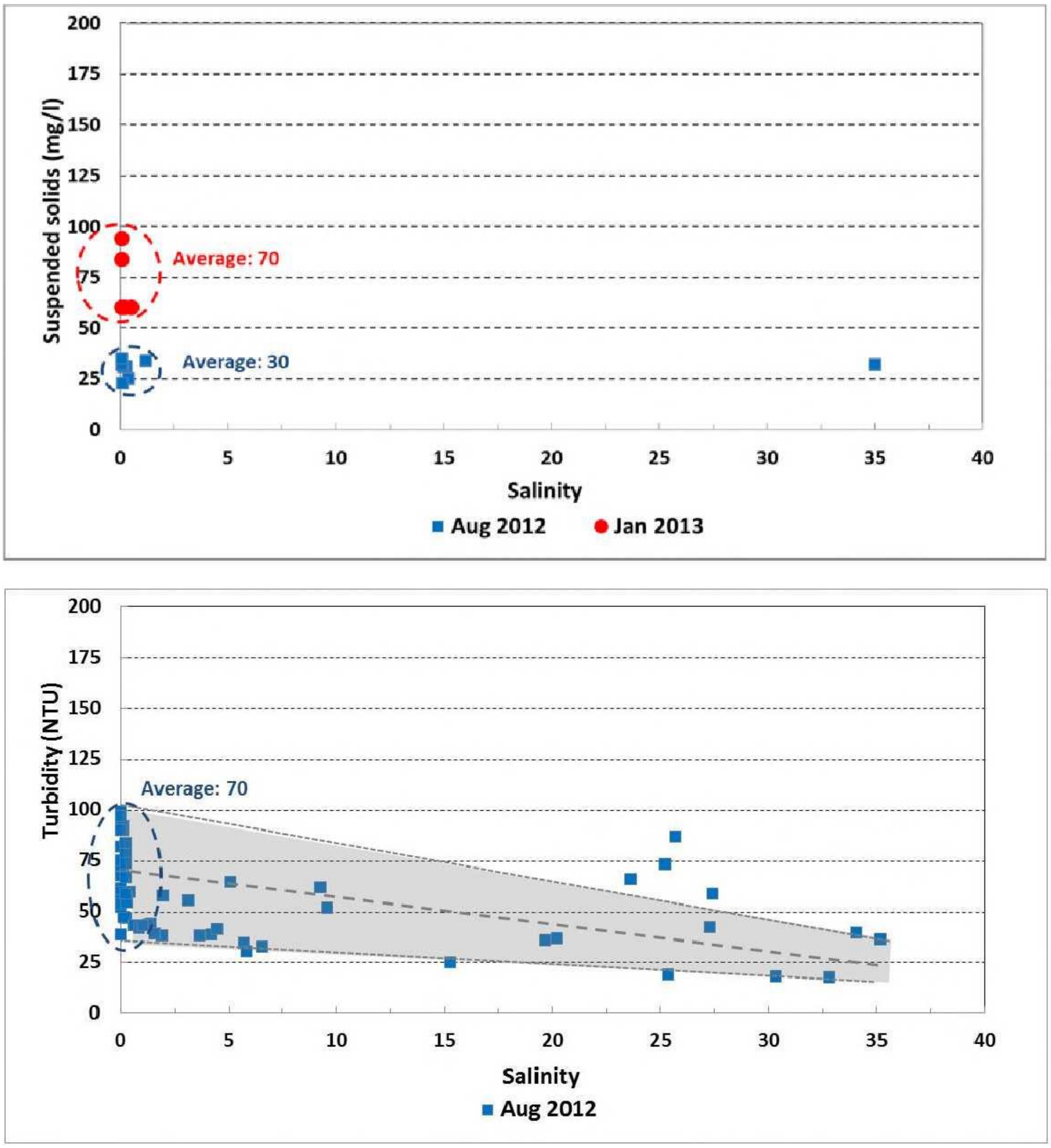

Figure 6.8: **Relationship between salinity and total suspended solid concentrations (top) and turbidity (bottom) measured in the Mzimvubu Estuary during August 2012 and January 2013**

During August 2012 and January 2013, limited data for total suspended solid (TSS) were collected in the Mzimvubu Estuary – only surface waters (Figure 6.8). Estimated average river inflows were significantly lower during August 2012 (20-30 m^3/s) compared with January 2013 (110 m^3/s). Limited data on TSS show average TSS concentrations in river water (salinity = 0) to be lower in August 2012 (30 mg/ℓ) than in January 2013 (70 mg/ℓ). For this period, turbidity concentrations were only recorded in August 2012. Trends in turbidity reveals the high turbidity of river inflow (average 70 NTU) and decreases markedly moving towards more saline waters near the mouth (<25 NTU) (Figure 6.8).

Historical data collected by Harrison (unpublished data) during a high flow period measured turbidity levels averaging around 250 NTU. Also, on a site inspection on 10-12 May 2005 the estuary was dominated by river flow and exhibited relatively minimal tidal influence. The river water was discoloured and appeared muddy (Figure 6.9), and could be clearly distinguished from the much dearer marine water near the mouth. (The water in the two small rivers that mouth at Second Beach also appeared to be much clearer (less muddy).

Figure 6.8: Turbid waters of the Mzimvubu Estuary during high river flows (May 2005)

For this assessment is will be assumed that during lower flows, turbidity levels in the estuary would have been 20% less during the Reference Condition compared to the Present State as a result of land-use practices in the lower part of the catchment (dominant source of flows into the estuary during these periods). During higher flows, concentrations would have been 10% less compared with the Present State as a result of land-use practice in the upper catchment (origin of flow entering estuary during those periods).

Based on concurrent Secchi depth and surface water TSS data collected in the Mzimvubu Estuary during August 2012 and January 2013, a strong, inverse linear relationship was evident (Figure 6.10).

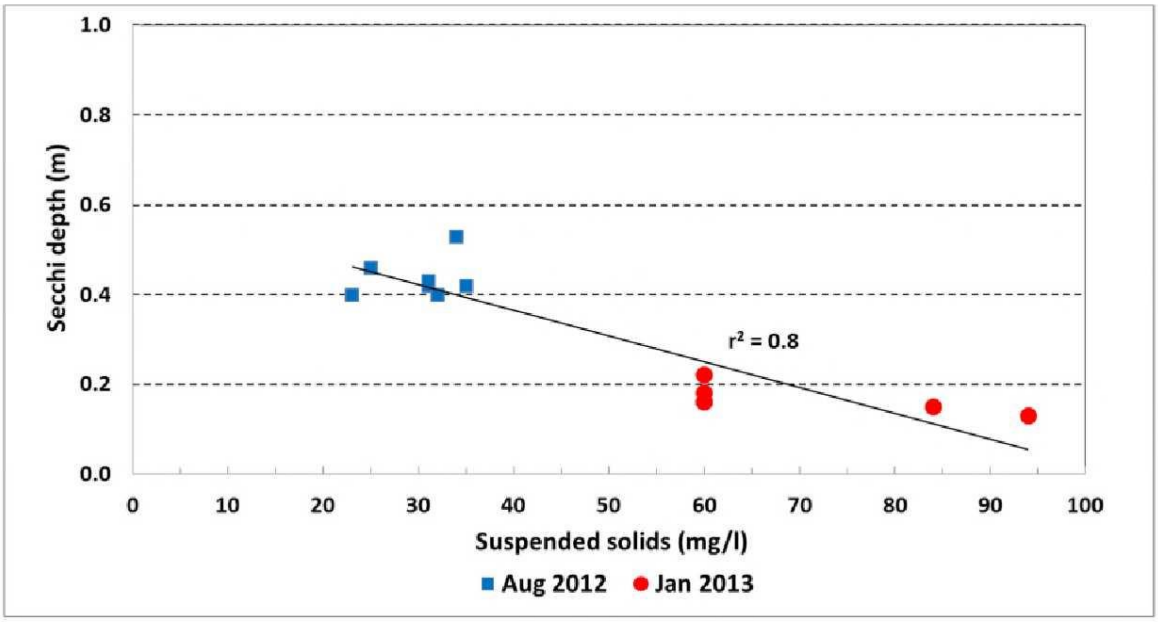

Figure 6.10: Relationship between Secchi depth and surface waters total suspended solid concentrations based on data collected during August 2012 and January 2013

6.6 Dissolved Inorganic Nutrients

Only limited data was available on inorganic nutrient concentrations in river inflow (31 points from Mar 2009 to Oct 2012 – DWA river water quality sampling point T36191141 on the Mzimvubu River) with no marked trends. Average concentrations were as follows:

- DIN = below detection (25 µg/ℓ)[2]
- DIP = below detection (5 µg/ℓ)[3]
- DRS = 7 100 µg/ℓ

Estimated concentration of inorganic nutrient is seawater along this part of the coast is expected to be relative low, e.g. DIN 50 µg/ℓ and DIP 20 µg/ℓ and DRS 100 µg/ℓ (DWAF, 1995).

The inorganic nutrient concentrations in an estuary are largely a function of the concentrations in the source waters, i.e. the river and the sea, as well as any physical (e.g. evaporation), geochemical (e.g. adsorption/desorption and flocculation) and/or biochemical processes (e.g. biological uptake and re-mineralisation) that occur within the estuary. The extent to which these processes affect inorganic nutrient characteristics in the Mzimvubu Estuary is discussed in this section.

An approach that is widely used to assess nutrient cycling and transformation in estuaries is the use of mixing diagrams (or property-salinity plots) (e.g. Ferguson et al., 2004; Eyre, 2000; Eyre & Balls, 1999). The mixing diagram approach consists of a plot of nutrient concentrations against salinity along the estuarine gradient. This provides a convenient method for visualising the net effect of nutrient processes within estuaries whereby deviation from the conservative mixing line is used to interpret results. For example, downward curvature in the mixing diagram implies nutrient uptake, while upward curvature implies nutrient release. Inorganic nutrient relationships measured in the Mzimvubu Estuary is presented in Figure 6.11. To orientate oneself in terms of the spatial distribution of nutrient concentrations along the estuary, the nutrient versus salinity plots should be compared with corresponding longitudinal salinity profiles provided in Chapter 6.1.

DIN relationships during August 1996, August 2012 and January 2013 were all similar, with highest concentrations associated with river inflow (salinity = 0) decreasing with increasing in salinity (Figure 6.11, top). Concentrations in seawater (salinity ~35) were typically <100 µg/ℓ. However, concentrations in river waters (salinity =0) varied among various surveys. Concentrations in river waters were lowest (100 µg/ℓ) during August 2012 when average river flows ranged between 20-30 m^3/s and highest (250 µg/ℓ) in August 1996 when average flows were 8 m^3/s. Mid-concentrations (175 µg/ℓ) were measured during January 2013 when average flows were highest (110 m^3/s).

The resolution of the DIN data sets, however, is not sufficient to distinguish between the DIN relationship among the various states (Table 4.1), other than the general relationship between DIN and salinity. The present state DIN concentrations for the estuary are therefore expected to range within a band, decreasing with increasing salinity (Figure 6.11, top grey area with average represented by grey dashed line). It is expected that DIN concentrations under the Reference Condition would have been 50 µg/ℓ across the salinity range (DWAF, 1995; De Villers & Thiart, 2007).

2 These concentrations are much lower than expected, also lower compared with measurements collected in freshwater in the estuary (see Figure 6.8). It was therefore not used in this assessment

3 These concentrations are much lower than expected, also much lower compared with measurements collected in freshwater in the estuary (see Figure 6.8). It was therefore not used in this assessment

DIP relationships during August 2012 and January 2013 were similar, with highest concentrations typically associated with river waters (salinity = 0) decreasing with increasing in salinity (Figure 6.11, middle). No marked relationship was evident in August 1996 – other than perhaps a slight inverse relationship between salinity and DIP – but all concentrations were low (<20 µg/ℓ). Concentrations in seawater (salinity ~35) were typically <20 µg/ℓ. However, concentrations in river waters (salinity =0) varied among various surveys. Concentrations in river waters were lowest (~0 µg/ℓ) during August 1996 when average river flows was 8 m^3/s and highest (60 µg/ℓ) in August 2012 when average flows were 20-30 m^3/s. Mid-concentrations (20 µg/ℓ) were measured during January 2013 when average flows were highest (110 m^3/s). The resolution of the DIP data sets, however, is not sufficient to distinguish between the DIP relationship among the various states (Table 4.1), other than the general relationship between DIP and salinity. The present state DIP concentrations for the estuary are therefore expected to range within a band, decreasing with increasing salinity (Figure 6.11, middle grey area with average represented by grey dashed line). It is expected that DIP concentrations under the Reference Condition would have been 10 µg/ℓ across the salinity range (DWAF, 1995; De Villers and Thiart, 2007).

The relationship between dissolved reactive silicate (DRS) and salinity reflected the naturally high concentrations of river waters (salinity = 0) compared with seawater (salinity = 35). Concentrations in seawater (salinity ~35) were typically <100 µg/ℓ. However, concentrations in river waters (salinity =0) varied among various surveys. Concentrations in river waters were lowest (5000 µg/ℓ) during August 1996 when average river flows was lowest (8 m^3/s) and highest (8000 µg/ℓ) in January 2013 when average flows were highest (110 m^3/s). Mid-concentrations (6000 µg/ℓ) were measured during August 2012 when average flows ranged between 20-30m^3/s. The resolution of the DSR data sets, however, is not sufficient to distinguish between the DRS relationship among the various states (Table 4.1), other than the general relationship between DIP and salinity. The present state DIP concentrations for the estuary are therefore expected to range within a band, decreasing with increasing salinity (Figure 6.11, bottom grey area with average represented by grey dashed line). It is expected that DRS concentrations under the Reference Condition would have been similar to Present.

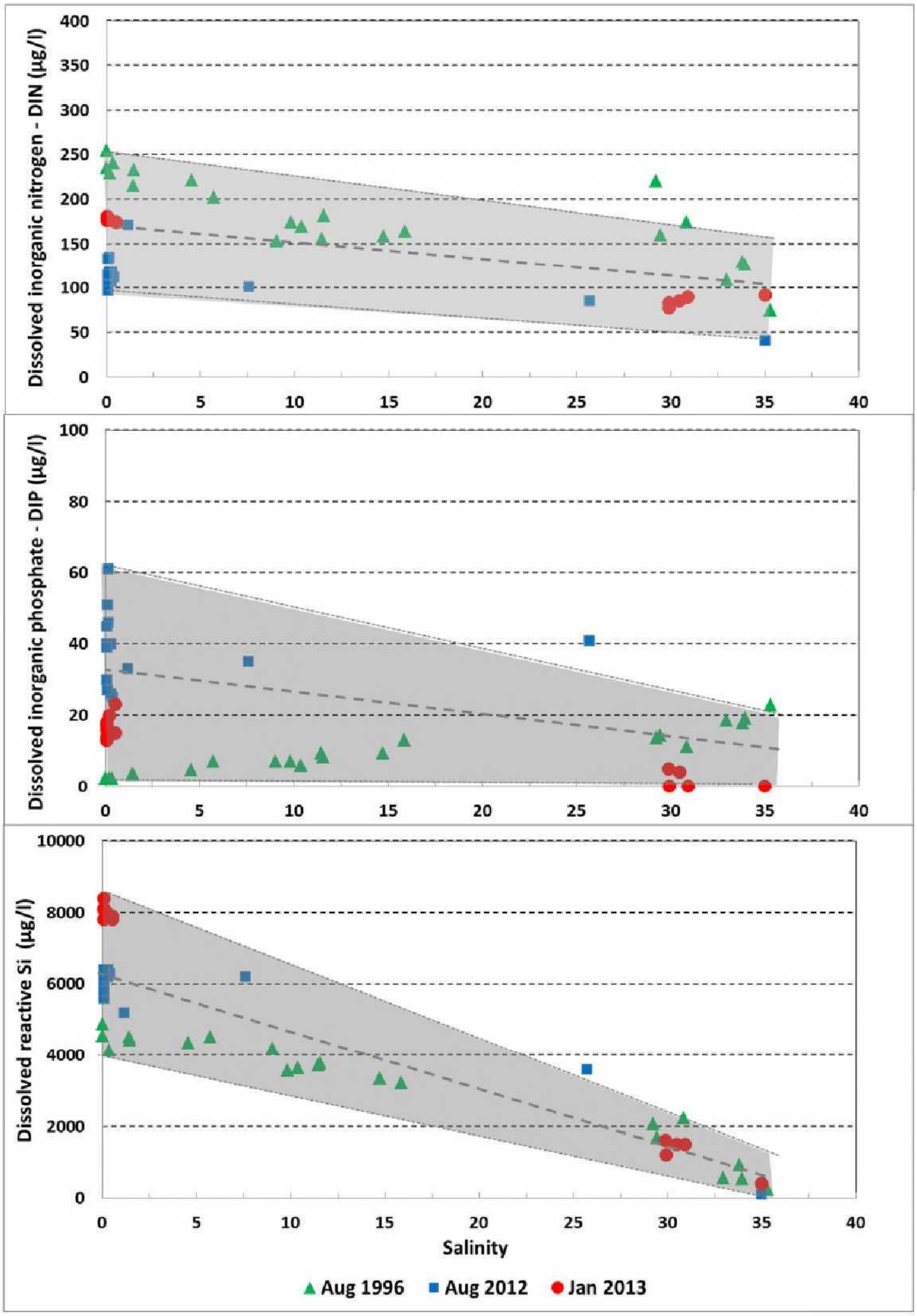

Figure 6.11: Relationship between inorganic nutrients (DIN, DIP and DRS) measured in the Mzimvubu Estuary during August 1996, August 2012 and January 2013

6.7 Organic matter

Limited data on organic nutrient concentrations in the Mzimvubu Estuary were collected during the January 2013 survey. There were no marked trends in the results and Total organic carbon average 3 mg/ℓ (Table 6.2). Kjeldahl nitrogen was below the detection limit of 1 mg/ℓ. Total P was also below the detection limit of 0.5 mg/ℓ.

