

**Spatial and Temporal Distribution of the Benthos in the Mfolozi-Msunduzi
Estuary, KwaZulu – Natal**

By

Sibusisiwe Gloria Ngqulana

Submitted to the Faculty of Science and Agriculture
in fulfillment of the requirements for the degree of
Master of Science



in the
Department of Zoology
University of Zululand

Supervisor: Prof D. P. Cyrus
Co-supervisor: Dr L. Vivier

January 2012

DECLARATION

I hereby declare that this thesis is the product of my own original work, and to the best of my knowledge, contains no material previously submitted for the award of any degree at another university. Any published information used was duly acknowledged.

ACKNOWLEDGEMENTS

First and foremost I'd like to acknowledge my Almighty God, who constantly surprises me with His goodness.

I will always be grateful to the late Dr Rodney Owen whom I started this research with, because of you I knew I had to finish this thesis.

I'd like to thank my supervisors Prof. Cyrus and Dr. Vivier who assisted me during this study. Thank you Dr Vivier for your guidance, advice, valuable contributions you made towards this study.

I'd like to thank my family who have always supported my decisions and have encouraged me throughout my extended studying career.

Thanks to the National Research Fund (NRF) for the funding I received for my years as a Masters student.

I am grateful to everyone in the zoology department who assisted me during this study.

ABSTRACT

The objectives of the study were to describe the subtidal component of the invertebrate benthic fauna and to investigate spatial and temporal distribution of the fauna. Samples were collected quarterly in 2009 to investigate seasonal patterns of the benthos of the system. Another aim of this study was to determine the benthic biomass of the Mfolozi – Msunduzi estuarine system.

Results indicated that 23 taxa were recorded in 2009 with 18 and 15 taxa in the Mfolozi and Msunduzi Estuary, respectively. The most abundant species were the burrowing ocypodid crab *Paratyloidiplax blephariskios* and the polychaete *Dendronereis arborifera*. These were followed by the polychaetes *Ceratonereis* sp., *Prionospio sexoculata* and the amphipods *Corophium triaenonyx*. Freshwater taxa, such as Simuliidae, Baetidae, Chironomidae and Ecnomidae were recorded in the upper reaches of the Mfolozi Estuary during summer, this was due to the area being dominated by freshwater inflow. No significant differences ($p < 0.05$) were found between sampling seasons and between sampling sites with regard to the mean number of taxa, mean densities ($N \cdot m^{-2}$), species richness (D), species evenness (J') and species diversity (H').

The cluster and MDS ordination showed that the benthic fauna of the system could be separated into three most important clusters, the first of which comprised mostly of the Msunduzi sites, indicating that seasonal changes did not influence the community structure of the Msunduzi Estuary. The second group comprised mostly of the Mfolozi winter (June and August) samples while the third group comprised the Mfolozi summer (March and November) samples and this clearly showed that seasonal changes played a major role in structuring the benthic community in the Mfolozi Estuary. The SIMPER results indicated that *P. blephariskios* and *D. arborifera* were the taxa most responsible for structuring the benthic community in both the Mfolozi and Msunduzi Estuaries.

BIOENV showed that the single variable most responsible for structuring the benthic assemblage in the system was sediment particle size, followed by sediment sorting coefficient and temperature. The best combination of environmental factors which played a role in the distribution and abundance of benthos were temperature, sediment particle size and the sorting coefficient. These results showed that sediment characteristics combined with natural seasonal variability (temperature), played the most important role in structuring the benthic community of the Mfolozi – Msunduzi system.

In terms of biomass, *P. blephariskios* was the greatest contributor to the benthic biomass of the system, followed by *D. arborifera*. The mean benthic biomass at the Mfolozi sites was very low, with highest values recorded at the mouth of the system, while the highest mean benthic biomass at the Msunduzi sites was recorded at sites MS2 and MS1, while the biomass of the remaining sites was less than 50 mg.m^{-2} . Seasonal variations were evident in the Mfolozi – Msunduzi system, with very low biomass of 1883 mg.m^{-2} dry weight in March, while the highest biomass was recorded in June (16827 mg.m^{-2} dry weight). The biomass decreased in August (13412 mg.m^{-2} dry weight) and again in November (12660 mg.m^{-2} dry weight).

TABLE OF CONTENTS

Abstract	i
Table of contents	iii
List of Tables	vi
List of Figures	vii
Chapter 1: Introduction	1
1.1 General Introduction	1
1.2 Factors affecting the abundance of benthic organisms in estuaries	2
1.3 Benthic Biomass	5
1.4 The Mfolozi-Msunduzi Estuarine System	5
1.4.1 Historical information on the system	5
1.4.2 Catchment Activities leading to Increased Siltation of the Mfolozi- Msunduzi estuary	6
1.5 Motivation.....	8
1.6 Objectives	10
CHAPTER 2: Study Area and Methods	11
2.1 Study Area	11
2.2 Materials and methods	12
2.2.1 Field procedures	12
2.2.2 Laboratory Procedures	14
2.2.3 Statistical analysis.....	15
CHAPTER 3: RESULTS	17
3.1 Physico-Chemical Parameters.....	17
3.1.1 Salinity	17
3.1.2 Temperature	18
3.1.3 Turbidity	18
3.1.4 Dissolved Oxygen (mg/l).....	19

3.1.5 Depth.....	19
3.2 Nutrients.....	21
3.2.1 Ammonia.....	21
3.2.2 Nitrate	22
3.2.3 Soluble Orthophosphate.....	23
3.2.4 Total Phosphate.....	23
3.2.5 Biochemical Oxygen Demand (BOD)	24
3.2.6 Chlorophyll-a	26
3.3 Sediment Characteristics (Sediment Grain Size, Organic Content and Sorting Coefficient)	28
3.4 Macrozoobenthos Composition	33
3.5 Biotic Indices	36
3.6 Seasonal distribution in the benthic community	38
3.7 Changes in the community structure.....	43
3.8 Relationships between environmental parameters and the benthic community	46
3.9 Relationships between the environmental parameters and the benthic community.....	49
3.10 Biomass.....	53
3.11 Comparisons with Historical Data	59
CHAPTER 4: DISCUSSION	64
4.1 Physico-chemical parameters.....	64
4.2 Nutrients.....	66
4.3 Sediment Characteristics (sediment grain size, organic content and sorting coefficient).....	68
4.4 Benthic Composition.....	70
4.5 Seasonal distribution in the benthic community	76
4.6 Changes in the zoobenthic community structure	77
4.7 Comparisons with Historical Data	79

4.8 Biomass.....	80
CHAPTER 5: CONCLUSION	83
REFERENCES.....	87

List of Tables

Table 1: The percentage distribution of sediment samples to the seven grain size classes, median phi, sorting coefficient and organic content from the Mfolozi-Msunduzi Estuarine system for each sampling period	32
Table 2: Mean densities ($N.m^{-2}$) of the benthos collected in the Mfolozi-Msunduzi Estuarine system during 2009.	41
Table 3: The species, mean similarity and percentage contribution of the dominant Benthic taxa in the Mfolozi and Msunduzi estuaries during the four seasons sampled in 2009.	47
Table 4: The species, mean similarity and percentage contribution of the dominant Benthic taxa in the Mfolozi-Msunduzi estuaries during the four seasons sampled in 2009.	48
Table 5: The weighted Spearman Correlation Coefficient values (p_w) between the benthic community and the physical parameters in the Mfolozi and Msunduzi estuaries during the four seasons sampled in 2009.	49
Table 6: Correlations between environmental variables.	52
Table 7: Biomass of the benthic invertebrates collected in the Mfolozi-Msunduzi Estuarine system.	57
Table 8: The Weighted Spearman Correlation Coefficient values (r_w) between the benthic community and physical parameters in the Mfolozi-Msunduzi Estuary over the three years.	62
Table 9: Numbers of Invertebrate Taxa and Mean Seasonal densities recorded in different Subtropical Estuaries.	71
Table 10: Dominant invertebrate Taxa and Mean biomass recorded in the selected Estuaries.	82

List of Figures

- Figure 1:** The Mfolozi-Msunduzi and the St. Lucia system sharing a common mouth (a) and after a separate mouth was excavated for the Mfolozi-Msunduzi Estuarine system (b) (Taylor 2006). **6**
- Figure 2:** The Mfolozi-Msunduzi Estuarine system, also showing the lower reaches of the St Lucia Narrows (Google Earth). **11**
- Figure 3:** The selected sampling sites in the Mfolozi (F1-6) and Msunduzi (S1-4) Estuaries. **13**
- Figure 4:** Salinity (a), Temperature (b) and Turbidity (c) recorded during four sampling seasons in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries during 2009. **20**
- Figure 5:** The dissolved oxygen (mg/l) (a) and depth (b) recorded during four sampling seasons in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries during 2009. **21**
- Figure 6:** Ammonia (a), nitrate (b) and soluble orthophosphate (c) recorded during four sampling seasons in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries during 2009. **21**
- Figure 7:** The total phosphate (a) and biochemical oxygen demand (b) recorded during four sampling seasons in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries during 2009. **26**
- Figure 8:** The chlorophyll-a values recorded during four sampling seasons in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries during 2009. **27**
- Figure 9:** Mean (+1STD) particle size (median phi value) (a), sorting coefficient (b) and organic content (%) (c) of the sediment at sampling sites in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries. **30**
- Figure 10:** Correlation between the % organic content and the Median phi (a) and sorting coefficient (b) of the sediments in the Mfolozi-Msunduzi system during 2009. **31**
- Figure 11:** Percentages Composition (Total densities) in the Mfolozi (a) and the Msunduzi (b) Estuaries in 2009. **35**

Figure 12: Mean (+1STD) number of taxa (a), density (b) and Species Richness (D) recorded in the Mfolozi (F1- F6) and Msunduzi (S1- S4) Estuaries in 2009. **37**

Figure 13: Mean (+1STD) Species Evenness (J') (a) and Species Diversity (H') (b) recorded in the Mfolozi (F1- F6) and Msunduzi (S1- S4) Estuaries in 2009. **38**

Figure 14: The dominant benthic taxa recorded in the Mfolozi estuary during each of the four sampling seasons (a-d) during 2009. **42**

Figure 15: The dominant benthic taxa recorded in the Msunduzi Estuary during each of the four sampling seasons (a-d) during 2009. **43**

Figure 16: Classification (a) and MDS ordination (b) constructed from Bray-Curtis similarities showing differences in the community structure and abundance between sites and seasons. (F = Mfolozi, S = Msunduzi; Dotted line represents percentage similarity). **45**

Figure 17: Canonical Correspondence Analysis (CCA) showing the correlation between the environmental parameters and the benthic community during the four sampling seasons in the Mfolozi-Msunduzi system during 2009. (1-40 = Samples, TP = Total Phosphate, PO₄ = Soluble Orthophosphate, DO = Dissolved Oxygen, Chl-a = Chlorophyll-a, BOD = Biochemical oxygen demand, TDS = Total dissolved solids). **51**

Figure 18: The mean biomass (+1STD) per site in the Mfolozi – Msunduzi Estuarine System (a), and seasonal variations in the mean biomass of the Mfolozi Estuary (b) and Msunduzi Estuary (c). **55**

Figure 19: The total biomass of the Mfolozi and Msunduzi Estuaries. **56**

Figure 20: Total Biomass of the benthic invertebrates in the Mfolozi (a) and the Msunduzi (b) estuaries. **58**

Figure 21: MDS ordination constructed from Bray-Curtis similarities showing differences in the community structure between the years 2007, 2008 and 2009. (F = Mfolozi, S = Msunduzi). **61**

Figure 22: Canonical Correspondence Analysis (CCA) showing the correlation between the environmental parameters and the benthic community during the three- year period in the Mfolozi-Msunduzi system. **63**

Chapter 1: Introduction

1.1 General Introduction

Estuaries are highly productive ecosystems due to the fact that they act as traps for nutrients that come from both the river and the marine environment (De Villiers and Hodgson 1999, Day 1981a). These nutrients are essential for promoting primary production in estuaries. Primary producers include mangroves, sea grasses, salt marshes and phytoplankton and benthic diatoms. Estuarine ecosystems generally support high benthic densities and biomasses due to the fact that they are rich in nutrients (De Villiers and Hodgson 1999). However, estuaries generally have lower species diversity compared to freshwater and marine ecosystems (De Villiers and Hodgson 1999, Day 1981a), due to the naturally variable environment which relatively few species can tolerate. Estuarine organisms are subjected to variable environmental conditions to which they have to adapt to. These include tidal inundation and fluctuations in salinity, runoff, temperature, turbidity and sediment type. Salinity in estuaries can change over a short period of time due to the tides. During periods of high rainfall in the catchment, flooding conditions can cause salinity in the estuary to decrease drastically and rapidly as more freshwater enters the system (McLusky 1989). An estuary can also become hypersaline during periods of drought due to low freshwater inflow and high rates of evaporation (Harrison 2003, Hastie and Smith 2006).

The habitat in estuaries, particularly the substrata, changes along the length of the estuary due to tidal currents and the speed of the current (Day 1981a). Estuarine sediments vary in terms of particle size and organic content, both of which affect the ability of benthic organisms to colonise the substratum. Sediment particle size and organic content also influence the feeding strategies of benthic organisms. For example, soft muddy substrata which usually have high organic content are generally colonized by deposit feeders, while suspension feeders are usually confined to areas with sand or firm mud (McLusky 1989). During flooding, the sediment may be eroded, sweeping most of the benthic organisms to the marine environment (Teske and Wooldridge 2001, Owen and Forbes 1997, Hastie and Smith 2006). Current speed and nutrient levels are also variable and add more stress on the benthic invertebrates and other biota found in estuaries (Elliott and Quintino 2007).

Estuaries are also subjected to anthropogenic stress, which includes sewage effluent discharge, waste disposal, agriculture runoff and construction adjacent to and within estuaries (Elliott and Quintino 2007). Anthropogenic factors can affect benthic communities and the ecological functioning of the estuarine ecosystem due to an increase in nutrient levels and turbidities, and they may also increase the sediment load entering the estuary (Cyrus 1988). Increased nutrient levels may lead to eutrophication, which depletes oxygen in water and this limits the growth of benthic organisms (Dallas and Day 2004). Increased turbidities in estuaries reduce the penetration of light, which prevents photosynthesis and reduces primary production (Dallas and Day 2004). High sediment loads result in the smothering of invertebrates and their habitats. Elliott and Quintino (2007) used the Pearson-Rosenberg model to detect anthropogenically stressed features in estuarine benthic communities and found that anthropogenically stressed communities were characterised by the presence of small organisms and r-strategists and by low species diversity.

South African estuaries are affected mostly by commercial or subsistence agricultural activities in their catchments (Turpie 2004). It was found that South African estuaries, particularly in KwaZulu-Natal, are prone to siltation due to sugar cane cultivation in their catchments (Heydorn 1986, Whitfield 2000). KwaZulu-Natal estuaries are also affected by establishment of industries in their catchments. Day (1981a) reported that these anthropogenic factors (agriculture and industrial development) lead to the degradation of estuaries through pollution and removal of the riparian vegetation. Turpie (2004) also reported that estuaries with large catchments are more degraded than estuaries with smaller catchments.

1.2 Factors affecting the abundance of benthic organisms in estuaries

Temporal and spatial distribution of benthic organisms in estuaries varies, depending on factors such as the substrate, salinity, availability of food and temperature (Day *et al.* 1989). Within the estuary, sediments are not uniformly distributed, and depend largely on the silt load associated with freshwater inflow (De Villiers and Hodgson 1999). The currents in the upper reaches are reduced and thus deposit coarser particles, while at the mouth tidal

influence results in coarse sand particles being pushed in the direction of the estuary. Finer particles are deposited in the middle reaches where the estuary is wider and currents are slower. Salinity and sediment characteristics (sediment particles and organic content) are regarded as the primary factors influencing the distribution patterns of the benthos (Teske and Wooldridge 2003, 2004). Teske and Wooldridge (2003) also suggest that there is a high degree of correlation between these two factors.

Food availability in the system determines the feeding techniques used by different benthic organisms (McLusky 1989). For example, the abundance of benthic suspension feeders fluctuates seasonally due to the fact that these organisms feed on phytoplankton whose densities vary throughout the year, while deposit feeders do not vary as much because they feed on detritus and microbes which have less variation throughout the year (McLusky 1989). Seasonal variations of phytoplankton are due to changes in temperature during seasons and also nutrient availability (McLusky 1989). Temperature influences the geographical distribution of organisms in estuaries occurring in the three biogeographic regions found in South Africa. These are the subtropical, warm temperate and cold temperate biogeographic regions (De Villiers and Hodgson 1999). The water temperatures in these regions are different, with the subtropics having warm water temperatures with a minimum of 16°C (Day 1981a). The warm temperate region, which includes the Eastern and Southern Cape coast, has a minimum of 12°C -14°C, while the cold temperate region is the coldest with minimum temperature less than 12°C (Day 1981a). The benthic species diversity and biomass decreases from the subtropical to the cold temperate region (De Villiers and Hodgson 1999). This means that the subtropical region, which includes all of the KwaZulu-Natal estuaries, has the highest species diversity and biomass, while the Western Cape estuaries, which are in the cold temperate region, have the lowest species diversity and biomass (De Villiers and Hodgson 1999).

Benthic macroinvertebrates are very important in aquatic systems as they form an important food source for larger crustaceans, benthic feeding fish and birds (Kalejta and Hockey 1991, Vivier 2011). They are also amongst the most sensitive aquatic fauna and as a result have been widely used as indicators of disturbances in aquatic ecosystems (Dauer 1993, Rosenburg and Resh 1993). Their diversity, abundance and biomass in ecosystems generally

indicate the health of that system and benthic studies are routinely carried out to assess the habitat quality of aquatic ecosystems (Rosenburg and Resh 1993).

In South Africa, many researchers have focused on the distribution, abundance and seasonal variation in estuarine benthic communities. The benthos of the St Lucia estuarine system, the largest and most important estuarine system in South Africa, which comprises an area of 325 km², has been intensively studied over the past few decades, probably due to its World Heritage importance and the fact that it has been greatly affected by human impacts (Millard and Broekhuysen 1970, Bolt 1975, Blaber *et al.* 1983, Owen and Forbes 1987, Pillay and Perissinotto 2005, Mackay *et al.* 2010). Mackay and Cyrus (1998) provided information on benthic invertebrates of the Mhlathuze Estuary before and after the construction of the Richards bay harbour. They reported that previously the estuary was dominated by a number of species of crustaceans, while after harbour construction polychaete had become more species rich due to disturbance of the habitats. A survey on the benthic fauna of the Nhlabane estuary following a dredger crossing showed that the recovery of the benthic community was slow in terms of seasonal changes (Vivier and Cyrus 1999). The benthos of the Mfolozi-Msunduzi system showed to be influenced by temperature, salinity and sediment characteristics (Ngqulana *et al.* 2010). This study also showed the impact of silt deposition on the benthos of the Msunduzi Estuary, and impacts of frequent flooding on the benthos of the Mfolozi Estuary. The impact of silt deposition on the benthos of the Msunduzi Estuary was the fact that the substrata was characterised by soft mud in which few organisms can adapt, while frequent flooding in the Mfolozi lead to most benthic organisms being swept away.

These studies clearly indicate how the benthic invertebrates respond to different environmental conditions and to habitat disturbances. These studies (Cyrus and Wepener 1997, Mackay and Cyrus 1998, Ngqulana *et al.* 2010) also showed the effects of siltation due to the establishment of mining and removal of riparian vegetation, which acts as traps of terrestrial sediments. Findings of this study coincided with the findings of Whitfield (2000) that most of KwaZulu-Natal estuaries are degraded due to siltation.

1.3 Benthic Biomass

Determination of estuarine benthic biomass provides an important estimate of the food available for predators and allows the evaluation of the various roles of the constituent species in a community (Kalejta and Hockey 1991, Hockey 1992). In the Kariega River Estuary it was determined that 50% of the macrobenthic biomass comprised filter-feeders, mainly the bivalve *Solen cylindraceus* (De Villiers and Hodgson 1999). The benthic biomass and abundance of the Mngazana River Estuary was found to be composed of mainly detritivorous brachyurans which included *Uca* spp. (De Villiers and Hodgson 1999). These studies have shown how the availability of food in the system influences the feeding strategies for these organisms (see 1.2). Studies on the benthic biomass of the St Lucia system by Bolt (1975), Blaber *et al.* (1983) and Owen and Forbes (1997) showed the changes in the benthic biomass of the system due to salinity changes and influence of flooding. Bolt (1975) and Blaber *et al.* (1983) showed differences in biomass for different sediment types, while Owen and Forbes (1997) showed the effect of different salinity regimes on the biomass of the benthos in this system.

1.4 The Mfolozi-Msunduzi Estuarine System

1.4.1 Historical information on the system

The Mfolozi-Msunduzi Estuarine system is located adjacent to the St Lucia system, 60km north-east of Richards Bay along the KwaZulu Natal coastline and is formed from the combination of the Mfolozi and Msunduzi Rivers (Begg 1978). The Mfolozi-Msunduzi Estuarine system historically has a very close and important relationship with the St. Lucia Estuarine system, which is the largest estuarine system in Africa and is also a World Heritage Site (Whitfield and Taylor 2009).

Historically, the Mfolozi-Msunduzi and St Lucia Estuarine systems both flowed into the St Lucia Bay, which then flowed out to sea through a combined mouth (Begg 1978) (Figure 1a). During drought periods, freshwater from the Mfolozi-Msunduzi Rivers would help keep the mouth open to the sea (Whitfield and Taylor 2009), and during periods of mouth closure also assisted in replacing evaporative water losses from Lake St Lucia (Vivier and Cyrus 2009). The Mfolozi floodplain papyrus and *Phragmites* swamps, which helped to trap sediments

carried by the Mfolozi and Msunduzi Rivers, were largely removed in the 1950s and planted with sugar cane (Begg 1978). In addition, canals and levees were also constructed in order to drain the swamps, which resulted in water flowing directly towards the estuarine area. Swamp removal led to sediments from the Mfolozi-Msunduzi silting up the mouth of St Lucia during flood periods, while aquatic plants and animals were smothered in the upper reaches of the St Lucia Narrows (Day 1981b). As a result, the mouths of the two systems were artificially separated in 1958, with the Mfolozi-Msunduzi diverted to discharge directly to the sea 1.5 km south of St Lucia (Figure 1b). It was subsequently noted that the Mfolozi-Msunduzi mouth was migrating northwards towards the St Lucia Mouth due to long-shore drift and in order to keep the two mouths apart, the Mfolozi-Msunduzi mouth had to be artificially and regularly breached at Mapelane (Whitfield and Taylor 2009).

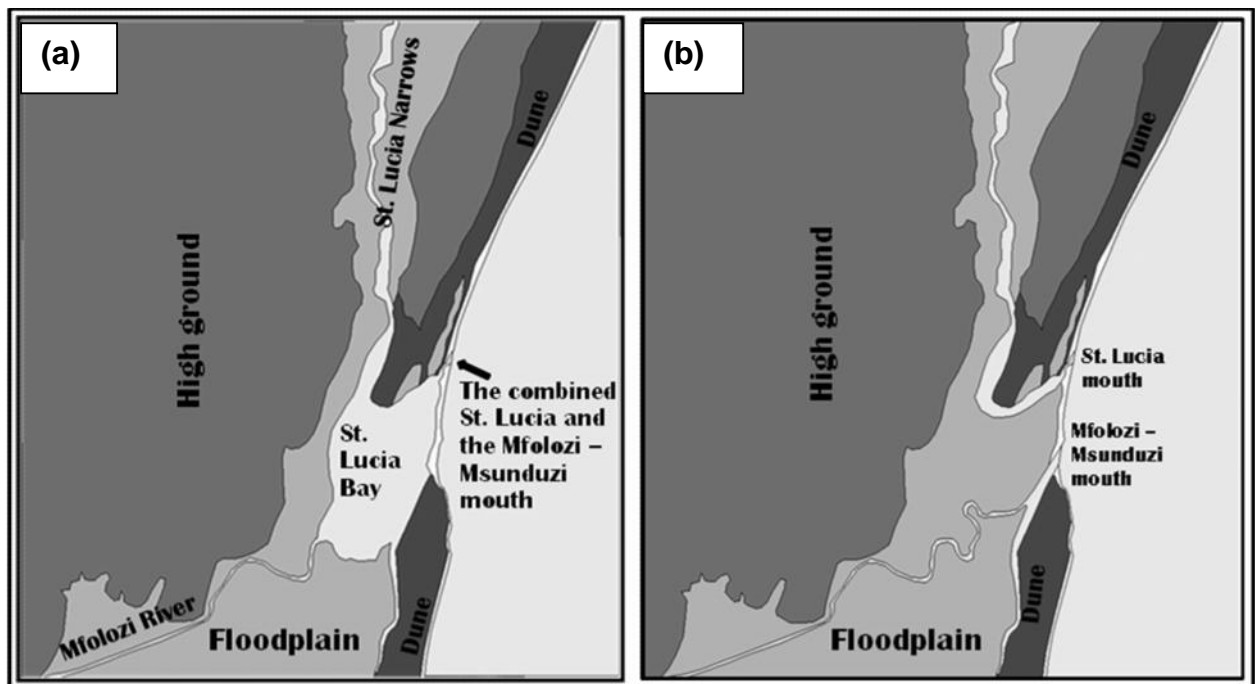


Figure 1: The Mfolozi-Msunduzi and the St. Lucia system sharing a common mouth (a) and after a separate mouth was excavated for the Mfolozi-Msunduzi Estuarine system (b) (Taylor 2006).

1.4.2 Catchment Activities leading to Increased Siltation of the Mfolozi- Msunduzi estuary
The Mfolozi-Msunduzi system has the second largest catchment (11 068km²) in KwaZulu-Natal (Lindsay *et al.* 1996). The majority of land in the catchment is used for agricultural purposes, either commercial or for subsistence farming. Part of the catchment is also under

natural vegetation as it lies within the Mfolozi-Hluhluwe Nature Reserve (Harrison *et al.* 2001, Grenfell and Ellery 2009 and Grenfell *et al.* 2009). The natural vegetation of the catchment consists of grassland, thicket, bush, forest and woodland. Large parts of the catchment are degraded due to overgrazing and poor catchment management practices (Harrison *et al.* 2001 and Grenfell and Ellery 2009). There is very little formal urban development in the catchment, although informal rural settlement abounds throughout the catchment. Industrial development is largely restricted to the Mtubatuba area with timber and sugar-cane milling in the lower catchment (Harrison *et al.* 2001, Berning *et al.* 2000). In the upper catchment, around Vryheid, there are also coal-mining and quarrying activities (Berning *et al.* 2000 and Grenfell *et al.* 2009). The Mfolozi floodplain is predominantly used for the cultivation of sugarcane, while a small part falls within the iSimangaliso Park (Harrison *et al.* 2001 and Grenfell and Ellery 2009). Water abstraction from the Mfolozi River for the town of Mtubatuba is one of numerous water abstraction activities which influence the water balance and flow of the Mfolozi River (Harrison *et al.* 2001). Richards Bay Minerals (RBM) also operates a water abstraction plant approximately 12km from the mouth in order to fill their Sokhulu reservoir, which further affects the flow of the system (Lindsay *et al.* 1996).

Levees, spillways and drains have been constructed in the floodplain to prevent water from overflowing to the farms during flooding conditions (Berning *et al.* 2000). Levees with an average height of three meters prevent flooding caused by the overflow of the Mfolozi banks and thus preventing damage to farms and cane fields (Berning *et al.* 2000). Levees were also built in areas where the farms border the river, and these areas include the south bank, the largest part of the Mfolozi River and the Msunduzi River (Berning *et al.* 2000). A drainage network of canals approximately 115km in length was constructed to remove flood water from the low-lying sugar cane fields in the floodplain towards the Mfolozi and Msunduzi Rivers (Berning *et al.* 2000). Two spillways were constructed to divert excess floodwater from the Mfolozi to the Msunduzi River so as to avoid the overflowing of the main Mfolozi River bank. The longest spillway in the system is approximately 1km in length and was constructed after cyclone Domoina in 1984. The function of the spillway is to decrease the velocity of water during floods, so that floodwaters flow across the floodplain, resulting in less sand being carried by the water which would, otherwise, have been deposited on the low-

lying farms (Berning *et al.* 2000). The second spillway also channels the floodwaters evenly over the sugar cane fields (Berning *et al.* 2000).

The above mentioned activities in the Mfolozi-Msunduzi catchment have been known to increase the sediment load which enters the estuarine system (Lindsay *et al.* 1996 and Berning *et al.* 2001). These aforementioned activities have been reported to lead to increased water turbidities in estuarine systems (Thrush *et al.* 2004). The Mfolozi-Msunduzi system is regarded as the most turbid estuary in South Africa due to its high sediment load (Lindsay *et al.* 1996). Agriculture has adverse effects on estuarine ecosystems with regard to sediment loads, due to burning, land clearing, planting and grazing. Elevated sediment loads result in clogging of gills, which interferes with respiration and ingestion in aquatic organisms (Berry *et al.* 2003). Smothering of benthic organisms also occurs as a result of increased sediment loads in estuarine systems, leading to mortality and changes in community structure (Berry *et al.* 2003). The habitat is altered due to changes in sediment grain size composition, which also affects the distribution of infaunal benthic organisms (Teske and Wooldridge 2003, Berry *et al.* 2003).

1.5 Motivation

Estuarine benthic invertebrates play an important role in the ecological functioning and health of aquatic ecosystems because they are generally sensitive to pollution and changes which occur in their environment or habitat (Rakocinski and Zapfe 2005). They form an important food source for fish, larger invertebrates and birds (Kalejta 1992). Because of their importance as primary consumers, they can be used to determine the annual production: biomass (P:B) ratios in estuaries (Rakocinski and Zapfe 2005). Masero *et al.* (1999) reported the dependence of wading birds on intertidal areas as they get to feed on macroinvertebrates during low tides. Heymans and Baird (1995) found that benthic invertebrates played a key role in the Kromme Estuary, South Africa, as an important food source for fish. Benthic organisms are also commonly used as bioindicators of estuarine system health as they display different tolerances to stress (van Dolah *et al.* 1999, Dauvin 2007). It was found that the benthic assemblage in the sand-flats adjacent to urban areas was different to that of the sand-flats in non-urban areas in the Port Hacking Estuary, Australia (Stark 1998, Lindegarth and Hoskin 2001). The aforementioned study showed that these differences in community

structure were caused by different concentrations of metals which enter the estuary through urban runoff.

The Mfolozi-Msunduzi system was, until recently, one of the least studied estuarine systems in terms of its biota, along the KwaZulu-Natal coastline. It was not until 2007 that Ezemvelo KZN Wildlife (EKZNW) identified the general lack of information on the Mfolozi-Msunduzi system as a gap in the estuarine information in KwaZulu-Natal and listed an investigation of the system as a priority project with Marine Coast Management (MCM). This led to a proposal by the Coastal Research Unit of Zululand (CRUZ) of the University of Zululand to survey the biotic and physico-chemical aspects of the estuary. The first quantitative benthic survey of the Mfolozi-Msunduzi system commenced in 2007 (Ngqulana *et al.* 2010). During this study, the system was sampled biannually in March and August 2007-2008. In this study, it was identified that the system was impoverished in terms of zoobenthic diversity. Using the results of this study, the potential of the Mfolozi-Msunduzi biota to re-colonize the adjacent St Lucia estuary when its mouth opened (Owen *et al.* 2010) was considered. The following, identified by Owen *et al.* (2010), were drivers leading to the present study being undertaken:

- The Mfolozi study was important for our understanding of the long term management options for St Lucia, given the state of St Lucia in the current drought.
- By increasing our understanding of the factors which influence the benthic community structure of the system, the outcomes of the Mfolozi-Msunduzi study would assist in the proposal to re-establish the historical link between the two estuaries so that St Lucia can again receive freshwater input from the Mfolozi and Msunduzi Rivers by understanding the factors which influence the benthic community structure of the system.
- The Mfolozi study also highlighted the importance of diverting water from the Mfolozi into St Lucia during low flows via a back channel.

A critical element in the biotic composition of the Mfolozi-Msunduzi system identified during the 2007-2008 study was the highly impoverished zoobenthic community in terms of the number of taxa and densities. The reasons for this needed to be further investigated. At the same time, it was reported that the Mfolozi-Msunduzi system supports a rich fish

community, of which certain fish species are regarded as primarily benthic feeders (Vivier and Cyrus 2009). In view of the impoverished benthic fauna, it became imperative to find out to what extent these fish were feeding on benthic organisms. The lack of data on the benthic biomass of the Mfolozi-Msunduzi system was therefore identified as a critical information gap which needed to be addressed. A further study on the benthic community of the Mfolozi-Msunduzi system to determine the benthic biomass of the system was therefore required, as it would provide the necessary information on the availability of food for fish and other benthic feeding organisms, such as migrating estuarine birds (Whitfield 1980 and Kalejta 1992). This study was also conducted to further investigate the spatial and temporal distribution of the benthos in the system in relation to important environmental influences such as riverine runoff, mouth conditions and the high silt load. This study was considered to be important as it will contribute towards setting and implementing management strategies for both the Mfolozi-Msunduzi Estuary as well as the St Lucia Estuary, to which it was previously connected.

1.6 Objectives

The overall objectives of the study were:

- To conduct a quarterly survey of the Mfolozi-Msunduzi Estuarine system during 2009 to investigate the spatial and temporal distribution of the benthos in the system, in terms of :
 - community structure
 - standing stock biomass
 - influence of environmental factors on the benthos of the Mfolozi-Msunduzi estuarine system.

CHAPTER 2: Study Area and Methods

2.1 Study Area

The Mfolozi-Msunduzi Estuarine system (28°24'S; 32°25'E) is classified as a river mouth (Whitfield 1992). The estuary forms a common mouth for the Mfolozi and the Msunduzi Rivers (Figure 2). River mouth estuaries are characterized by riverine mixing processes and small tidal prisms (Whitfield 1992). The Mfolozi River drains the second largest catchment in KwaZulu-Natal, with a catchment area of approximately 11 068 km² (Begg 1978). The Msunduzi drains a much smaller catchment of 559 km² (Begg 1978).

The Mfolozi River enters the floodplain through the Lebombo Mountains, while the Msunduzi River arises towards the southwest of the floodplain (Vivier *et al.* 2009). The Msunduzi River then combines with the Mfolozi River approximately 0.5 km from the combined mouth of the system (Vivier *et al.* 2009) (Figure 2). The Mfolozi-Msunduzi system is located in a subtropical region characterized by summer rainfall and this is reflected by freshwater inputs being higher in summer (63 m³.s⁻¹) compared to winter (3 m³.s⁻¹) (Lindsay 1996).



Figure 2: The Mfolozi-Msunduzi Estuarine system, also showing the lower reaches of the St Lucia Narrows (Google Earth).

2.2 Materials and methods

2.2.1 Field procedures

The Mfolozi-Msunduzi estuarine system was sampled quarterly in 2009 during March (autumn), June (winter), August (spring), and November (summer) 2009. Ten sampling sites were selected and were mapped by GPS coordinates to ensure that the same site was sampled every sampling season, with six and four sites along the lengths of the Mfolozi and Msunduzi Estuaries, respectively (Figure 3). Each site was selected to represent a progression from the upper to the lower reaches of the two estuaries, in order to produce comparable results. In the Mfolozi Estuary sites F5 and F6 represented the upper reaches, sites F3 and F4 were in the middle while F1 and F2 were in the lower reaches. In the Msunduzi Estuary S4 was in the upper reaches, S2 and S3 in the middle reaches and S1 lower reaches. A Zabalocki-type Ekman grab, sampling an area of 0.0236 m², was used to collect benthic and sediment samples. Five benthic replicates were randomly collected at each site. Each grab sample was emptied into a 25 l bucket, stirred and then washed and sieved through a 0.5 mm mesh sieve. If the sample contained muddy sediments, the contents were agitated and the whole sample was poured through a 0.5 mm mesh sieve. The sample was washed to remove as much mud as possible and then stored in a plastic honey jar. If the sample contained a lot of coarser sand and shells, the contents in the bucket were stirred vigorously and the supernatant was poured through a 0.5 mm mesh sieve. This process was repeated five times to ensure that all the animals were washed from the sand and the sample was then stored in a plastic honey jar. The contents of the bucket were then poured through a 1 mm mesh sieve and any animals retained were added to the sample. A solution of 10% formalin was added to each sample to preserve the organisms. Phloxine B dye was added to the formalin to stain the animals to facilitate sorting in the laboratory. One sediment sample was collected at each site from the substrate surface down to approximately 5cm depth using a Zabalocki-type Ekman grab, for sediment grain size and organic content analysis. Organic samples were preserved in 10% formalin.

Water quality parameters of the system, including salinity, temperature, oxygen concentration and pH were measured concurrently with benthic sampling using a YSI Multiprobe. A water sample was also collected mid-water in a two-litre bottle at each site for nutrient analysis. These samples were analysed for nitrate, nitrite, ammonia, biochemical oxygen demand,

ortho-phosphate, total phosphate and chlorophyll-a concentrations by the accredited Mhlathuze Water Board analytical laboratory using standard techniques. DWAF (1995) water quality guidelines were used for compliance with national standards. For variables for which no national water quality guidelines were available, comparable Australian-New Zealand water quality guidelines (ANZECC 2000) were used.

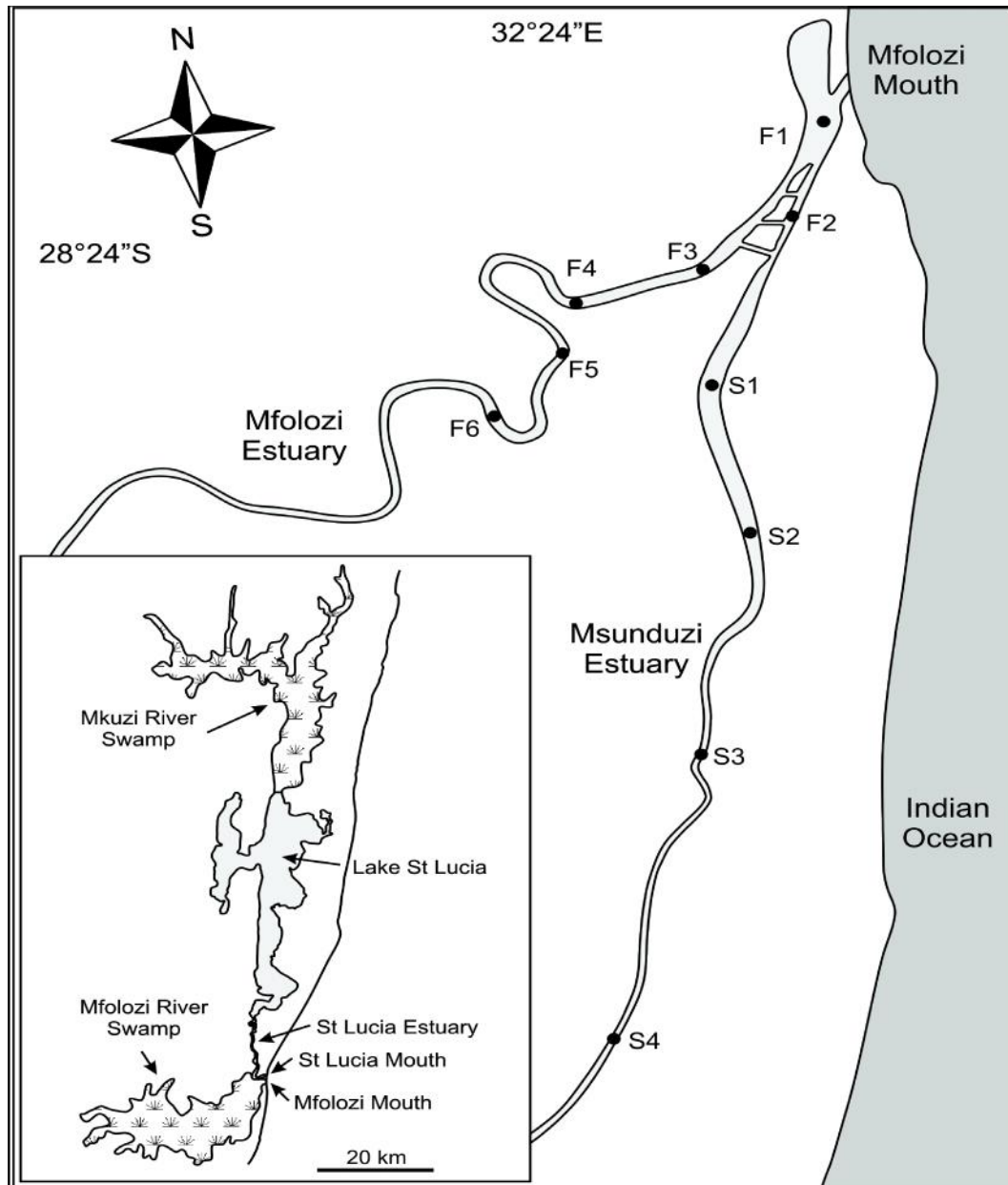


Figure 3: The selected sampling sites in the Mfolozi (F1-6) and Msunduzi (S1-4) Estuaries.

2.2.2 Laboratory Procedures

Samples were transported to the laboratory for sorting. The benthic organisms were identified to species level where possible and counted. Taxa were identified using keys and descriptions in Day (1967) for polychaetes and Griffiths (1976) for amphipods. Freshwater taxa were identified using a field guide for aquatic invertebrates of South African rivers by Gerber and Gabriel (2002). The density of each benthic taxa was calculated per square metre. This was done by calculating an average of the five grabs taken at each site and then dividing the average by the area of the grab (0.0236 m²). These densities were then graphically presented using pie charts to show abundance and contribution of taxa in the system per season.

For biomass determination, a number of organisms of each species were washed, dried to constant weight at 60°C in a Gallenkamp oven for 24 hours and weighed on a Sartorius Micro M500P balance. Animal shells of gastropods or bivalves were dissolved in a nitric acid solution. The average biomass for each species was determined and the average biomass of the benthic community was calculated for each season. Biomass was expressed as g.m⁻² dry weight. In comparative literature on benthic biomass, biomass was also expressed as dry weight.

Sediment samples were analysed by using the wet sieving method for grain size, sorting coefficient and organic content by the Environmental Mapping and Surveying Ltd. The description of the sediment characteristics used in the results and discussion follow those used by Gray (1981), which are as follows:

Median phi: 1.0 = Coarse Sand

2.0 = Medium sand

3.0 = Fine sand

>4.0 = Mud

Sorting coefficient: <0.4 = Very well sorted

0.4 - 0.5 = well sorted

0.5 - 0.7 = moderately well sorted

0.7 - 1.0 = moderately sorted

1.0 - 2.0 = poorly sorted

2.0 - 4.0 = very poorly Sorted

> 4.0 = extremely poorly sorted

Organic Content: <0.5% = low

2.0 – 4.0% = medium

>4.0% = high

2.2.3 Statistical analysis

The DIVERSE function in PRIMER was used to analyse for species diversity indices, such as mean abundance (N), mean number of taxa (S), Shannon-Wiener diversity (H'), Margalef's species richness (D) and Species Evenness (J). These were used to determine changes in benthic composition between the Mfolozi and Msunduzi Estuaries, between sites and between seasons during the study period. Single factor analysis of variance (ANOVA) was used to test the significance of temporal and spatial differences between these indices.

Multivariate analysis (PRIMER statistical package) was used to detect any differences in the community structure between sites and seasons using hierarchical clustering and ordination (Clarke & Warwick 2001). Transformation of the data (Log x+1) was followed by Hierarchical clustering on a Bray-Curtis similarity matrix and Multi-Dimensional Scaling (MDS) to delineate groups with distinct community structure. Species that contributed most to the similarity within *a priori* identified groups were examined using the SIMPER (Similarity Percentages) routine. The significance of any differences between community groups was tested using analysis of similarity (ANOSIM). The BIOENV function in PRIMER was used to determine which abiotic factors were most responsible for structuring the benthic community. Canonical Correspondence analysis (CCA) in CANOCO (Ter Braak

and Smilauer 1998) was used to further explore the relation between temporal and spatial changes in the benthic community composition and environmental variables.

For comparisons with historical data, the current data were incorporated with the historical benthic data (Ngqulana *et al.* 2010) recorded biannually in 2007 and 2008. This three-year data set was then analysed in order to test for any significant differences between sampling years (2007, 2008 and 2009), sites and the estuaries using the function analysis of similarity (ANOSIM). Cluster and MDS ordination were used to detect any differences between the years, sites and seasons. BIOENV was used to determine which environmental factors were important in the distribution patterns of the benthos during the three-year period. CANOCO was used to test for correlations between the fauna and the environmental factors.

CHAPTER 3: RESULTS

3.1 Physico-Chemical Parameters

3.1.1 Salinity

Salinity in the Mfolozi-Msunduzi Estuarine system during the study period varied from marine to freshwater (Figure 4a). In autumn the mouth of the system was open and higher salinities were recorded in the lower reaches, with a salinity of 35.0 at the mouth (F1) decreasing towards the upper reaches where it reached 0.2. In the Msunduzi estuary, salinity ranged from 30.0 in the lower reaches (S1) to 2.4 in the upper reaches (S4). In autumn and winter, salinities were higher at the mouth, decreasing towards the upper reaches of the of the Mfolozi estuary.

The mouth was again open in winter and the salinity was 34.0 at the mouth, decreasing towards the upper reaches with a salinity of 6.0 in the upper reaches of the Mfolozi estuary. The same trend was observed in the Msunduzi estuary, where salinity varied from 24.0 in the lower reaches decreasing to 1.1 in the upper reaches. The mouth was closed in spring and salinities in the Mfolozi estuary were higher at the mouth, decreasing towards the upper reaches, while salinities in the Msunduzi estuary ranged from 14.0 to 16.4. The salinity ranged from 32.0 at the mouth, decreasing towards the upper reaches with a salinity of 8.2 at site F6 in spring.

In summer the mouth of the system was open and the Mfolozi estuary was dominated by freshwater inflow. As a result of this, the system had very low salinities, ranging from 0.2 at the mouth to 0.1 in the upper reaches, while in the Msunduzi estuary salinities ranged from 1.3 to 0.9 in the upper reaches.

3.1.2 Temperature

Water temperatures in the system followed a typical seasonal pattern, ranging from 18°C to 30°C (Figure 4b). In autumn temperatures were between 24°C and 30°C. In summer temperatures remained at 26°C throughout the system. In winter, temperatures recorded in the Mfolozi estuary ranged from 23°C in the lower reaches, gradually decreasing to 20°C in the upper reaches, while temperatures ranged from 20°C in the lower reaches of the Msunduzi estuary to 18°C in the upper reaches. In spring, temperatures remained at 20°C for all of the Mfolozi and Msunduzi sampling sites. It was noted that in autumn, temperatures increased towards the upper reaches of both the Mfolozi and Msunduzi Estuaries. In winter, temperatures were higher in the lower reaches, decreasing towards the upper reaches of both the Mfolozi and Msunduzi estuaries.

3.1.3 Turbidity

Turbidities were related to flow conditions in the system, being generally lower during low flow conditions in winter and high during high flows in summer. Turbidities of the system were generally lower at the mouth, increasing towards the upper reaches (Figure 4c). However, this was not the case in the Msunduzi estuary during summer, when turbidities were higher in the lower reaches, decreasing towards the upper reaches. In autumn, winter and spring, turbidities were generally higher in the Msunduzi than in the Mfolozi estuary.

Turbidity in autumn, under open mouth and moderate flow conditions, ranged from 17 NTU at the mouth to 216 and 622 NTU in the upper reaches of the Mfolozi and Msunduzi estuaries, respectively (Figure 4c). In winter turbidities ranged from 1 NTU in the lower reaches to 15 and 76 NTU in the upper reaches of the Mfolozi and Msunduzi estuaries, respectively. In spring, under closed mouth and low flow conditions, turbidities ranged from 58 NTU at the mouth to 34 NTU in the upper reaches of the Mfolozi estuary. In summer, the Mfolozi Estuary was in flood just prior to sampling and as a result very high turbidities were recorded in this estuary. Turbidities ranged from 1288 NTU at the mouth to 1290 in the upper reaches of the Mfolozi Estuary. A reverse turbidity gradient was observed in the Msunduzi estuary, ranging from 479 NTU in the lower reaches to 81 NTU in the upper reaches. This

reflected the extent to which flood waters from the Mfolozi had pushed back up the Msunduzi estuary.

3.1.4 Dissolved Oxygen (mg/l)

The dissolved oxygen concentrations recorded in the system are illustrated in Figure 5a. In general, the Mfolozi-Msunduzi system was well oxygenated throughout the study period, with oxygen concentrations ranging from 4.0 mg/l to 11.4 mg/l. In autumn, oxygen concentrations in the system remained above the target value (5 mg/l, DWAF 1995). These concentrations ranged from 7.0 mg/l to 10.0 mg/l. High oxygen concentrations were recorded in the Mfolozi estuary in winter, ranging from 10.0 mg/l in the upper reaches to 11.4 mg/l at the mouth. The Msunduzi Estuary showed lower oxygen concentrations than the Mfolozi, ranging from 7.3 mg/l in the upper reaches to 10.4 mg/l at site S2.

The lowest oxygen concentration (4.0 mg/l), which was below the target value for coastal areas (5 mg/l, DWAF 1995), was recorded in the upper reaches of the Mfolozi Estuary in Spring at sites F5 and F6, under closed mouth and low flow conditions. The highest oxygen concentration (7.0 mg/l) was recorded at the mouth (F1) during spring. The Msunduzi estuary had higher oxygen concentrations than the Mfolozi Estuary in spring, with 7.0 mg/l at sites S3 and S4, and 8.0 mg/l at sites S1 and S2. In summer the lowest oxygen concentrations were recorded at sites S2 (9.0 mg/l), S3 and S4 (9.2 mg/l) while the remaining sites of the system ranged from 10.0 mg/l to 11.0 mg/l.

3.1.5 Depth

The Mfolozi-Msunduzi Estuarine system was generally shallow at the mouth, becoming deeper towards the upper reaches (Figure 5b). The water depth in the system was affected by mouth and flow conditions. The Mfolozi estuary ranged from 0.5 m at the mouth, becoming deeper at site F4 (2.0 m), while depth in the Msunduzi estuary ranged from 0.6 m at site S2 to 1.40 m at site S4.

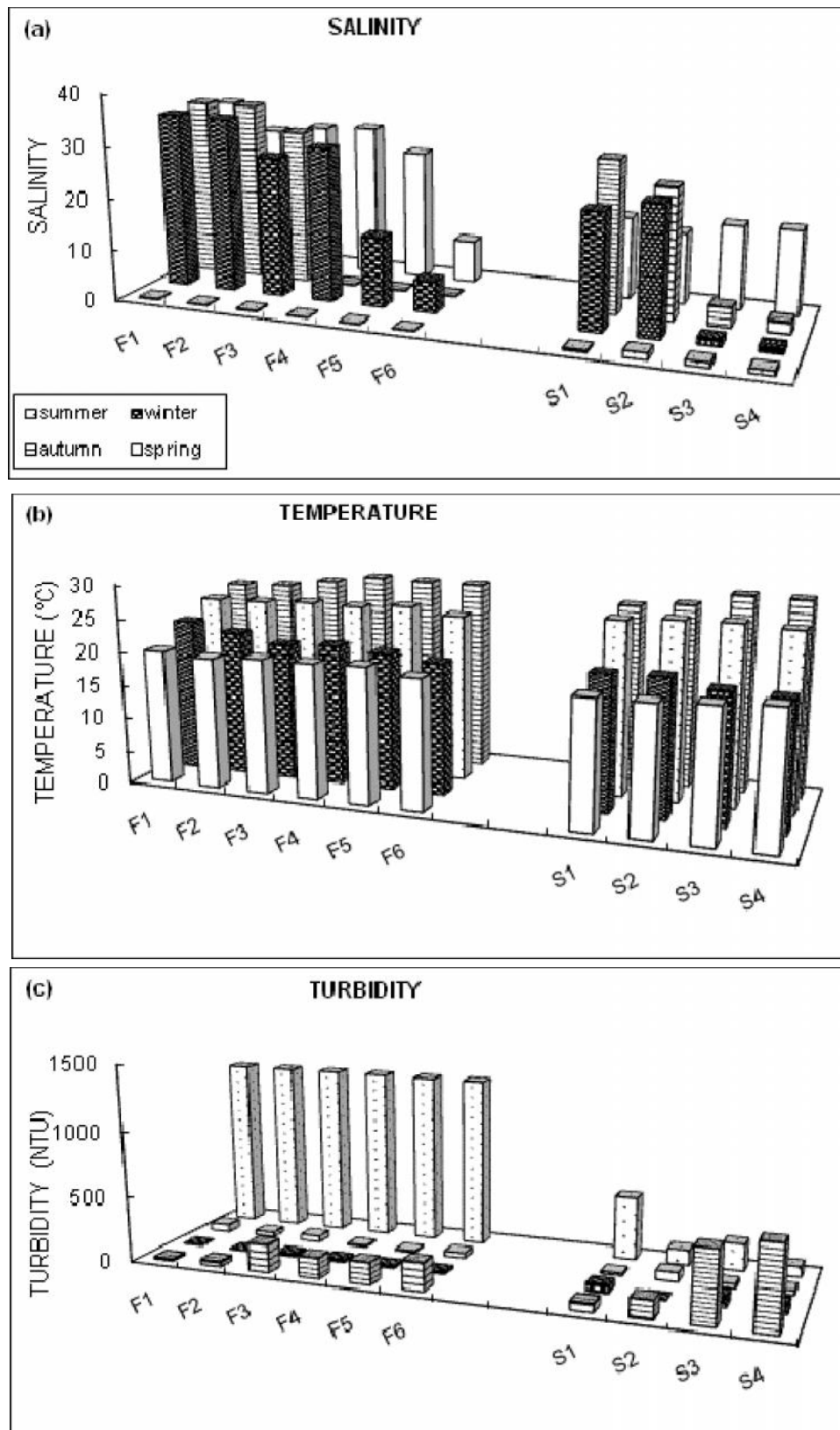


Figure 4: Salinity (a), Temperature (b) and Turbidity (c) recorded during four sampling seasons in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries during 2009.

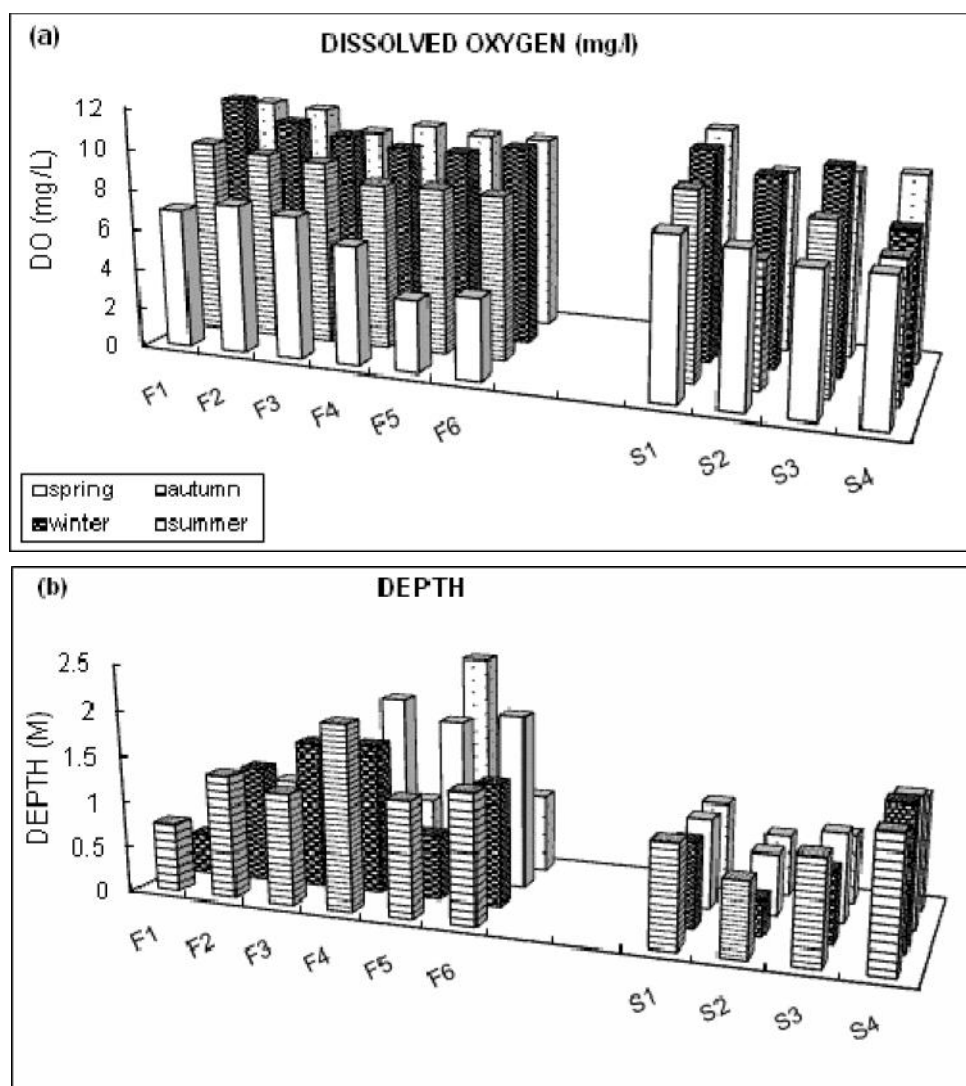


Figure 5: The dissolved oxygen (mg/l) (a) and depth (b) recorded during four sampling seasons in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries during 2009.

3.2 Nutrients

3.2.1 Ammonia

Ammonia concentrations in the system during winter, spring and summer were lower than the recommended target value of 0.15 mg/l (ANZECC 2000) ranging from 0.03 mg/l to 0.11 mg/l (Figure 6a). Ammonia data of the system during autumn were unfortunately lost. Ammonia concentrations were higher in winter compared to the other three seasons sampled, from 0.11 mg/l at sites F3 and F4, followed by a decrease to 0.09 mg/l at sites F5 and F6. Ammonia concentrations in the Msunduzi estuary ranged from 0.06 mg/l to 0.10 mg/l.