Table 6.2: Average concentrations of TOC, Kjeldahl Nitrogen and TP measured in the Mzimvubu Estuary in January 2013

Parameter	n	Average Concentration
Total organic carbon (mg/ℓ)	13	3
Kjeldahl Nitrogen (NH4-N plus Organic N) (mg/ℓ)	3	<1
Total P (inorganic plus organic P) (mg/ℓ)	13	< 0.02/<0.5

6.8 Toxic Substances

The only available data on toxic substances in the Mzimvubu Estuary is that on metals collected by Songca et al (2013). A comparison between their average results and quality guidelines recommended for the Western Indian Ocean (UNEP/Nairobi Convention Secretariat and CSIR, 2009) is presented in Table 6.3.

Table 6.3: Average metal concentrations measured in the Mzimvubu Estuary during Janaury to Marhc 2013 (Songca et al, 2013), as well as recommended quality guidelines for the protection of marine aquatic life

	Mean in Water (μg/ℓ)	Mean in Sediment (mg/kg)	WIO Guidelines	
			Water	Sediment
Cd	1.2	7.2	5.5	0.68
Ni	7.8	9.7	70	15.9
Pb	25	669	4.4	30.2
Zn	23	61.7	15	124

Results suggest that lead concentrations in the system are a concern – as concluded by the authors. Most other metals were within recommended concentrations except Cd that were also above recommended concentrations in sediments, but not as severe as lead. The other attributed the lead contamination from urban activities along the banks of the estuary.

Table 6.2: Summary of hydrodynamic and water quality characteristics for various abiotic states in the Mzimvubu Estuary (differences in state between reference condition and present/future scenarios – due to anthropogenic influences other than flow - are indicated)

PARAMETER	STATE 1: Significant saline penetration	STATE 2: Intermediate saline penetration	STATE 3: Limited saline penetration	STATE 4: Freshwater dominated
Flow range (m³/s)	1-3	3-10	10-30	>30
Mouth condition	Open, but constricted	Open	Open	Wide open
Water level	None	None	None	Extensive during floods
Tidal range	<1.0 m	1.5 m	1.5 m	2.0 m
Dominant circulation process	Tide	Tide and Fluvial	Fluvial	Fluvial
Retention	2 – 4 weeks	1 – 2 weeks	1 – 5 days	< 1 day
Stratification	Relatively well mix	Strong stratification on middle and lower reaches	Strong stratification on lower reaches	Limited in mouth area
Salinity	30 20 10	25 15 0	20 0 0	5 0 0
Temperature (°C)	Summer 24 24 24 Winter 18 19 19	Summer 24 24 24 Winter 18 18 19	Summer 24 24 24 Winter 18 18 18	Summer 24 24 24 Winter 18 18 18
pH	8 8 8	8 8 8	8 8 8	8 8 8
DO (mgl/l)	9 7 7	9 9 7	9 9 9	9 9 9
Turbidity (NTU)	Reference 30 30 50 Present and Future 40 40 60	Reference 30 40 60 Present and Future 40 50 70	Reference 80 150 150 Present and Future 90 160 160	Reference 230 230 230 Present and Future 250 250 250

PARAMETER	STATE 1: Significant saline penetration	STATE 2: Intermediate saline penetration	STATE 3: Limited saline penetration	STATE 4: Freshwater dominated
DIN (µg/l)	Reference 100, 100, 80 Present and Future 100, 130, 150	Reference 100, 80, 80 Present and Future 120, 140, 180	Reference 80, 80, 80 Present and Future 130, 180, 180	Reference 100, 100, 100 Present and Future 180, 180, 180
DIP (µg/l)	Reference 10, 10, 10 Present and Future 10, 15, 25	Reference 10, 10, 10 Present and Future 15, 20, 30	Reference 10, 10, 10 Present and Future 15, 30, 30	Reference 15, 15, 15 Present and Future 30, 30, 30
DRS (µg/l)	1500, 3000, 4500	2000, 3500, 6000	3000, 6000, 6000	6000, 6000, 6000

NOTE: For the purposes of this assessment the estuary was sub-divided into three zones representing from left to right: Lower, Middle and Upper Zones (see Figure 4.1)

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APPENDIX C

MICROALGAE IN THE MZIMVUBU ESTUARY: PREDICTED RESPONSES TO MANAGED FRESHWATER INPUTS

MICROALGAE IN THE MZIMVUBU ESTUARY: PREDICTED RESPONSES TO MANAGED FRESHWATER INPUTS

Mzimvubu Estuary, January 2013

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July 2013

1. INTRODUCTION

Phytoplankton and the microphytobenthos (MPB), collectively termed microalgae, are primary producers and form the base of the food chain in estuaries. A peak in phytoplankton biomass typically indicates the river-estuary interface zone, a brackish zone in the estuary characterised by high biomass and diversity. As freshwater inflow is reduced the extent of the river-estuary interface zone changes and the flow requirements of the estuary are set based on the acceptable change.

Changes in river flow affect the hydrodynamics, salinity and water quality patterns, ultimately altering the structure and function of the associated estuary. One of the greatest threats to estuaries is eutrophication, defined as "*enrichment of water by nutrients, especially compounds of nitrogen (N) and phosphorus (P), causing an accelerated growth of algae and other forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned*" (Painting *et al*. 2007). Eutrophication is a process supported by the combined effects of elevated nutrients that support algal growth and reduced river flow or increased residence time. The increased residence time in the estuary supports the growth of primary producers, which includes the rapid growth of microalgae. There is generally a strong association between planktonic primary production and algal biomass (Boyer *et al*. 2009).

Phytoplankton biomass, using chlorophyll *a* as an index, is a good indicator of the nutrient status of an estuary. As an example, the Mhlanga Estuary receives large volumes of treated waste water and phytoplankton chlorophyll *a* frequently exceeds 200 $\mu g.l^{-1}$, which is typical of a eutrophic system. Species composition is also a good indicator of the nutrient and hydrodynamic status of an estuary. Dinoflagellates are typically abundant when the estuary is nutrient-rich and stratified. They occur in the middle reaches of an estuary where salinity is >5 ppt whereas cyanophytes (blue-green algae) are common in nutrient-rich water where salinity is <5 ppt. Phytoplankton diversity is largely determined by the water residence time in estuaries (Ferreira *et al*. 2005); i.e. the diversity is a function of the capacity of the algal species to grow faster than they are flushed from the estuary (Figure 1). Based on long-term studies of six Portuguese estuaries (1929-1998), Ferreira *et al*. (2005) showed that an increase in residence time led to an increase in the number of phytoplankton species. In addition, they developed a conceptual model that showed the effects of nutrient concentrations on phytoplankton diversity in relation to changes in flushing time. As nutrient concentrations increase and estuaries become more eutrophic, phytoplankton diversity is likely to decrease.

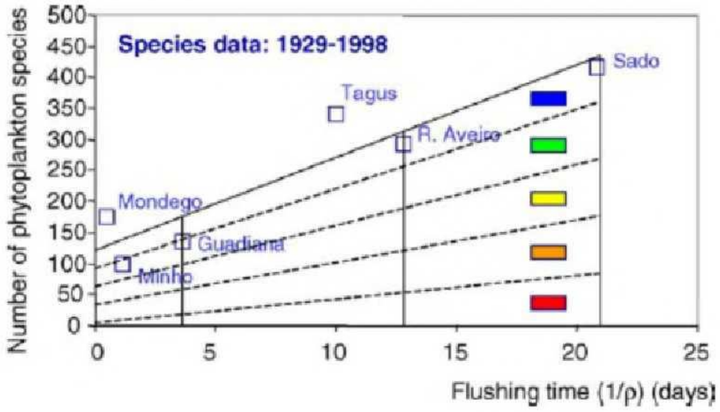

Figure 1. Scaling of phytoplankton species composition into five quality classes (blue: better; red: worse). The divisions shown are conceptual (Ferreira *et al*. 2005).

Benthic diatoms are known to respond to salinity and most references describe diatoms as freshwater, brackish or marine species (Bate *et al*. 2013). In addition, diatoms have proven to be useful indicators of trophic status, particularly in freshwater ecosystem studies (Taylor *et al*. 2007). As such, knowledge of diatom ecology is a vital component of estuarine management it is therefore imperative that they, and phytoplankton, are included in Resource Directed Measures (RDM) studies.

There is no information available on the microalgae in the Mzimvubu Estuary. Historically, it is expected that the high river flow and frequency of floods would have kept the microalgal biomass low; median benthic chlorophyll *a* content <11 $mg.m^{-2}$ (Snow 2007).

2. MATERIALS AND METHODS

2.1 Study site

The Mzimvubu Estuary is a permanently open estuary located on the subtropical east coast of South Africa, near Port St. Johns. The Mzimvubu River has four main tributaries, the Tsitsa, Tina, Kinira and the Mzintlava Rivers that drain a catchment area of approximately 19 853 km^2 (DWA, 2005). The Mzimvubu River basin has a mean annual run-off (MAR) of 2 900 x 10^6 m^3 and is considered to be South Africa's largest undeveloped river. The estuary has been given a relatively high conservation importance rating (36^{th}), placing it within the top 15% of South Africa's estuaries. An interim mean annual base flow provision of 338 x 10^6 m^3 has been allocated for the ecological Reserve of the estuary.

Predominant rock formations in the catchment include mudstone, sandstone and shale of the Karoo Sequence. A consequence of the predominant geological strata and the climate is that the river basin is dominated by clay, clayey loam and sandy loam soils that are prone to erosion. Overgrazing has exacerbated the erosion problems, particularly in areas where there is a high density of villages.

Seven sampling sites were included for phytoplankton measurements in August 2012 (Figure 2), six in January 2013, and six sampling sites for benthic microalgae (both sampling sessions. Phytoplankton was collected from the mouth to the site where there was no evidence of saline intrusion. Benthic microalgae were collected at sites where there was a clear intertidal zone and were accessible by boat, from the mouth to 6.4 km.

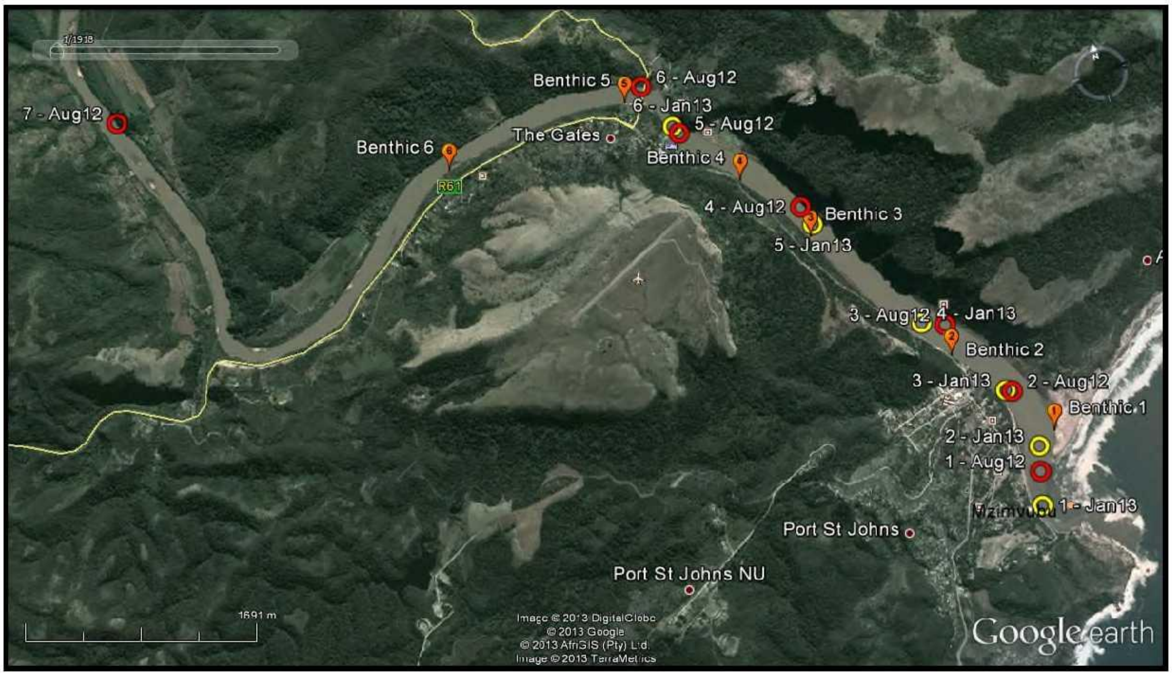

Figure 2. Google Earth image of the Mzimvubu Estuary showing sampling sites for phytoplankton (red and yellow rings) and benthic microalgae (orange markers).

2.2 Phytoplankton chlorophyll a

Water samples (250 ml) were gravity filtered through Whatman GF/C filters then stored in the dark of a cooler box until they could be frozen. The chlorophyll *a* was extracted by placing the frozen filters into 10 ml of 95% ethanol (Merck 4111). After extraction for 24 hours, spectrophotometric determinations of chlorophyll *a* were performed according to Nusch (1980). Absorbance was measured before and after acidification of extracts with 10% HCl.

2.3 Phytoplankton identification

Water samples for phytoplankton enumeration were collected at the surface, 0.5 m, 1.0 m and then at 1.0 m intervals to the bottom. The water samples were fixed with 1.5 ml of 1% (v/v) glutaraldehyde solution. Glutaraldehyde was preferred to a 10% neutral formalin solution as formalin can cause flagellates to lose their flagella making identification difficult (Lund *et al*. 1958, Boney 1989). Samples were then placed in 60 ml settling chambers and allowed to settle for 24 hrs then counted following the Utermöhl method of cell enumeration as modified by Snow *et al*. (2000). Water samples were turbid so smaller volumes (20 ml or 30 ml) were necessary. Water flow was strong and turbulent in January 2013 so only surface and bottom samples (2 m) were analysed for phytoplankton community structure. Functional and dominant groups were categorised into flagellates, dinoflagellates, chlorophytes (greens), cyanophytes (blue-greens), diatoms and euglenoids. It is important to note that all flagellates were included as phytoplankton in this study. Many flagellates do not contain chloroplasts and are more correctly classified as protozoans.

2.4 Benthic chlorophyll a

Four replicate intertidal benthic samples were collected from premarked locations (20 mm internal diameter circle) at low tide from each site by scraping a known area of surface sediment (<2 mm depth) just above the estuarine water level. Four subtidal samples were collected from each site using a 20 mm internal diameter corer attached to an extension pole and the surface sediment was scraped from the core. Both intertidal and subtidal samples were stored in the dark of a cooler box until they could be frozen. The chlorophyll *a* was extracted by placing 30 ml of 95% ethanol (Merck 4111) onto the samples. After extraction for 24 hours, spectrophotometric determinations of chlorophyll *a* were performed according to Nusch (1980). Absorbance was measured before and after acidification of extracts with 0.1 N HCl.

2.5 Benthic diatom collection and identification

The epipelon was sampled based on the method described by Round (1981) and the details described in Bate et al. (2004). Samples were taken using a length of PVC piping (~15 mm I.D.) that was drawn across the sediment and allowed to fill with a mixture of surface sediment and water. This process was repeated up to five times in different positions in order to get a sample that was representative of the different micro-habitats. The mixture was stored in a plastic sample container (250 ml). In a field laboratory, some of the settled material was placed in a Petri dish and a sheet of lens tissue paper (covering ca. 100% of the sediment surface) was placed on top of the wet sediment. On the same day (ca. 6 hours later) the lens tissue was carefully removed with as little sediment as possible. In this way only living cells that had attached to the lens tissue were sampled. The lens tissue from each sample was placed in glass bottles and transported to the laboratory. There is no time limit at this stage to process the diatoms further. To each glass bottle containing the lens tissues, 2 ml of saturated $KMnO_4$ and 2 ml of 10 M HCl was added. This mixture was heated on a hot plate at ca. 80°C until the solution cleared (~20-40 mins) and became a transparent straw colour. All acid cleaned samples were washed with distilled water using five consecutive spins (2000 rpm for 10 mins). Permanent light microscopy slides were made with 1-2 drops of diatom 'digest', placed onto an acid-washed cover slip (previously stored in ethanol) and allowed to dry in air. Cover slips treated in this manner allow the drop of sample to spread more evenly. Once completely dry, a small amount of Naphrax® mounting medium (Northern Biological

Supplies, U.K.) was dotted onto a glass microscopy slide and the cover slip placed over it. Air trapped under the slide and the Naphrax were dispersed by heating the slide on a hot plate (~60°C). The Naphrax was allowed to dry for 2-3 days

Diatom frustules were examined under a Zeiss Axioplan light microscope with Differential Interference Contract (DIC) optics. Using a television camera (JVC KY-F3), images of the dominant taxa were visualised using the AnalySIS image analysis programme (©1999, Soft Imaging System GmbH). Diatom valves were counted in each sample using 1000x magnification until the obvious dominant was established. At least one of every taxon was made into a digital image. All the images were then printed and used in the counting procedure. This achieves two important aspects, (1) a digital image of each taxon and (2) a count of the total number of taxa. The nomenclature of Archibald (1983), Bate *et al.* (2004), Riznyk (1973) and Taylor *et al.* (2007) were used.