In spring, ammonia concentrations ranged from 0.03 mg/l to 0.09 mg/l, decreasing from sites F1 and F2 towards the upper reaches of the Mfolozi estuary. In the Msunduzi estuary, ammonia concentrations increased from site S1 (0.03 mg/l) towards site S3 in the upper reaches (0.08 mg/l). The Mfolozi estuary showed lower ammonia concentrations in summer compared to the other seasons sampled, being 0.03 mg/l at all the Mfolozi sites, while in the Msunduzi estuary ammonia concentrations ranged from 0.03 mg/l to 0.06 mg/l.

3.2.2 Nitrate

Nitrate concentrations in the system ranged from 0.08 mg/l to 3.26 mg/l, with highest concentrations being recorded in the Mfolozi estuary (Target Value 0.05 mg/l, ANZECC 2000) (Figure 6b). These values were consistently higher in the lower reaches and lower in the upper reaches of the system in autumn, winter and spring. In autumn nitrate values ranged from 0.08 mg/l in the upper reaches and site F3, to 2.82 mg/l at sites F1 and F2 of the Mfolozi estuary. In the Msunduzi estuary, nitrate values ranged from 0.08 mg/l at sites S3 and S4 in the upper reaches to 1.86 mg/l at site S2.

The Mfolozi nitrate concentrations in winter ranged from 0.10 mg/l in the upper reaches to 3.26 mg/l in the lower reaches, while in the Msunduzi Estuary it ranged from 0.10 mg/l in the upper reaches to 2.92 mg/l in the lower reaches. In spring, nitrate concentrations in the Mfolozi estuary ranged from 0.08 mg/l in the upper reaches to 3.13 mg/l in the lower reaches, while in the Msunduzi estuary concentrations were higher in the upper reaches (1.54 mg/l) compared to the lower reaches (1.24 mg/l).

In summer, nitrate concentrations were lower than during the previous seasons sampled. Concentrations in the Mfolozi estuary remained the same at all sites sampled (0.04 mg/l), while in the Msunduzi estuary it ranged from 0.40 mg/l at site MS1 to 1.30 mg/l.

3.2.3 Soluble Orthophosphate

The soluble orthophosphate concentrations in the Mfolozi-Msunduzi system were generally higher than the target value (0.005 mg/l, ANZECC 2000), ranging from 0.05 mg/l to 0.16 mg/l. In autumn, winter and spring, concentrations remained uniform (0.05 mg/l) at all sites sampled (Figure 6c). In summer, under high flow conditions, concentrations in the Mfolozi estuary were generally high ranging from 0.11 mg/l to 0.16 mg/l. The soluble orthophosphate concentrations in the Msunduzi estuary remained uniform at 0.05 mg/l.

3.2.4 Total Phosphate

Total phosphate concentrations in the system generally exceeded the target value of 0.20 mg/l (ANZECC 2000), ranging from 0.10 to 8.61 mg/l. The total phosphate concentrations were higher in the Mfolozi estuary in summer when compared to the other seasons (Figure 7a). In autumn concentrations in the Mfolozi estuary gradually increased from 0.25 mg/l in the lower reaches to 1.02 mg/l at site F6. Total phosphate concentrations in the Msunduzi ranged from 0.08 mg/l at site S4 to 0.23 mg/l at site S2.

Concentrations remained at 0.05 mg/l throughout the Mfolozi estuary in winter, but ranged from 0.07 mg/l to 0.24 mg/l in the Msunduzi. In spring, the total phosphate concentrations were high at the mouth (0.49 mg/l), decreasing towards the upper reaches of the Mfolozi estuary (0.05 mg/l). In the Msunduzi estuary, the total phosphate concentrations ranged from 0.05 mg/l to 0.27 mg/l, being highest at site S2 (0.27 mg/l).

In summer, the total phosphate concentrations in the Mfolozi estuary were higher than the other seasons sampled, ranging from 4.28 mg/l at F2 to 8.61 mg/l at site F6. In the Msunduzi estuary total phosphate concentrations ranged from 0.09 mg/l at site S4 to 0.44 mg/l in the lower reaches.

3.2.5 Biochemical Oxygen Demand (BOD)

The BOD concentrations in the system were higher in autumn compared to winter, spring and summer (Figure 7b). BOD values in the Mfolozi estuary ranged from 1.6 mg/l at site F6 to 2.6 mg/l at site F3 and from 2.6 mg/l(S3) to 2.9 mg/l (S4) in the Msunduzi estuary. BOD remained low at all sites sampled of 1.0 mg/l in winter.

In spring all sites showed similar BOD concentrations of 1.0 mg/l, except for site S4, which had a BOD concentration of 1.4 mg/l. The BOD concentrations in summer ranged from 0 to 2.0 mg/l in the Mfolozi estuary, while all Msunduzi sites had a BOD concentration of 2.0mg/l.

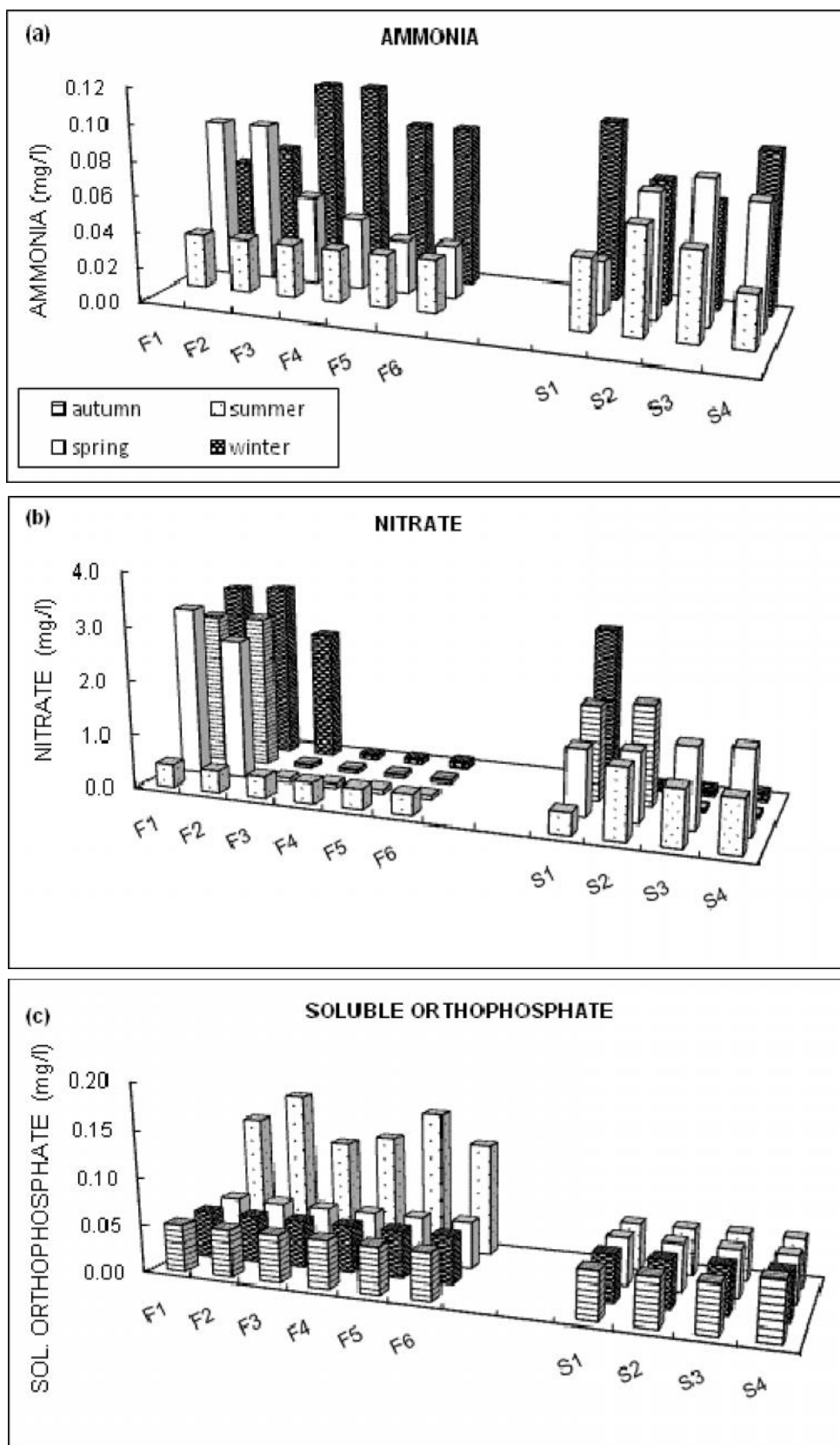


Figure 6: Ammonia (a), nitrate (b) and soluble orthophosphate (c) recorded during four sampling seasons in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries during 2009.

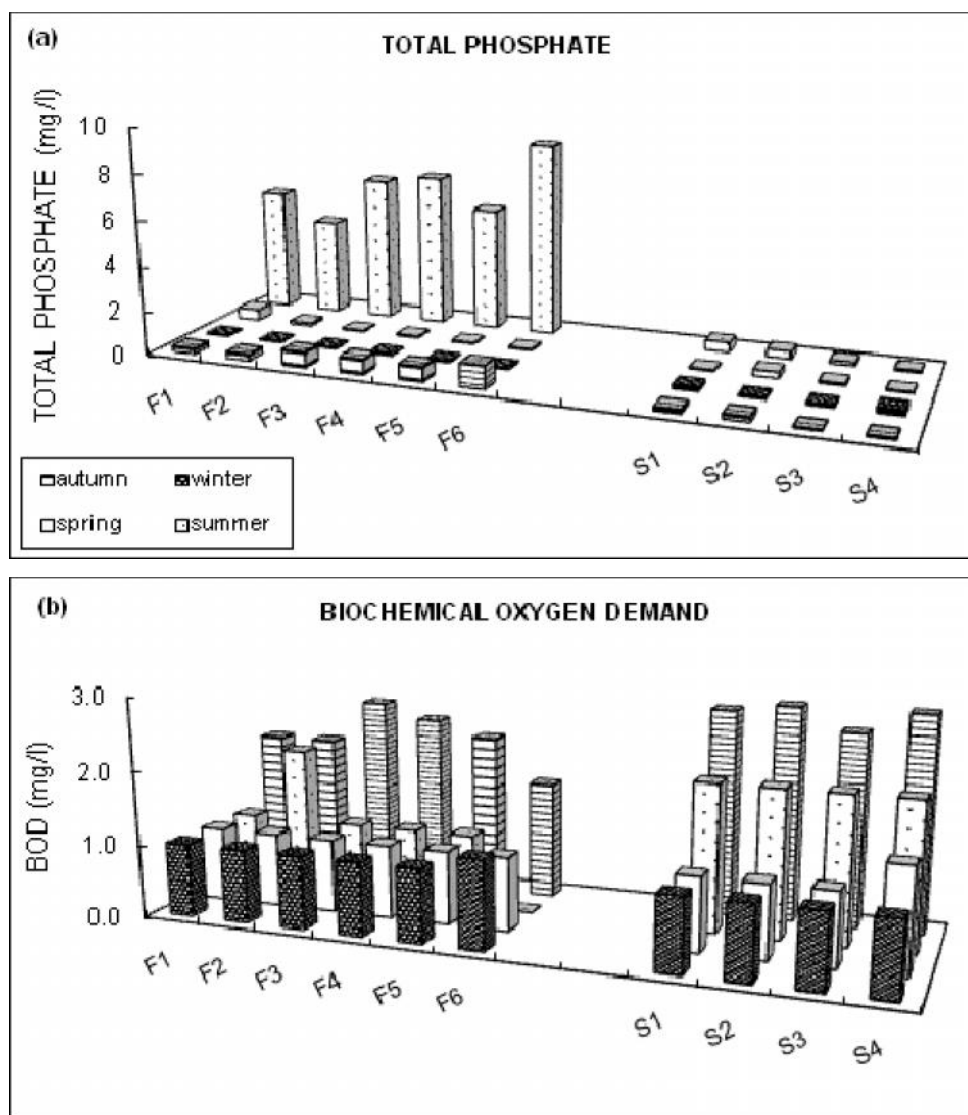


Figure 7: The total phosphate (a) and biochemical oxygen demand (b) recorded during four sampling seasons in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries during 2009.

3.2.6 Chlorophyll-a

The chlorophyll-a concentrations were generally extremely high in the Mfolozi-Msunduzi system considering the target value of 2 $\mu\text{g/l}$ (ANZECC 2000). The autumn chlorophyll-a data for sites F1, F2, S3 and S4 were lost. There were very few sites which had chlorophyll-a concentrations less than the target concentration, and those sites were, F3, S1 and S4 (0.3 $\mu\text{g/L}$) in autumn, F1 (0.7 $\mu\text{g/l}$) in winter and F2 and F6 (0.3 $\mu\text{g/l}$) in summer (Figure 8).

In autumn, chlorophyll-a concentrations ranged from 0.3 to 52.7 $\mu\text{g/l}$ in the Mfolozi estuary, with highest chlorophyll-a at site F2 (Figure 8). In the Msunduzi estuary, concentrations ranged from 0.3 $\mu\text{g/l}$ to 22.9 $\mu\text{g/l}$, with the highest concentration at site S4. In winter chlorophyll-a concentrations in the Mfolozi estuary ranged from 0.7 $\mu\text{g/l}$ to 28.6 $\mu\text{g/l}$, gradually increasing from the lower reaches towards the upper reaches. In the Msunduzi estuary chlorophyll-a concentrations ranged from 3.9 $\mu\text{g/l}$ to 31.2 $\mu\text{g/l}$, with the highest chlorophyll-a recorded at site S3.

In spring the chlorophyll-a concentrations of the Mfolozi estuary ranged from 3.4 $\mu\text{g/l}$ to 31.2 $\mu\text{g/l}$, while in the Msunduzi estuary concentrations ranged from 2.3 $\mu\text{g/l}$ to 4.0 $\mu\text{g/l}$. In summer, concentrations in the Mfolozi estuary ranged from 0.3 $\mu\text{g/l}$ to 8.6 $\mu\text{g/l}$. Chlorophyll-a concentrations in the Msunduzi estuary ranged from 4.0 $\mu\text{g/l}$ to 14.3 $\mu\text{g/l}$ with site S4 having the highest chlorophyll-a.

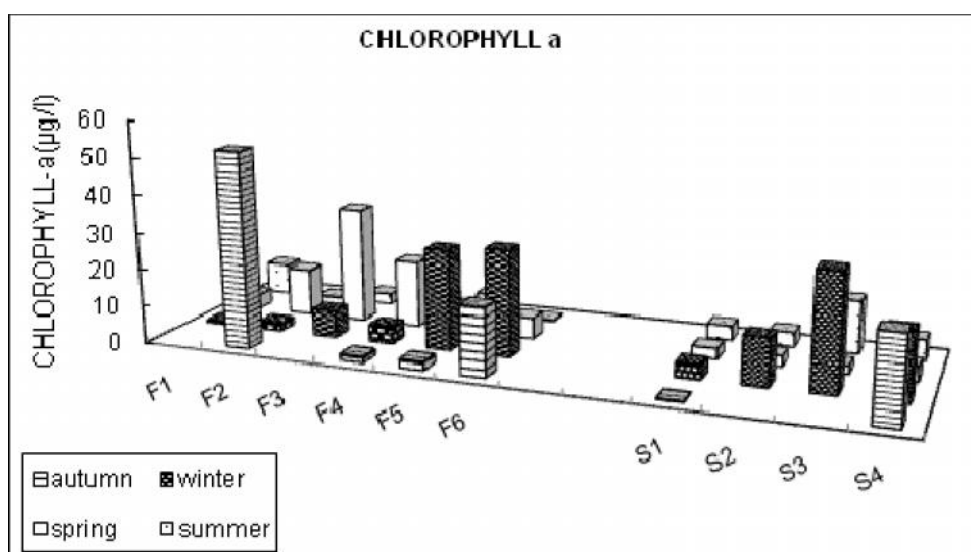


Figure 8: The chlorophyll-a values recorded during four sampling seasons in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries during 2009.

3.3 Sediment Characteristics (Sediment Grain Size, Organic Content and Sorting Coefficient)

During the study period the sediments in the system varied from coarse sand to mud (Figure 9a, Table 1). The Msunduzi sites were all muddy throughout the study period with a median phi value of 4.5, whereas the Mfolozi estuary sites ranged from very coarse sands at the sites F4-F6 to fine sands at sites F1-F3. In the Mfolozi estuary in autumn and winter the mouth (F1) was characterised by mud with a median phi value of 4.5 (Table 1). The remaining sites in the Mfolozi estuary varied between medium and coarse sand (Table 1). All the Mfolozi sites were muddy in spring with the exception of sites F4 and F5 located in the upper reaches, which were characterised by coarse sand. In summer the mouth was again characterised by coarse sand with a median phi value of 1.5, while the remaining sites were all muddy with a median phi value of 4.5 (Table 1).

The sediments of the Mfolozi-Msunduzi system varied from very well sorted to poorly sorted, with mean sorting coefficients between 0.3 and 0.7 (Figure 9b). The Mfolozi sites F2, F3 and F5 showed wide ranges from very well sorted to poorly sorted, while the remaining Mfolozi sites ranged between well sorted and moderately well sorted. The substratum of the Msunduzi estuary was consistently very well sorted during the entire study period, with a sorting coefficient of 0.3. The substratum of the Mfolozi estuary was very well sorted at the mouth in autumn with a sorting coefficient of 0.3, while the remaining Mfolozi sites varied from moderately sorted to poorly sorted, with a sorting coefficient between 1.0 and 2.0 (Table 1). The lower reaches were very well sorted in winter and spring with a sorting coefficient of 0.3, while the upper reaches varied between moderately well sorted and moderately sorted, with the sorting coefficients between 0.5 and 0.7 (Table 1). In summer the sediments of the estuary varied from very well sorted to poorly sorted, with sites F3 and F5 being very well sorted with sorting coefficients of 0.5 and 0.3 respectively.

The organic content of the Mfolozi-Msunduzi sediments varied from low (<0.5%) to medium (2-4%) (Figure 9c). Site F5 had the lowest organic content compared with the other sites sampled in the system, with a mean value of 0.27%, while site S2 had a higher mean organic content compared with other sites of the system, with a mean value of 2.22%.

The percentage organic content of the sediment in the system was found to be higher in the muddy and very well sorted sites compared with sites which were characterised by coarse and poorly sorted sands. Sites S4 in winter and S1 and F1 in spring had a low percentage of organic content, regardless of the fact that they were muddy and very well sorted (Table 1).

There was a negative correlation between sediment organic content and the sorting coefficient (Figure 10a). This reflects the fact that well-sorted sediments generally have a high organic content and poorly sorted sediments have a low organic content. A strong positive correlation was noted between the organic content and the grain size (median phi), which shows that sediments which are muddy or characterised by fine sand generally have a high organic content and that coarse sands have a low organic content (Figure 10b).

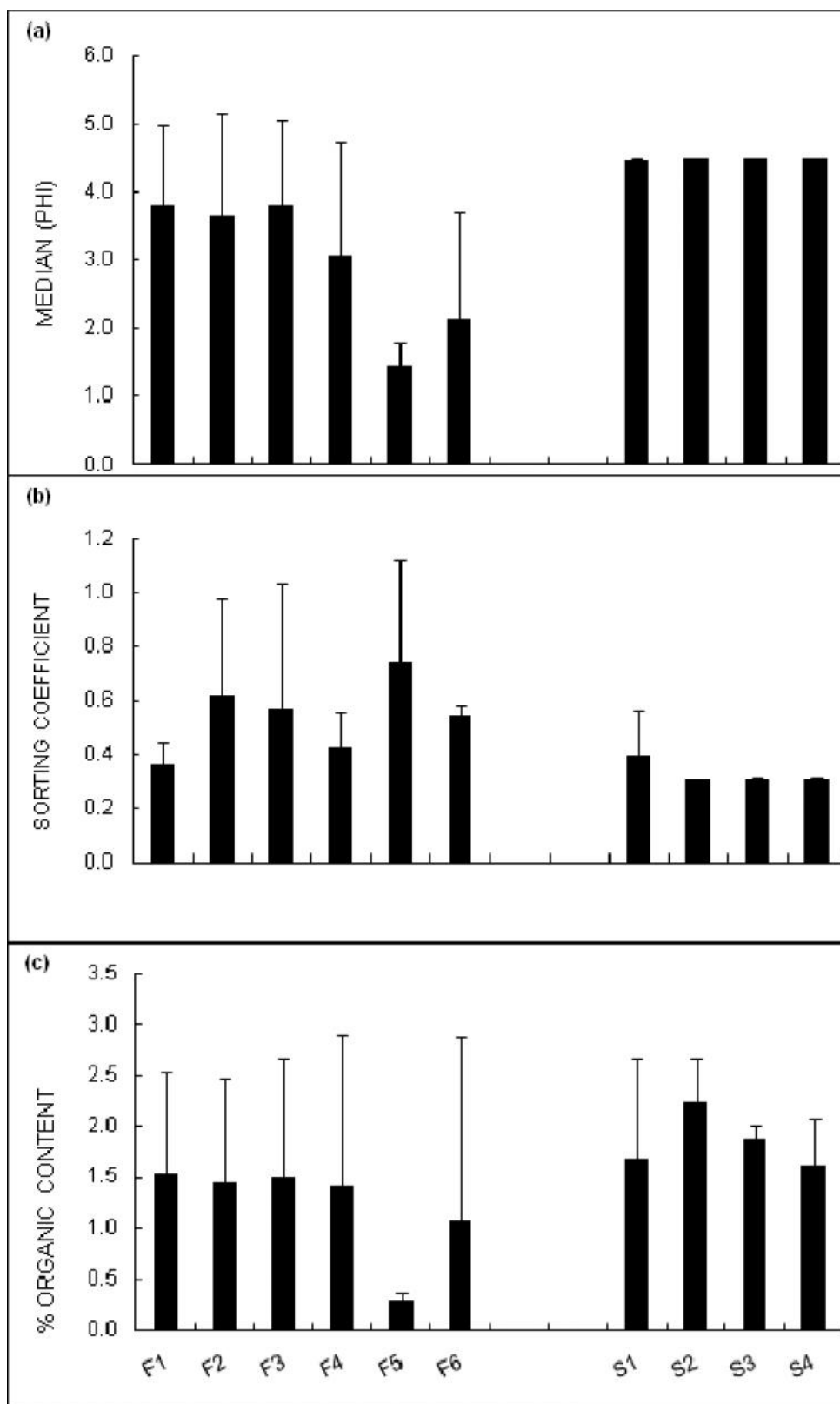


Figure 9: Mean (+1STD) particle size (median phi value) (a), sorting coefficient (b) and organic content (%) (c) of the sediment at sampling sites in the Mfolozi (F1-F6) and Msunduzi (S1-S4) Estuaries.

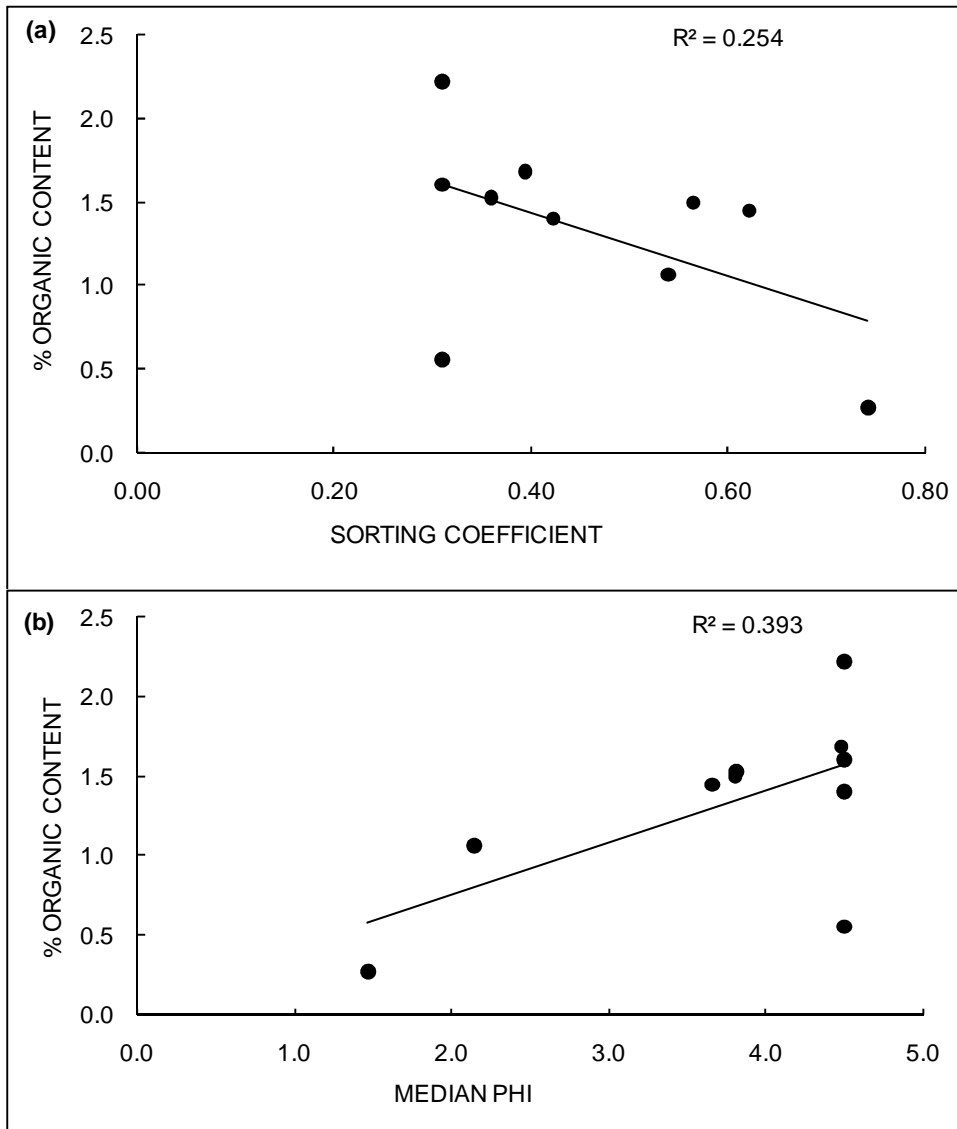


Figure 10: Correlation between the % organic content and the Median phi (a) and sorting coefficient (b) of the sediments in the Mfolozi-Msunduzi system during 2009.

TABLE 1: The percentage distribution of sediment samples to the seven grain size classes, median phi, sorting coefficient and organic content from the Mfolozi-Msunduzi Estuarine system for each sampling period (VCS = very coarse sand, CS = coarse sand, MS = medium sand, FS = fine sand and VFS = very fine sand) (A-autumn, W-winter, SP- spring, summer).

SITE	%GRAVEL	%VCS	%CS	%MS	%FS	%VFS	%MUD	Median (phi)	Sorting coefficient	% organic content
F1A	0.00	0.00	0.08	0.46	0.61	0.46	98.40	4.49	0.31	3.028
F1W	0.00	0.00	0.44	0.89	0.00	0.00	98.67	4.49	0.31	1.76
F1SP	0.00	0.00	0.00	0.21	0.41	0.00	99.38	4.50	0.31	1.04
F1S	0.00	0.13	5.99	64.82	27.05	1.14	0.86	1.75	0.51	0.28
F2A	0.05	0.49	20.99	68.14	9.82	0.39	0.11	1.40	0.54	0.064
F2W	0.00	0.00	1.27	8.70	17.99	2.35	69.70	4.28	1.13	2.20
F2SP	0.00	0.00	0.00	0.00	0.11	0.05	99.84	4.50	0.31	2.26
F2S	0.00	0.25	0.25	0.99	4.41	4.10	90.00	4.44	0.51	1.26
F3A	0.00	0.03	0.48	59.34	39.53	0.56	0.07	1.90	0.37	0.003
F3W	0.00	0.00	0.00	0.22	0.00	0.00	99.78	4.50	0.31	2.11
F3SP	0.00	0.00	0.00	0.28	0.46	0.00	99.26	4.50	0.31	2.67
F3S	0.00	0.00	1.61	17.19	8.92	0.52	71.75	4.30	1.27	1.21
F4A	0.00	0.08	1.92	51.52	43.95	2.52	0.00	1.95	0.52	0.112
F4W	0.00	0.49	26.92	63.38	6.70	0.81	1.71	1.27	0.55	0.26
F4SP	0.00	0.00	0.00	0.18	0.70	0.18	98.94	4.49	0.31	1.95
F4S	0.00	0.00	0.07	0.68	0.48	0.00	98.78	4.49	0.31	3.27
F5A	0.39	2.01	35.16	56.16	6.11	0.12	0.06	1.19	0.59	0.376
F5W	0.00	0.25	13.87	67.28	17.47	0.25	0.88	1.53	0.53	0.25
F5SP	0.00	0.74	31.54	59.77	7.03	0.34	0.58	1.24	0.55	0.15
F5S	0.00	0.12	5.82	50.91	22.38	1.44	19.34	1.90	1.30	0.30
F6A	0.04	0.69	26.05	61.44	11.16	0.44	0.17	1.34	0.56	0.176
F6W	0.00	0.11	14.41	72.34	10.71	0.54	1.89	1.50	0.50	0.12
F6SP	0.00	1.10	33.59	57.35	7.53	0.10	0.32	1.24	0.59	0.16
F6S	0.00	0.00	0.26	1.95	3.21	0.63	93.95	4.47	0.50	3.80
S1A	0.00	0.09	0.18	0.46	0.65	0.37	98.25	4.49	0.31	1.545
S1W	0.00	0.00	0.00	0.12	0.85	0.49	98.54	4.49	0.31	3.11
S1SP	0.00	0.00	0.00	0.14	1.60	0.63	97.64	4.49	0.31	0.96
S1S	0.00	0.16	1.02	3.86	8.47	0.16	86.33	4.42	0.64	1.13
S2A	0.00	0.00	0.18	0.42	0.49	0.18	98.73	4.49	0.31	2.472
S2W	0.00	0.00	0.00	0.00	0.45	0.11	99.44	4.50	0.31	2.66
S2SP	0.00	0.00	0.00	0.00	0.33	0.08	99.59	4.50	0.31	1.66
S2S	0.00	0.00	0.27	0.32	0.43	0.00	98.99	4.49	0.31	2.09
S3A	0.00	0.00	0.08	0.49	1.06	0.82	97.55	4.49	0.31	1.648
S3W	0.00	0.00	0.00	0.14	0.42	0.00	99.43	4.50	0.31	1.93
S3SP	0.00	0.00	0.00	0.00	0.46	0.00	99.54	4.50	0.31	1.89
S3S	0.00	0.00	0.14	0.36	0.29	0.07	99.14	4.50	0.31	1.99
S4A	0.00	0.00	0.24	0.72	0.85	0.85	97.34	4.49	0.31	2.087
S4W	0.00	0.00	0.00	0.09	0.27	0.18	99.46	4.50	0.31	1.26
S4SP	0.00	0.00	0.00	0.00	0.16	0.00	99.84	4.50	0.31	1.95
S4S	0.00	0.00	0.08	0.34	0.34	0.00	99.25	4.50	0.31	1.13

3.4 Macrozoobenthos Composition

A total of 23 taxa was recorded in the Mfolozi-Msunduzi Estuarine system during the study period, with 18 and 15 taxa recorded in the Mfolozi and Msunduzi estuaries, respectively (Table 2). The most abundant species were throughout the system the brachyuran *Paratyloidiplax blephariskios* with a mean total density of 1040 N.m⁻² and the polychaete *Dendronereis arborifera* 784 N.m⁻². These were followed, in descending order of importance according to densities, by the polychaetes *Ceratonereis* sp. (167 N.m⁻²), *Prionospio sexoculata* (106 N.m⁻²) and the amphipod *Corophium triaenonyx* (83 N.m⁻²).

Dendronereis arborifera was by far the most abundant species in the Mfolozi estuary, accounting for 59% of the benthic densities. This was followed by *Ceratonereis* sp. and *P. sexoculata*, while *Paratyloidiplax blephariskios*, Baetidae and Oligochaete sp.1 were also recognised as abundant taxa in this estuary (Figure 11a). In the Msunduzi estuary, *P. blephariskios* was the most abundant species, accounting for 77% of benthic densities. This was followed by *C. triaenonyx*, *D. arborifera* and Oligochaete sp.1. It was noted that *D. arborifera*, *P. blephariskios* and Oligochaete sp. occurred in both estuaries, while taxa such as Ecnomidae, Baetidae, *Orchestia ancheiodos*, *Eumarcia paupercula*, *Glycera longipinnis*, *Glycera natalensis*, *Dendronereides zululandica*, *Prionospio cirrifera* and *Nephtys sphaerocirrata* were only recorded in the Mfolozi estuary. Taxa such as Oligochaete sp.2, *Grandidierella bonnieroides*, *Aapseudes digitalis* and *Mesopodopsis africana* occurred only in the Msunduzi Estuary (Figure 11b).

Differences in the species composition between the Mfolozi and Msunduzi estuaries were very distinct. The benthic community of the Mfolozi estuary was mainly composed of polychaetes, while the benthic community of the Msunduzi was mainly composed of the mud crab *P. blephariskios* and amphipods, which included *Grandidierella bonnieroides*, Lyssianassidae sp. and *C. triaenonyx*. *Dendronereis arborifera*, which accounted for 59% of the benthic densities in the Mfolozi estuary, only accounted for 6% of the benthic densities in the Msunduzi estuary. Polychaetes, such as *Ceratonereis* sp. and *P. sexoculata*, were dominant in the Mfolozi estuary, accounting for 13% and 8% of the benthic densities, but occurred at very low densities in the Msunduzi estuary. *Paratyloidiplax blephariskios*, the

most abundant species in the Msunduzi estuary, only accounted for 5% of the benthos in the Mfolozi Estuary. *Corophium triaenonyx* was another abundant species in the Msunduzi estuary but occurred at very low densities in the Mfolozi estuary.

Paratyloidiplax blephariskios and *C. triaenonyx* were abundant at the sites which were characterised by muddy substrata, while *D. arborifera*, *Ceratonereis* sp. and *P. sexoculata* were associated with sandy substrata (see Figure 11 and Table 1). The appearance of a mysid *Mesopodopsis africana* and Simuliidae in autumn was unusual as these taxa were only recorded during this season. Taxa such as the polychaetes *Glycera longipinnis*, *Glycera natalensis*, Oligochaete sp. 2, a bivalve *Eumarcia paupercula* and a freshwater invertebrate Ecnomidae were only recorded in winter 2009. *Dendronereides zululandica* and Oligochaete sp. 2 only occurred in spring.

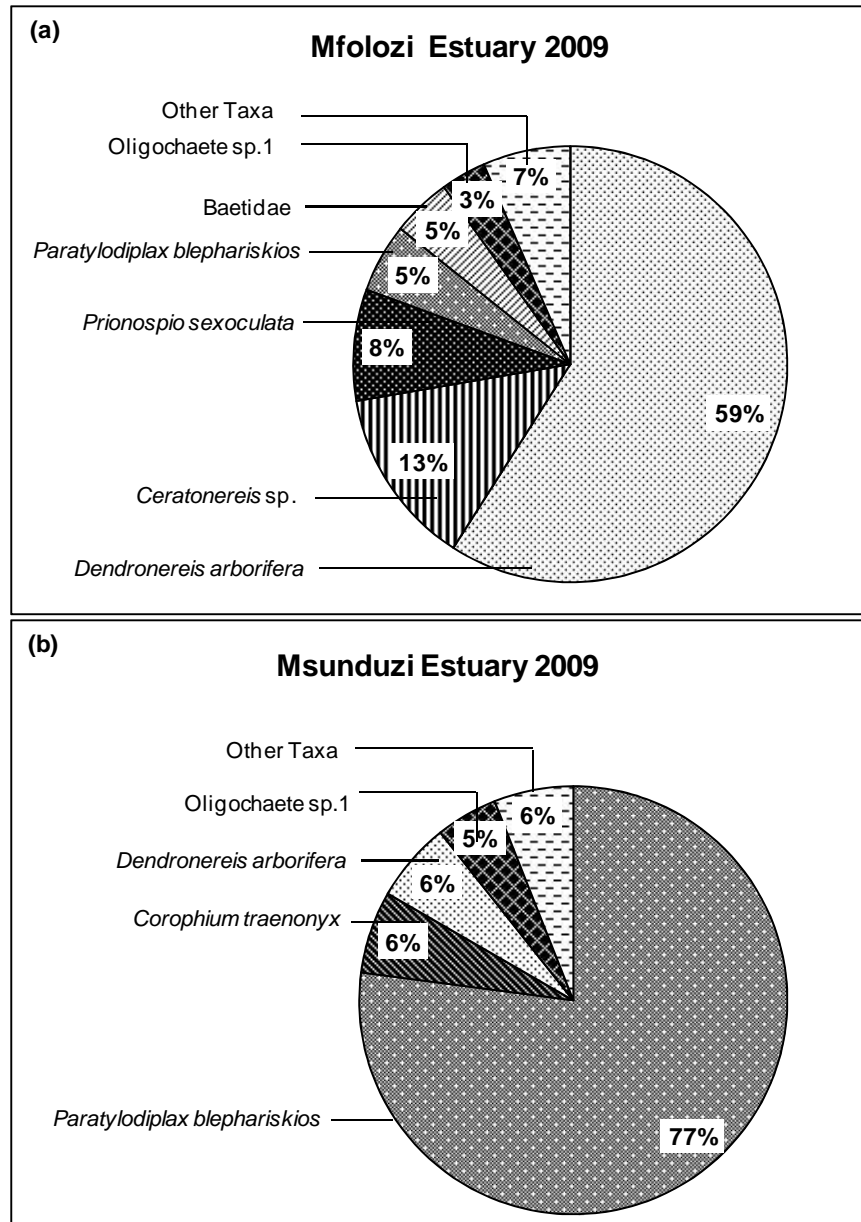


Figure 11: Percentage Composition (Total densities) in the Mfolozi (a) and the Msunduzi (b) Estuaries in 2009.

3.5 Biotic Indices

There were no significant differences ($p < 0.05$) between sampling seasons and between sampling sites with regard to the mean number of taxa, mean densities ($N.m^{-2}$), Species Richness (D), Species Evenness (J') and Species Diversity (H'). The highest mean number of taxa, mean densities ($N.m^{-2}$) and Species Richness (D) were recorded in the lower reaches of the Mfolozi estuary (F1-F3), gradually decreasing towards the upper reaches of the Mfolozi estuary (F4-F6) (Figure 12a-c). The lowest mean number of taxa, mean densities ($N.m^{-2}$) and Species Richness (D) were recorded in the upper reaches of the Msunduzi estuary at site S4. The mean number of taxa, mean densities ($N.m^{-2}$) and Species Richness (D) in the lower reaches of the Msunduzi estuary were lower than in the Mfolozi lower reaches, however, they were higher than the upper reaches of the Mfolozi estuary.

The mouth (F1) had the highest Species Evenness (J') while the other sites displayed similar values (Figure 13a). The highest Species Diversity (H') was recorded at site F2 while the lowest value of species diversity (H') was recorded at site F4 (Figure 13b). The Species Diversity (H') values which were recorded in the upper reaches of the Mfolozi estuary (F4-F6) were similar to those recorded in the Msunduzi estuary.

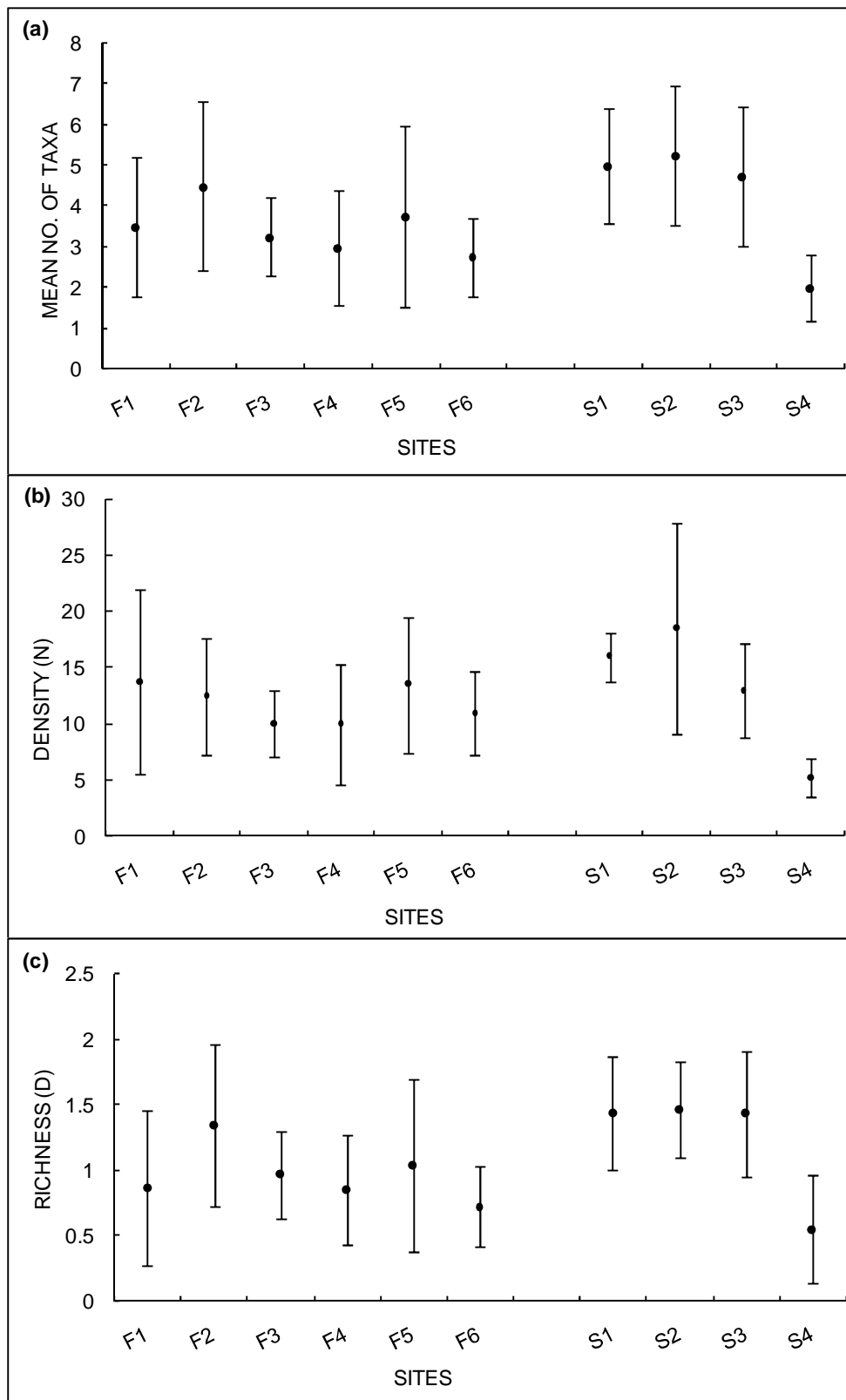


Figure 12: Mean (+1STD) number of taxa (a), density (b) and Species Richness (D) recorded in the Mfolozi (F1- F6) and Msunduzi (S1- S4) Estuaries in 2009.

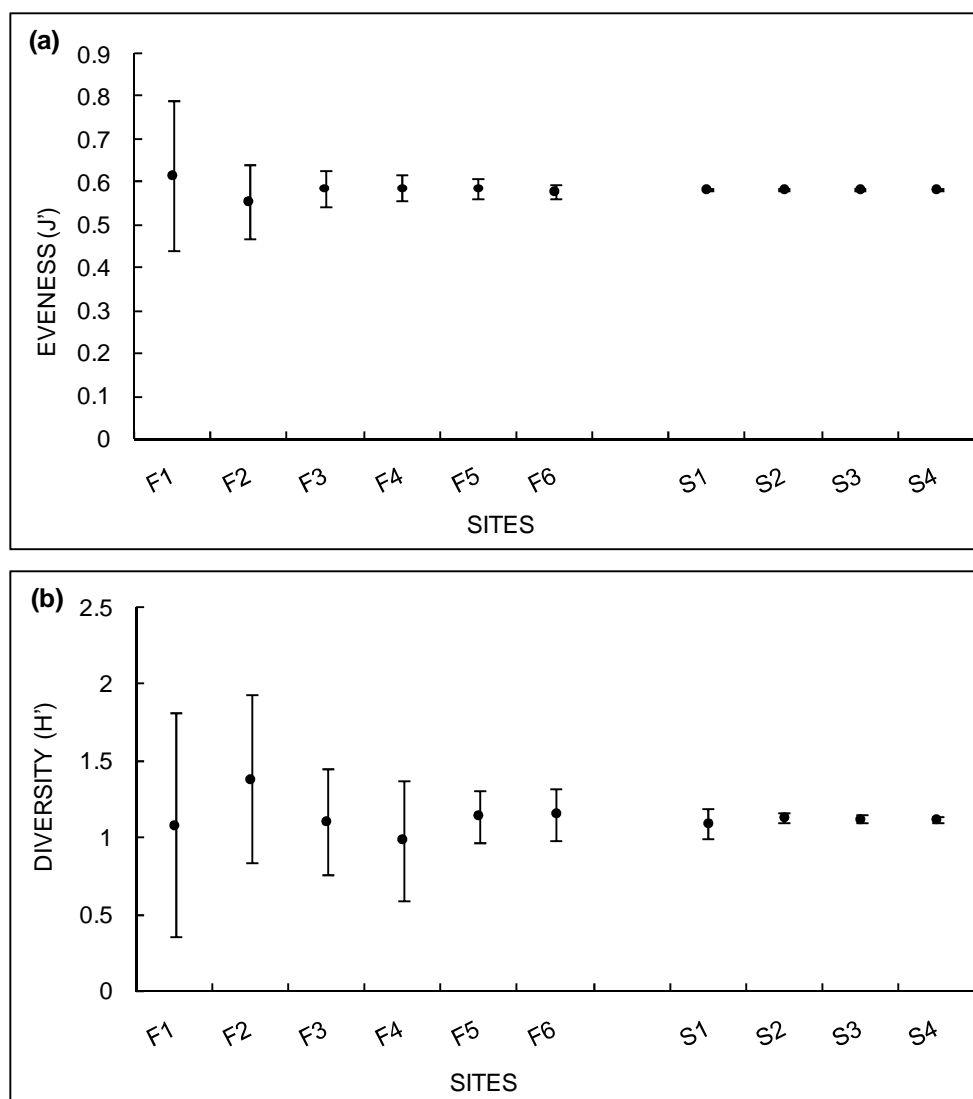


Figure 13: Mean (+1STD) Species Evenness (J') (a) and Species Diversity (H') (b) recorded in the Mfolozi (F1- F6) and Msunduzi (S1- S4) Estuaries in 2009.

3.6 Seasonal distribution in the benthic community

The seasonal distribution of the benthic community of the Mfolozi and Msunduzi estuaries is shown in Figure 14a-d and Figure 15a-d. The number of taxa per site ranged between one and four in autumn and in this season the benthic community had very low densities compared with other seasons (Table 2). *Dendronereis arborifera* occurred at high densities compared to other taxa recorded in autumn in the Mfolozi estuary, with a mean density of 32 N.m⁻², accounting for 38% of the benthic community of the system (Table 2). Baetidae accounted for 26% during this season, followed by *Ceratonereis* sp. (16%), and Simuliidae (12%).

Other taxa, which include *P. blephariskios*, *Oligochaete* sp.1, and *C. triaenonyx*, only comprised 8% of the benthic community of the Mfolozi estuary during this season. Freshwater taxa (*Baetidae* and *Simuliidae*) were only recorded in the upper reaches (F5, F6 and S4) of the Mfolozi and Msunduzi Estuaries, this being a reflection of the relative freshwater conditions in the system at this time. In the Msunduzi estuary in autumn *P. blephariskios* accounted for 40% of the benthic community, followed by *C. triaenonyx* (20%) and *Ceratonereis* sp. (12%) (Figure 15a).

Polychaetes such as *Glycera natalensis*, *Nephtys sphaerocirrata*, *Prionospio cirrifera* and a bivalve, *Eumarcia paupercula*, were only recorded in winter. *Dendronereis arborifera* occurred at highest densities compared with other species during this season in the Mfolozi estuary, with a mean density of 345 N.m⁻², while *P. blephariskios* (229 N.m⁻²), occurred at highest densities in the Msunduzi estuary (Table 2). *Dendronereis arborifera* occurred at highest densities compared to the other seasons and it accounted for 71% in the benthic community of the Mfolozi estuary during this season. In the Msunduzi estuary *P. blephariskios* accounted for 85%. No freshwater taxa were recorded in the system during this season.

In spring, *P. blephariskios* was the most abundant species compared to other taxa recorded in the Msunduzi estuary accounting for 85% in the benthic community of this estuary (Figure 15c). The Mfolozi estuary was again dominated by *D. arborifera* accounting for 48%, followed by *P. sexoculata* (22%) and *P. blephariskios* (13%) (Figure 14c). The unusual appearance of the polychaete *Dendronereides zululandica* during this season in the Mfolozi estuary was noted as this species was not recorded during the other seasons sampled, with a mean density of 13 N.m⁻². This species was recorded at the mouth and in the upper reaches of the Mfolozi Estuary but was not recorded in the Msunduzi estuary.

Paratyloidiplax blephariskios was again the most abundant species in the Msunduzi estuary in summer, with densities of 405 N.m⁻², accounting for 73% of the benthic community of the system (Table 2, Figure 15d). *Dendronereis arborifera* only accounted for 31% in the benthic

community of the Mfolozi estuary during this season, and was followed by *Oligochaete* sp. 1 (29%) (Figure 15d). Three freshwater taxa were recorded during this period in the upper reaches of the Mfolozi and the Msunduzi estuaries and they included Baetidae, Chironomidae and Ecnomidae (Table 2). It was noted that *C. triaenonyx* had increased in densities compared to other seasons in the Msunduzi estuary (Table 2).

TABLE 2: Mean densities (N.m⁻²) of the benthos collected in the Mfolozi – Msunduzi Estuarine system during 2009.

Taxon	MFOLOZI ESTUARY							Mean	MSUNDUZI ESTUARY				Mean	MFOLOZI ESTUARY				Mean	MSUNDUZI ESTUARY				Mean
	F1	F2	F3	F4	F5	F6	S1		S2	S3	S4	Autumn		Winter	Spring	Summer	Autumn		Winter	Spring	Summer		
<i>Oligochaete</i> sp.1	0	2	0	0	15	23	7	11	49	0	0	15	1	0	0	25	7	15	8	8	0	18	
<i>Oligochaete</i> sp. 2	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	1	0	2	0	1	
Capitellidae	0	0	0	2	2	0	1	6	0	0	0	2	0	0	0	3	1	2	0	0	0	1	
<i>Ceratonereis</i> sp.	34	4	4	2	97	17	26	2	2	4	0	2	14	86	4	1	26	2	4	2	0	2	
<i>Dendronereis arborifera</i>	85	15	15	146	265	182	118	2	36	28	11	19	32	345	68	27	118	19	13	24	30	21	
<i>Dendronereides zululandica</i>	4	0	2	0	2	11	3	0	0	0	0	0	0	0	13	0	3	0	0	0	0	0	
<i>Glycera longipinnis</i>	0	4	2	0	0	0	1	2	0	0	0	1	0	1	0	3	1	1	0	0	2	1	
<i>Glycera natalensis</i>	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
<i>Nephtys sphaerocirrata</i>	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
<i>Prionospio sexoculata</i>	44	28	4	23	0	0	17	4	2	0	0	2	0	35	31	0	17	2	2	4	0	2	
<i>Prionospio cirrifera</i>	0	4	0	0	0	0	1	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	
<i>Eumarcia paupercula</i>	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
<i>Corophium triaenonyx</i>	4	0	0	0	0	0	1	13	55	8	3	20	3	0	0	0	1	20	4	13	59	24	
<i>Grandidierella bonnieroides</i>	0	0	0	0	0	0	0	2	12	2	0	4	0	0	0	0	0	4	8	0	8	5	
Lyssianassidae sp.	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0	0	1	0	0	0	1	
<i>Orchestia ancheiodos</i>	0	4	0	0	0	0	1	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	
<i>Apeudes digitalis</i>	0	0	0	0	0	0	0	4	6	2	0	3	0	0	0	0	0	3	2	2	8	4	
<i>Mesopodopsis africanus</i>	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	1	0	0	0	1	
<i>Paratyloidiplax blephariskios</i>	47	2	0	13	0	0	10	360	585	34	0	245	3	13	18	7	10	245	229	324	405	301	
Baetidae	0	4	6	11	17	15	9	0	0	0	0	0	23	0	0	13	9	0	0	0	0	0	
Chironomidae	0	0	0	0	2	15	3	0	0	2	0	1	0	0	7	4	3	1	0	0	2	1	
Ecnomidae	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
Simuliidae	0	6	6	0	2	0	2	0	0	2	0	1	10	0	0	0	2	1	0	0	0	0	
Total	218	78	40	199	405	263	201	411	747	83	18	315	86	487	141	88	201	315	271	380	555	380	
Total no. of Taxa	6	12	7	7	9	6	18	12	8	8	3	15	7	9	6	10	14	15	8	8	8	15	

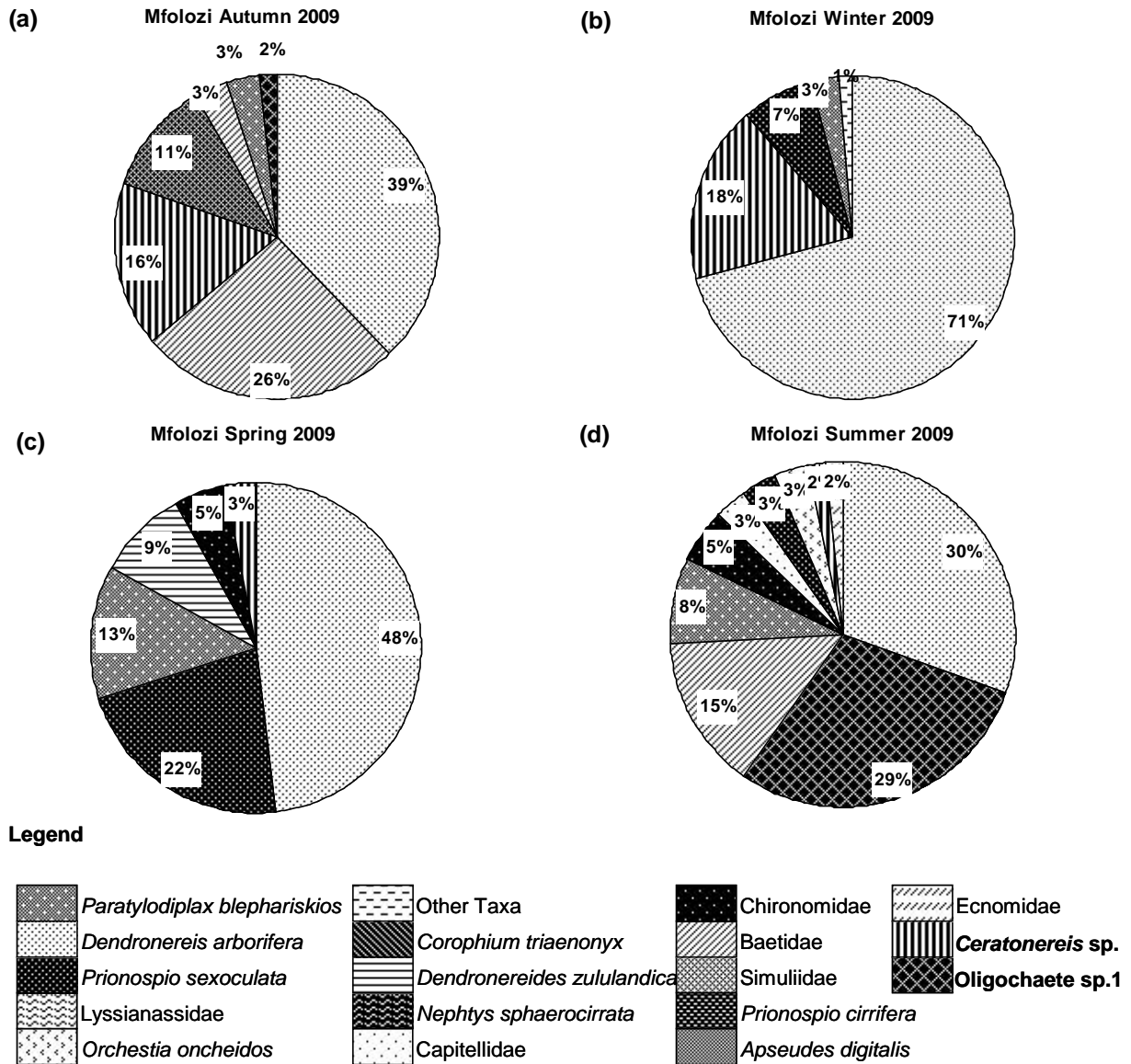


Figure 14: The dominant benthic taxa recorded in the Mfolozi Estuary during each of the four sampling seasons (a-d) during 2009.