3. RESULTS

3.1 Phytoplankton chlorophyll a

30 August 2012: Average phytoplankton chlorophyll a showed no distinct trend with distance from the estuary mouth, ranging from 3.51 ± 1.41 $\mu g.l^{-1}$ at the mouth and 4.58 ± 1.46 $\mu g.l^{-1}$ 3.2 km upstream (Figure 3). A single sample was measured for chlorophyll a in the shallow (<0.5 m) upper reaches, 10.6 km from the mouth, which had a chlorophyll a content of 10.18 $\mu g.l^{-1}$. Phytoplankton chlorophyll a is usually highest near the surface but this was not the case in the Mzimvubu Estuary where concentrations that are typical of oligotrophic to mesotrophic conditions (<10 $\mu g.l^{-1}$) were measured throughout the water column.

30 January 2013: Chlorophyll a was highest (>7 $\mu g.l^{-1}$) in the surface water at the mouth (0.5 and 0.8 km from mouth) and averaged 4.14 ± 0.34 $\mu g.l^{-1}$ (3.2 km) to 7.79 $\mu g.l^{-1}$ (0.5 km; shallow and well mixed) (Figure 4). There were no discernable trends in chlorophyll a with distance from the mouth and with depth, excluding the elevated biomass at the mouth.

3.2 Phytoplankton community structure

30 August 2012: The flagellates and diatoms increased in cell density with distance from the estuary mouth suggesting the river was the primary source of these phytoplankton groups (Figure 3). Flagellates increased from 475 ± 243 $cells.ml^{-1}$ (1.1 km) to a maximum of 3424 ± 216 $cells.ml^{-1}$ (4.9 km), and diatoms from 4893 ± 683 $cells.ml^{-1}$ (0.5 km) to 14591 ± 1436 $cells.ml^{-1}$ (4.9 km). Dinoflagellates were present, but in low density, at sites in the lower and middle reaches (up to 629 ± 481 $cells.ml^{-1}$ at 1.1 km). Chlorophytes were present throughout the estuary with highest densities in the middle and upper reaches (up to 1295 ± 511 $cells.ml^{-1}$ at 4.4 km). Total phytoplankton cells were strongly influenced by the high density of diatoms in the estuary, increasing with distance from the mouth. There was a poor association between phytoplankton community structure and chlorophyll *a*; cell density was >10 000 $cells.ml^{-1}$ from 3.3 km to the head of the estuary, typical of phytoplankton blooms, but chlorophyll *a* was considerably lower than 20 $\mu g.l^{-1}$, the threshold for blooms.

30 January 2013: All phytoplankton groups had low density (<1000 $cells.ml^{-1}$) in the turbid, fast flowing waters. The highest density of flagellates was present in the surface water (606 $cells.ml^{-1}$) 3.2 km from the mouth (Figure 4), with no cells recorded near the mouth. Diatoms were highest at the mouth (711 $cells.ml^{-1}$) and gradually decreased in density with distance upstream. Dinoflagellates were present but at low density (<100 $cells.ml^{-1}$) in the lower 2 km of estuary. There were no chlorophytes recorded. Chlorophyll *a* was highest at the mouth where diatom density was highest but the association between chlorophyll *a* and cell density was poor throughout the rest of the estuary

Mzimvubu Estuary RDM   Estuarine Microalgae

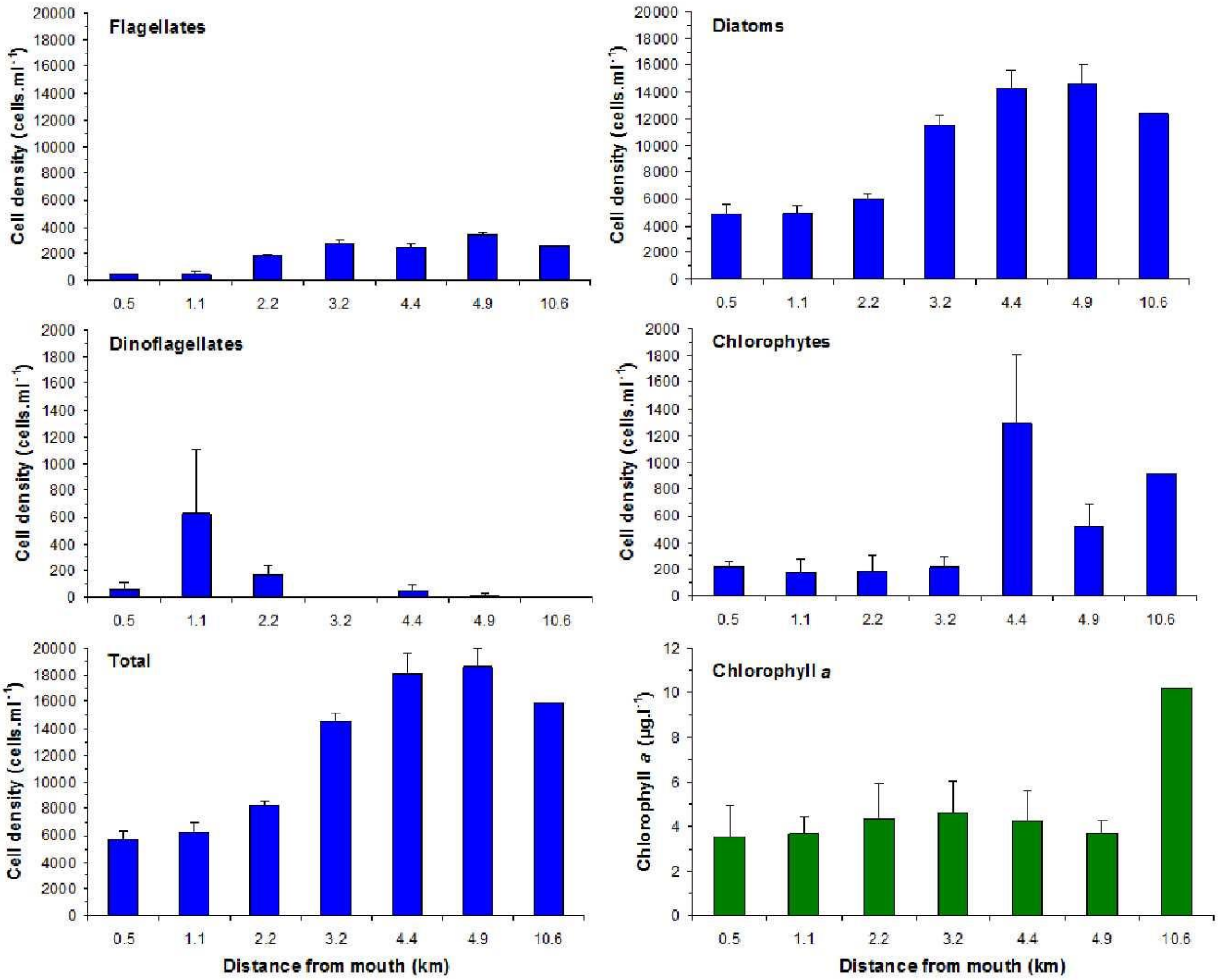

Figure 3. Average phytoplankton community composition and chlorophyll a along the length of the Mzimvubu Estuary, 30 August 2012.

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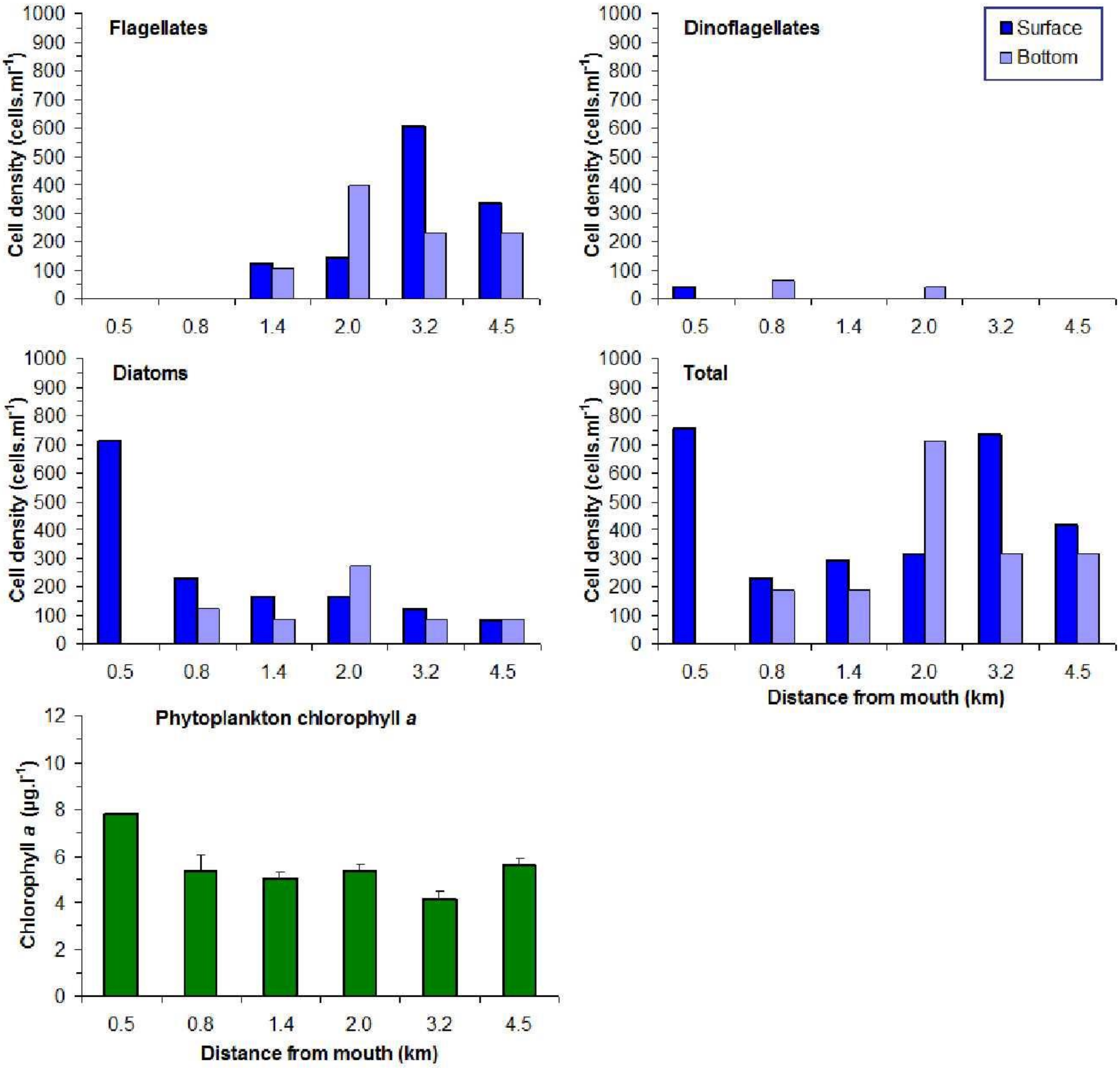

Figure 4. Surface and bottom phytoplankton community composition and average chlorophyll a along the length of the Mzimvubu Estuary, 30 January 2013.

3.3 Benthic chlorophyll a

30 August 2012: Average benthic chlorophyll *a* in the intertidal zone ranged from 1.75 ± 0.58 mg.m^{-2} (0.7 km) to 13.43 ± 0.58 mg.m^{-2} (1.7 km) (Figure 5), and from 1.17 ± 0 mg.m^{-2} (0.7 km) to 5.26 ± 1.75 mg.m^{-2} (3.8 km) subtidally. Average benthic chlorophyll *a* content was 6.03 ± 1.41 mg.m^{-2} (intertidal) and 3.50 ± 0.72 mg.m^{-2} (subtidal).

30 January 2013: Average benthic chlorophyll *a* ranged from 2.74 ± 0.83 mg.m^{-2} (3.0 km) to 14.21 ± 0.57 mg.m^{-2} (1.7 km) in the intertidal zone (Figure 5), and from 7.41 ± 1.79 mg.m^{-2} (3.0 km) to 16.44 ± 2.56 mg.m^{-2} (1.7 km) in the subtidal zone. Average content was 6.78 ± 0.86 mg.m^{-2} (intertidal) and 10.33 ± 1.00 mg.m^{-2} (subtidal).
The median content in the intertidal zone was 4.09 mg.m^{-2} (August 2012) and 5.89 mg.m^{-2} (January 2013), which is regarded as low (<11 mg.m^{-2}) based on the classification scheme of Snow (2007).

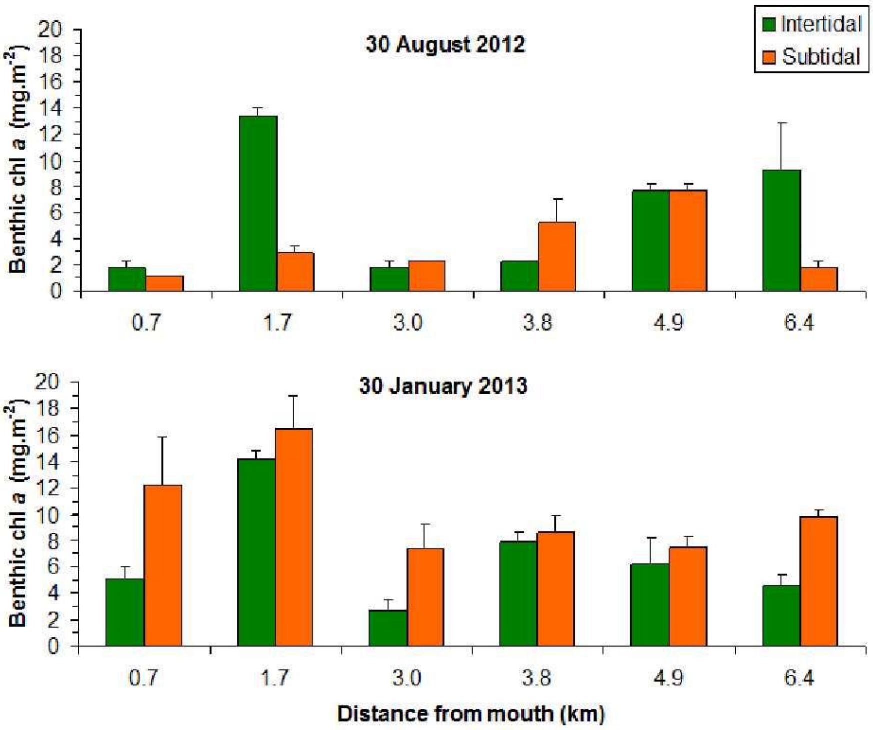

Figure 5. Intertidal and subtidal benthic chlorophyll a along the longitudinal axis of the Mzimvubu Estuary, 30 August 2012 and 30 January 2013.

3.4 Benthic diatom community structure

30 August 2012: The benthic diatoms in the Mzimvubu Estuary were dominated (>10% relative abundance at a particular site) by *Navicula gregaria, Nitzschia palea, Encyonopsis minuta* and *Fragilaria fasciculata*. All of these species are cosmopolitan, found in water with elevated electrolyte content and have a broad ecological range; i.e. are found in oligotrophic to eutrophic environments making them poor indicators of ecological health.

30 January 2013: The dominant diatoms included Navicula cryptocephala, Navicula gregaria, Nitzschia palea, Cocconeis placentula, Denticula kuetzingii, Gyrosigma scalproides, Navicula vandamii, Achnanthes minutissima, Tryblionella calida, Navicula erifuga, Navicula rostellata and Cymbella kappii. Almost all of the species are found in electrolyte-rich environments (excl. A. minutissima that favours clean, fresh water). Cocconeis placentula is typically found in meso- to eutrophic conditions, whereas N. vandamii, T. calida and N. erifuga are found in eutrophic conditions.

The general community composition in the estuary indicates that the estuary was brackish or electrolyte-rich for a period of time leading up to sampling. The species composition is comprised of taxa typically found in oligotrophic environments as well as a number found in eutrophic conditions (Appendix 1). However, unlike the Orange River estuary where the vast majority of the 70-plus taxa are indicators of eutrophic conditions, the diatoms in the Mzimvubu Estuary show a broad range of tolerances. This may be representative of drainage from the large catchment, as well as the variability within the estuary itself; relatively undisturbed in the upper reaches and more urbanised near Port St. Johns.