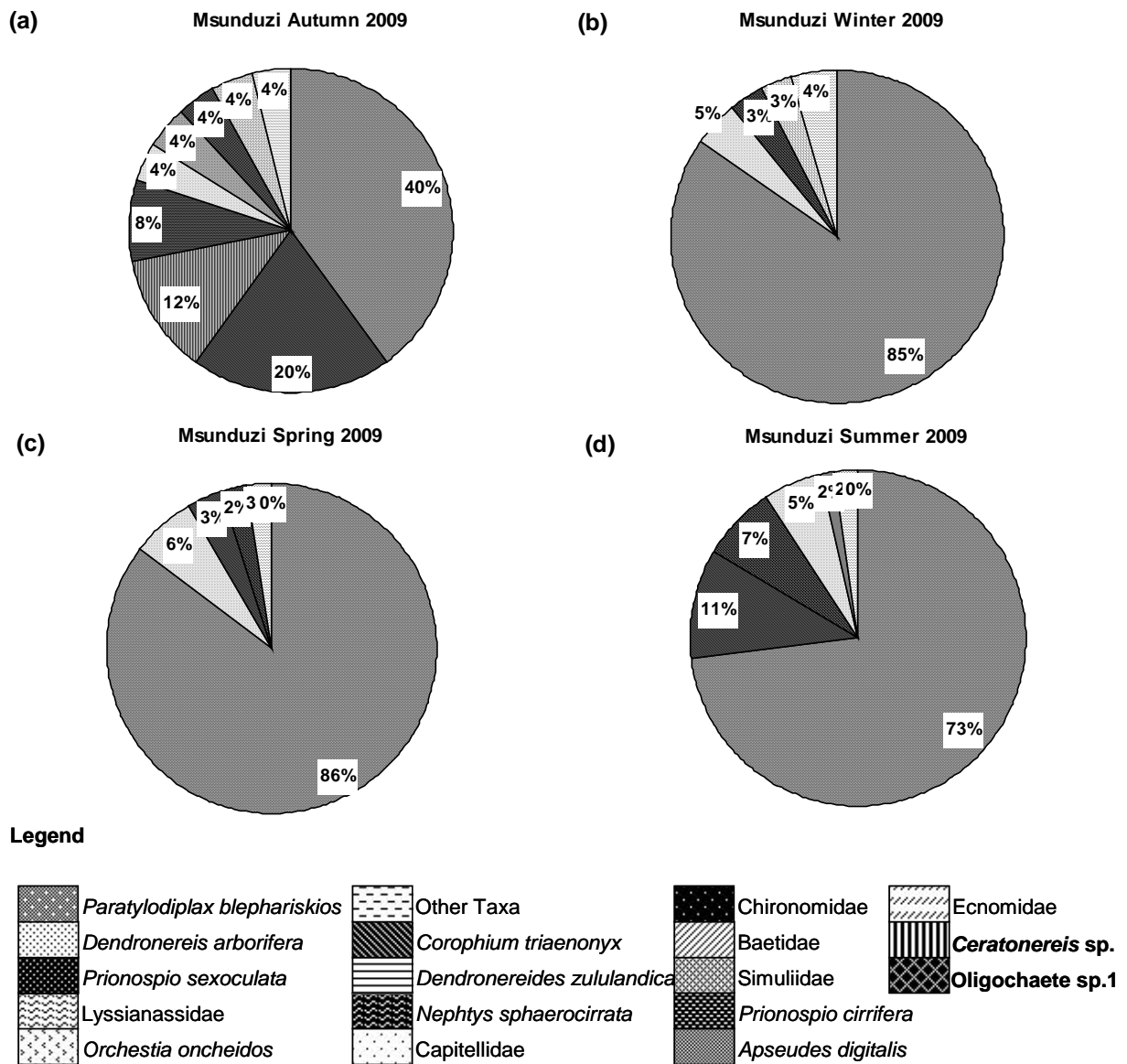


Figure 15: The dominant benthic taxa recorded in the Msunduzi Estuary during each of the four sampling seasons (a-d) during 2009.

3.7 Changes in the community structure

The Analysis of Similarity (ANOSIM) revealed significant differences ($p < 0.05$) in the benthic community of the system, between seasons ($R = 0.23$, $p = 0.001$), between all ten sampling sites ($R = 0.21$, $p = 0.004$) and between the Mfolozi and Msunduzi estuaries ($R = 0.17$,

$p=0.004$). Within the Mfolozi Estuary there were significant differences between seasons ($R=0.46$, $p=0.001$) but not between sampling sites and between the upper (F4-F6) and lower (F1-F3) reaches. Within the Msunduzi Estuary, significant differences were found between the sampling sites ($R=0.34$, $p=0.005$) and between the upper and the lower reaches ($R=0.37$, $p=0.005$) but not between seasons.

The cluster and MDS ordination clearly showed differences between the Mfolozi and Msunduzi estuaries (Figure 16a and b). Cluster and MDS ordination distinguished five distinct groups at similarity of 30%. It was noted that group II comprised mostly of the Msunduzi sites, indicating that seasonal changes did not influence the community structure of the Msunduzi Estuary. Group III comprised mostly of the Mfolozi winter and spring samples while group V comprised of the Mfolozi autumn and summer samples and this clearly showed that seasonal changes played a major role in structuring the benthic community in the Mfolozi Estuary. Site F1 was different from the other groups because only one species was recorded at this site in summer, and it occurred at very low densities.

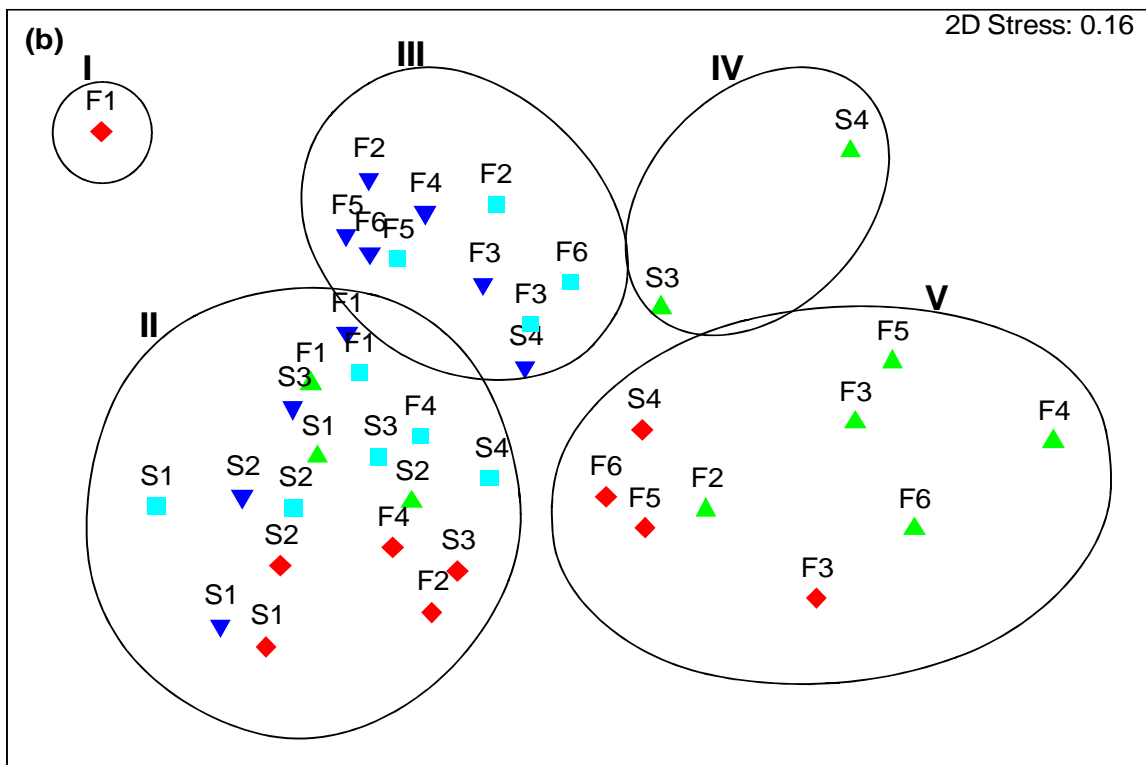
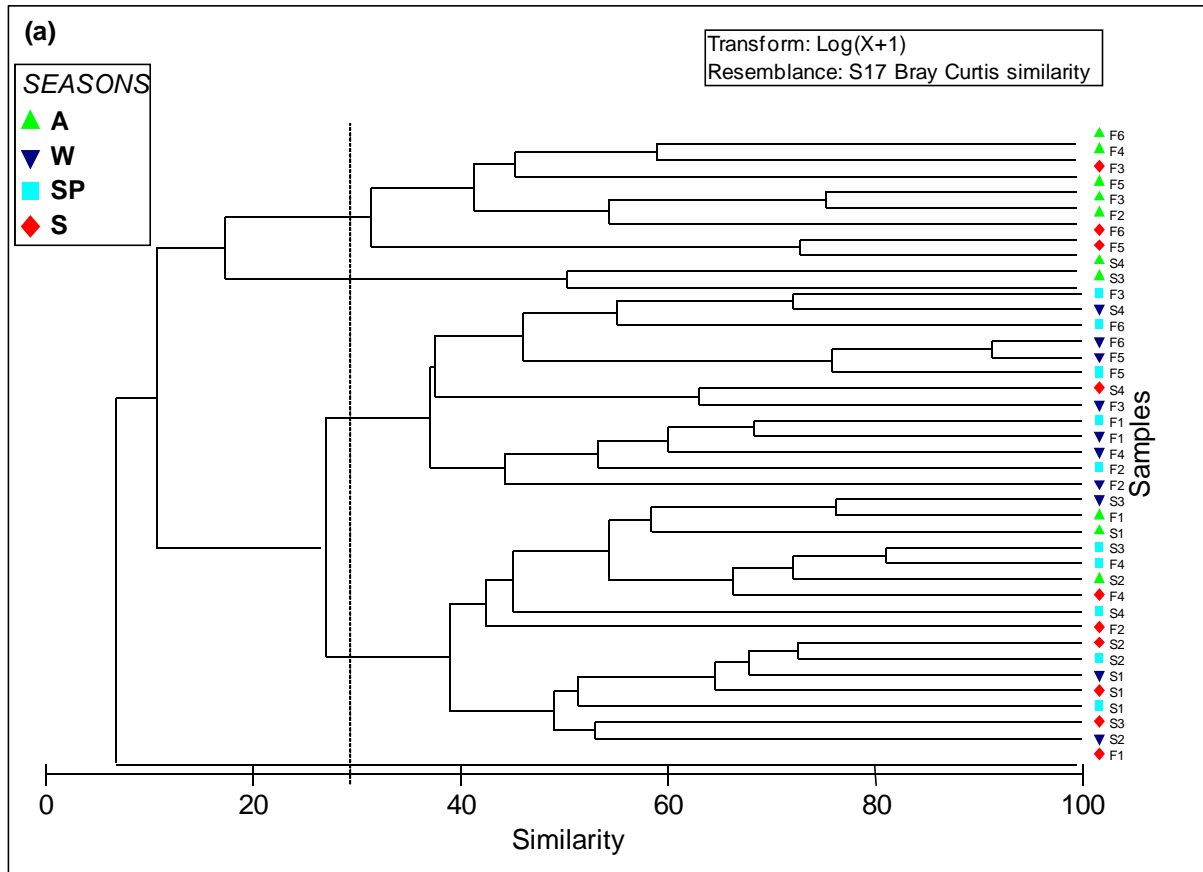


Figure 16: Classification (a) and MDS ordination (b) constructed from Bray-Curtis similarities showing differences in the community structure and abundance between sites and seasons. (F = Mfolozi, S = Msunduzi; Dotted line represents percentage similarity).

The SIMPER (Similarity Percentages) results showed that the mean similarity within the benthic assemblage of the Mfolozi and Msunduzi Estuaries was 25.6% and 34.5%, respectively (Table 3). The SIMPER results also indicated that *D. arborifera* and *P. blephariskios* were the taxa most responsible for structuring the benthic community in both the Mfolozi and Msunduzi estuaries. *Dendronereis arborifera*, *Ceratonereis* sp., Baetidae, *P. sexoculata* and *P. blephariskios* were important taxa in structuring the benthic community in the Mfolozi estuary, while in the Msunduzi estuary, *Ceratonereis* sp. was replaced by *P. blephariskios* as the second most important species in this estuary. Baetidae and *P. sexoculata* were also replaced by *C. triaenonyx* and Oligochaete sp.1 as the 3rd and 4th most important species in the Msunduzi estuary. *Dendronereis arborifera* was particularly important in structuring the benthic community of the Mfolozi and Msunduzi estuaries, as it contributed 56.7% and 35.7% of the mean similarity within the communities of the estuaries respectively. *Paratyloidiplax blephariskios* contributed only 4.9% to the similarity in the Mfolozi estuary, while in the Msunduzi estuary these mud crabs contributed 34.3% to the mean similarity.

The SIMPER results also showed that the mean similarity within the benthic assemblage of the system between the four seasons was 25.4% in autumn, 37.2% in winter, 39.6% in spring and 23.1% in summer (Table 4). Baetidae, *D. arborifera* and Simuliidae were the taxa most responsible for structuring the benthic community of the system in autumn. *Dendronereis arborifera* was the second most important species, contributing 16.5% during this season. In winter, spring and summer, *D. arborifera* was the most important species, which contributed 54.8% in winter, 64.7% in spring and 35.7% in summer. In spring *P. blephariskios* was the second most important species in the benthic community of the system, replacing *Ceratonereis* sp. which was the second most important species in winter. *Paratyloidiplax blephariskios* contributed 15.3% of the mean similarity in the community of the system.

3.8 Relationships between environmental parameters and the benthic community

The weighted Spearman correlation coefficients for the correlation between the benthic community structure and environmental parameters are shown in Table 5. The single variable most responsible for structuring the benthic assemblage of the Mfolozi-Msunduzi estuarine system during the four sampling seasons, was sediment particle size (Median phi), followed

by sediment sorting coefficient and temperature. The best combination of environmental factors which played a role in the distribution and abundance of benthos were temperature, sediment particle size and the sorting coefficient. The second and third best combination of environmental factors included percentage organic content and pH. These results showed that sediment characteristics combined with natural seasonal variability (temperature) played the most important role in structuring the benthic community of the Mfolozi-Msunduzi system.

Table 3: The species, mean similarity and percentage contribution of the dominant benthic taxa recorded in the Mfolozi and Msunduzi Estuaries over the four seasons sampled in 2009.

<u>Species</u>	<u>Average Similarity</u>	<u>Contribution%</u>
Mfolozi Estuary: Average similarity: 25.59		
<i>Dendronereis arborifera</i>	14.50	56.68
<i>Ceratonereis</i> sp.	2.91	11.39
Baetidae	2.73	10.66
<i>Prionospio sexoculata</i>	1.30	5.09
<i>Paratylo diplax blephariskios</i>	1.26	4.93
Crustacean larvae	1.18	4.62
Msunduzi Estuary: Average similarity: 34.45		
<i>Dendronereis arborifera</i>	12.31	35.73
<i>Paratylo diplax blephariskios</i>	11.81	34.27
<i>Corophium</i> sp.	6.01	17.45
Oligochaete sp.1	1.27	3.69
Average dissimilarity between the Mfolozi and Msunduzi Estuaries = 78.04		

Table 4: The species, mean similarity and percentage contribution of the dominant benthic taxa recorded in the Mfolozi-Msunduzi estuarine system during the four seasons sampled in 2009.

Species	Average Similarity	Contribution%
Autumn Average similarity: 25.39		
Baetidae	7.39	29.11
<i>Dendronereis arborifera</i>	4.21	16.58
Simuliidae	3.06	12.04
Winter Average similarity: 37.22		
<i>Dendronereis arborifera</i>	20.4	54.82
<i>Ceratonereis</i> sp.	8.99	24.16
<i>Prionospio sexoculata</i>	3.7	9.94
<i>Paratylo diplax blephariskios</i>	3.15	8.46
Spring Average similarity: 39.57		
<i>Dendronereis arborifera</i>	25.61	64.72
<i>Paratylo diplax blephariskios</i>	6.05	15.28
<i>Dendronereides zululandica</i>	2.9	7.32
<i>Corophium triaenonyx</i>	2.81	7.09
Summer Average similarity: 23.08		
<i>Dendronereis arborifera</i>	8.23	35.67
<i>Paratylo diplax blephariskios</i>	4.74	20.52
Oligochaete sp.1	2.12	9.18
<i>Glycera longipinnis</i>	1.24	5.37
Baetidae	1.24	5.36
<i>Corophium triaenonyx</i>	0.91	3.93
Average dissimilarity between seasons:		
	A & W = 81.76	
	A & SP = 82.96	
	W & SP = 63.75	
	A & S = 80.25	
	W & S = 76.48	
	SP & S = 74.88	

Table 5: The Weighted Spearman Correlation Coefficient values (ρ_w) between the benthic community and physical parameters in the Mfolozi and Msunduzi Estuaries over the four seasons sampled in 2009.

No. of Variables	ρ_w	Variables
Single variable		
1	0.331	Median phi
1	0.314	Sorting Coefficient
1	0.31	Temperature
Best combination		
3	0.414	Temperature, Median phi, Sorting Coefficient
4	0.407	Temperature, Median phi, Organic Content, Sorting Coefficient
5	0.398	Temperature, pH, Median phi, Organic Content, Sorting Coefficient

3.9 Relationships between the environmental parameters and the benthic community

Further analysis of the influence of environmental parameters on the benthic community using Canonical Correspondence Analysis (CCA) (Figure 17). It showed the correlation between the benthic community structure and the abiotic factors (Figure 17). It showed that a number of abiotic factors such as sediment particle size (median phi), percentage organic content and sorting coefficient were most important in structuring the benthic community of the system. These were followed by temperature, turbidity, soluble phosphates, total phosphates, depth, nitrate, nitrite, chlorophyll-a, TDS, ammonia, BOD and salinity. The least important variables in structuring the benthic community of the system were the pH and oxygen.

There was an expected strong correlation between the sediment particle size (median phi) and percentage organic content, which indicated that high organic content was recorded at the sites where the sediment particles were small (Table 6). There was also an expected negative correlation between the percentage organic content and the sorting coefficient indicating that percentage organic content was low in poorly sorted sediments and high in well sorted sediments. There was no correlation between the sediment characteristics (sediment particle size and percentage organic content) and temperature, and this was due to the fact that natural temporal variability changes in the system did not directly influence the sediments in the

system. There was no correlation between the sediment particle size and turbidity, indicating that high turbidities during summer did not affect the sediment particle size.

Total phosphates and soluble orthophosphates were positively correlated with high turbidities and high temperatures, indicating that concentrations of these nutrients were highest during summer and are associated with flooding conditions in the Mfolozi River. In contrast, nitrate, nitrite and BOD were not seasonally influenced, and as a result there was no correlation between temperature and these nutrients. There was a negative correlation between temperature and salinity which indicates that highest salinities were recorded during winter, with the system being more river dominated during flooding conditions experienced during summer. This was also confirmed by a positive correlation between temperature and turbidity, indicating that highest turbidities were recorded in summer. Chlorophyll-a was strangely negatively correlated with nitrate and BOD and showed no correlation with total and orthophosphate levels. The fact that there was no correlation between nitrate and phosphates would suggest that these nutrients originate from different upland sources and enter the system during different times.

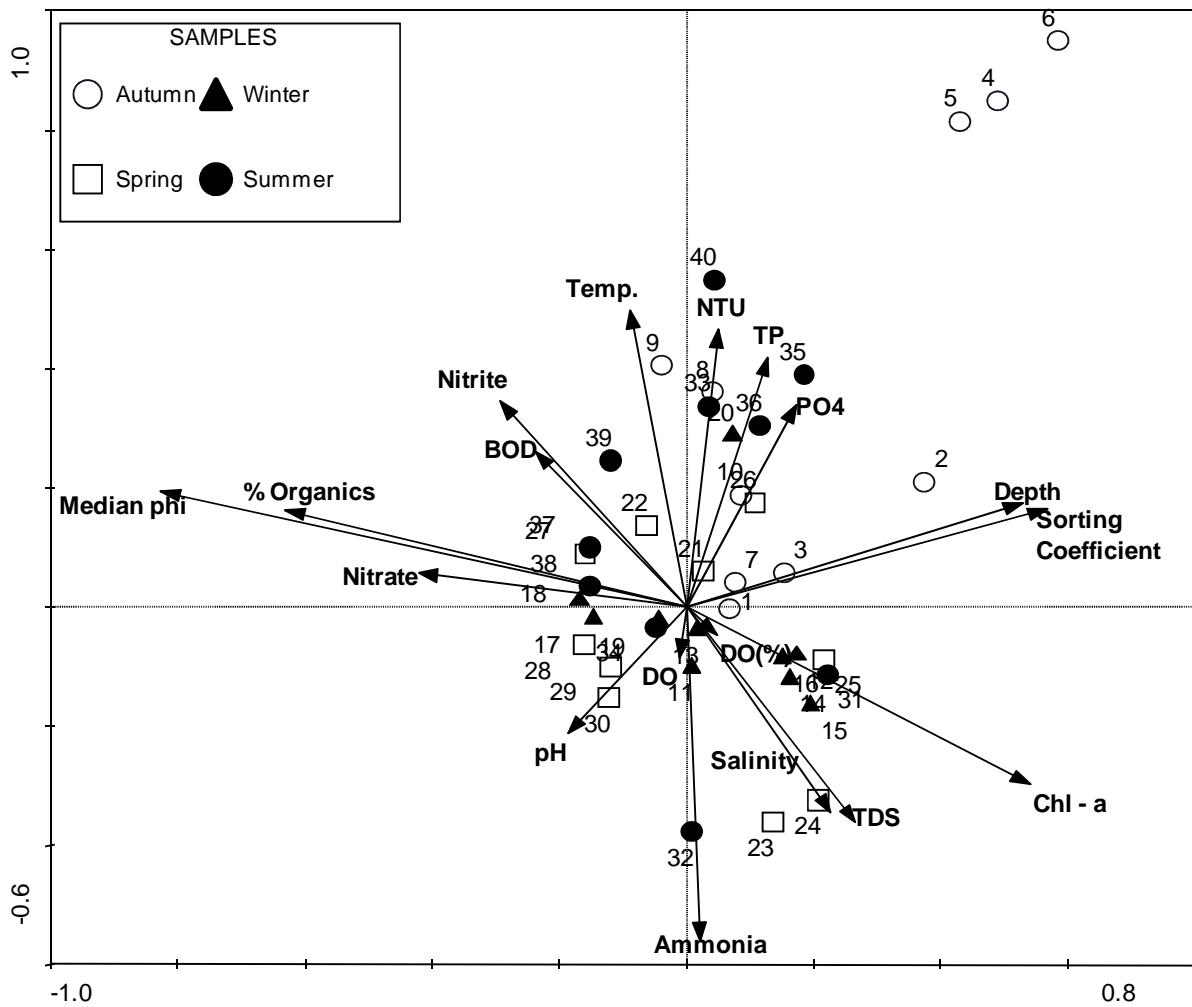


Figure 17: Canonical Correspondence Analysis (CCA) showing the correlation between the environmental parameters and the benthic community during the four sampling seasons in the Mfolozi-Msunduzi system during 2009. (1-40 = Samples, TP = Total Phosphate, PO4 = Soluble Orthophosphate, DO = Dissolved Oxygen, Chl-a = Chlorophyll-a, BOD = Biochemical oxygen demand, TDS = Total dissolved solids)

TABLE 6: Correlation between environmental variables (red numbers indicate a significant correlation).

Marked correlations are significant at $p < .050$
N=40 (Casewise deletion of missing data)

	TEMP	SAL	TDS	OXY	OXY%	PH	NTU	DEPTH	MEDPHI	ORG	SORT	AMM	NITRATE	NITRITE	OR_P	TP	BOD	CHLOR_A
TEMP	1.00	-0.35	-0.33	0.25	0.34	0.12	0.41	0.02	-0.14	-0.10	0.17	-0.78	-0.15	0.24	0.23	0.27	0.74	-0.17
SAL	-0.35	1.00	0.98	-0.14	0.20	0.22	-0.57	-0.05	0.09	0.14	-0.21	0.22	0.61	-0.56	-0.44	-0.46	-0.07	0.05
TDS	-0.33	0.98	1.00	-0.17	0.13	0.18	-0.56	0.01	0.06	0.10	-0.19	0.20	0.64	-0.55	-0.44	-0.45	-0.05	0.03
OXY	0.25	-0.14	-0.17	1.00	0.88	0.78	0.34	-0.39	0.13	0.14	0.19	0.12	0.19	0.35	0.35	0.33	-0.03	-0.02
OXY%	0.34	0.20	0.13	0.88	1.00	0.81	0.13	-0.38	0.09	0.13	0.14	-0.02	0.34	0.09	0.14	0.12	0.15	-0.03
PH	0.12	0.22	0.18	0.78	0.81	1.00	0.04	-0.37	0.08	0.02	0.11	0.19	0.40	0.12	0.10	0.04	0.02	-0.11
NTU	0.41	-0.57	-0.56	0.34	0.13	0.04	1.00	-0.07	0.02	0.08	0.44	-0.31	-0.33	0.82	0.93	0.93	-0.08	-0.22
DEPTH	0.02	-0.05	0.01	-0.39	-0.38	-0.37	-0.07	1.00	-0.44	-0.42	0.31	-0.14	-0.31	-0.12	0.01	-0.11	0.07	0.10
MEDPHI	-0.14	0.09	0.06	0.13	0.09	0.08	0.02	-0.44	1.00	0.81	-0.37	0.19	0.37	0.15	-0.03	-0.01	-0.01	-0.23
ORG	-0.10	0.14	0.10	0.14	0.13	0.02	0.08	-0.42	0.81	1.00	-0.35	0.16	0.33	0.23	0.04	0.15	-0.16	-0.18
SORT	0.17	-0.21	-0.19	0.19	0.14	0.11	0.44	0.31	-0.37	-0.35	1.00	-0.11	-0.12	0.39	0.46	0.44	-0.18	-0.08
AMM	-0.78	0.22	0.20	0.12	-0.02	0.19	-0.31	-0.14	0.19	0.16	-0.11	1.00	0.25	-0.06	-0.18	-0.21	-0.63	0.09
NITRATE	-0.15	0.61	0.64	0.19	0.34	0.40	-0.33	-0.31	0.37	0.33	-0.12	0.25	1.00	-0.21	-0.23	-0.24	-0.04	-0.12
NITRITE	0.24	-0.56	-0.55	0.35	0.09	0.12	0.82	-0.12	0.15	0.23	0.39	-0.06	-0.21	1.00	0.82	0.86	-0.26	-0.22
OR_P	0.23	-0.44	-0.44	0.35	0.14	0.10	0.93	0.01	-0.03	0.04	0.46	-0.18	-0.23	0.82	1.00	0.90	-0.21	-0.20
TP	0.27	-0.46	-0.45	0.33	0.12	0.04	0.93	-0.11	-0.01	0.15	0.44	-0.21	-0.24	0.86	0.90	1.00	-0.31	-0.22
BOD	0.74	-0.07	-0.05	-0.03	0.15	0.02	-0.08	0.07	-0.01	-0.16	-0.18	-0.63	-0.04	-0.26	-0.21	-0.31	1.00	-0.08
CHLOR_A	-0.17	0.05	0.03	-0.02	-0.03	-0.11	-0.22	0.10	-0.23	-0.18	-0.08	0.09	-0.12	-0.22	-0.20	-0.22	-0.08	1.00

KEY:

TEMP. = Temperature,	ORG=Organic content,
SAL=Salinity,	SORT=Sorting coefficient,
TDS=Total dissolved oxygen,	AMM=Ammonia,
OXY=Oxygen mg/l,	OR_P=Orthophosphates,
OXY%=Oxygen %,	TP=Total phosphate,
NTU=Turbidity,	BOD=Biochemical oxygen demand,
MEDPH=Median phi,	CHLOR_A=Chlorophyll-a

3.10 Biomass

The mean benthic biomass (mg.m^{-2} dry weight) per site is shown in Figure 18a. The mean biomass at the Mfolozi sites was very low, with highest values recorded at the mouth of the system, at site F1 (70 mg.m^{-2}). In the Msunduzi estuary, highest mean biomass was recorded at sites S2 and S1, while the mean biomass of the remaining sites was less than 50 mg.m^{-2} (Figure 18a). Figure 18b shows seasonal variations of the biomass in the Mfolozi estuary. In this estuary, the lowest mean biomass was recorded in autumn (1278 mg.m^{-2}), while the highest biomass was recorded in winter (10718 mg.m^{-2}). The mean biomass decreased to 4737 mg.m^{-2} in spring and in summer (1829 mg.m^{-2}). In the Msunduzi estuary, highest biomass was recorded in summer (10830 mg.m^{-2}) (Figure 18c). The lowest mean biomass was recorded in autumn (605 mg.m^{-2}), and increasing to 6108 mg.m^{-2} in winter and 8675 mg.m^{-2} in spring. When the two estuaries were compared (Figure 19), it was noted that the mean biomass in the Msunduzi estuary (26218 mg.m^{-2}) was higher than the biomass in the Mfolozi estuary (18563 mg.m^{-2}).

In terms of biomass, *P. blephariskios* was the greatest contributor to the benthic biomass throughout the system, followed by *D. arborifera* (Table 7). *Ceratonereis* sp. was recorded throughout the four sampling seasons, but only contributed 14.9 mg.m^{-2} to the mean biomass of the system (Table 7). Oligochaete sp.1, which was common throughout the four sampling seasons, only contributed 10.4 mg.m^{-2} to the mean biomass of the system. Highest biomass for this species was recorded in summer. The remaining 21 taxa, including *Ceratonereis* sp., Oligochaete sp.1 and *P. sexoculata*, only contributed 1% to the benthic biomass of the system.

In the Mfolozi estuary, *D. arborifera* (63%) dominated the benthic biomass (Figure 19a). This was followed by *P. blephariskios* (35%) and *P. sexoculata* (1%). Other taxa only contributed 1% to the total biomass of the estuary. *Paratyloidiplax blephariskios* completely dominated the biomass of the Msunduzi estuary, contributing 99% to the total biomass of the estuary (Figure 19b). The remaining taxa only contributed 1% to the biomass of the estuary (Figure 19b). It was noted that *P. blephariskios* contributed the majority in the muddy sites (see Table 1), while *D. arborifera* was the greatest contributor to the biomass of the sandy sites.

Paratyloidiplax blephariskios and *D. arborifera* dominated the biomass of the system during all the four sampling periods (Figure 20a-d). *Paratyloidiplax blephariskios* was by far the greatest contributor to the biomass of the system, contributing 73% in autumn, 74% in winter, 94% in spring and 97% in summer. *Dendronereis arborifera* contributed 26% in autumn and 24% in winter.