4. DISCUSSION

River flow was estimated to be 20 – 30 $m^3.s^{-1}$ in August 2012, restricting the intrusion of saline water to 2.0 – 3.0 km upstream of the mouth during the low tide and 4.5 km on the high tide (CSIR, 2013). River flow was considerably higher in January 2013, where the estimated flow of ~110 $m^3.s^{-1}$ prevented saline intrusion during the low tide and restricted the intrusion to 3.0 km on the high tide. Average temperature ranged from 14 to 21°C in August 2012 (riverine water being cooler than more saline water) and ~24°C in January 2013. The pH averages 7.8 in the estuary, with a narrow range of 7.5 to 8.5 throughout and with little difference between flows and seasons. The estuary was well oxygenated (>6 $mg.l^{-1}$), ranging between 6 and 11 $mg.l^{-1}$; [DO] are higher in fresher and/or colder waters compared with saline and/or warmer waters. The estuary is consistently turbid, increasing with river flow and distance from the estuary mouth. Total Suspended Solids (TSS) was ~30 $mg.l^{-1}$ in August 2012 and ~70 $mg.l^{-1}$ in January 2013. There is no clear relationship between river flow and nutrient concentration. However, DIN and DIP are typically low in seawater, <100 $\mu g.l^{-1}$ and <20 $\mu g.l^{-1}$ respectively, and 100 – 250 $\mu g.l^{-1}$ and 0 – 60 $\mu g.l^{-1}$ in the river water respectively. Dissolved reactive silicate ranges from <100 $\mu g.l^{-1}$ in the sea to 5000 – 8000 $\mu g.l^{-1}$ in river water. DIN, DIP and DRS concentrations were likely to have been 50 $\mu g.l^{-1}$, 10 $\mu g.l^{-1}$ and similar to present respectively.

Phytoplankton biomass, using chlorophyll *a* as an index, was slightly higher in January 2013 (5.22 ± 0.24 $\mu g.l^{-1}$) than August 2012 (4.27 ± 0.50 $\mu g.l^{-1}$) despite the higher river flow. The diatoms and flagellates were the most dominant groups in August 2012 (79% and 16% respectively) and January 2013 (50% and 46% respectively). The dinoflagellates and chlorophytes were only present in low cell density; dinoflagellates 2% and 4% in August and January respectively, and chlorophytes 4% in August only.

Average benthic chlorophyll *a* was 6.03 ± 0.50 $mg.m^{-2}$ (intertidal) and 3.50 ± 0.58 $mg.m^{-2}$ (subtidal) in August 2012, and 6.78 ± 0.98 $mg.m^{-2}$ (intertidal) and 10.33 ± 1.78 $mg.m^{-2}$ (subtidal) in January 2013. The highest content was consistently recorded in the sediment nearest to Port St. Johns indicating a possible localised source of nutrients into the estuary.

Microalgal biomass and community composition results indicate that the estuary has slightly elevated productivity, typical of an oligo- to mesotrophic system. Phytoplankton cell density was highest between four and five kilometres in August 2012, which could indicate the presence of a river-estuary interface zone; an area in the estuary where a distinct peak in phytoplankton biomass and community structure occurs. However, river flow was high and cell density was also high in the upper reaches of the estuary suggesting that the river was the primary source of phytoplankton cells. In January 2013, there was no clear evidence of a river-estuary interface zone (REI) and it is likely that the estuary was behaving as a river mouth at the time of sampling with the majority of productivity occurring out to sea.

Responses to reduced flow:

Under reference conditions, the river flow would have been strong and nutrient concentrations lower resulting in the water having a low residence time and the benthos would have been a more unstable environment (frequent deposition and scouring events). This would have prevented the establishment of microalgal communities, limiting chlorophyll *a* in the water column to <5.0 $\mu g.l^{-1}$ and on the benthos to <15 $mg.m^{-2}$. A slight increase in the lower reaches would have been expected during extended periods (>2 weeks) of low flow (states 1 and 2). The phytoplankton community would have been dominated by diatoms with fewer chlorophytes and dinoflagellates.

The slight decrease in river flow (~4%), increase in turbidity (~5%) and increase in nutrient concentrations (DIN 54% and DIP 48%) has seen microalgal biomass increase throughout the estuary. Phytoplankton chlorophyll *a* is ~5 $\mu g.l^{-1}$ during high flows (states 3 and 4) and is likely to increase as residence time and vertical salinity stratification increases (5 to 20 $\mu g.l^{-1}$). As river flow decreases (states 1 and 2) dinoflagellates should become more established in the developing river-estuary interface zone (responding to vertical salinity stratification and nutrients) and the relative abundance of chlorophytes has increased in the river water in response to nutrients.

Benthic chlorophyll *a* has increased slightly in response to slightly lower flows, reduction in floods (~5%), elevated nutrients (particularly in the vicinity of Port St. Johns), and the slight increase in muddiness (~5%), which favours the establishment of epipelic taxa. In addition, ~15% of taxa in the lower estuary at present are typically found in eutrophic conditions. A further reduction in river flow is likely to favour an increase in biomass and shift in community to epipelic taxa.

Table 1. Summary of water quality characteristics, phytoplankton and benthic microalgae in different zones under the four abiotic states in the Mzimvubu Estuary (adapted from CSIR, 2013).

PARAMETER	STATE 1: Significant saline penetration			STATE 2: Intermediate saline penetration			STATE 3: Limited saline penetration			STATE 4: Freshwater dominated		
Salinity	30	20	10	25	15	0	20	0	0	5	0	0
Temperature (°C) – Summer	24	24	24	24	24	24	24	24	24	24	24	24
Temperature (°C) – Winter	18	19	19	18	18	19	18	18	18	18	18	18
pH	8	8	8	8	8	8	8	8	8	8	8	8
DO (mgl/l)	>8	>8	7	>8	>8	>8	>8	>8	9	>8	>8	>8
Turbidity (NTU) – Reference	30	30	50	30	40	60	80	150	150	230	230	230
Turbidity (NTU) – Present and Future	40	40	60	40	50	70	90	160	160	250	250	250
DIN (µg/l) – Reference	100	100	80	100	80	80	80	80	80	100	100	100
DIN (µg/l) – Present and Future	100	130	150	120	140	180	130	180	180	180	180	180
DIP (µg/l) – Reference	10	10	10	10	10	10	10	10	10	15	15	15
DIP (µg/l) – Present and Future	10	15	25	15	20	30	15	30	30	30	30	30
DRS (µg/l)	1500	3000	4500	2000	3500	6000	3000	6000	6000	6000	6000	6000
Phytoplankton chl. *a* ($\mu g.l^{-1}$) – Reference	5	5	2.5	5	5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Phytoplankton chl. *a* ($\mu g.l^{-1}$) – Present and Future	10	20	15	5	15	10	5	5	10	5	5	5
Benthic microalgal chl. *a* ($mg.m^{-2}$) – Reference	15	10	5	15	10	5	5	5	5	5	5	5
Benthic microalgal chl. *a* ($mg.m^{-2}$) – Present and Future	25	15	15	20	10	10	15	5	5	15	5	5

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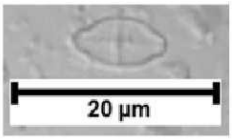
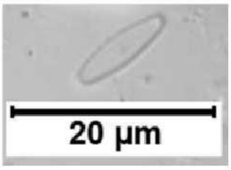
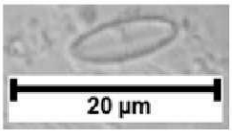
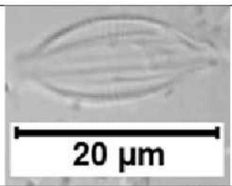
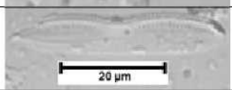
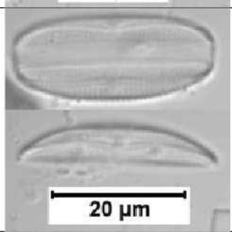
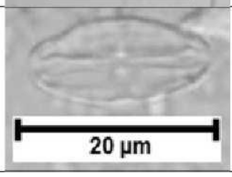
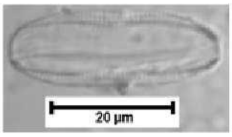
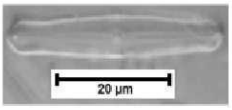
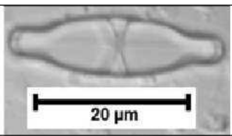
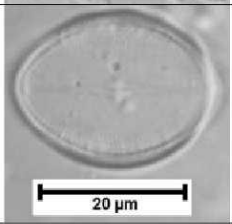
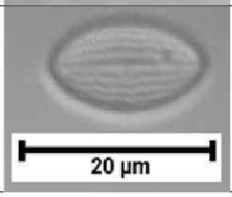
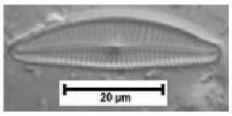
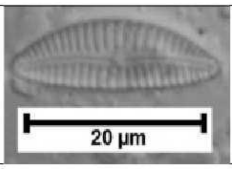
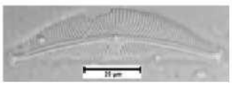
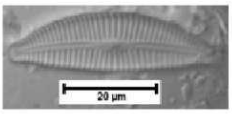
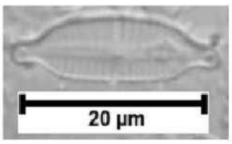
Snow, G.C. 2007. Contributions to the use of microalgae in estuarine freshwater reserve determinations. PhD Thesis, Nelson Mandela Metropolitan University. 249 pp.

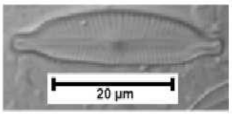
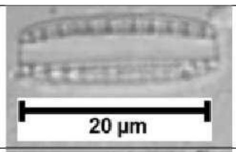
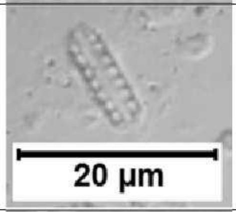
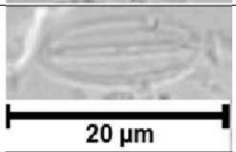
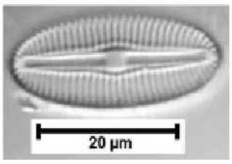
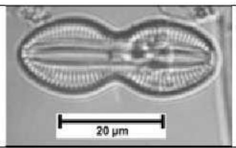
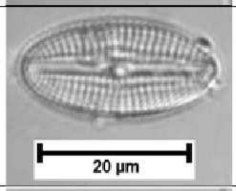
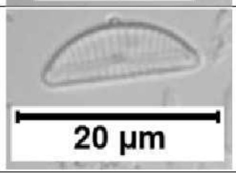
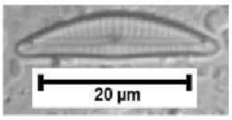
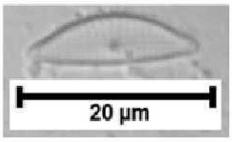
Taylor, J.C., Harding, W.R., Archibald, C.G.M. 2007. *An illustrated guide to some common diatom species from South Africa* (WRC Report TT 282/07).

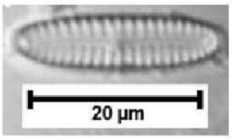
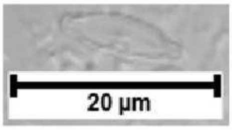
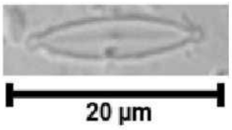
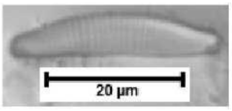
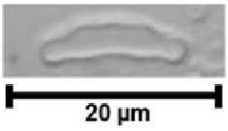
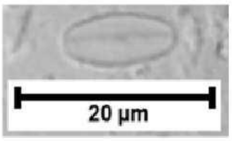
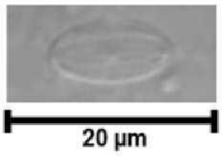
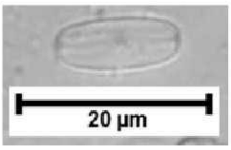
APPENDIX TO BE COMPLETED BEFORE 29 JULY

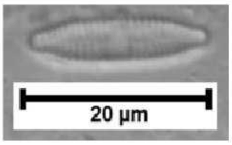
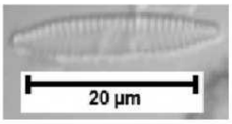
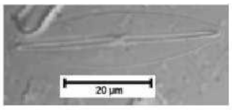
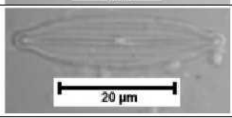
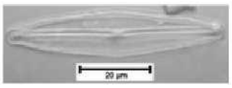
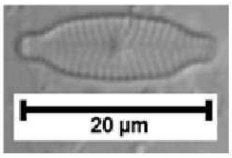
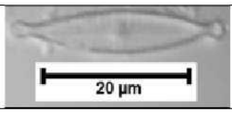
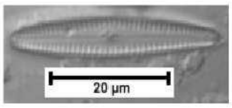
APPENDIX 1. BENTHIC DIATOMS OF THE MZIMVUBU ESTUARY, AUGUST 2012 AND JANUARY 2013.

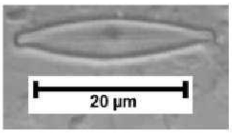
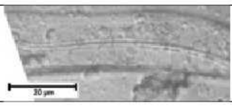
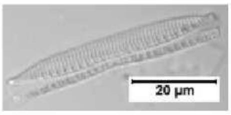
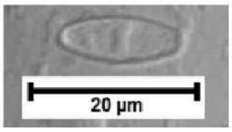
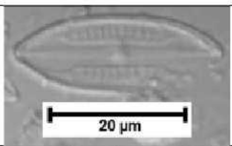
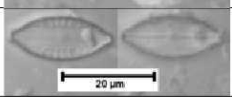
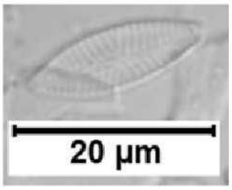
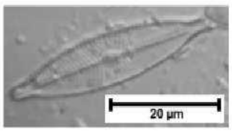
LM Image	Species	Sites											
		1I	1S	2I	2S	3I	3S	4I	4S	5I	5S	6I	6S
	*Achnanthidium exiguum* (Grunow) Czarnecki Source: Taylor *et al.* 2007. Cosmopolitan sp. found in broad ecological range; tolerates industrial and other waste water, grows under very low light, tolerates temperatures up to 40°C. Optimum conditions are alkaline waters with moderate to elevated electrolyte content.			2									
	*Achnanthidium minutissimum* (Kützing) Czarnecki Source: Taylor *et al.* 2007. Found in well oxygenated, clean fresh waters. Usually attached to substrate by short mucilage stalk.	7	7	23 20	21								
	*Achnanthidium saprophilum* (Kobayasi & Mayama) Round & Bukhtiyarova Source: Taylor *et al.* 2007. Found in organically rich & eutrophic fresh waters.			2									
	*Amphora coffeaeformis (*Agardh) Kützing Source: Taylor *et al.* 2007. Cosmopolitan sp. found in waters with high electrolyte content; brackish/saline.	3	1 1	5	1								
	*Amphora commutata* Grunow Source: Lange-Bertalot 2000				1								
	*Amphora copulata* (Kützing) Schoeman & Archibald Source: Taylor *et al.* 2007. Cosmopolitan sp. found in moderate electrolyte waters (incl. brack).	3	4 1	1									
	*Amphora montana* Krasske Source: Taylor *et al.* 2007. Cosmopolitan sp. found in alkaline waters, rarely dominant.			3 2									
	*Amphora ovalis* (Kützing) Kützing Source: Taylor *et al.* 2007. Cosmopolitan sp. found in waters with moderate electrolyte content, incl. brackish & saline.			2	2								

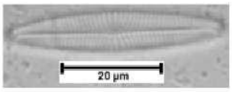
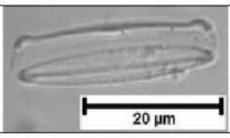
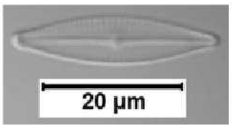
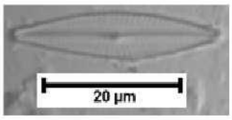
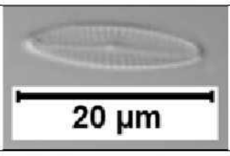
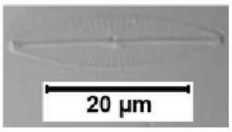
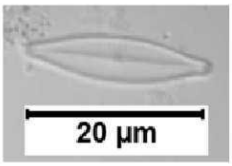
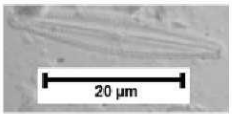
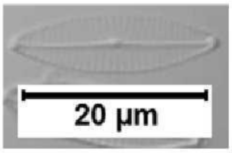
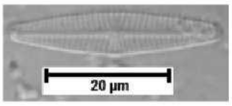
	*Caloneis aequatorialis* Hustedt Source: Taylor *et al.* 2007. Tropical/sub-tropical sp. found in alkaline waters.		1	2										
	*Capartogramma crucicula* (Grunow ex Cleve) Ross Source: Taylor *et al.* 2007. Tropical/subtropical sp.			1										
	*Cocconeis pediculus* Ehrenberg Source: Taylor *et al.* 2007. Cosmopolitan epiphytic sp. found in moderate/high electrolyte waters, incl. brack.			1										
	*Cocconeis placentula* Ehrenberg Source: Taylor *et al.* 2007. Found in meso- to eutrophic waters.		1	4 20	2									
	*Craticula ambigua* (Ehrenberg) DG Mann Source: Taylor *et al.* 2007. Cosmopolitan found in electrolyte-rich, eutrophic water. Resistant to critical/strong levels of pollution.													
	*Cymbella kappii* (Cholnoky) Cholnoky Source: Taylor *et al.* 2007. Cosmopolitan sp. found in weakly alkaline, oligo- to mesotrophic waters of low to moderate electrolyte content.		1	2	3									
	*Cymbella kolbei* Hustedt Source: Taylor *et al.* 2007. Cosmopolitan sp. found in oligotrophic, alkaline waters.		1	5 1	1									
	*Cymbella tumida* (Brébisson) Van Heurck Source: Taylor *et al.* 2007. Cosmopolitan sp. found in oligo- to mesotrophic waters of moderate electrolyte content.			1										
	*Cymbella turgidula* Grunow Source: Taylor *et al.* 2007. Cosmopolitan sp. found in oligo- to mesotrophic, alkaline waters with moderate electrolyte levels.		3	8 4	3									
	*Cymbopleura amphicephala* (Naegeli) Krammer Source: Taylor *et al.* 2007. Cosmopolitan sp. found in oligo- to mesotrophic waters with low to moderate electrolyte content.			2										