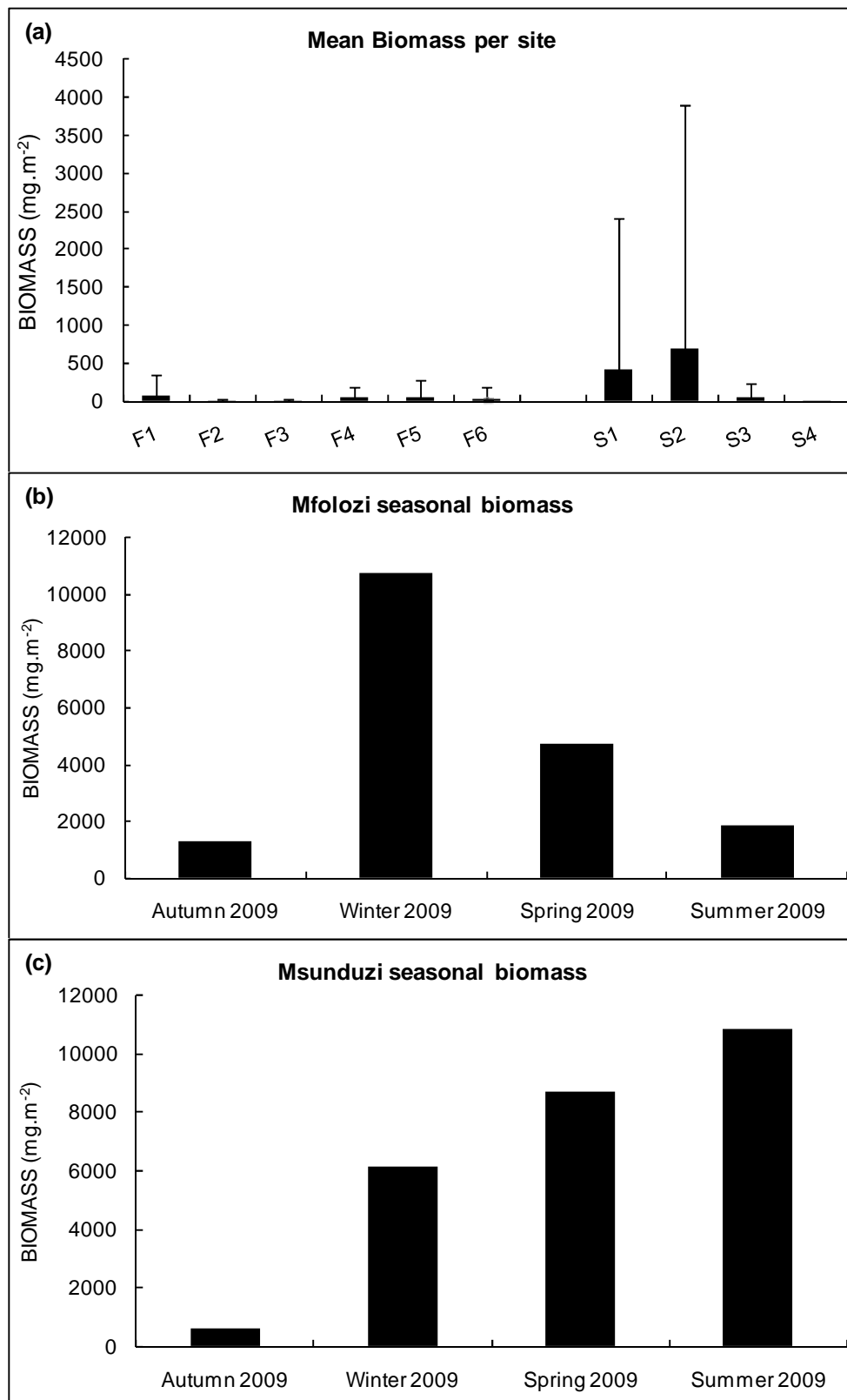


Figure 18 The mean biomass (+1STD) per site in the Mfolozi – Msunduzi Estuarine System (a), and seasonal variations in the mean biomass of the Mfolozi Estuary (b) and Msunduzi Estuary (c)

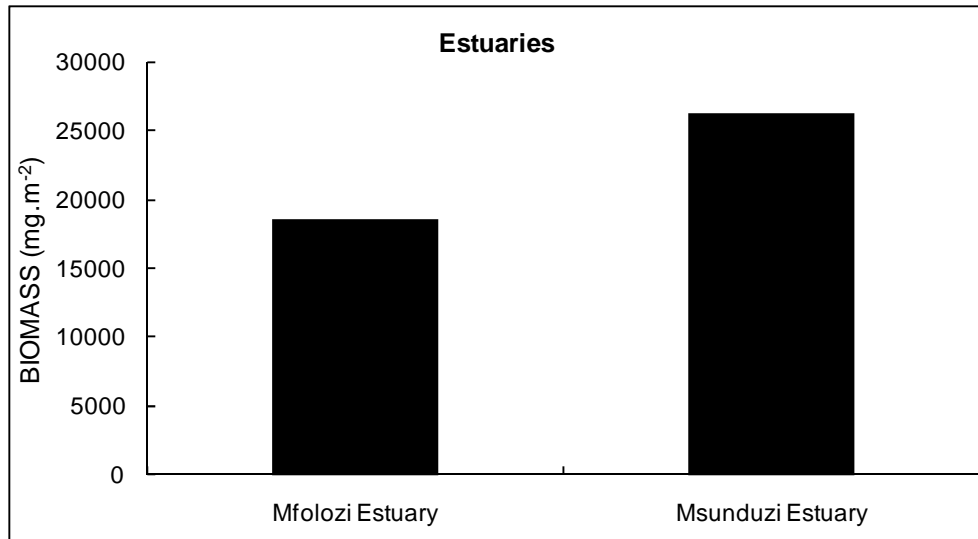


Figure 19: The total biomass of the Mfolozi and Msunduzi estuaries.

TABLE 7: Biomass of the benthic invertebrates collected in the Mfolozi – Msunduzi Estuarine system.

Taxon	Mfolozi Estuary						Msunduzi Estuary				Mean		Mfolozi Estuary				Msunduzi Estuary			
	F1	F2	F3	F4	F5	F6	S1	S2	S3	S4	Mfolozi Estuary	Msunduzi Estuary	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
<i>Oligochaete sp.1</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	6.2	0.9	0.0	0.0	15.9	0.2	0.9	0.9	4.2
<i>Oligochaete sp. 2</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Capitellidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0
<i>Ceratonereis sp.</i>	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	14.1	0.8	7.5	46.0	2.3	0.8	0.2	0.4	0.2	0.0
<i>Dendronereis arborifera</i>	0.3	0.1	0.1	0.6	1.1	0.7	0.0	0.1	113.1	45.7	2906.2	315.4	800.5	8492.4	1670.6	661.3	43.5	52.2	97.9	121.8
<i>Dendronereides zululandica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0
<i>Glycera longipinnis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	1.1	0.0	4.4	0.0	8.8	0.0	0.0	0.0	1.1
<i>Glycera natalensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
<i>Nephtys sphaerocirrata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
<i>Prionospio sexoculata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	73.1	4.7	0.0	155.5	136.8	0.0	0.0	1.6	3.1	0.0
<i>Prionospio cirrifera</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0
<i>Eumarcia paupercula</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Corophium traenonyx</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.2	0.1	0.1	2.3	0.5	0.0	0.0	0.0	0.1	0.1	0.4	1.7
<i>Grandidierella bonnieroides</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.8
Lyssianassidae sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Orchestia ancheiodos</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
<i>Apseudes digitalis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.6
<i>Mesopodopsis africanus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
<i>Paratyloidiplax blephariskios</i>	1.2	0.1	0.0	0.3	0.0	0.0	9.5	15466.5	894.1	0.0	1625.1	25887.2	448.3	2017.4	2914.0	1120.8	560.4	6052.5	8571.0	10703.3
Baetidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6	0.0	16.8	0.0	0.0	9.5	0.0	0.0	0.0	0.0
Chironomidae	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.8	0.5	0.0	0.0	0.0	0.0
Ecnomidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	10.5	0.0	0.0	0.0	0.0
Simuliidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.9	0.1	3.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Total	4.6	0.1	0.1	1.0	1.2	1.0	9.5	15471.5	1008.2	45.8	4640.8	26221.2	1278.0	10718.3	4737.5	1829.3	604.7	6108.4	8674.6	10833.6

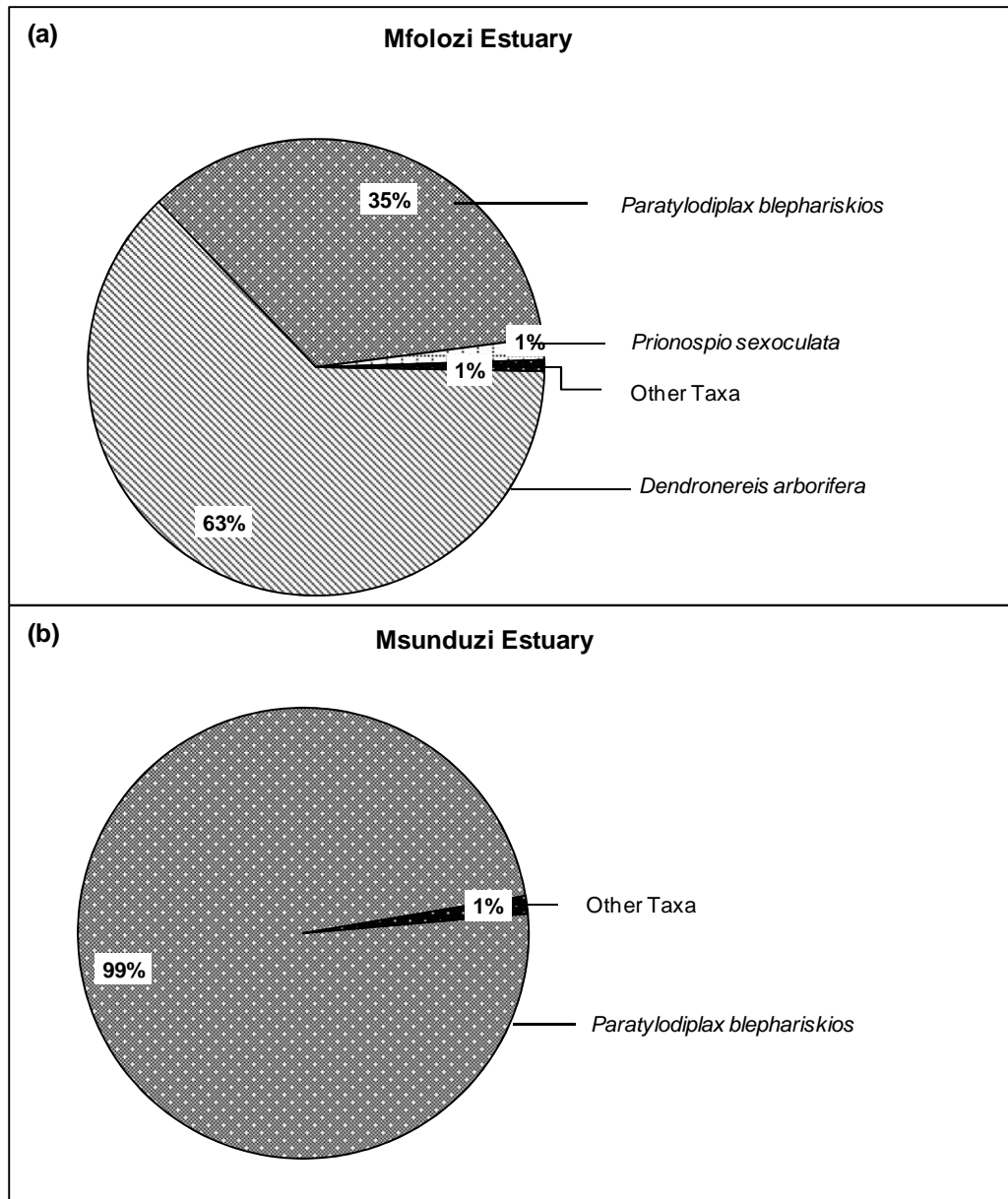


Figure 20: Total Biomass of the benthic invertebrates in the Mfolozi (a) and the Msunduzi (b) estuaries.

3.11 Comparisons with Historical Data

The current data were combined with historical data (Ngqulana *et al.* 2010) comprising samples taken biannually in 2007 and 2008. The three-year data were combined in order to test for any significant differences between the years 2007, 2008 and 2009, between sites and between estuaries. The analysis of similarity (ANOSIM) was used to test the significance of these differences. Cluster and MDS ordination were used to detect any differences between the years. BIOENV was used to determine which environmental factors were important in the distribution patterns of the benthos during the three- year period. CCA in CANOCO was used to test which environmental factors best correlated with the benthic community structure.

The analysis of similarity revealed significant differences ($p < 0.05$) in the benthic community of the Mfolozi-Msunduzi system, between sampling years ($R = 0.29$, $p = 0.001$), between sampling sites ($R = 0.12$, $p = 0.001$) and between the Mfolozi and Msunduzi Estuaries ($R = 0.12$, $p = 0.003$). The cluster and MDS plots showed a strong temporal gradient according to sampling years, with six groups being distinguished from these plots at a similarity of 25% (Figure 21 and 22). There were three large sample groups that could be distinguished, viz. Group I, which mostly comprised the 2009 Mfolozi samples from the upper reaches, Group III, which was mostly composed of 2009 Mfolozi and Msunduzi samples, and Group IV, which was mostly composed of 2007 Mfolozi and Msunduzi samples with a few samples from 2008 and 2009. All of the 2007 samples were in this group, except for one sample which was grouped with two 2008 samples in Group II.

The single environmental variable best correlated with the benthic assemblage of the Mfolozi-Msunduzi estuarine system during the three sampling years was turbidity, followed by organic content and temperature (Table 8). High turbidities reflect high freshwater flows during river flooding conditions. The best combination of environmental factors which played a role in structuring the benthic assemblage of the system comprised turbidity and organic content (Table 8), followed by turbidity, sediment particle size (median phi) and organic content. The last best combination included salinity (Table 8).

The above results were confirmed using Canonical Correspondence Analysis (CCA), which also showed that during the three sampling years, turbidity, sediment particle size (median phi) and organic content were the most important environmental factors in structuring the benthic community of the Mfolozi-Msunduzi system (Figure 22). These results confirm the strong influence of riverine processes in the system. Figure 22 also showed that sediment particle size was positively correlated with organic content, and indicated that the muddy sediments in the system had higher organic content. There was no correlation between the sediment characteristics (organic content and sediment particle size) and turbidity. There was also no correlation between temperature and the sediment characteristics. This indicated that the sediments in the system were not affected by turbidity, salinity and temperature. There was an unexpected negative correlation between the sediment particle size and depth, which suggested that highest median phi values were recorded in shallow sites.

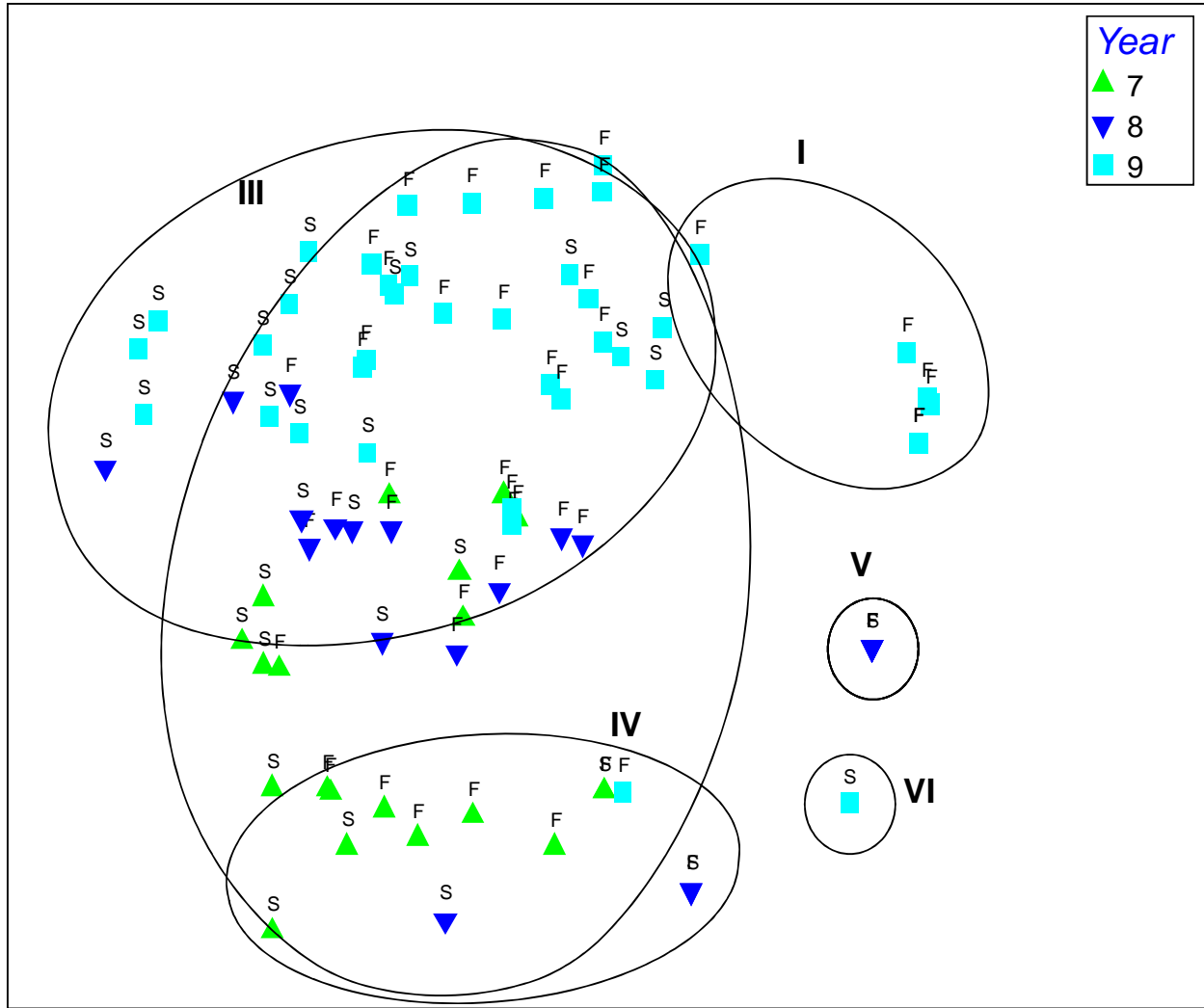


Figure 21: MDS ordination constructed from Bray-Curtis similarities showing differences in the community structure between the years 2007, 2008 and 2009. (F = Mfolozi, S = Msunduzi).

Table 8: The Weighted Spearman Correlation Coefficient values (ρ_w) between the benthic community and physical parameters in the Mfolozi-Msunduzi Estuary over the three years.

No. of Variables	ρ_w	Variables
Single variable		
1	0.168	Turbidity
1	0.033	Organic content
1	0.017	Temperature
Best combination		
2	0.226	Turbidity, Organic content
3	0.186	Turbidity, Median phi, Organic content
4	0.187	Salinity, Turbidity, Median phi, Organic content
5	0.167	Temperature, Salinity, Turbidity, Median phi, Organic content

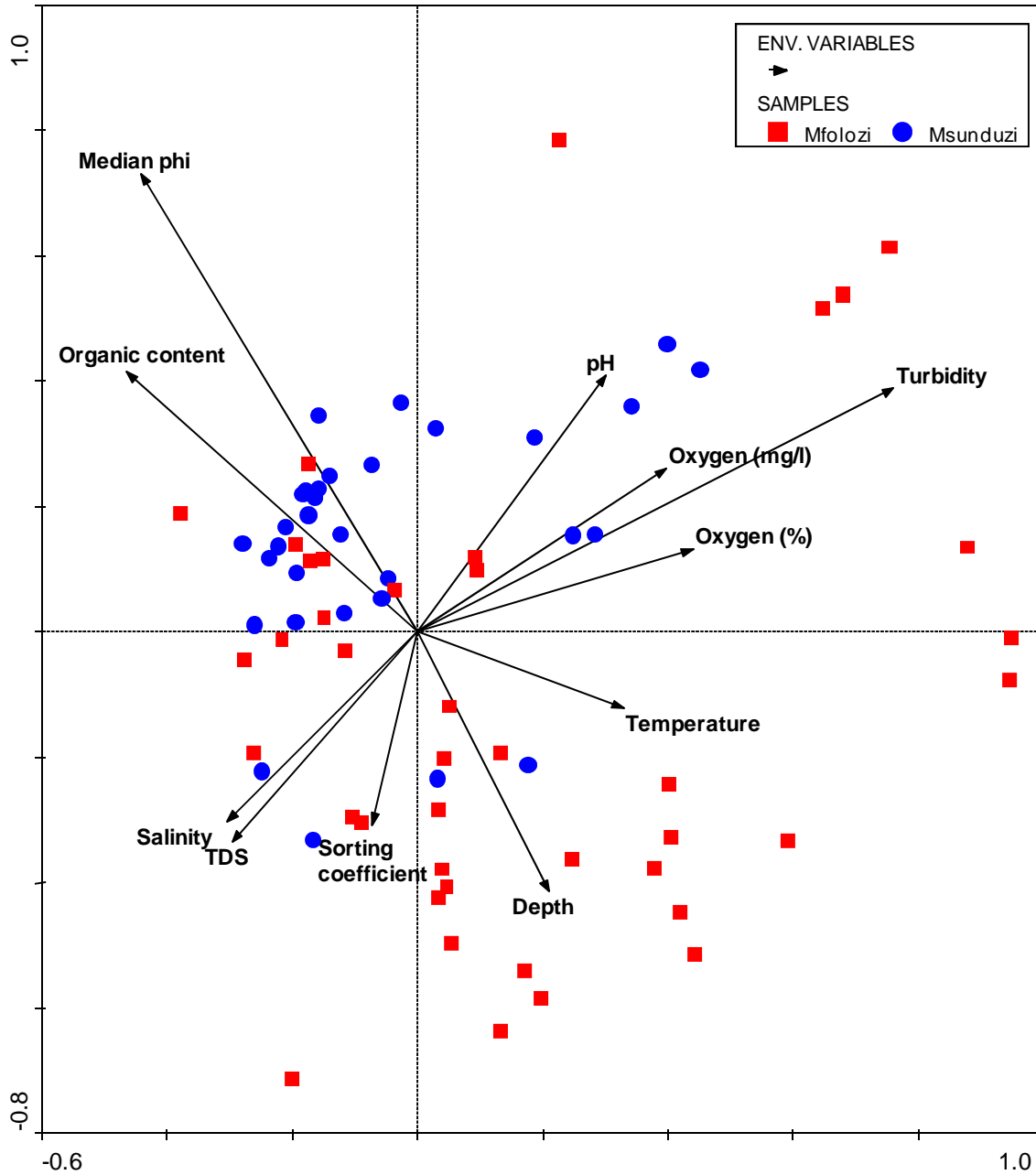


Figure 22: Canonical Correspondence Analysis (CCA) showing the correlation between the environmental parameters and the benthic community during the three- year period in the Mfolozi-Msunduzi system.

CHAPTER 4: DISCUSSION

4.1 Physico-chemical parameters

Salinities in the Mfolozi-Msunduzi system, as in other east coast estuaries, are usually high when the mouth is open and low when the mouth is closed, which usually depends on the frequency of rainfall occurring in the catchment (Harrison 2003). In 2007-2008, salinities were found to be high in the system in autumn and very low in spring (Ngqulana 2008). In autumn 2007 and 2008 the mouth of the system was open with a salinity gradient ranging from 0.9 to 35.9 (Ngqulana 2008). These salinity conditions were similar to those recorded during the current study. When the mouth was open, a strong salinity gradient was evident, with salinities being higher at the mouth and decreasing towards the upper reaches. In the Thukela estuary between 1997 and 1998, Mackay and Cyrus (1998a) recorded low salinities during autumn and summer (3.3-5.1) when the mouth was open and higher salinities in winter and spring (25.2-31.1), while Mackay *et al.* (2002) recorded salinities between 27 and 36 in the Thukela estuary during low flow periods in August 2001. Van der Elst *et al.* (1999) reported that the temporary open/closed Siyaya Estuary had increased salinities (13) in the lower reaches when the mouth was open. Salinities in the Mhlanga Estuary were high before mouth closure and decreased to less than 10 during the closed mouth phase (Whitfield 1980). Blaber *et al.* (1984) also recorded very low salinities in the Mdloti Estuary, except when the mouth was open. In the summer of 2009, the Mfolozi-Msunduzi system was open and relatively fresh. These conditions were different from the other seasons when the mouth was open mainly because the Mfolozi River had come down in flood shortly before sampling. These results show that a river-dominated estuary such as the Mfolozi system is relatively fresh during and shortly after a flood event, after which a salinity gradient will be established when the flood waters recede while the mouth remains open. When the mouth then subsequently closes during low flow conditions due to long-shore drift, the system will again gradually become fresh-water dominated, with relatively low salinities.

Water temperatures during the present study showed typical seasonal changes similar to those recorded during the 2007-2008 study conducted by Ngqulana *et al.* (2010) and in other

subtropical estuaries. These include the Thukela estuary (summer maximum of 32°C, winter minimum of 22°C) (Mackay and Cyrus 1998b), Mdloti estuary (13°C in winter and 27°C in summer) (Blaber *et al.* 1984, Cyrus 1988) and the Mhlanga Estuary (summer maximum temperature of 30°C and a winter minimum of 14°C) (Whitfield 1980).

High turbidities in estuarine systems are generally associated with high rainfall and runoff from the catchment (Harrison 2004). Whitfield (1980), Harrison and Whitfield (1995) found that turbidities were low during low-flow, closed mouth conditions in the Mhlanga estuary, but increased after rainfall in the catchment during summer. Similarly, in the Mdloti estuary, high turbidities were also related to high rainfall periods (Blaber *et al.* 1984). Harrison (2003) reported that in the Manzimtoti, Little Manzimtoti and Mhlanga estuaries, highest turbidities were recorded when these systems had breached after heavy rainfalls. Harrison (2004) also reported turbidities between 5-10 NTU in selected subtropical estuaries during their closed mouth periods. The Mfolozi-Msunduzi system during the present study was very turbid when the mouth was open, which corresponds to turbidities recorded during 2007 and 2008 (Ngqulana *et al.* 2010). Open mouth conditions in the system are associated with increased runoff from the catchment, which increases turbidities. Cyrus (1988) reports that when the St Lucia mouth was opened, large quantities of suspended particulate matter from the rivers increased the turbidities of the St Lucia system. The large quantities of suspended particulate matter in the Mfolozi-Msunduzi system are due to poor catchment management practices in the Mfolozi and Msunduzi catchment combined with naturally highly erosive soils (Lindsay *et al.* 1996).

In the Thukela estuary, high turbidities were recorded in autumn and summer, while low turbidities were recorded in winter and spring (Mackay and Cyrus 1998b). Very low turbidities ranging from 5-10 NTU were recorded in the Thukela estuary during the winter of 2001 (Mackay *et al.* 2002). In the Mfolozi-Msunduzi system, markedly lower turbidities ranging from 34 NTU to 58 NTU were recorded under closed mouth conditions. Higher turbidities were recorded in the Mfolozi estuary during summer, compared to the Msunduzi estuary. This is due to the fact that the large Mfolozi catchment produces a very high sediment load, whereas the

Msunduzi has a relatively small catchment. High turbidities can change the functioning of estuarine systems by reducing light penetration for photosynthesis, reducing primary production. The high fine sediment load associated with high turbidities in estuaries can also smother benthic invertebrates and their habitats, thereby decreasing the densities of benthic organisms (Dallas and Day 2004).

4.2 Nutrients

According to the ANZECC (2000) and DWAF (1995) recommended target values for nutrients in coastal marine waters, the Mfolozi-Msunduzi system is eutrophic. Nitrate and phosphate concentrations, which are essential nutrients for primary production in aquatic systems, exceed the target values.

Ammonia is a very common pollutant and is usually linked to industrial effluents and sewage (Dallas and Day 2004). Blaber *et al.* (1984) reported high levels of ammonia in the Tongati Estuary due to treated sewage effluents. Ammonia concentrations in the Mfolozi-Msunduzi system in winter and spring were lower than the recommended target value of 0.15mg/l (ANZECC 2000), with a maximum concentration of 0.11 mg/l (see Figure 5a). This trend was also recorded in the Sundays River estuary, where ammonia concentrations were higher in winter than in summer (Emmerson 1989). This is due to the fact that ammonia is flushed out during high flows in summer leading to low concentrations, while during low winter flows it accumulates in the estuary, particularly when the mouth is closed. Ammonia concentrations in the Mfolozi-Msunduzi system were lower compared to those recorded in the Sundays River estuary (0.42 mg/l - 0.55 mg/l) (Emmerson 1989).