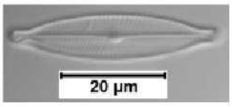
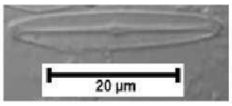
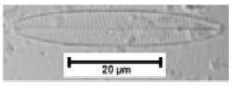
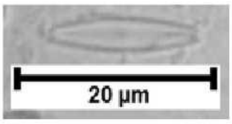
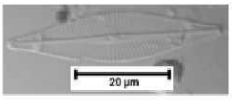
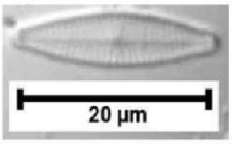
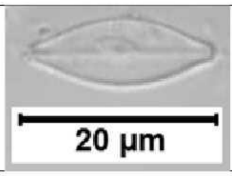
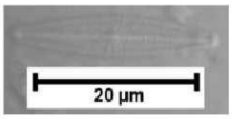
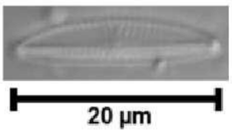
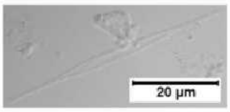
	*Cymbopleura naviculiformis* (Auerswald) Krammer Source: Taylor *et al.* 2007. Cosmopolitan sp. found in oligo- to mesotrophic waters with low to moderate electrolyte content.		1										
	*Denticula kuetzingii* Grunow Source: Taylor *et al.* 2007. Cosmopolitan sp. found in moderate to high electrolyte waters.		2	13	6								
	*Denticula sundayensis* Archibald Source: Taylor *et al.* 2007. Cosmopolitan sp. found in brackish waters.	1											
	*Diploneis* sp.												
	Diploneis elliptica (Kützing) Cleve Source: Taylor *et al.* 2007. Cosmopolitan sp. found in oligotrophic standing waters, typically of moderate electrolyte content.			2	2								
	*Diploneis interrupta* (Kützing) Cleve Source: Lange-Bertalot 2000.		2										
	*Diploneis smithii* (Brébisson) Cleve Source: Lange-Bertalot 2000/Taylor *et al.* 2007. Found in brackish to weakly saline inland waters.		7	2									
	*Encyonema minutum* (Hilse) DG Mann Source: Taylor *et al.* 2007. Cosmopolitan sp. found in oligotrophic waters with moderate electrolyte content.	1	1	4	1								
	*Encyonema silesiacum* (Bleisch) DG Mann Source: Taylor *et al.* 2007. Cosmopolitan sp. found in oligotrophic to eutrophic waters. May tolerate strongly polluted waters.				1								
	*Encyonema ventricosum* (Agardh) Grunow Source: Taylor *et al.* 2007. Cosmopolitan sp. found in alkaline, well oxygenated waters.			1	1								

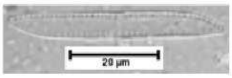
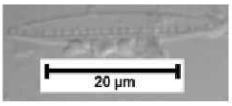
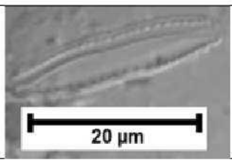
	*Encyonopsis leei* var. *sinensis* Metzeltin & Krammer Source: Taylor *et al.* 2007. Described for single site in China but frequently found in RSA. Occurs in slightly acidic, oligo- to mesotrophic water of low/moderate electrolyte content.			1 2									
	*Encyonopsis minuta* (Grunow) Krammer Source: Taylor *et al.* 2007. Cosmopolitan sp. found in calcareous waters with moderate electrolyte content. Requires O_2-rich environment.			2									
	*Encyonopsis subminuta* Krammer & Reichardt Source: Taylor *et al.* 2007. Cosmopolitan sp. found in calcareous waters with moderate electrolyte content. Requires O_2-rich environment.			1 1	4								
	*Eunotia minor* (Kützing) Grunow Source: Taylor *et al.* 2007. Occurs in circumneutral waters (pools & springs)		1	1									
	*Eunotia pectinalis* var. undulata (Ralfs) Rabenhorst Source: Taylor *et al.* 2007. Found in circumneutral to weakly acidic, electrolyte-poor waters.			1									
	*Fallacia monoculata* (Hustedt) DG Mann Source: Taylor *et al.* 2007. Cosmopolitan sp. found in broad range of waters of moderate to high electrolyte content.			1									
	*Fallacia pygmaea* (Kützing) Sickle & Mann Source: Taylor *et al.* 2007. Cosmopolitan sp. found in elevated electrolyte waters. Tolerant of critical pollution.		1	2									
	*Fallacia tenera* (Hustedt) DG Mann Source: Taylor *et al.* 2007. Cosmopolitan found in high to very high electrolyte water (brackish).				1								
	*Fragilaria biceps* (Kützing) Lange-Bertalot Source: Taylor *et al.* 2007. Cosmopolitan sp. found in meso- to eutrophic waters. Easily suspended from benthos of rivers and lakes.			1									

	*Fragilaria capucina* var. rumpens (Kützing) Lange-Bertalot Source: Taylor *et al.* 2007. Cosmopolitan sp. found in oligo- mesotrophic waters.		1		2								
	*Fragilaria capucina* var. vaucheriae (Kützing) Lange-Bertalot Source: Taylor *et al.* 2007. Wide ecological range, not clearly defined.			1									
	*Fragilaria investiens* (W Smith) Cleve-Euler Source: Lange-Bertalot 2000.												
	*Fragilaria tenera* (WM Smith) Lange-Bertalot Source: Taylor *et al.* 2007. Cosmopolitan sp. found in meso- to eutrophic waters.			4									
	*Fragilaria ulna* var. *acus* (Kützing) Lange-Bertalot Source: Taylor *et al.* 2007. Cosmopolitan sp. found in meso- to eutrophic, alkaline fresh waters. Easily suspended.			1									
	*Frustulia crassinervia* (Kützing) Cleve Source: Taylor *et al.* 2007. Possible cosmopolitan sp. occurring in oligotrophic, low electrolyte waters.		1										
	*Frustulia krammeri* Lange-Bertalot & Metzeltin Source: Lange-Bertalot 2000			1									
	*Frustulia rostrata* Hustedt Source: Taylor *et al.* 2007. Found in acidic standing or flowing waters.		1										
	*Frustulia saxonica* Rabenhorst Source: Taylor *et al.* 2007. Cosmopolitan sp. found in dystrophic, acidic, electrolyte-poor waters.			1									
	*Geissleria decussis* (Hustedt) Lange-Bertalot Source: Taylor *et al.* 2007. Cosmopolitan sp. found in eutrophic, unpolluted or moderately polluted water with slight to average electrolyte content.		1	1									
	*Gomphonema* aff. *lagenula* Source: Taylor *et al.* 2007. Unknown ecology			1									
	*Gomphonema affine* Kützing Source: Taylor *et al.* 2007. Tropical/sub-tropical sp. tolerant of elevated electrolyte concentrations.		3										

	*Gomphonema parvulum* (Kützing) Kützing sensu stricto Source: Taylor *et al.* 2007. Cosmopolitan sp. found in wide range of waters (small pools to lakes & rivers). Tolerant of extreme pollution.		20	5 15	1								
	*Gyrosigma balticua* (Ehrenberg) Rabenhorst Source: Hartley 1996				2								
	*Gyrosigma scalproides* (Rabenhorst) Cleve Source: Taylor *et al.* 2007. Cosmopolitan sp. found in fresh water of moderate/elevated electrolytes. Tolerates turbid conditions.			5	1								
	*Hantzschia amphioxys* (Ehrenberg) Grunow Source: Taylor *et al.* 2007. Cosmopolitan sp. that favours periodically dry habitats.	3	1	1									
	*Hantzschia distinctepunctata* Hustedt Source: Taylor *et al.* 2007. Cosmopolitan sp. found in electrolyte-rich & brackish waters.	24	11	1	3								
	*Luticola mutica* (Kützing) DG Mann Source: Taylor *et al.* 2007. Cosmopolitan sp. common to brackish conditions & areas prone to drying out.		2										
	*Mastogloia elliptica* (Agardh) Cleve Source: Taylor *et al.* 2007. Cosmopolitan brackish sp.		1	1									
	*Mastogloia larerostrata* Hustedt Source: Lange-Bertalot 2000.		1										
	*Navicula* sp.			1									
	*Navicula antonii* Lange-Bertalot Source: Taylor *et al.* 2007. Cosmopolitan sp. found in moderate to high electrolyte waters. Tolerant of strongly polluted conditions (eutrophic to hypereutrophic).	1		1	4								
	*Navicula capitatoradiata* Germain Source: Taylor *et al.* 2007. Cosmopolitan sp. found in eutrophic waters with high electrolyte (brackish) content. Tolerant of critical levels of pollution		4	5	2								

	*Navicula cincta* (Ehrenberg) Ralfs Source: Taylor *et al.* 2007. Possible cosmopolitan sp. found in oligotrophic, calcareous waters.			2 7	4								
	*Navicula cincta* var. leptocephala (Brebisson) Grunow Source: Archibald 1983.	2											
	*Navicula cryptocephala* Kützing Source: Taylor *et al.* 2007. Cosmopolitan sp. with wide ecological amplitude; occurring in weakly acidic, oligotrophic, electrolyte-poor to weakly alkaline, eutrophic and moderately electrolyte-rich waters. Can tolerate critical levels of pollution.	6 301	27	3	5								
	*Navicula cryptotenella* Lange-Bertalot Source: Taylor *et al.* 2007. Common cosmopolitan sp. tolerant of oligo- to eutrophic conditions.	1	5	16									
	*Navicula diserta* Hustedt Source: Archibald 1983	1											
	*Navicula germainii* Wallace Source: Taylor *et al.* 2007. Cosmopolitan sp. found in eutrophic waters. Tolerant of critical levels of pollution.	1											
	*Navicula gregaria* Donkin Source: Taylor *et al.* 2007. Common cosmopolitan sp. found in fresh/brackish environments, tolerant of strongly polluted environments.	110 200	13 300	33	33								
	*Navicula heimansioides* Lange-Bertalot Source: Taylor *et al.* 2007. Cosmopolitan sp. found in weakly acidic/ circumneutral, oligotrophic, electrolyte-poor waters.			3 1									
	*Navicula recens* (Lange-Bertalot) Lange-Bertalot Source: Taylor *et al.* 2007. Cosmopolitan sp. found in eutrophic waters with elevated electrolyte levels (incl. brack). Tolerant of critical levels of pollution.	5	1										
	*Navicula riediana* Lange-Bertalot & Rumrich Source: Taylor *et al.* 2007. Common sp. found in alkaline, eutrophic, electrolyte-rich waters.			56 2									

	*Navicula rostellata* Kützing Source: Taylor *et al.* 2007. Cosmopolitan sp. tolerant of critically polluted habitats.	2		5									
	*Navicula schroeteri* Meister Source: Taylor *et al.* 2007. Cosmopolitan sp. found in eutrophic and electrolyte-rich waters. Tolerant of strongly polluted conditions.	1	1										
	*Navicula symmetrica* Patrick Source: Taylor *et al.* 2007. Cosmopolitan sp. found in eutrophic and electrolyte-rich waters. Tolerant of strongly polluted conditions.			1									
	*Navicula tenelloides* Hustedt Source: Taylor *et al.* 2007. Cosmopolitan, aerophilic sp. found in broad electrolyte and trophic status ranges. Tolerates extreme pollution.			3									
	*Navicula trivialis* Lange-Bertalot Source: Taylor *et al.* 2007. Cosmopolitan sp. found in eutrophic with moderate electrolyte waters. Tolerates dessication & strongly polluted conditions.			2									
	*Navicula vandamii* Schoeman & Archibald Source: Taylor *et al.* 2007. Cosmopolitan sp. found in alkaline, eutrophic and electrolyte-rich waters.			7									
	*Navicula veneta* Kützing Source: Taylor *et al.* 2007. Cosmopolitan sp. found in electrolyte-rich/brackish waters. Tolerant of eutrophic & very polluted conditions.	1			1								
	*Navicula zanonii* Hustedt Source: Taylor *et al.* 2007. Tropical to sub-tropical sp. found commonly in alkaline waters.		2										
	*Navicymbula pusilla* (Grunow) Krammer Source: Taylor et al. 2007. Cosmopolitan sp. with broad tolerance to eutrophic and saline environments.		1		1								
	*Nitzschia acicularis* (Kützing) W Smith Source: Taylor *et al.* 2007. Planktonic & benthic sp. tolerant of high electrolyte and strong, but not extreme, pollution levels.	4		2	18								

	*Nitzschia clausii* Hantzsch Source: Taylor *et al.* 2007. Cosmopolitan sp. found in brackish coastal waters & electrolyte-rich inland waters. Often associated with industrial effluent & tolerant of strongly polluted conditions.			1									
	*Nitzschia dissipata* (Kützing) Grunow Source: Taylor *et al.* 2007. Cosmopolitan sp. found in moderate to high electrolyte waters only.	1	1										
	*Nitzschia dissipata* var. *media* (Hantzsch) Grunow Source: Taylor *et al.* 2007. Cosmopolitan sp. found in moderate to high electrolyte waters only.				3								
	*Nitzschia elegantula* Grunow Source: Taylor *et al.* 2007. Cosmopolitan sp. found in electrolyte-rich waters.		1	2									
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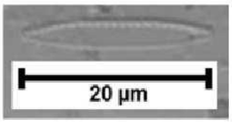
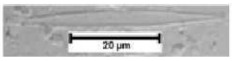
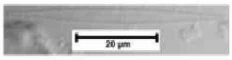
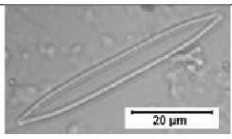
	*Nitzschia frustulum* (Kützing) Grunow Source: Taylor *et al.* 2007. Cosmopolitan sp. found in electrolyte-rich/ brackish waters. Tolerant of critical pollution.		3										
	*Nitzschia gracilis* Hantzsch Source: Taylor *et al.* 2007. Cosmopolitan sp. found in eutrophic, electrolyte-rich waters. Tolerant of moderate pollution.			1	2								
	*Nitzschia iremissa* Cholnoky Source: Taylor *et al.* 2007. Little known sp., seems to be tolerant of elevated pollution.			1									
	*Nitzschia linearis* (Agardh) W Smith Source: Taylor *et al.* 2007. Cosmopolitan with wide ecological range. Favours circumneutral O_2-rich water of mod./ high electrolyte content. Tolerates mod. pollution.				1								
	*Nitzschia littorea* Grunow Source: Taylor *et al.* 2007. Cosmopolitan coastal sp.	2	1										
	*Nitzschia palea* (Kützing) W Smith Source: Taylor *et al.* 2007. Common cosmopolitan sp. frequently found in heavily polluted and high electrolyte waters.		7	47 12	16								

	*Nitzschia reversa* W Smith Source: Taylor *et al.* 2007. Cosmopolitan coastal sp.	1											
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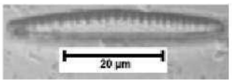	*Nitzschia sinuata* var. *delognei* (Grunow) Lange-Bertalot Source: Taylor *et al.* 2007. Cosmopolitan sp. found in alkaline, meso- to eutrophic waters with moderate/high electrolyte content. Tolerant of moderate pollution.			1									
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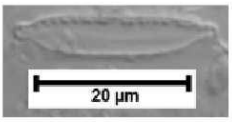
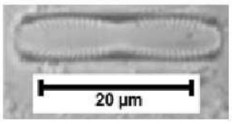
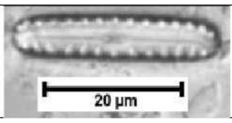
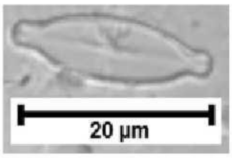
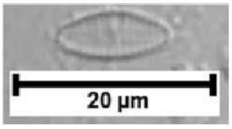
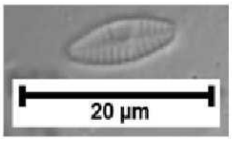
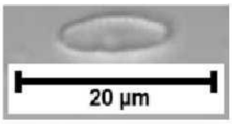
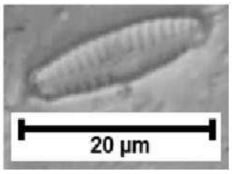
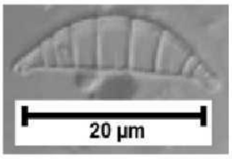
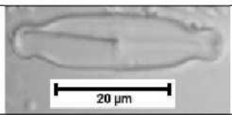
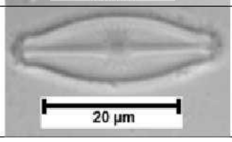
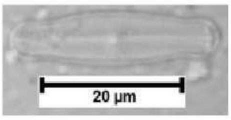
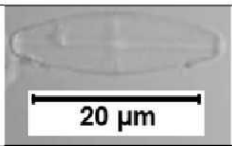
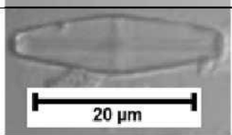
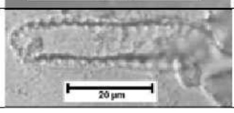
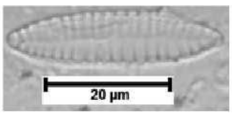
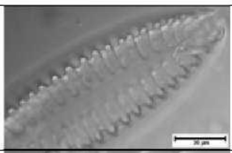
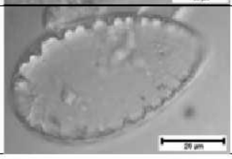
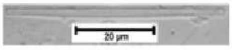
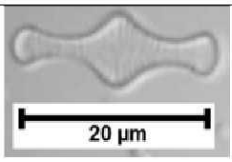
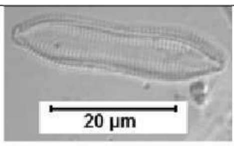
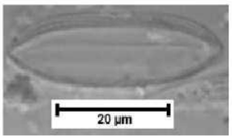
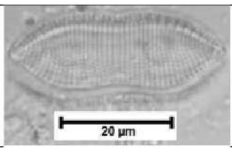
	*Nitzschia umbonata* (Ehrenberg) Lange-Bertalot Source: Taylor *et al.* 2007. Common sp. found in eutrophic, electrolyte-rich waters. Tolerates extreme pollution.		1		1								
	*Pinnularia subcapitata* Gregory Source: Taylor *et al.* 2007. Cosmopolitan sp. found in oligotrophic, electrolyte-poor waters.			1	1								
	*Pinnularia borealis* Ehrenberg sensu lato Source: Taylor *et al.* 2007. Cosmopolitan aerophilic sp.			1									
	*Placoneis elginensis* (Gregory) EJ Cox Source: Taylor *et al.* 2007. Cosmopolitan sp. found in a range of waters; particularly unpolluted to slightly polluted.			2	1								
	*Planothidium engelbrechtii* (Cholnoky) Round & Bukhityarova Source: Taylor *et al.* 2007. Abundant in saline and high electrolyte level inland waters. Can tolerate critical/very heavy organic pollution.				2								

	*Planothidium frequentissimum* (Lange-Bertalot) Round & Bukhityarova Source: Taylor *et al.* 2007. Common sp. found in circumneutral to alkaline waters with moderate/high electrolyte content. Tolerates critical pollution.		1	2	1								
	*Reimeria sinuata* (Gregory) Kociolek & Stoermer Source: Taylor *et al.* 2007. Cosmopolitan aerophilic sp. Typically found in montane biotopes (mosses, springs & streams).			15	2								
	*Reimeria uniseriata* Sala, Guerrero & Ferrario Source: Taylor *et al.* 2007. Found in alkaline, meso- to eutrophic waters with moderate electrolyte content. Grows in high turbidity.	1	2	1									
	*Rhopalodia operculata* (Agardh) Håkansson Source: Taylor *et al.* 2007. Cosmopolitan sp. found in moderate to high electrolyte water.		1	1 1									
	*Sellaphora* sp.			1									
	*Sellaphora mutatoides* Lange-Bertalot & Metzeltin Source: Metzeltin *et al.* 2005.			2	1								
	*Sellaphora pupula* (Kützing) Mereschkowsky sensu lato Source: Taylor *et al.* 2007. Cosmopolitan sp. found in broad spectrum of electrolyte-rich waters. Some populations found in strongly polluted conditions.			4 1	1								
	*Stauroneis dubitabilis* Hustedt Source: Lange-Bertalot 2000	2	3										
	*Stauroneis tackei* (Hustedt) Krammer & Lange-Bertalot Source: Bate et al. 2004.		1										
	*Surirella* sp.				1								
	*Surirella angusta* Kützing Source: Taylor *et al.* 2007. Cosmopolitan sp. found in eutrophic waters with moderate electrolyte content.			3									

	*Surirella linearis* W Smith Source: Metzeltin *et al.* 2005.		1										
	*Surirella ovalis* Brébisson Source: Taylor *et al.* 2007. Cosmopolitan sp. found in electrolyte-rich water.		1										
	*Tabularia fasciculata* (Agardh) Williams & Round Source: Taylor *et al.* 2007. Cosmopolitan sp. with broad ecological range. Tends to favour moderate/high electrolyte content. Been found in critical industrial wastewater.				6								
	*Tabellaria flocculosa* (Roth) Kützing Source: Taylor *et al.* 2007. Common in electrolyte-poor, oligotrophic, circumneutral/weakly acidic waters.			1									
	*Tryblionella apiculata* Gregory Source: Taylor *et al.* 2007. Cosmopolitan sp. found in electrolyte-rich waters. Tolerant of strongly polluted conditions.		1	2	1								
	*Tryblionella calida* (Grunow) DG Mann Source: Taylor *et al.* 2007. Cosmopolitan sp. found in eutrophic waters with elevated electrolytes.		15										
	*Tryblionella coarctata* (Grunow) DG Mann Source: Taylor *et al.* 2007. Cosmopolitan sp. found in brackish waters.			1									

APPENDIX D

MACROPHYTES OF THE MZIMVUBU ESTUARY

MACROPHYTES OF THE MZIMVUBU ESTUARY

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July 2013

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1. SUMMARY

The Mzimvubu Estuary is classified as a river mouth as it is large, narrow and channel like and the habitat available for macrophyte colonization is limited. Field surveys in 2012 and 2013 showed that the dominant macrophytes were reeds, *Phragmites* spp and lagoon hibiscus *Hibiscus tiliaceus*. These plants have an important function as they protect the estuary banks from erosion. Both dominant species are indicative of low salinity water and representative of river mouth conditions. Some mangrove trees (*Bruguiera gymnorrhiza,* black mangrove) have established on the west bank of the estuary near the mouth among the reeds (0.03 ha). There are a number of seedlings but the long term survival of these salt tolerant trees is unknown. A few red mangrove (*Rhizophora mucronata*) trees were also found. The mangroves are probably an opportunistic, temporary habitat although they were recorded in the estuary in 1999. This and other habitats in the Mzimvubu Estuary are dynamic changing in response to bank scouring by floods and salinity variations. Past habitat areas were calculated using 1938 images rectified and mapped in ESRI™ ArcGis 10. A vegetation map was produced using 2009 images as more recent images had cloud cover making mapping difficult. The floodplain habitats (approximately 44 ha) have been disturbed by development and agriculture. Most of the swamp forest (5 ha in total) occurs in the first 2.5 km from the mouth of the Mzimvubu Estuary and there have been slight increases in this habitat. The reed and sedge habitat (16 ha) extends along the length of the estuary. There have been localised losses of reeds due to development of property and the removal of reeds to make access to the river easier. However there has been an overall increase in reed and sedge habitat due to colonisation of sand banks on the west bank near the mouth.

2. INTRODUCTION

The Mzimvubu Estuary (31°37'52" S, 29°32'59" E) is situated on the subtropical coast of South Africa, with its mouth opening into the Indian Ocean at Port St. Johns (DWAF, 2008; van Niekerk & Turpie, 2012). It forms part of the Mzimvubu to Keiskamma Water Management Area, and is classified as a river mouth with a very large catchment area (19 853 km^2) (DWAF, 2008). The total surface area of the estuary is 150.99 ha (van Niekerk & Turpie, 2012). With a mean annual run-off (MAR) of 2893.8 $x10^6$ m^3/yr, the system contributes 7% of the total MAR of estuaries in South Africa (van Niekerk & Turpie, 2012). The estuarine health state of the Mzimvubu Estuary is considered to be fair (i.e. habitat state/abiotic = good; biological state = fair), and has a Present and Recommended Health Category of C (i.e. moderately modified) (van Niekerk & Turpie, 2012). In addition to this, the estuary is ranked as the 35^{th} most important estuary in terms of conservation importance (Turpie & Clark, 2007). The most prevalent pressures experienced in the Mzimvubu Estuary include a moderate level of pollution as a result of poor catchment management, as well as high levels of fishing effort and bait collection (van Niekerk & Turpie, 2012). Additionally, the estuary is considered to be an important nursery area, and based on its physico-chemical and physical characteristics (i.e. river-dominated) it is known to be an important nursery area and breeding ground for species such as the White Steenbras, Kob and the Zambezi shark (van Niekerk & Turpie, 2012). The estuary was visited in August 2012 and January 2013 to document the distribution and species composition of the macrophyte habitats in relation to the controlling environmental factors. These data will then be used to assess the ecological water requirements of the estuary. A vegetation map for present conditions was produced from the field surveys. The distribution and area covered by different macrophyte habitats was compared with the earliest aerial photograph available for 1938. These changes would then provide input to the present ecological status of the estuary.

Macrophytes in the Mzimvubu Estuary are naturally limited due to the steep banks and little available habitat. However those present have important functions such as preventing the banks from erosion. Sediment deposition on the Cremorne Estate grassed bank was clearly visible after the August 2012 flood (Photo 1). The photograph shows that the adjacent natural reed areas accumulated this sediment with no visible impacts. The macrophytes provide suitable habitat for a variety of fauna. Crabs were found near the mouth and birds find shelter in the fringing reeds and sedges.

3. MATERIALS AND METHODS

3.1 Field Surveys

The estuary was visited on 29 and 30 August 2012. On 9 August a small flood had passed through the system. Sediment deposition was particularly visible where the riparian vegetation had been cleared. The estuary was visited again on 30 and 31 January 2013. During these surveys the dominant macrophytes were identified and their distribution along the length of the estuary noted.

The distribution, height and diameter at breast height (1.5 m) of the mangroves were measured and compared with data collected in 2011 (Hoppe-Speer 2013). The heights of the reeds were measured at a number of sites along the length of the estuary. Reeds were sampled on the west and east bank mostly at the same sites as the microphytobenthos sampling sites. Reed height was measured for 12 of the tallest reeds at each site. The width of the reed stand was measured from the water's edge inland. Reeds were collected for nutrient analysis and the leaf tissue content of nitrogen and phosphorus were determined to investigate whether this could be used to identify sites of nutrient enrichment.

Total nitrogen and total phosphorus were measured using the persulphate digestion method modified from Purcell and King (1996). The leaves were oven-dried at 60 °C for 48 hours and finely ground, following which 0.05 g of each sample was digested in alkaline potassium persulphate for one and a half hours in an autoclave. The digest was analysed for nitrate using the sulfanylamide-α-naphtyl-ethylenediamine chloride procedure as outlined in Purcell and King (1996) while total phosphorus was determined following oxidisation with a mixed reagent comprising ammonium molybdate, ascobic acid, aqueous H_2SO_4 and potassium antimomyl tartrate, as described in Strickland and Parsons (1972). Standard solutions of potassium nitrate and potassium dihydrogen phosphate were prepared at the same time as the samples and absorbance read at 540 and 885 nm for the nitrate and phosphate respectively in a UV/VIS spectrophotometer. The concentrations of nutrients were determined from highly significant regression equations ($R > 98\%$).

3.2 Changes over time in the Habitats of the Mzimvubu Estuary

The present and past distribution of the estuary habitats were mapped using aerial images obtained from National Geo-spatial Information (previous Chief Directorate: Surveys and Mapping). Best recent images for habitat assessment were 2009 orthorectified images. Bing aerial images from 2011 were also referred to but unfortunately the mouth area where the main reed and sedge stands are located was covered by cloud. Past habitat areas were calculated using 1938 images rectified and mapped in ESRI™ ArcGis 10. Due to the poor quality of the 1938 images orthorectifying of the images were difficult which would have introduced some error into the final calculation of the habitat areas. This related particularly to the open water habitat area, which made the final habitat area of 1938 difficult to assess since open water area represented 75 % of the habitat in 2009. Aerial images from 1952, 1969 and 1977 for the mouth region were also assessed for changes in reed and sedge habitat over time although the area was not mapped.

4. RESULTS AND DISCUSSION

4.1 Species Composition and Macrophyte Habitats

The uMzimbuvu Estuary supports mainly reeds and sedges with smaller areas of swamp forest and mangrove habitat. Table 1 and Figure 1 indicates the dominant macrophyte habitats and species in the Mzimvubu Estuary. Some salt marsh species are present and these include *Triglochin striata* Ruiz & Pav,., *Stenotaphrum secundatum* (H. Walter) Kuntze, *Sporobulus virginicus* (L.) Kunth, *Cynodon dactylon* (L.) Pers, *Juncus effusus* L., *Juncus kraussii* Hochst subsp. *kraussii,* and *Juncus littoralis C.A Mey.* The dominant reed and sedge species were *Phragmites australis* (Cav.) Steud and *Schoenoplectus scirpoides*. Swamp forest was represented by lagoon hibiscus *Hibiscus tiliaceous* L. Alien invasive species such as *Lantana camara* L., *Sesbania punicea* (Cav.) Benth. and *Arundo donax* L. were abundant. Gum trees and bamboo also grew in the intertidal zone (Photo 2).

Macroalgae were noticeably absent which is typical of a river mouth. Some *Ulva* was found attached to old tree trunks (Photo 3). Towards the mouth on the west bank there is a healthy fringe of reeds backed by swamp forest and then lush coastal forest (Photo 4). A large sedge area occurs near the mouth with reeds upstream of this (Photo 5). The dominant sedge *Schoenoplectus scirpoideus* is thought to tolerate wave action better than reeds because of its stronger stems.

The mangroves are probably an opportunistic, temporary habitat. They were recorded in the estuary in 1999 (Adams *et al*., 2004). This and other habitats in the Mzimvubu estuary would be dynamic changing in response to bank scouring by floods and salinity variations. A healthy population of mangroves was found in this study and included *Rhizophora mucronata* Lam., and *Bruguiera gymnorrhiza* (L.). Lam. Beyond the estuarine fringe is lush coastal forest which extends to watersheds up to 60 km from the coast (DWAF 2005). According to DWAF (2005) the coastal vegetation consists of coastal grasslands, valley bushveld, coastal forests and dune forest. On the landward side, this coastal forest is replaced by patches of thicket and bushveld dominated by *Acacia karroo* (Kululwa *et al*. 2008).

Table 1 Macrophyte habitats in the Mzimvubu Estuary (2013).

Habitat type	Defining features, typical/dominant species	Area (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	345
Intertidal sand and mudflats	Intertidal zone consists of sand/mud banks that are regularly flooded by freshwater inflows. This habitat provides a possible area for microphytobenthos to inhabit. Peripheral species present include the grass species: *Cynodon dactylon* and *Stenotaphrum secundatum.*	26
Macroalgae	*Ulva* species growing on some rocks and dead tree trunks. They are not abundant in the water column or as epiphytes because of the high river inflow.	-
Swamp forest	Dominat species present is lagoon hibiscus *Hibiscus tiliaceus.*	5

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Habitat type	Defining features, typical/dominant species	Area (ha)
Mangroves	The following species are present and belong to the Rhizophoraceae family: *Rhizophora mucronata* and *Bruguiera gymnorrhiza*.	0.03
Reeds and sedges	The following species have been recorded, and belong to the families Cyperaceae, Juncaceae & Poaceae: *Bolboschoenus maritimus*, *Schoenoplectus scirpoides*, *Juncus kraussii*, *Phragmites mauritianus* and *Phragmites australis*.	16

4.2 Reed Height and Nutrient Concentrations

Reed (*Phragmites australis*) height and nutrient concentrations were measured along the length of the estuary on the east and west bank to assess whether these data could indicate sites of nutrient enrichment. Leaf total nitrogen concentrations varied significantly ($p < 0.05$) at the different sites. Concentrations on the west bank were significantly higher than those on the east side ($p < 0.05$, DF = 26, mean = 63.81 ± 0.01 μM). Total phosphorus concentrations also varied significantly across the different sites. On the east bank, the highest concentration (0.77 ± 0.01 mM) was at Site 3 east and the lowest at Site 4 east. On the west side the highest concentration was at Site 3 west (0.82 ± 0.01 mM) and the least at Site 1 west. There was no difference in phosphorus concentrations on the east and west banks of the river. There were also no correlations between phosphorus and total oxidised nitrogen concentrations in leaves of *P. australis* at the different sites and no relationship between reed height and nutrient concentrations. The height of the reeds varied along the length of the estuary between 2 and 3 m tall. Overall the reed characteristics measured were not indicative of nutrient enrichment or point source inputs along the Mzimvubu Estuary.

Table 2 Reed sampling sites, height and leaf nutrient concentrations.