Concentrations of nitrate were relatively high in the system, exceeding the mean of 0.038 mg/l recommended by DWAF (1995) for South African coastal marine systems. Nitrate concentrations were relatively high in the lower reaches of the system in autumn, winter and spring and very low in summer. It was also noted that nitrate concentrations were relatively low

in the upper reaches of the Mfolozi Estuary. This suggested that the nitrates primarily originated from the Msunduzi River, particularly when the mouth was closed in spring. These concentrations indicated the use of agricultural fertilizers in the sugar cane plantations in the land adjacent to the Mfolozi-Msunduzi system. Fertilizer application in river catchments significantly contributes to eutrophication of aquatic ecosystems (Dallas and Day 2004). This increases nitrate concentrations, which then promote rapid primary production in aquatic ecosystems. Eutrophication may change the biomass of benthic invertebrates, and can also limit the growth of organisms. This is due to the fact that eutrophication leads to depletion of oxygen and this becomes a challenge for organisms (Dallas and Day 2004). High nitrate concentrations in the Swartkops, Mgeni and Oliphants estuaries have been associated with increased fertilizer runoff (Dallas and Day 2004). Blaber *et al.* (1984) also recorded high nitrate concentrations derived from the use of agricultural fertilizers in the Mdloti estuary.

Phosphates are produced during the process of weathering but are also produced by anthropogenic activities such as untreated sewage discharge and runoff from cultivated land. Phosphates also promote the growth of aquatic plants, which are then available for primary consumers. Elevated concentrations of phosphates may also lead to eutrophication (de Jonge and Elliott 2002). Phosphate concentrations were relatively high in the Mfolozi Estuary, particularly during open mouth and high flow periods, suggesting that phosphates primarily come down the Mfolozi River. Phosphate concentrations in the Mfolozi Estuary were also higher in summer than in the other seasons. DWAF (1995) recommended phosphate concentrations of <0.062 mg/l for coastal marine systems and the Mfolozi-Msunduzi phosphate concentrations exceeded this mean, particularly during high flow conditions. Dallas and Day (2004) reported that nutrient concentrations are mostly linked to seasonal variability because high concentrations of nutrients are recorded after high rainfall. Eyre and Ferguson (2006) also reported that nutrient concentrations increase immediately after a flood, which indicates erosion and leaching of material from the catchment. High phosphate concentrations in the Mfolozi Estuary during high flows and open mouth conditions was due to the runoff from the sugarcane farms and to sewage effluent coming from the rural settlements in the upper areas of the catchment.

Chlorophyll-a concentrations reflect the biomass and abundance of phytoplankton in estuaries, which is directly dependent on nutrient availability. Nitrates, phosphates and ammonia are major nutrients that promote primary production and therefore eutrophication in aquatic ecosystems (Dallas and Day 2004). Elevated chlorophyll-a concentrations, combined with high temperature and oxygen concentrations, reflect high levels of the above mentioned nutrients. Chlorophyll-a concentrations were very high in the Mfolozi-Msunduzi system, which is suggested to be related to high phosphate and nitrate concentrations that cause an increase in primary production. Chlorophyll-a was significantly reduced after a flood in the Brunswick Estuary, Australia, and this was due to fast flowing water, which limits the accumulation of nutrients (Eyre and Ferguson 2006). A similar situation was observed in the Mfolozi-Msunduzi system, where chlorophyll-a concentrations were reduced in summer compared to the other seasons.

4.3 Sediment Characteristics (sediment grain size, organic content and sorting coefficient)

The ability of sediments to erode from the catchment to an estuary is influenced by factors such as the vegetation cover of the catchment, the type of soil and the slope of the catchment (Mead and Moores 2004). These factors can also control the quantity of sediments which are transported from the catchment to the river and into the estuary (Mead and Moores 2004). Ultimately, however, catchment management practices can greatly influence the amount of sediment available for erosive transport. Vegetation plays the most important role in limiting sediment transportation, by acting as sediment stabilizer and filter during heavy rainfall (Mead and Moores 2004). Instream vegetation can also influence sediment transport in a river and Vivier *et al.* (2010) and Vivier and Cyrus (2009) stress the fact that before the Mfolozi papyrus swamp was removed for sugarcane plantations, it acted as sediment filter and only allowed relatively sediment-free water to enter the Mfolozi-Msunduzi-St Lucia system.

During the present study, there were marked differences in sediment characteristics between the Mfolozi and the Msunduzi estuaries, which reflected the difference in riverine influence on the two estuaries. The Mfolozi estuary varied from coarse sand in the upper reaches to mud in the lower reaches, while the Msunduzi estuary was uniformly muddy throughout. The sediments

ranged from being well sorted at the mouth to poorly sorted in the upper reaches of the Mfolozi estuary, while the Msunduzi sites were all well sorted. This reflected the periodic flooding of the Mfolozi estuary which scours the system and deposits silt in the mouth area, while the Msunduzi estuary is seldom flushed and is therefore prone to silt deposition from the catchment and from the Mfolozi estuary. Ngqulana (2008) and Ngqulana *et al.* (2010) described the sediment of the system as characterized by coarse sand to mud, with the Mfolozi estuary having coarse sand to mud and the Msunduzi estuary being characterised by muddy substrata.

The Mlalazi estuary substratum, a permanently open estuary, was characterized by fine sand at the mouth, muddy in the middle reaches and coarse sand in the upper reaches (Mabaso 2002). The sediments of the Mhlathuze estuary were characterised by sand at sites close to the mouth and muddy at sites further away from the mouth (Owen *et al.* 2000), reflecting a typical tidal action influence at the mouth. The mouth of the Mfolozi-Msunduzi system was characterised by mud during low flows and sand during high flow and open mouth conditions, this being due to the fact that in winter and spring under low flows, a higher silt load was being deposited at the mouth, while during high flows in summer and autumn the silt load at the mouth was scoured out to the sea.

Organic material in sediments is very important for benthic organisms as many feed on detritus in and on the sediment. Gray (1981) stated that coarse sediments have low organic contents, compared to sediments consisting of silt and fine sand particles. During this study, muddy sites were found to have a higher organic content compared to sandy sites (Table 1). Similarly, in the Mlalazi estuary, it was observed that sites which were characterised by coarse sand had low organic content compared to sites which were characterised by fine to very fine sand (Mabaso 2002). The organic content of the Mfolozi-Msunduzi sediment was reported to be relatively low (<0.5% to 4%) (Ngqulana *et al.* 2010), compared to that of the St. Lucia and the Mhlathuze estuaries (max > 20%) (Owen *et al.* 2000). This is perhaps typical of a river-dominated system, in which fine sediment and organics continually get scoured out to sea during frequent flood events, particularly in the Mfolozi estuary. This is also evident in the Thukela estuary, where

Mackay and Cyrus (1998a) recorded organic contents of up to 14% in the muddy backwater areas, as opposed to 2% at the sandy midstream sites. The organic content of the Mfolozi system during the present study was different from the previous study conducted by Ngqulana *et al.* (2010), reaching up to 20% in the lower reaches during the spring season of 2008, while it was very low in the autumn of 2007 and 2008 (Ngqulana *et al.* 2010). This provides further evidence that frequent flood scouring of the system often flushes the accumulated organic material out to sea, creating highly variable sediment characteristics.

4.4 Benthic Composition

A total of 17 benthic taxa was recorded in the Mfolozi-Msunduzi estuarine system during 2007 and 2008 (Ngqulana *et al.* 2010), while 23 taxa were recorded in the system in 2009. These numbers were markedly lower compared to other subtropical estuaries, such as the Mngazana, Thukela, Mlalazi, Mhlathuze and St. Lucia estuaries (Table 9). This difference is most notable when compared with another river dominated system, the Thukela estuary, in which 170 taxa were recorded (Mackay and Cyrus 1998a). Even a small temporary open/closed (TOC) estuary such as the Nhlabane estuary, had a higher species richness, with 32 taxa (Vivier 2011). River dominated estuaries generally support a relatively low number of species as they are prone to constant flooding, which leads to unstable sediments that are frequently scoured during floods (Wooldridge and Deyzel 2009). There are a few opportunistic taxa that are able to rapidly recolonise a system after severe scouring of the sediments. The frequent flushing and associated scouring of sediments during floods in the Mfolozi estuary, in combination with the high silt load draining from the catchment into the Msunduzi estuary, explains the relatively low species richness in the Mfolozi-Msunduzi system.

The Mfolozi-Msunduzi estuarine system was also found to be impoverished in terms of benthic densities compared to other estuaries, such as the St. Lucia, Mhlathuze, Nhlabane and Thukela Estuarine systems (Table 9). Mean densities per season during the present study ranged between 729-4008 organisms m⁻², which is very low compared to these other systems. Again, this is most notable when compared to the Thukela estuary, in which densities of more than 15 000

organisms per m⁻² were recorded. Lowest densities in the Mfolozi system were recorded during summer and autumn, when high runoff from the catchment caused frequent scouring of the estuary sediments (Table 9). Benthic communities are ecologically important as they play a pivotal role in the diets of many fish, macrocrustacea and shorebirds and can influence the abundance and the species composition of these tertiary consumers (Currie and Small 2006). The low benthic densities in the Mfolozi-Msunduzi system can therefore be expected to lead to reduced numbers of benthic feeding fish and waders. Vivier and Cyrus (2009), Vivier *et al.* (2010) reported that juvenile fish species, which usually become benthic feeders after their copepod feeding phase, were largely absent in the Mfolozi-Msunduzi system due to the relatively low benthic densities.

TABLE 9: Numbers of invertebrate taxa and mean seasonal densities recorded in different subtropical estuaries. Classification into estuary type follows Whitfield (1992).

Estuary	Estuary Type	Nb. Taxa	Mean Densities			
			Autumn	Winter	Spring	Summer
Mfolozi-Msunduzi	River Mouth	17 (Ngqulana 2008 and Ngqulana <i>et al.</i> 2010)	3 855	–	4 471	–
Mfolozi-Msunduzi	River Mouth	23 (this study)	729	4 008	2 369	2 745
St Lucia	Coastal Lake	22 (Owen and Forbes 1997)	–	457	–	41 399 (MacKay <i>et al.</i> 2011)
Nhlabane	Temporarily open/closed	32 (Vivier and Cyrus 1999)	14 538	20 381	–	21 375 (Vivier and Cyrus 1999)
Mhlathuze	Estuarine Bay	113 (MacKay and Cyrus 1998b)	9 785	9 067	33 265	16 959
Malazi	Permanently open	36 (Mbaso 2002)	15 884	31 157	–	–
Thukela	River Mouth	170 (MacKay and Cyrus 1998a)	<15 000	>90 000	–	–
Mrgazana	Permanently open	209 (Branch and Grindley 1979)	–	–	–	–

The Mfolozi-Msunduzi Estuarine system was dominated by polychaetes, amphipods and the mudcrab *P. blephariskios*. Polychaetes and amphipods often form a dominant component in estuarine benthos, followed in numerical importance by bivalves and gastropods (Day 1981b). Polychaetes and amphipods were also found to be dominant in the subtidal zoobenthos of the Great Berg Estuary (Wooldridge and Deyzel 2009), Mhlathuze estuary (MacKay and Cyrus 1998a) and Nhlabane estuary (Vivier and Cyrus 1999). The absence of bivalves and gastropods from the Mfolozi-Msunduzi benthos, which is probably related to the high silt load in the system, is one of the most notable differences between this system and the other Zululand estuarine systems such as the St Lucia and Mhlathuze estuaries.

The Mfolozi and the Msunduzi estuaries had distinct differences in terms of their benthic composition. The Mfolozi estuary supported a number of polychaete species, while the Msunduzi estuary supported amphipods and the ocypodid crab. It was also noted that the Mfolozi estuary was dominated by the polychaete, *D. arborifera*, while the Msunduzi estuary was dominated by the brachyuran *P. blephariskios*. Ngqulana *et al.* (2010) also reported that the benthic composition of the two estuaries was markedly different, which was attributed to the difference between the substrata of the two estuaries. Teske and Wooldridge (2003) reported that sediment particle size is one of the primary factors responsible for limiting the distribution of benthic organisms in South African estuaries. This importance of substratum characteristics in determining the distribution of the benthic organisms in estuarine systems was also emphasised by Cyrus and Wepener (1997, 1998) in the Nhlabane and Mhlathuze estuaries. Sediments are important habitats for benthic organisms and if the substratum of an estuary is continuously disturbed, species which are not able to re-establish themselves will be lost.

The Mfolozi estuary is subject to periodic flooding (Begg 1979) and this result in the presence of unstable sediments. The dominance of polychaetes such as *D. arborifera* and *P. sexoculata* in the Mfolozi estuary and the concurrent absence of amphipods and molluscs from this area are regarded as indicative of disturbed substrata (Owen *et al.* 2010). Many polychaetes are regarded as relatively tolerant to habitat disturbance and also anthropogenic factors that affect the ecological functioning of the estuary (Wildsmith *et al.* 2009, Silva *et al.* 2011). The substratum in the upper reaches of the Mfolozi was characterized by frequently scoured, poorly sorted sandy sediments, which prevent the establishment of less tolerant burrowing benthic organisms or organisms adapted to more muddy substrata, such as many crustaceans (amphipods, tanaids, mysids and brachyurans) (Owen *et al.* 2010, Ngqulana *et al.* 2010). The tanaid *A. digitalis* occurred in higher densities in muddy areas than in the sandy areas of the Nhlabane coastal lake (Vivier and Cyrus 1999). The amphipod *Corophium triaenonyx* was also found to be more abundant in muddy rather than in sandy substrata in the Nhlabane estuary (Vivier and Cyrus 1999). The absence of silt in both the Mdloti and Tongati led to the absence of burrowing benthic organisms (Blaber *et al.* 1984). The dominance of the polychaete *D. arborifera* in the

Mfolozi Estuary is therefore suggested to reflect its tolerance to unstable sandy sediments. Branch and Grindley (1979) report that *D. arborifera* is a tolerant species to habitat disturbances, as it occurs in low oxygen areas in the Mngazana estuary, Eastern Cape. Groenewald (2010) also noted that in the Mngazana estuary, the polychaete *P. sexoculata* occurred mostly in coarse sand sediments. As with *D. arborifera*, *P. sexoculata* is also known to have a wide geographical distribution (Day 1967). In summary, the unstable substrata in the Mfolozi estuary have resulted in it supporting mostly polychaetes such as *D. arborifera* and *P. sexoculata*, which appear to be tolerant of such frequently scoured sediments. During winter this estuary has areas that contain silt but these support very few burrowing organisms due to frequent scouring from flooding.

The Msunduzi estuary is very muddy due to a high rate of silt deposition. The high silt deposition is partially caused by a spillway in the upper Mfolozi River floodplain which was constructed to channel excess Mfolozi floodwater evenly over sugar cane fields in the direction of the Msunduzi River (Berning *et al.* 2001). Most importantly, the spillway decreases the speed with which floodwaters flow across the floodplain and into the Msunduzi River. The 1000m long spillway was constructed after the Domoina floods in 1984 (Berning *et al.* 2001). When the Mfolozi River flow exceeds $760 \text{ m}^3\text{s}^{-1}$, the sediment-laden water starts flowing over the spillway onto the floodplain and in the direction of the Msunduzi River. The reduction in flow velocity means that a large portion of the fine sediments will be deposited in the Msunduzi River (Berning *et al.* 2001). The small catchment of the Msunduzi River, combined with the presence of the spillway, means that flows in the Msunduzi River are never high enough to scour the accumulated silty sediments. Also, when the Mfolozi River comes down in flood, the sediment laden water is pushed back up the Msunduzi estuary. These are the reasons why the Msunduzi estuary remained muddy throughout the study. The nature of the substratum of the Msunduzi estuary is deleterious for most benthic organisms as the high silt load smothers these organisms. Silva *et al.* (2011) state that most benthic organisms cannot inhabit muddy sediments comprising more than 80% silt and clay as these can clog the siphons and gills of these organisms. Fine silty sediments increase turbidities in estuaries (Cyrus 1988) and this also prevents the occurrence of filter-feeding organisms, such as bivalves. During the present study, the Msunduzi estuary was

more turbid than the Mfolozi estuary, except when the Mfolozi was in flood. The absence of bivalves in the Msunduzi estuary indicates that the high turbidities do not favour the presence of filter-feeding organisms. The very low densities of *D. arborifera* in the Msunduzi estuary was probably also related to the high silt content in the sediments of this estuary, as this polychaete builds its tubes with sand containing silt so the tubes will be hard enough not to collapse (Day 1967).

The above two paragraphs highlight the negative impacts of the removal in the 1950s of the Mfolozi floodplain papyrus and *Phragmites* swamp. The removal of the swamp had two serious consequences for the benthos of the Mfolozi-Msunduzi system. The frequent flooding of the Mfolozi estuary caused periodic scouring of the sediments and displacement of most of the benthic organisms. The second impact is the huge load of silt deposited in the Msunduzi estuary and parts of the Mfolozi estuary, which potentially smothers the organisms. The combined effect of these two factors means that the Mfolozi-Msunduzi system is a very unstable environment for benthic organisms, as they experience periodic cycles of heavy silt deposition alternated by scouring.

The most abundant species in the Msunduzi estuary was *P. blephariskios*, indicating that this species prefers the muddy substratum of the Msunduzi estuary. *Paratyloidiplax blephariskios* was recorded in the lower reaches of the Mfolozi estuary only when these sites were characterised by fine muddy sand, but occurred only at very low densities. Owen (1999) and Owen (2003) noted the importance of the nature of the substratum for this crab, this being the most important factor in the distribution and abundance of *P. blephariskios* in the Mhlathuze and St. Lucia estuaries (Owen 1999). In both these systems, the distribution of the crab was restricted to muddy areas.

The tanaid *A. digitalis* and amphipods such as *C. triaenonyx* and *G. bonnieroides* were recorded in the Mfolozi estuary but occurred only at very low densities. Mackay *et al.* (2010) reported that *A. digitalis* and *G. bonnieroides* are deposit feeders and thus prefer locations with high organic

content and mud. *Apseudes digitalis* and *G. bonnieroides* were recorded in lower densities in the Mfolozi-Msunduzi system during the present study compared to the 2007-2008 study (Ngqulana *et al.* 2010). In the Mfolozi-Msunduzi system, *A. digitalis* occurred in more muddy substrata, while in the St. Lucia system, this species was associated with both sandy (Mackay *et al.* 2010) and muddy substrata (Bolt 1975 and Blaber *et al.* 1983). *Apseudes digitalis* and *P. blephariskios* were also the most abundant species in the Mhlathuze estuary, particularly in muddy areas (Mackay and Cyrus 1998a). This was attributed to the fact that these organisms were able to inhabit muddy areas with high organic content. *Grandidierella bonnieroides* occurred in high densities in muddy areas in the St. Lucia estuary (Mackay *et al.* 2010). Although this amphipod did not occur in high densities in the Mfolozi-Msunduzi estuary, it was primarily recorded in the Msunduzi estuary. These tube dwelling amphipods generally avoid areas that are too sandy due to the unstable nature of sandy substrate with low organic content. Low densities of the tanaids and amphipods in the Mfolozi-Msunduzi system indicated that these organisms prefer substrata which have a higher organic content.

Paratyloidiplax blephariskios, *A. digitalis*, and *G. bonnieroides* were found to be dominant in muddy areas of the Mhlathuze estuary, while a few polychaetes were recorded in these sites (Mackay and Cyrus 1998a). *Paratyloidiplax blephariskios* is a very important organism in the benthos of subtropical estuaries as it occurs in high densities in muddy substrata (Owen 2003). Densities of *P. blephariskios* in St. Lucia averaged 1500 N.m⁻² (Owen and Forbes 1997), which were similar to those recorded during this study (1040 N.m⁻²). However, densities of *P. blephariskios* recorded during this study were much lower than those recorded in the Mhlathuze estuary (3000 N.m⁻²) (Owen and Forbes 1997). Owen and Forbes (2002) reported that *P. blephariskios* was a euryhaline species, having a salinity tolerance range between 5 and 60. The absence of this crab in the upper sites of the Msunduzi was probably due to the low salinities frequently recorded in the upper Msunduzi. Ngqulana *et al.* (2010) reported that salinities in the upper Msunduzi sites were often lower than 5, which reflects the river-dominated nature of the system and suggests that the occurrence of this mud crab would be limited at these sites. Owen and Forbes (1997) reported that densities of *P. blephariskios* in St Lucia decreased from the

lower to the upper Narrows over a distance of approximately 20 kilometres with decreasing salinities, even though the substratum in the upper Narrows was suitable for the crab.

4.5 Seasonal distribution in the benthic community

Heavy rains during the summer season often lead to flood conditions in estuaries, and these result in the scouring of sediments. This may flush many benthic organisms out to sea, thereby eliminating many benthic and epibenthic species and also reducing species densities (Currie and Small 2006). The stability of the substrata in estuaries is therefore affected by such floods during wet seasons, and this result in the substrata being unstable for species colonization (Currie and Small 2006). Owen and Forbes (1997) noted that the polychaetes *Marphysa macintoshi* and *D. arborifera* had disappeared after the 1984 and 1987 cyclonic floods in the St Lucia estuary. The disappearance of these polychaetes was due to them being swept away by the flood (Owen and Forbes 1997). The scouring of accumulated sediments in estuaries during river flooding also removes detritus from the sediment which leads to a scarcity of food for the estuarine benthic fauna, which in turn reduces benthic densities and fish populations (Whitfield and Harrison 2003).

Very low benthic densities were recorded in the Mfolozi estuary in autumn of 2009 due to the fact that the system had come down in flood and the sediment was scoured away, which resulted in most of the benthic organisms being swept away. Owen and Forbes (1997) reported that errant species, such as *D. arborifera* and *Ceratonereis* sp., are more likely to be swept away by the scouring action of the flood. This explains the reduced benthic densities during high flows in summer and autumn, particularly of *D. arborifera* and *Ceratonereis* sp. The virtual absence of *P. sexoculata* in autumn and summer is also due to these polychaetes being swept away by high freshwater flows during these seasons. River dominated estuaries usually have low salinities during high flow conditions due to the high freshwater inflow into the estuary from the river (Mackay and Cyrus 1998b). Mackay and Cyrus (1998b) recorded more freshwater taxa than estuarine taxa in the Thukela estuary due to the strong river influence in this estuary, which resulted in low salinities for most of the time. This explains the appearance of freshwater taxa

such as Simuliidae, Baetidae, Chironomidae and Ecnomidae in the upper Mfolozi and Msunduzi estuaries in autumn and summer, where salinities of 0.1 and 0.2, respectively, were found (Figure 4).

High benthic densities were recorded in winter in the Mfolozi-Msunduzi estuarine system under low flow conditions compared to other seasons sampled. Mabaso (2002) also recorded higher densities during winter in the Mlalazi estuary. Significant differences between dry and wet seasons were found in the Caeté estuary, Brazil, where higher benthic densities and species richness was recorded during low flow season (Silva *et al.* 2011). During low flow conditions, which occur in winter and spring in KZN, benthic densities usually increase due to a reduced scouring effect by flood waters, resulting in a more stable habitat (Mabaso 2002). Sediments are more stable during low flows compared to high flows as fine sediments settle out and accumulate in the substrata during low flows (Currie and Small 2006). This explains the relatively high densities recorded in winter compared to autumn, spring and summer in the Mfolozi-Msunduzi system. The same trend was also observed in this system during 2007-2008, where high densities were recorded in winter compared to autumn (Ngqulana 2008).

4.6 Changes in the zoobenthic community structure

During this study, ANOSIM showed spatial significant differences in the benthic community between the Mfolozi and Msunduzi Estuaries, which suggested that spatial factors strongly affected the benthic composition of the estuaries. Spatial distribution of benthic macroinvertebrates along an estuarine gradient is related to environmental factors such as salinity, sediment type and depth (Barros *et al.* 2008 and Fujii 2007). Significant differences were also recorded between seasons within the Mfolozi estuary and reflected that the benthic community structure of this estuary was significantly influenced by natural seasonal variations. However, within the Msunduzi estuary, significant differences between sites clearly indicated that spatial variations were primarily responsible for structuring the benthos of this estuary, rather than seasonal differences. CCA (CANOCO) and BIOENV (PRIMER) (see Figure 16 and

Table 6) revealed that sediment characteristics and temperature played a major role in the spatial and temporal distribution of the Mfolozi-Msunduzi system.

Salinity is generally considered to be the most important factor in the structuring of benthic communities in estuaries (Teske and Wooldridge 2003). Changes in the community structure of the benthos of St. Lucia Narrows during 1983-1994 periods were attributed to changes in salinities (Owen and Forbes 1997). Ngqulana *et al.* (2010) reported that salinity was the most important factor in structuring the benthos of the Mfolozi-Msunduzi system during 2007-2008, which was strongly correlated with temperature. This was because high salinities were recorded in summer under open mouth conditions, while low salinities were recorded in winter, under low flow, closed mouth conditions. During the present study, salinity was negatively correlated with temperature, as highest salinities were recorded during winter and spring when temperatures were low, while low salinities were recorded during summer and autumn when temperatures were high (Figure 16 and Table 6). The reason for this anomaly is that in summer, flooding conditions of high flow and low salinity are followed by periods of high salinity when the flow recedes and the wide open mouth allows a strong tidal influence. Sampling during high flow conditions invariably show low salinities throughout the system, whereas sampling during open mouth conditions following floods show a strong salinity gradient in the system. Another reason would be that in spring temperatures were low and the mouth was closed but the salinity gradient was prominent. In spring 2007 and 2008 the Mfolozi-Msunduzi system was relatively fresh and the mouth was closed (Ngqulana 2008 and Ngqulana *et al.* 2010).

Teske and Wooldridge (2001, 2003) suggest that even though salinity is an important factor influencing the distribution of estuarine macroinvertebrates, euryhaline species appear to be more independent of salinity in terms of their distribution. Teske and Wooldridge (2004) suggest that due to the independence of euryhaline estuarine species to salinity variations, it is more appropriate to consider the sediment types in order to explain some of the distribution patterns of estuarine benthic organisms. In addition to salinity, sediment type is one of the most important factors in determining the spatial patterns in the benthos of estuaries (Vivier and Cyrus 1999,

Teske and Wooldridge 2003, Barros *et al.* 2008). During the dry season survey in Port Curtis, Australia, it was found that sediment structure played an important role in the structuring of the benthic community, whereas salinity only had a minor influence on the benthos (Currie and Small 2006). Fujii (2007) also found that spatial patterns in the benthic distribution of estuaries were closely related to the sediments and salinity. Sediment particle size, organic content and salinity were the most important environmental variables influencing the distribution of benthos of the Mlalazi estuary between 1999 and 2000 (Mabaso 2002).

4.7 Comparisons with Historical Data

Comparative analysis of the benthic data from the Mfolozi system recorded over the three-year period (2007-2009), showed that there were significant temporal differences between sampling years ($R=0.29$, $p=0.001$) as well as spatial differences between sites ($R=0.12$, $p=0.001$) and between the Mfolozi and Msunduzi estuaries ($R=0.12$, $p=0.003$). These results clearly showed that both temporal and spatial factors played a primary role in structuring the benthic community of the system. These differences are expected due to the highly variable riverine flows from the catchment which affects the substrata and salinity regimes of the system. Van Heerden (2011) reported that the dynamic Mfolozi system is influenced by fluvial factors which then interact with marine processes to continually reshape the estuary.

The results (Table 9) showed that sediment characteristics (particle size and organic content) and turbidity were the most important environmental factors in structuring the benthic community of the Mfolozi-Msunduzi system. The constantly changing sediments in the Mfolozi estuary and the constantly muddy Msunduzi estuary are the cause of the differences in the benthic communities as well as for the significant differences between the two estuaries, with the Mfolozi estuary experiencing frequent flooding and scouring of the sediments. Sediment particle size and organic content were found to be important factors in determining the benthic community structure of the Thukela estuary between 1997, 1998 and in 2001 (Mackay and Cyrus 1998b, Mackay *et al.* 2002). Cyrus and Blaber (1987) as well as Dallas and Day (1994) report that in areas where turbidities are high, the species diversity and probable densities would be reduced. This was

found to be true for the Mfolozi estuary as high turbidities were found to be related to flooding and low benthic densities.

These two factors (high turbidity and related sediment characteristics) clearly indicated the results of human induced impacts on this estuary. Richards *et al.* (1993) suggest that humans can increase the transportation of large sediments into streams by land use, such as removal of the riparian vegetation and agriculture practices. The high sediment loads that are brought in to the estuary by runoff and increased turbidities due to suspended matter prevent the colonization of most benthic taxa in the Mfolozi-Msunduzi system. Dallas and Day (1994) also state that increased turbidities affect the habitat of benthic organisms by changing the stability of the substrata, while feeding techniques and respiratory organs are also affected. This is true for the Mfolozi-Msunduzi system as most of benthic organisms are potentially smothered by the high silt load and the frequent flooding creates unsuitable conditions for benthic populations to be re-established.

4.8 Biomass

During this study the biomass of the benthos of the Mfolozi-Msunduzi estuarine system was dominated by two species, the polychaete *D. arborifera* and the burrowing crab *P. blephariskios* (Table 10). Blaber *et al.* (1983) in South Lake, St Lucia, Whitfield (1980) in the Mhlanga estuary and Kalejta and Hockey (1991) in the Berg River estuary (Table 10), noted that polychaetes were the greatest contributors to the biomass of these systems. This was not the case in the Mfolozi-Msunduzi estuarine system, where *P. blephariskios* completely dominated the biomass of the Msunduzi estuary. The mean benthic biomass of the Mfolozi estuary (4.64 g.m^{-2}) was, however, substantially lower than that of the Msunduzi estuary (11.20 g.m^{-2}). This was due to the fact that this species is known to occur in high densities in areas characterized by mud, and it has been reported by Owen (1999) and Owen (2003) that this crab forms an important component of estuarine benthos in soft muddy substrata. *Paratyloidiplax blephariskios* was also an important component in the benthic biomass of the Mhlathuze estuary (Mackay and Cyrus 1998a), where the higher benthic biomass in muddy sites compared to sandy sites was due to muddy sites

supporting higher densities of *P. blephariskios*. The high biomass of *P. blephariskios* was also attributed to its size. Bolt (1975) reported that because these crabs are much larger than the other benthic organisms occurring in an estuary, their contribution to the biomass would be important for benthic organisms preying on this crab.