Sites	Description	Plant height (m)	Stand width (m)	TP (mM)	TN (μM)
1 east	Mangroves & reeds	2.94 + 0.39	>25	0.81 + 0.01	63.8 + 0.01
2 east	Opposite road sign (D)	2.75 + 0.19	24	0.71 + 0.01	63.8 + 0.01
3 east	Between Cermorne & road sign (C)	2.81 + 0.39	5	0.75 + 0.0	63.8 + 0.02
4 east	Downstream Cremorne (B)	3.33 + 0.45	22.5	0.77 + 0.01	63.8 + 0.03
5 east	Cremorne (A)	2.14 + 0.63	7.4	0.74 + 0.01	63.7 + 0.01
1 west	At town creek	2.12 + 0.31	*	0.71 + 0.0	63.8 + 0.03
3 west	Lower reaches	2.85 + 0.38	17	0.82 + 0.01	63.7 + 0.02
4 west	Lower reaches	2.90 + 0.43	4	0.72 + 0.01	63.8 + 0.03
6 west	Up from bridge	3.01 + 0.47	4	0.76 + 0.0	63.9 + 0.01

- The reeds at the town creek line an artificial channel that inputs to the estuary

4.3 Changes in the Mangroves

Colloty (2000) and Adams *et al.* (2004) reported no mangroves in the Mzimvubu Estuary in 1999, however Hoppe-Speer (2013) found them in the estuary in 2011. Mangroves had been reported in the Mzimvubu Estuary by Ward and Steinke (1982, 1 ha) and the loss between then and 1999 was thought to be due to flooding and removal. Ward and Steinke (1982) reported *Avicennia marina* and *Bruguiera gymnorrhiza* whereas Hoppe-Speer (2013) also found *Rhizophora mucronata*. In 2013 there were only 3 large *R. mucronata* trees, the dominant species was *B*

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gymnorrhiza which tends to occur in lower salinity environments compared to the other mangrove species. There were a number of large trees with numerous seedlings below the adults (Photo 6). Size classes were indicative of pulsed recruitment, possibly as a result of a sea storm or exceptional high tide distributing propogules along the shore. The large trees occur in a distinct line. There were 23 trees greater than 2 m and 12 *B gymnorrhiza* trees between 1 and 1.9 m with many seedlings less than 50 cm in height.

4.4 Changes over time in the Macrophyte Habitats

Floodplain area (approximately 66 ha) has decreased over time with losses due to development (commercial/tourism) as well as agriculture (Table 3). In 1938 the images indicate that these habitats were already disturbed. There are historical records that state that "an area some 10 km distant from the river mouth had been cultivated to supply passing naval vessels with fresh produce". The banks of the estuary are bounded by steep slopes with little floodplain in most sections of the estuary. The two main floodplain areas are around the bridge on the east bank and 3 km upstream from the mouth also on the east bank. This represents 90 % of the floodplain of the Mzimvubu Estuary. Floodplain habitat does not include reeds and sedges.

There is some macroalgal growth on the rocks possibly indicating nutrient input. They are not abundant in the water column or as epiphytes because of the high river inflow. Sites of point source run-off were observed (Photo 7) and sediments were soft and muddy in the reed areas. There have been localised losses of reeds due to development of property and the removal of reeds to make access to the river easier. Riparian vegetation within the 5 m contour of the estuary has been disturbed by human activities with roads running parallel to both banks. The extent of invasive species in this habitat is indicative of disturbance. Field observations in 2012 and 2013 found the alien Spanish reed *Arundo donax* in the upper reaches along the banks of the estuary. These could not be distinguished from other reed species on the images and they were included in the total 16 ha of reed and sedge habitat along the length of the estuary.

Mangroves were mapped as 13 individuals in 2009 and were assessed in a field trip in January 2013. They could not be identified in the 1938 images, or in the 1952, 1969 and 1977 images. They have established due to the formation of the reed and sedge habitat at the mouth which was also not present in earlier images (Figure 2). This area was a bare sand bank but due to a change in mouth morphology the area has become stabilised and colonized by vegetation. Interestingly between 2009 and 2011 there also appeared to be changes in composition between the reed and sedge species (Figure 3).

Swamp forest could also not be identified in the 1938 image due to the poor quality of the aerial photographs making it difficult to distinguish between coastal forest and swamp forest. Most of the swamp forest (5 ha in total) occurs in the first 2.5 km from the mouth of the Mzimvubu Estuary (Figure 4).

The extent of mud and sand banks has decreased slightly since 1938. However this has been mapped with low confidence due to the poor quality of the earlier images. Figure 2 shows the changes in the mouth of the Mzimvubu Estuary and the sand banks. The main sand banks occur in the upper reaches of the estuary and extend well into the river component. The images from 2009 were from a normal flow year with sand banks obvious in the upper reaches. However the 2011 Bing images were after a flood event and these sand banks were not visible.

There are possible errors related to the mapping of the estuarine habitats were due to the misalignment of the 5 m contour used to mark the lateral boundary of the estuary. This made it

There are possible errors related to the mapping of the estuarine habitats were due to the misalignment of the 5 m contour used to mark the lateral boundary of the estuary. This made it very difficult to map the narrow floodplain areas where the banks are steep, especially in the upper reaches of the estuary. Around the bridge on the eastern side it was also not possible to distinguish between reeds and sedge habitat and floodplain (Figure 6).

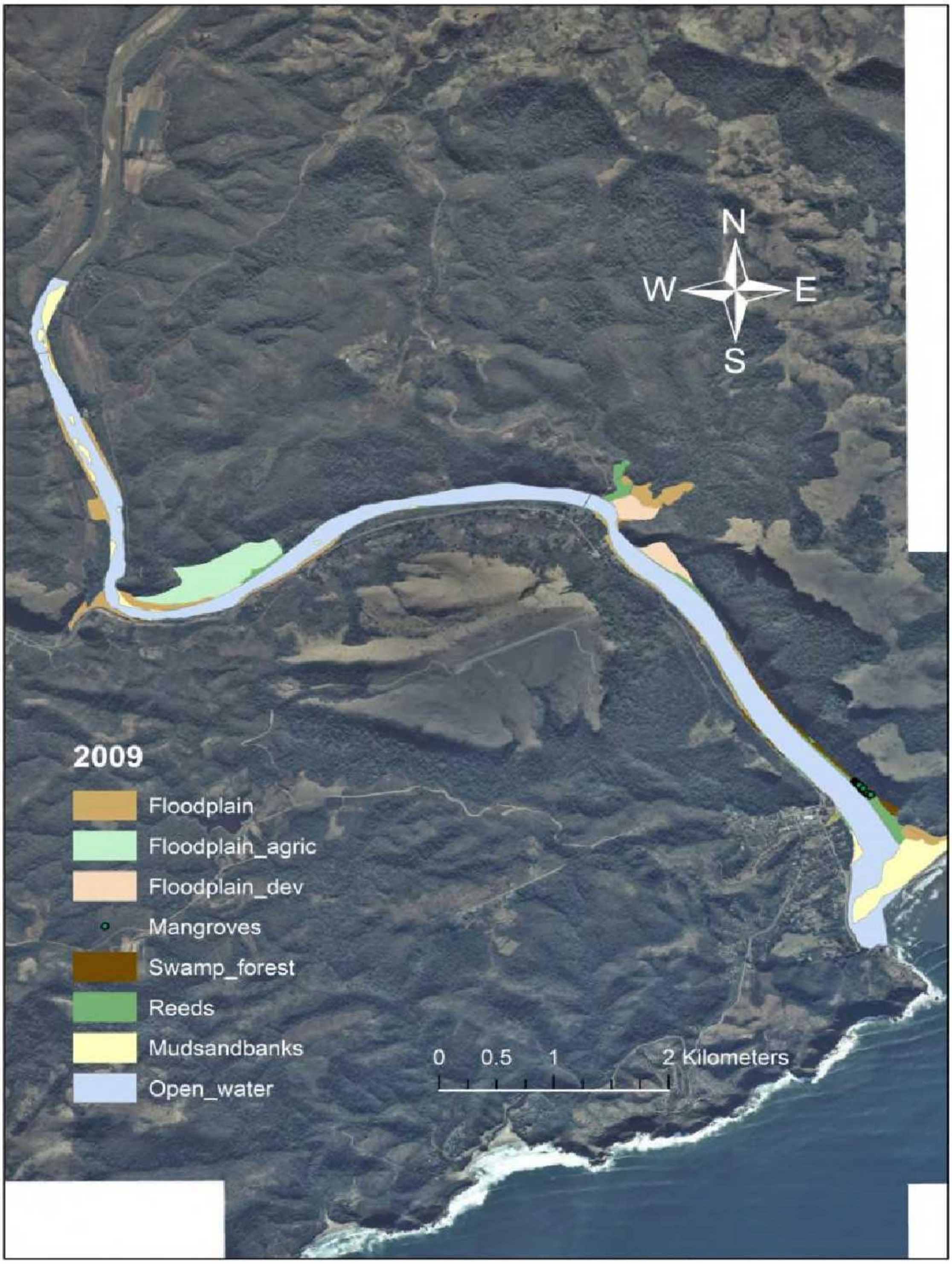

Figure 1 Distribution of habitats in the Mzimvubu Estuary (2009).

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Table 3 Area covered by different habitats in the Mzimvubu Estuary in 2013 compared with 1938

Habitat	Area (ha) in 1938	Area (ha) in 2013
Floodplain agriculture	24	26
Floodplain developed	0	10
Floodplain undisturbed	38	30
Mangroves	0	0.03
Swamp forest	1	5
Reeds & sedges	10	16
Mud & sandbanks	27	26
Open water surface area		345

4.5 Present Ecological State

The data in Table 3 were used to inform the changes in the macrophyte habitats over time. If floodplain area occupies approximately 66 ha, 10 ha are now developed and 26 ha have been transformed as a result of agriculture then this represents a loss of 55% of floodplain habitat. Reeds and sedges have increased from the 1938 aerial photograph from 10 to 16 ha. This represents a 38% increase in this habitat but should be interpreted with caution as a large percentage of this change is due to an increase in area on the east bank of the mouth due to sediment deposition as a result in a change in mouth configuration. This area could easily be eroded by the next large flood.

In the reference condition macrophytes would cover 77 ha, now they cover 51 ha which represents a 34% loss of habitat. The 51 ha is composed of 30 ha floodplain vegetatation, 16 ha reeds and sedges, 5 ha swamp forest and 0.03 ha mangroves.

4.6 Response of Macrophytes to further Water Resource Development Scenarios

Scenarios 1, 2 and 3 represent very little change in flow and related abiotic conditions in response to the present state. Scenario 4 is a futuristic scenario used to test the sensitivity of the estuary to flow reduction. This scenario represents a 60% decrease in flow relative to reference conditions.

Salinity for Scenarios 1 and 2 was the same as present conditions. For Scenario 3 salinity increased from 13 to 18 ppt in the lower reaches and from 2 to 6 ppt in the middle reaches. These salinity changes are still within the tolerance range of the dominant reeds and so no major habitat changes are expected in response to this. For Scenario 4 the salinity in the lower reaches increases from 12 ppt (reference conditions) to 23 ppt and from 2 to 13 ppt in the middle reaches. Conditions in the middle reaches would still favour reeds and sedges whereas the higher salinity conditions in the lower reaches may result in salt marsh displacing the reed and sedge habitat. Increase in catchment disturbance and mud input would encourage macrophyte growth along the banks. The large increase in DIN and DIP would provide favourable conditions for the growth of all macrophytes.

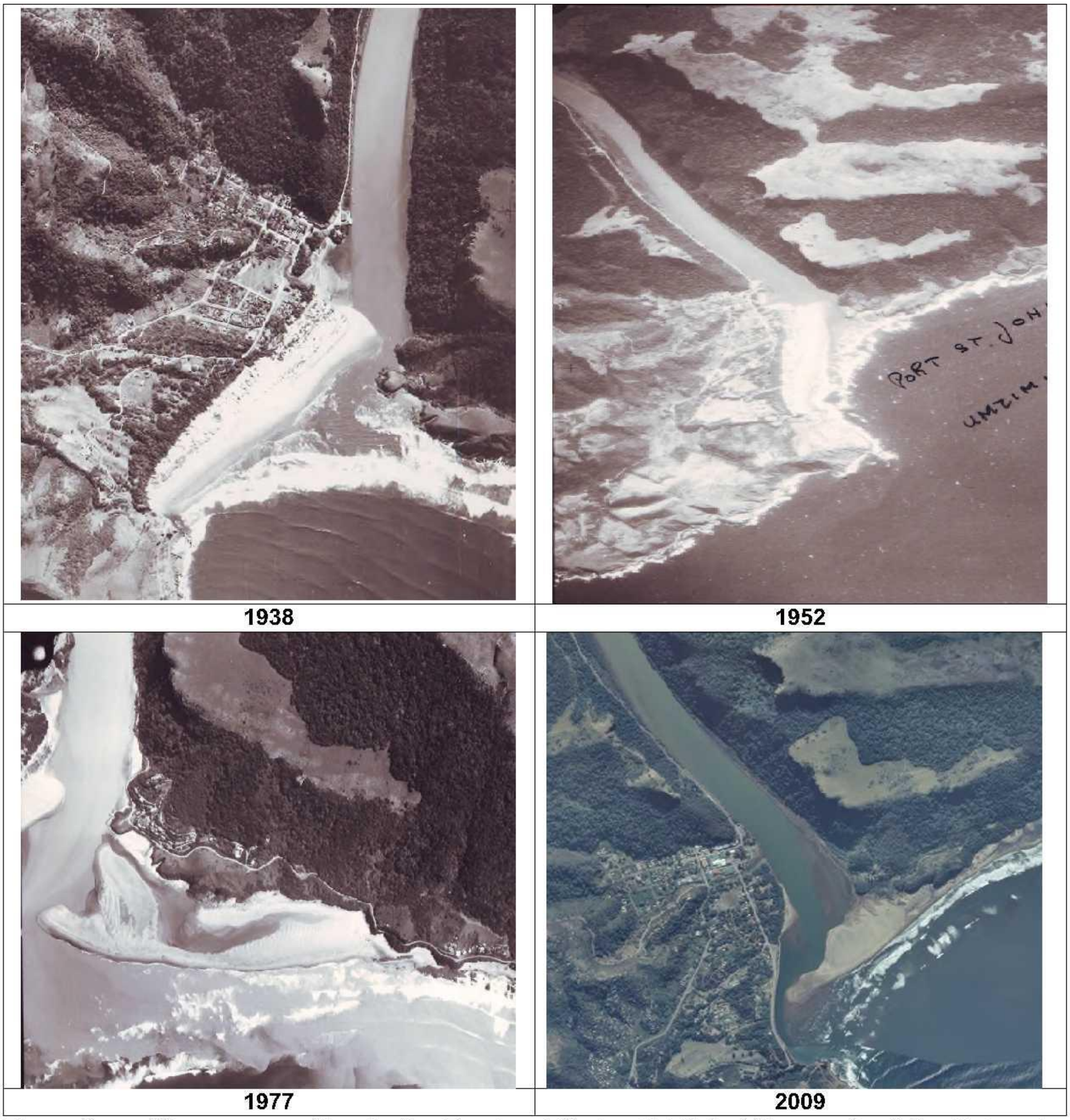

Figure 2 **Changes over time in the Reed and Sedge Habitat at the mouth of the Mzimvubu Estuary.**

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Figure 3 Changes in the Reed / Sedge Habitat Species Composition

Figure 4 Distribution of Swamp Forest in the Mzimvubu Estuary.

Misalignment of 5 m contour at bridge

Difficulty in determining 5 m boundary in steep narrow sections.

Figure 5 Problems Associated with the 5 m Contour used as the Lateral Boundary of the Mzimvubu Estuary.

Figure 6 Floodplain area on north/east bank of bridge. The red line represents the 5 m contour.

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APPENDIX E

FISH FAUNA OF THE MZIMVUBU ESTUARY

FISH FAUNA OF THE MZIMVUBU ESTUARY
CAMERON MCLEAN

1. INTRODUCTION

Estuaries serve as nursery areas for a number of estuarine-dependent marine fish, providing a sheltered, productive environment which is essential to the survival of these species. Apart from these euryhaline marine species, estuarine fish communities are also represented by a combination of stenohaline marine species, those restricted to estuaries, and euryhaline freshwater species (Blaber 1985). Estuarine fish species can also be divided into functional guilds based on trophic position and food preference. The three primary food sources in estuaries are detritus, phytoplankton and aquatic macrophytes (Bennet 1989), the former representing the dominant food source in subtropical systems.

Harrison (2003) in a national survey of South African estuaries provides the only scientific information related to the fish fauna of this estuary. The aim of this study was to provide an assessment of the fish fauna in the Mzimvubu Estuary using pre-existing information (primarily Harrison 2003) and observations made during an August 2012 field visit.

2. METHODS

2.1 Study area

The Mzimvubu Estuary (31°37'52" S, 29°32'59" E), Port St Johns, is a large river mouth system situated in the sub tropical bioregion of the South Africa. The estuary covers an area of 151 ha (van Niekerk & Turpie, 2012), draining a catchment of 19852 km^2 that originates in the central Drakensberg. The mean annual runoff (MAR) of the catchment equates to approximately 2900 x 10^6 m^3, 7% of the total MAR of estuaries in South Africa, and represents the largest free flowing system in the country.

Typical of river mouth estuaries, freshwater dominates physical processes in the Mzimvubu, with salinities tending towards oligohaline conditions in the upper and middle reaches of the system. During high flow events the system behaves as a river and ultimately influences the physico-chemical conditions in the adjacent coastal environment. Due to the large catchment this river carries a significant amount of sediment, leading to high turbidities and silt deposition. By virtue of the freshwater dominance, depths and sediments in the system are highly dynamic.

Harrison (2003) was the primary source of data used in this report (add detail). In addition, a reference community for permanently open subtropical estuaries was constructed from taxa that were recorded at a frequency of greater than or equal to seventy percent, from the national fish survey conducted by Harrison (2003). Each taxa was assigned an estuarine dependence category as described in Table 1.

Table 1: The major categories of fish that utilize southern African estuaries (after Whitfield 1998)

Categories	Description of categories
I	Estuarine species which breed in South African estuaries.
II	Euryhaline marine species which usually breed at sea with the juveniles showing varying degrees of dependence on South African estuaries.
III	Marine species which occur in estuaries in small numbers but are not dependent on these systems
IV	Euryhaline freshwater species, whose penetration into estuaries is determined by salinity tolerance. Include some species which may breed in both freshwater and estuarine system.
V	Obligate catodromous species which use estuaries as transit routes between the marine and freshwater environments.

3. RESULTS

A total of 1098 fish, representing 28 taxa and 14 families was collected from the Mzimvubu Estuary during Harrison's (2003) nationwide survey (Table 2). The Mugilidae and Gobiidae families were represented by the most number of species, 7 and 6, respectively. The Ambassidae, Carangidae and Sparidae families were each represented by 2 species. The Estuarine Round-herring *Gilchristella aestuaria* was the dominant species in the study accounting for 37.8% of the total catch, followed by the Spotted Grunter *Pomadasys commersonnii* (19.6 %), and *Liza spp.* (7.6 %). Collectively the Mugilidae family accounted for 24.7 % of the total catch.

The modeled fish community for subtropical open estuaries was very similar to the actual catches, with only seven species not recorded in the system during the snapshot survey. The species not recorded were: *Scomberoides lysan, Hilsa kelee, Leiognathus equula, Liza tricuspidens, Liza macrolepis, Valamugil robustus and Silago sihama*

Table 2: Fish collected and percentage contribution in the Mzimvubu during Harrison's nationwide study, and a modeled list determined for permanently open subtropical systems.

Family	Taxa	EDC	Harrison (2003) modelled	Harrison (2003) no.	Harrison (2003) % contribution
Ambassidae	*Ambassis natalensis*	I	x	10	0.9
	Ambassis gymnocephalus			31	2.8
Carangidae	*Caranx heberi*	II			
	Caranx sexfasciatus	II	x	10	0.9
	Caranx ignobilis			6	0.5
	Scomberoides lysan	II	x		
Cichlidae	*Oreochromis mossambicus*	IV	x	1	0.1
Clupeidae	*Gilchristella aestuaria*	I	x	415	37.8
	Hilsa kelee	II	x		
Elopidae	*Elops machnata*	II	x	7	0.6
Gobiidae	*Glossogobius callidus*	I	x	13	1.2
	Caffrogobius gilchristi			4	0.4
	Caffrogobius natalensis			1	0.1

Family	Taxa	EDC	Harrison (2003) modelled	Harrison (2003) no.	Harrison (2003) % contribution
	Oligolepis acutipennis	I	x	29	2.6
	Oligolepis keiensis			24	2.2
	Psammogobius knysnaensis			8	0.7
Haemulidae	*Pomadasys commersonnii*	II	x	215	19.6
Leiognathidae	*Leiognathus equula*	II	x		
Monodactylidae	*Monodactylus falciformis*	II	x	2	0.2
Mugilidae	*Liza alata*	II	x		
	Liza dumerilii	I	x	11	1.0
	Liza macrolepis	II	x		
	liza sp	II		83	7.6
	Liza tricuspidens	II	x		
	Mugil cephalus	II	x	37	3.4
	mugillidae	II		82	7.5
	Myxus capensis	IV	x	32	2.9
	Valamugil buchanani	II	x		
	Valamugil cunnesius	II	x	9	0.8
	Valamugil robustus	II	x		
	Valamugil sp	II		11	1.0
Platycephalidae	*Platycephalus indicus*	II		1	0.1
Sciaenidae	*Argyrosomus japonicus*	II	x	11	1.0
Sillanginidae	*Silago sihama*	II	x		
Soleidae	*Solea bleekeri*	II	x	23	2.1
Sparidae	*Acanthopagrus berda*	II	x	11	1.0
	Rhabdosargus holubi	II	x	10	0.9
Teraponidae	*Terapon jarbua*	II	x	1	0.1
	Total no.			**1098**	**100.0**
	Total taxa		**27**	**28**	

4. DISCUSSION

Typically river mouth estuaries are considered to be relatively species poor in comparison with permanently open estuaries due to, *inter alia*, the prevailing low salinities that preclude many marine associated taxa, and unstable sediments and relatively low residence times that result in impoverished food resources. The 28 taxa recorded by Harrison falls in the upper range of species collected in other subtropical river mouth systems (13-34 species). The modelled community for subtropical open estuaries comprises 27 species, indicating that in spite of the highly dynamic physic chemical conditions, the system is still favourable for a relatively large number of taxa.

The catch, in terms of numbers, was dominated by the estuarine resident *Gilchristella aestuaria*. This result is somewhat surprising given the strong flows that characterise this estuary, and the species known susceptibility to changes in flow . Strydom *et al*. (2002), in a study of two warm temperate estuaries, showed that despite the more abundant food sources in the Great Fish Estuary, *G. aestuaria* densities were still lower than the Kariega Estuary. Strydom *et al*., (2002) found larvae and juvenile densities of *G. aestuaria* to be inversely related to river flow, citing the flushing out of larvae and early juveniles in the Great Fish as a possible explanation. *G. aestuaria* do, however, possess a number of characteristics that assist in guarding against the impacts of high flow. In KZN, *G. aestuaria* spawns during winter in order to take advantage of the stable and productive conditions associated with this season (Whitfield 1980c). Melville-Smith et al. (1981) showed that in the Sundays Estuary the larvae avoid ebb-tide surface flows in order to maintain their position in the middle and upper reaches. It is probable that this species takes advantage of any slack water present during high flows in order to prevent flushing out of the system. In addition, a report compiled by CSIR (1983) showed that the Mzimvubu displayed a remarkably high zooplankton: benthic invertebrate biomass suggesting that *G. aetuaria* would have a competitive advantage as a zooplanktivore,

The Large proportion of mugilids is not particularly surprising given the success of this group in South African estuaries (James *et al*. 2005). Traits that contribute to the prominence of this group in South African estuaries, include extended spawning seasons which guard against recruitment failure, strong euryhalinity, and a detritus based diet, which in the case of estuaries essentially represents a perennial food source (Cowley *et al*. 2001).

The system is also important for a number of angling targeted taxa, most notably *Pomadasys commersonnii* and *Argyrosomus japonicas*. Both species are estuarine dependant marine species that utilize the system extensively as nursery grounds. Adults also frequent the system due to the favorable foraging conditions in the system. *A. japonicas* in particular favours high turbidity conditions for foraging. Both species have been exploited heavily by anglers, with anglers suggesting there has been a major decline in both populations in recent years. This trend is not unique to the Mzimvubu, the National Spatial Biodiversity Assessment provided quantitative data of these declines across the country, indicating the relative to pristine conditions, populations of *P. commersonnii* and *A. japonicas* have declined to < 40 % and 4 %, respectively.

The Mzimvubu is well known as a nursery and pupping ground for the Zambezi shark *Charcharhinus leucas*. Little is known regarding the ecology of this species, however, the turbid waters and associated freshwater olfactory cues provided by this system provide favorable conditions for this species. It remains unclear the relative importance of this system for the conservation of this species, however, initial indications suggest that the paucity of large freshwater dominated systems along the coastline, high incidences of shark attacks in the area, and initial acoustic records from the Natal Sharks Boars would suggest that this system is of considerable importance for the conservation of this near threatened species.

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APPENDIX F

SPECIALIST STUDY ON BIRDS

MZIMVUBU ENVIRONMENTAL WATER REQUIREMENTS STUDY: ESTUARINE COMPONENT

Specialist study on birds

Jane Turpie

March 2013

1. INTRODUCTION

This study forms part of an assessment of the potential impacts on the Mzimvubu River system in the Eastern Cape of further developments of water resources that are being considered by the Department of Water Affairs. This specialist study on avifauna forms part of a broader study which investigates the freshwater requirements of the estuary and addresses the implications of different development scenarios affecting river flows into the Mzimvubu Estuary. In determining estuarine water requirements (EWR), a scenario-based approach will be used that is based on the baseline description of the estuary, its predicted reference state and the predicted state under a range of scenarios. This specialist report provides the baseline description for birds and discusses the likely factors that would influence avifaunal community composition on this estuary.

2. STUDY AREA AND METHODS

The Mzimvubu estuary is one of the largest on the Wild Coast. The river system rises in the Drakensberg and has a catchment area of about 19 925km2 which is located in a summer rainfall area. Much of the catchment lies in communal land areas of the former Transkei, and has been historically overgrazed, such that summer floods carry heavy loads of silt. The lower part of the estuary runs through a gorge of Table Mountain sandstone which is vegetated with indigenous forest.

Figure 1: Lower reaches of the Mzimvubu River showing the location of the estuary at Port St Johns

Day (1981) defined the estuary as extending 6-9km from the mouth. Within this area the estuary is about 200m wide and was then about 2m deep along most of its length, widening to about 400m near the mouth, which features a prominent sandbar. The estuary is crossed by a road bridge about 4.2km from the mouth.

Figure 2. Map showing the estuary and the counting sections used in the avifaunal study.

The avifaunal assessment was based on available information and two field trips undertaken in August 2012 and January 2013. During the field trips, birds were counted along the length of the estuary up to 12km upstream of the mouth. For this the estuary was divided into three sections of approximately 4km length - a lower section (up to the bridge), middle section (up to the 90 degree bend) and an upper section. Available data on birds included count data from surveys undertaken in January 2002 and January 2012 as part of studies of the Wild Coast being undertaken by the author (Turpie et al. 2004, Turpie & Whittington in prep). Like most Wild Coast estuary, the Mzimvubu was not included in the national count of birds undertaken in 1979-81. In addition, while there are several older texts that describe the estuary and aspects of its flora and fauna (e.g. Day 1981), none include mention of the birds.

3. RESULTS

Count data from this and earlier studies are summarised in Table 1. Earlier counts (Jan 2002 and Jan 2012) were done from the banks, and only covered the area as far as the first 90 degree bend, about 8km upstream. These counts recorded 9 and 10 species, respectively and 30 – 57 birds apart from terns. A tern roost at the estuary in Jan 2002 numbered about 600 birds. During this study, almost double the numbers of birds (besides terns) and 50% more bird species were counted in summer 2013, but this was largely due to the counts of waterfowl, most of which were counted in the upper section of the estuary. The highest number of waterbird species (20) was recorded in winter 2012, during which time there was also a tern roost at the mouth. The species composition has varied considerably between the different counts, even within the summer counts.

Table 1: Raw Count Data for Four Counts, and Summary Data for Summer and Winter

	Jan-02 Summer	Jan-12 Summer	Sep-12 Winter	Jan-13 Summer	Winter	Summer (max)
Reed Cormorant			1		**1**	
Whitebreasted Cormorant			1		1	
African Black Duck			3	2	3	2
Egyptian Goose		17	8	17	8	17
Redbilled Teal						
Spurwing Goose			23	63	23	63
Yellowbilled Duck			14	24	14	24
Cattle Egret			1		1	
Little Egret	1					1
Grey Heron	1	1	4		4	1
Hadeda Ibis			10	5	10	5
Hamerkop	1	2				2
African Fish Eagle	3		1	1	1	3
Osprey			1		1	
Blacksmith Lapwing		1	6	2	6	2
Common Sandpiper	2		2	4	2	4
Common Greenshank		1		1		1
Grey Plover		2				2
Little Stint				2		2
Sanderling	33					33
Three-Banded Plover			2		2	
Water Dikkop			2	3	2	3
Whitefronted Plover	13			2		13
Kelp Gull		2	2		2	2
Swift Tern		3	43	1	43	3
Common Tern	600					600
Giant Kingfisher			1		1	
Malachite Kingfisher				1		1
Pied Kingfisher		1				1
Cape Wagtail		3	4		4	3
African Pied Wagtail	3		6	2	6	3
TOTAL	**657**	**33**	**135**	**130**	**135**	**791**
Total excluding terns	**57**	**30**	**92**	**129**	**92**	**188**
Species	**9**	**10**	**20**	**15**	**20**	**24**

The composition of birds during the winter and summer counts of this study is summarised in Figure 3 and their distribution along the estuary is summarised in Table 2.

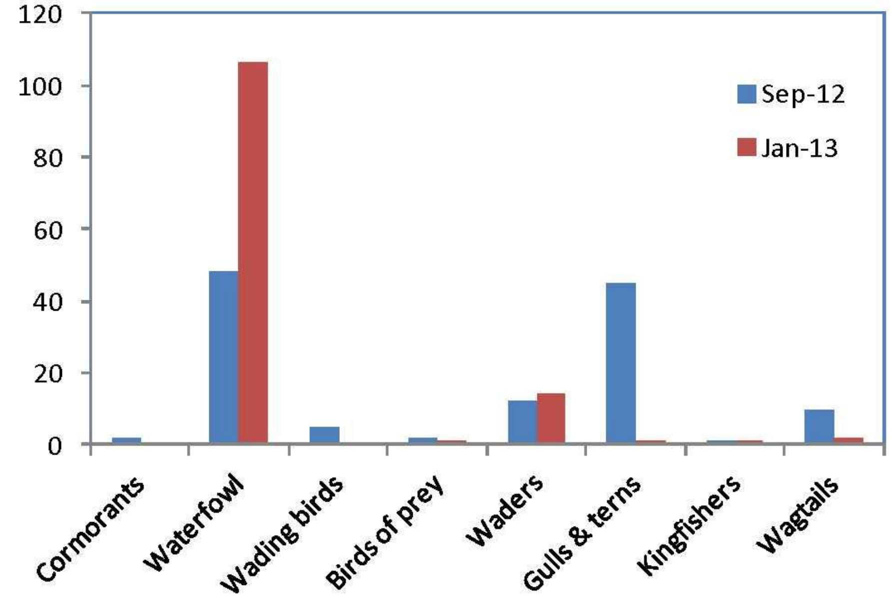

Figure 3: Numbers of Birds of Different Groups counted during this Study in Summer and Winter

Table 2: Distribution of Bird Groups along the Estuary in Winter and Summer

	Sep 2012 (Winter)				**Jan 2013 (Summer**			
	Mouth	**Lower**	**Middle**	**Upper**	**Mouth**	**Lower**	**Middle**	**Upper**
Cormorants		1		1				
Waterfowl		2	7	39		4	13	89
Wading birds			4	10		3	1	1
Birds of prey			1	1				1
Waders		6	2	4	3	11		
Gulls & terns	45				1			
Kingfishers			1			1		
Wagtails		6	2	2		2		

4. DISCUSSION

The Mzimvubu estuary has a relatively depauperate bird fauna especially along its middle to lower reaches. At the mouth, the estuary provides suitable habitat for certain waders, gulls and terns, though numbers of these birds fluctuate since these habitats are variable over time. Large numbers of Common Tern, Sanderlings and Whitefronted Plovers were counted at the mouth in 2002, whereas these species have never been recorded in appreciable numbers in subsequent counts.

Above the mouth, typically estuarine habitats such as intertidal mudflats, shallows and banks are very limited due to the steep-sided nature of the gorge. In all the counts there are only low numbers of the species that are typical of muddier intertidal areas. These habitats are relatively limited in the estuary, and occur mainly in the form of narrow margins. Low numbers of mudflat-associated waders may also be ascribed to low densities of benthic invertebrates.

The waterfowl and some of the wading birds take advantage of the sandy beaches and islands that are found at the 90 degree bend and further up the river as roosting areas. The estuary provides suitable fringing and bank vegetation for perching piscivores. While fish eagles have been recorded in most counts, numbers of kingfishers are low.

From about 8km up the estuary, the estuary becomes more riverine in appearance, with overhanging trees providing shelter for shy waterfowl, and sandy banks providing loafing and roosting areas for waterfowl and wading birds. Fish eagles and Osprey were also seen mainly in the upper estuary. While waterfowl were generally found in the upper estuary, some were observed near the mouth on the day following the count, during a spate of high flow.
Piscivorous birds are low in number along the whole estuary. While suitable perches are available, the silt-laden water probably makes the estuary unattractive to these birds.
Given descriptions of the estuary as having once been a deeper system, it is quite possible that numbers of certain species have increased as it has become silted up, creating shallow and marginal habitats. Numbers of piscivores might have been higher in the natural condition when silt loads would have been lower and fish abundance higher. Among the birds that are dominant in recent counts, three species are largely terrestrial in nature - Hadeda Ibis, Spurwinged Goose and Egyptian Goose. These species have are likely to have become more common in recent years, as a result of general population and range expansions.

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