This pattern was also recorded in South Lake, St. Lucia, in 1981-82, where the benthic biomass was found to be higher in muddy sites compared to sandy sites (Blaber *et al.* 1983). The biomass in sandy substrata ranged from 0.56 g.m⁻² to 3.23 g.m⁻², while the biomass in muddy substrata ranged from 1.07 g.m⁻² to 8.55 g.m⁻² (Blaber *et al.* 1983). The biomass from the sandy substrata of South Lake was similar to that recorded in the sandy sites of the Mfolozi-Msunduzi estuarine system during the present study (0.001 g.m⁻² and 3.41 g.m⁻²). In contrast, the biomass of the muddy substrata of South Lake from (1.07 g.m⁻² to 8.55 g.m⁻²) (Blaber *et al.* 1983) was much higher than that of the equivalent substrate in the Mfolozi-Msunduzi system (0.070 g.m⁻² to 33.84 g.m⁻²). An anomaly in this pattern was reported from South Lake, St. Lucia, during 1972 and 1973, when the benthic biomass from sandy sites was reported to range between 1.08 g.m⁻² and 3.26 g.m⁻², while lower biomass, ranging from 0.013 g.m⁻² to 0.235 g.m⁻² was recorded at the muddy sites of Lake St. Lucia (Bolt 1975). The reason for this anomaly was that the benthic composition was on the sandy sites was dominated by larger species such *Solen cylindraceus* (Bolt 1975).

Table 10 presents comparable biomass data from a number of South African estuaries. The mean benthic biomass of the Mfolozi-Msunduzi system was higher than that reported by Bolt (1975) in Lake St Lucia between 1972 and 1973 (0.68 g.m⁻²) and by Blaber *et al.* (1983) in 1981 and 1982 (Table 10). The benthic biomass of the Mfolozi-Msunduzi was also higher than that of the Bot River estuary (6.29 g.m⁻²) (De Decker and Bally 1985) and Mhlanga estuary in 1978 (Whitfield 1980), but lower than that of the Swartvlei estuary (Whitfield 1989) and Berg River estuary (Kalejta and Hockey 1991) (Table 10). Although the benthic densities in the Mfolozi-Msunduzi system were very low, these results show that the benthic biomass in the system was relatively high. This was attributed to high biomass of *P. blephariskios* and its large size

compared to other benthic organisms. It has been suggested by Owen (1999) and Owen (2003) that *P. blephariskios* tends to dominate the benthic biomass in muddy estuaries in which it occurs. This complete biomass dominance of *P. blephariskios* is mostly related to its large size. It could however also be difficult for predators to catch this crab as it burrows 5-10cm in the mud (Vivier pers. comm.).

TABLE 10: Dominant invertebrate taxa and mean biomass recorded in the selected estuaries. Classification into estuary type follows Whitfield (1992).

Estuary	Type	Dominant Taxa	Mean Biomass
Mfolozi-Msunduzi	River Mouth	<i>P. blephariskios</i> and <i>D. arborifera</i> (this study)	7.92 g.m ⁻²
St. Lucia (South Lake)	Coastal Lake	<i>Marphysa macintoshi</i> (Bolt 1975)	0.68 g.m ⁻²
St. Lucia (South Lake)	Coastal Lake	<i>Solen cylindraceus</i> and <i>Marphysa macintoshi</i> (Blaber <i>et al.</i> 1983)	2.63 g.m ⁻²
Mhlanga	Temporarily Open/Closed	<i>C. triaenonyx</i> , <i>Ceratonereis erythraensis</i> and <i>D. arborifera</i> (Whitfield 1980)	1.5 g.m ⁻²
Berg	Permanently open	<i>C. erythraensis</i> , <i>Ceratonereis keiskamma</i> and <i>Hydrobia</i> sp. (Kalejta and Hockey 1991)	19.39 g.m ⁻²
Bot	Permanently open	<i>Arcuatula capensis</i> (de Decker 1985)	6.29 g.m ⁻²

The maximum benthic biomass in the Mfolozi-Msunduzi Estuarine system was recorded in winter. Similarly, Bolt (1975) recorded maximum benthic biomass in Lake St. Lucia in July and minimum biomass in January. No such seasonal patterns were found by Blaber *et al.* (1983) in South Lake between 1981 and 1982. A decrease in benthic biomass was also noted in the Mhlanga estuary during summer months (Whitfield 1980). The decrease in benthic biomass in estuaries during open mouth periods is due to the scouring of sediments and also the fact that large areas of the estuary are tidally exposed when water levels are low (Whitfield 1980).

CHAPTER 5: CONCLUSION

The Mfolozi-Msunduzi estuarine system displayed a relatively low macrobenthic species diversity compared to other subtropical estuaries such as the nearby St. Lucia estuary and the Mhlathuze and Mlalazi estuaries, due to low species richness as well as low benthic densities of the majority of species. In this study there were marked differences between the sediments of the two estuaries. The Mfolozi estuary was mostly characterised by sandy sediments, while the Msunduzi estuary was characterised by mud. This resulted in marked differences between the benthic composition of the Mfolozi and Msunduzi Estuaries. The Mfolozi estuary supported primarily polychaetes, while the Msunduzi estuary supported crustaceans such as amphipods, tanaids and brachyurans, which showed preference for muddy substrata. The polychaete *D. arborifera* occurred in high densities in the Mfolozi estuary, whilst the burrowing crab *P. blephariskios* was dominant in the Msunduzi estuary.

BIOENV and CCA analysis showed that sediment characteristics were the primary factors which played a role in structuring the benthic community of the Mfolozi-Msunduzi system. In contrast, the benthic community of the Msunduzi estuary was primarily forged by spatial changes in this estuary. Sediment characteristics in estuaries are often responsible for determining the spatial patterns of the benthic invertebrates (Vivier and Cyrus 1999, Teske and Wooldridge 2003, Fujii 2007). This study also confirmed that spatial differences in sediment characteristics were the most important environmental variables in determining the benthic distribution of the Mfolozi-Msunduzi estuarine system. This was followed by temporal changes in temperature, which reflected natural seasonal variations in the estuarine environment.

In terms of the benthic biomass of the system, two species were dominant, namely, the polychaete *D. arborifera* in the Mfolozi estuary and the mud crab *P. blephariskios* in the Msunduzi Estuary. *Paratyloidiplax blephariskios*, however, completely dominated the Mfolozi-Msunduzi system in terms of biomass. This coincides with reports from elsewhere that stated that this species contributes the most to the biomass of subtropical estuaries, particularly in

muddy areas (Owen 2003). The Msunduzi estuary had a higher mean biomass (11.20 g. m^{-2}) than the Mfolozi estuary (4.64 g. m^{-2}), largely due to its higher *P. blephariskios* densities. It was also noted that maximum biomass was recorded in winter, which decreased in summer. Higher benthic biomass during winter has also been reported from other estuaries (Boltt 1975, Whitfield 1980 and Kalejta and Hockey 1991).

Biomass in the Mfolozi-Msunduzi system was low in sandy areas and high in muddy areas, which can be attributed to the high densities of the mud crab *P. blephariskios* in muddy areas. However, the Mfolozi-Msunduzi system remains impoverished in terms of benthic biomass due to the fact that the rest of the benthic organisms only occurred in low densities and biomass and contributed little towards food for most benthic feeders. This was also evident in a study on the diet of selected benthic feeding fish (Nhleko 2011). The benthos was poorly represented in the diets of these fish, mainly due to the low benthic densities. The fish were found to feed mostly on copepods, which remained relatively abundant throughout the system (Jerling *et al.* 2010). It has also been reported by Vivier *et al.* (2009) that a number of benthic feeding fish species disappeared from the system at the end of their obligate plankton feeding phase at a length of 30-50mm. Even though the benthic biomass in the system was relatively high due to the abundance of *P. blephariskios*, other benthic organisms such as polychaetes, amphipods and tanaids were recorded in low densities and biomass. This meant that the Mfolozi-Msunduzi system was unable to provide sufficient food for many benthic feeding fish recorded in the system (Vivier *et al.* 2009).

The St. Lucia estuary mouth has been closed since 2002, except for a six month period in 2007. During the prolonged mouth closure of the St. Lucia system, the Mfolozi-Msunduzi system, which opens frequently during flooding events and summer high flows, has a very large potential in acting as a nursery area for juvenile marine spawning and estuarine fish. Juvenile marine fish were abundant in the system indicating the importance of this estuary for juvenile fish (Vivier *et al.* 2010). The low benthic densities in the system can, however, not support a large benthic feeding fish population. In terms of the long-term closure of the St. Lucia system, the Mfolozi-

Msunduzi system is also important for maintaining *P. blephariskios* populations, which are declining in the adjacent St. Lucia system Owen (2010).

Turpie (2004) and Turpie *et al.* (2002) reported that many KwaZulu-Natal estuaries were among the most important in terms of conservation status of the country. The Mfolozi-Msunduzi system was one of the estuaries that were rated relatively high in terms of biodiversity importance due to the service it provides for the St Lucia system (Turpie *et al.* 2002). The prolonged mouth closure of the St Lucia system makes it the most important nearby estuary for juvenile fish and other organisms which utilize estuaries during their early life stages. Turpie and Chesterman (2011) noted that although the Mfolozi-Msunduzi system is conserved as a World Heritage Site, it is highly influenced by anthropogenic factors and poorly managed.

Although the poor management of the Mfolozi-Msunduzi catchment and its associated high sediment load has led to unstable substrata and impoverished benthic invertebrates, conservation of the Mfolozi-Msunduzi system is still very important for juvenile marine fish which utilize this system as a nursery ground. Due to its importance, there is a need to ensure that the Mfolozi-Msunduzi system's health is improved and maintained.

Even though there is a lack of information on the species richness and diversity of the benthic fauna of the system before the removal of the swamps, restoration of the Mfolozi Swamps in the floodplain would help reduce the amount of fine sediments accumulating in the system leading to mouth closure during dry periods. This means the estuary would also function as a river mouth estuary as before and the stress facing the benthic organisms, which are constantly scoured with the sediments during floods in the system, would be reduced. However, due to a lack of information on the fauna of the system prior to the swamp removal, it is very difficult to compare the present changes in the fauna with the conditions prior to the swamp removal. However, changes in the benthic fauna of the St Lucia system reflect the impact of the swamp removal and the excavation of the separate mouth for the Mfolozi-Msunduzi system. This has been shown by

the reduction of some benthic species, which is believed to be due to the prolonged mouth closure of the system which prevents their recruitment to the marine environment. After re-establishment of the swamps, there will be a need for ongoing monitoring of water quality, benthos, fish and other biota of the system. This would help with the design of proper catchment management plans. Maintaining conservation management strategies by implementing biomonitoring programmes would help to improve the ecological integrity and biodiversity of this system.

REFERENCES

- ANZECC. 2000. Australian and New Zealand guidelines for fresh and marine water quality. Canberra, Australia, Australia and New Zealand Environment and Conservation Council. National water quality management strategy No. 4.
- BARROS, F., HATJE, V., FIGUEIREDO, M.B., MAGALHAES, W.F., DOREA, H.S. and EMIDIO, E.S. 2008. The Structure of the Benthic Macrofaunal Assemblages and Sediments Characteristics of the Paraguacu Estuarine System, NE, Brazil. *Estuarine, Coastal and Shelf Science* **78**: 753-762.
- BEGG, G. 1978. The estuaries of Natal. Town and Regional Planning Report 41. 657pp.
- BERNING, C., DU PLESSIS, L. A. and VILJOEN, M. F. 2001. Loss functions for structural flood mitigation measures, *Water SA*, **27** (1): 35-38.
- BERNING, C., VILJOEN, M. F. and DU PLESSIS, L. A. 2000. Loss functions for sugar-cane: Depth and duration of inundation as determinants of extent of flood damage, *Water SA*, **26**(4): 527-530.
- BERRY, W., RUBINSTEIN N. MELZIAN, B. and HILL, B. 2003. The Biological Effects of Suspended and Bedded Sediment (SABS) in Aquatic Systems: A Review, Internal Report, <http://water.epa.gov>.
- BLABER, S.J.M., HAY, D.G., CYRUS, D.P. and MARTIN, T.J. 1984. The Ecology of Two Degraded Estuaries on the North Coast of Natal, South Africa, *South African Journal of Zoology* **19**: 224-240.
- BLABER, S.J.M., KURE, N.F., JACKSON, S. and CYRUS, D.P. 1983. The benthos of south lake, St Lucia following a period of stable salinities, *South African Journal of Zoology* **18**: 311-319.

- BOLTT, R.E. 1975. The Benthos of some Southern African Lakes, Part V: The Recovery of the Benthic Fauna of St Lucia Lake Following a Period of Excessively High Salinity. *Transactions of the Royal Society of South Africa*, **41**: 295-323.
- BRANCH, G.M. and GRINDLEY, J.R. 1979. Ecology of southern African estuaries, Part XI. Mngazana: a mangrove estuary in Transkei. *South African Journal of Zoology*, **14**(3): 149-170.
- CLARKE K. R and GORLEY R. N. 2006, Primer V6: Manual user/ Tutorial. Primer-E Ltd. Plymouth Marine Lab, United Kingdom. 190pp.
- CLARKE, K. R., WARWICK, R.M. 2001. Change in marine communities: An approach to statistical analysis and interpretation (2nd ed.), Plymouth: Primer-E.
- CURRIE, D. R. and SMALL, K.J. 2006. The Influence of dry-season Conditions on the Bottom Dwelling Fauna of an East Australian sub-tropical estuary, *Hydrobiologia*, **560**:345–361.
- CYRUS, D. P. 1988. Turbidity and other Physical Factors in Natal Estuarine Systems Part 1: Selected Estuaries. *Journal of the Limnological Society of Southern Africa*, **14**(2):60-71.
- CYRUS, D. P. and WEPENER, V. 1997. Dune mining and the Nhlabane system: can biodiversity and the nursery function be maintained? *Southern African Journal of Aquatic Sciences*, **23** (1):103-113.
- CYRUS, D. P. and BLABER, S.J.M. 1987. The potential effects of dredging activities and increased silt load on St. Lucia system with special reference to turbidity and estuarine fauna. *Water SA*, **14** (1): 42-47.
- DALLAS, H. F. and DAY, J. A., 2004. The effect of water quality variables on aquatic ecosystems: A review, WRC Report No. TT224/04.

- DAUER, D. M. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. *Marine Pollution Bulletin*, **26**: 249–257.
- DAUVIN, J. C. 2007. Paradox of estuarine quality: Benthic indicators and indices, consensus or debate for the future, *Marine Pollution Bulletin*, **55**: 271–281.
- DAY J.W., JUN C.A., HALL S., KEMP W. and YA'NEZ – ARANCIBIA, M. 1989, *Estuarine Ecology*. John Wiley and Sons, New York. 588pp.
- DAY, J.H. 1967. A Monograph on the Polychaeta of Southern Africa. Part 1: Errantia and Part 2: Sedentaria. Trustees of the British Museum (Natural History), London, 878pp.
- DAY, J.H. 1981a. Estuarine Fauna *In* J.H. Day (ed.), Estuarine ecology with particular reference to southern Africa, A.A. Balkema, Cape Town: 251-329.
- DAY, J.H. 1981b. Summaries of Current Knowledge of 43 Estuaries in Southern Africa. *In* J.H. Day (ed.), Estuarine ecology with particular reference to southern Africa, A.A. Balkema, Cape Town: 251-329.
- De DECKER, H. P. and BALLY, R. 1985, The Benthic Macrofauna of the Bot River Estuary, South Africa, with a note on its meiofauna. *Transactions of the Royal Society of South Africa*, **45**(3): 379-396.
- De VILLIERS, C. and HODGSON, A. 1999. Studies on estuarine macroinvertebrates: The macrobenthos *In*: Estuaries of Southern Africa, (Eds) B. R. Allanson and D. BAIRD, Cambridge University Press, Cambridge 169-173 pp.
- DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1995. South African Water Quality Guidelines for Coastal Marine Waters. Volume 1: Natural Environment.
- DYE, A.H. 1978. Aspects of the Ecology of Meiofauna in Mngazana Estuary, Transkei, *South African Journal of Zoology*, **14**(2): 67-73.

- ELLIOTT, M. and DE JONGE, V. N., 2002. The management of nutrients and potential eutrophication in estuaries and other restricted water bodies, *Hydrobiologia*, **475/476**: 513–524.
- ELLIOTT, M. and QUINTINO, V. 2007. The Estuarine Quality Paradox, Environmental Homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas, *Marine Pollution Bulletin*, **54**: 640–645.
- EMMERSON, W.D. 1989. The Nutrient Status of the Sundays River Estuary, South Africa, *Water Research*, **23**(8): 1059-1067.
- EYRE, B. D. and FERGUSON, A. J. P. 2006. Impact of a flood event on benthic and pelagic coupling in a sub-tropical east Australian estuary (Brunswick), *Estuarine, Coastal and Shelf Science*, **66**: 111-122.
- FUJII, T. 2007. Spatial patterns of benthic macrofauna in relation to environmental variables in an intertidal habitat in the Humber estuary, UK: Developing a tool for estuarine shoreline management, *Estuarine, Coastal and Shelf Science*, **75**: 101-119.
- GERBER, A. and GABRIEL, M. J. M 2002. Aquatic Invertebrates of South African Rivers: Field Guide, Institute for Water Quality Studies, Department of Water Affairs and Forestry, 149pp.
- GRAY, J.S. 1981. The ecology of marine sediments: an introduction to the structure and function of benthic communities. Cambridge Studies in Modern Biology: 2. Cambridge University Press, Cambridge, 185pp.
- GRENFELL, S. E., ELLERY, W. N. and GRENFELL, M. C. 2009. Geomorphology and dynamics of the Mfolozi River floodplain, KwaZulu-Natal, South Africa, *Geomorphology*, **107**: 226–240.
- GRENFELL, S.E. and ELLERY, W.N. 2009. Hydrology, sediment transport dynamics and geomorphology of a variable flow river: The Mfolozi River, South Africa, *Water SA*, **35**(3): 271-282.

- GRIFFITHS, C. L. 1976. *Guide to the benthic marine amphipods of Southern Africa* South African Museum, Cape Town, 106 pp.
- GROENEWALD, C. J. 2010. Macrobenthic community structure across an inter- and subtidal gradient in a mangrove estuary, MSc Thesis, Nelson Mandela Metropolitan University, 107pp.
- HARRISON, T. 2004. Physico-chemical characteristics of South African estuaries in relation to the zoogeography of the region. *Estuarine, Coastal and Shelf Science*, **61**: 73-87.
- HARRISON, T. D. 2003. Biogeography and community structure of fishes in south African estuaries. PhD thesis, Rhodes University, 229pp.
- HARRISON, T. D., COOPER, J. A. G. and RAMM, A. E. L. 2000. State of South African Estuaries, Geomorphology, Ichthyofauna, Water Quality and Aesthetics, *Department of Environmental Affairs and Tourism State of the Environment Series Report 2*: 127 pp.
- HARRISON, T. D., HOHLS, D. R, MEARA, T. P. and WEBSTER, M. S. 2001. South African estuaries: catchment land-cover, National Summary Report, 27pp.
- HARRISON, T.D., WHITFIELD, A.K., 1995. Fish community structure in three temporarily open/closed estuaries on the Natal coast. *Ichthyological Bulletin of the J.L.B. Smith Institute of Ichthyology*, **64**:1-80.
- HASTIE, B. F. and SMITH, S. D. 2006. Benthic macrofaunal communities in intermittent estuaries during a drought: Comparisons with permanently open estuaries. *Journal of Experimental Marine Biology and Ecology*, **330**: 356 - 367.

- HEYDORN, A.E.F. 1986. An assessment of the state of the estuaries of the Cape and Natal in 1985/6. *South African National Scientific Programmes Report No. 130*. Pretoria: CSIR.
- HEYMANS, J. J. and BAIRD, D. 1995. Energy flow in the Kromme Estuarine Ecosystem, St Francis Bay, South Africa, *Estuarine, Coastal and Shelf Science*, **41**: 39-59.
- JERLING, H. L., VIVIER, L., CYRUS, D. P. and OWEN, R. K. 2010. Initial characterisation of the mesozooplankton community of the Mfolozi-Msunduzi estuarine system, KwaZulu-Natal, South Africa, during a low-flow period, *African Journal of Aquatic Science*, **35**(2): 117-122.
- KALEJTA, B. 1992, Distribution, biomass and production of *Ceratonereis erythraensis* (Fauvel) and *Ceratonereis keiskamma* (Day) at the Berg River estuary, South Africa. *South African Journal of Zoology*, **27** (3): 121-129.
- KALEJTA, B. and HOCKEY, P.A.R. 1991. Distribution, abundance and productivity of benthic invertebrates at the Berg River estuary, *South Africa, Estuarine, Coastal and Shelf Science*, **33**: 175-191.
- LINDEGARTH, M. AND HOSKIN, M. 2001. Patterns of distribution of macro-fauna in different types of estuarine, soft sediment habitats adjacent to urban and non-urban areas, *Estuarine, Coastal and Shelf Science*, **52**: 237-247.
- LINDSAY, P., MASON, T. R., PILLAY, S. and WRIGHT, C. I., 1996. Suspended particulate matter and dynamics of the Mfolozi estuary, KwaZulu-Natal: Implications for environmental management, *Environmental Geology*, **28**: 40-51.
- MABASO, S. H. P. 2002. The macrobenthos of the Mlalazi estuary, KwaZulu-Natal. Unpublished MSc Thesis, University of Zululand. 148pp.

- MACKAY, C. F. and CYRUS, D. P. 1998a. A review of the macrobenthic fauna of the Mhlathuze estuary: setting the ecological reserve, *Southern African Journal of Aquatic Sciences*, 24(1):111-129.
- MACKAY, C. F. and CYRUS, D. P. 1998b. A review of the potential impact of reduced river on the bird and macrobenthic fauna of the Thukela River, CRUZ Investigational Report No. 61: 1-52.
- MACKAY, C. F., CYRUS, D. P., JERLING, H. L. and BUTHELEZI, P. P. 2002. Status of invertebrates in the Thukela Estuary, CRUZ Investigational Report No. 97:1-62.
- MACKAY, C.F. and CYRUS D.P. 1998b, A Review of the Macrobenthic Fauna of the Mhlathuze Estuary: Setting the Ecological Reserve, *Southern African Journal of Aquatic Sciences*, **24**(1): 111-129.
- MACKAY, C.F., CYRUS, D.P. and RUSSELL, K.L. 2010, Macrobenthic Invertebrate Responses to Prolonged Drought in South Africa's Largest Estuarine Lake Complex, *Estuarine, Coastal and Shelf Science*, **86**: 553-567.
- MASERO, J.A., PÉREZ-GONZÁLEZ, M., BASADRE, M. and OTERO-SAAVEDRA, M. 1999. Food supply for waders (Aves: Charadrii) in an estuarine area in the Bay Of Cádiz (SW Iberian Peninsula), *Acta Oecologica*, **20** (4):429-434.
- MCLUSKY, D. S. 1989. The estuarine ecosystem, Blackie, Glasgow.
- MILLARD, N.A.H and BROEKHUYSEN, G.J. 1970. The Ecology of South African Estuaries, Pan X St Lucia: A second report. *Zoologica Africana*, **5**(2): 277-307.
- NGQULANA, S. G. 2008. Benthic distribution and abundance in the Mfolozi-Msunduzi Estuary, KwaZulu-Natal, Honours project, University of Zululand, 18pp.
- NGQULANA, S.G., OWEN, R.K., VIVIER, L. and CYRUS, D.P. 2010, Benthic distribution and abundance in the Mfolozi-Msunduzi Estuary, KwaZulu-Natal. *African Journal of Aquatic Science*, **35**(2): 123-133.

- NHLEKO, J. B. B. 2011. Unpublished MSc data. University of Zululand.
- OWEN, R. K. (1999). Aspects of the ecology and physiology of the burrowing crab *Paratyloiplax blephariskios* Stebbing (Brachyura: Ocypodidae). Unpublished PhD Thesis, University of KwaZulu-Natal.
- OWEN, R.K. 2003, A Short Note on Factors Affecting the Geographic Distribution of the Burrowing Ocypodid Crab, *Paratyloiplax blephariskios*: Temperature, Habitat and Competition, *African Journal of Aquatic Science* **28**(1): 57-60.
- OWEN, R.K. and FORBES, A.T. 1997, Salinity, floods and the infaunal macrobenthic community of the St Lucia estuary, KwaZulu-Natal, South Africa, *South African Journal of Aquatic Science*, **23**(1): 14-30.
- OWEN, R.K., CYRUS, D.P., VIVIER, L. and JERLING H.L. 2010, The Potential for Zoobenthic Fauna Dispersal into the St. Lucia Estuary from the Mfolozi-Msunduzi Estuarine System, KwaZulu-Natal, South Africa, *African Journal of Aquatic Science* **35**: 135-140.
- OWEN, R.K., FORBES, A.T., CYRUS, D.P. and PIPER, S.E. 2000, Physical Determinants of the Distribution and Abundance of the Burrowing Ocypodid Crab *Paratyloiplax blephariskios* Stebbing in the St. Lucia and Mhlathuze Estuaries, KwaZulu-Natal, South Africa, *African Journal of Aquatic Science* **25**:23-32.
- PILLAY, D. and PERISSINOTTO, R. 2008, The Benthic Macrofauna of the St. Lucia Estuary During the 2005 Drought Year, *Estuarine, Coastal and Shelf Science*, **77**: 35-46.
- RAKOCINSKI, C.F., ZAPFE, G.A., 2005. Macrobenthic process-indicators of estuarine condition. *In*: Bortone, S.A. (Ed.), *Estuarine Indicators*, CRC Marine Science Series. CRC Press, pp. 316–331.
- RICHARDS, C., HOSTG, H. and ARTHUR, J.W. 1993. Identification of predominant environmental factors structuring stream macroinvertebrate communities within a large agricultural catchment, *Freshwater Biology*, **29**: 285-294.

- ROSENBERG, D. M. and RESH, V. H. 1993. *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman and Hall, New York, United States of America.
- SILVA, R. F., FILHO, J. S. R., SOUZA, S. R. and SOUZA-FILHO, P. W. 2011. Spatial and temporal changes in the structure of soft-bottom benthic communities in an Amazon estuary (Caeté estuary, Brazil), *Journal of Coastal Research*, **64**: 440-444.
- STARK, J. S. 1998. Heavy metal pollution and macrobenthic assemblages in soft sediments in two Sydney estuaries, Australia, *Marine and Freshwater Research*, **49** (6): 533-540.
- TAYLOR, R. H. 2006. Ecological responses to changes in the physical environment of the St Lucia Estuary. Norwegian University of Life Sciences, Norway.
- TER BRAAK, C.F.J. and ŠMILAUER, P. 1998, CANOCO reference manual and user's guide to CANOCO for Windows: software for canonical community ordination (Version 4). Ithaca, New York: Microcomputer Power.
- TESKE, P. R. and WOOLDRIDGE, T. H. 2001. A comparison of the macrobenthic faunas of permanently open and temporarily open/closed South African estuaries. *Hydrobiologia*, **464**: 227–243.
- TESKE, P. R. and WOOLDRIDGE, T. H. 2004. Affinities of some common macroinvertebrates to salinity and sediment type: empirical data from Eastern Cape estuaries, South Africa. *African Zoology*, **39**:183–192.
- TESKE, P.R. and WOOLDRIDGE, T.H. 2003, What Limits the Distribution of Subtidal Macrobenthos in Permanently Open and Temporarily Open/Closed South African Estuaries? Salinity vs. Sediment Particle Size, *Estuarine, Coastal and Shelf Science*, **57**: 225-238.

- THRUSH, S. F., HEWITT, J. E., CUMMINGS, V. J., ELLIS, J. I., HATTON, C., LOHRER, A. and NORKKO, A. 2004. Muddy waters: Elevating sediment input to coastal and estuarine habitats, *Frontiers in Ecology and the Environment*, **2**(6): 299-306.
- TURPIE, J. K., ADAMS, J. B., JOUBERT, A., HARRISON, T. D., COLLOTY, B. M., MAREE, R. C., WHITFIELD, A.K., WOOLDRIDGE, T. H., LAMBERTH, S. J., TALJAARD, S. and VAN NIEKERK, L. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation. *Water SA*, **28**: 191 - 206.
- TURPIE, J.K. and CHESTERMAN, S. 2011. The value of estuaries in northern KwaZulu-Natal with particular reference to the Mfolozi and St Lucia systems, *In*: GC Bate, AK Whitfield & AT Forbes (Eds), A review of studies on the Mfolozi Estuary and associated flood plain, with Emphasis on information required by Management for future reconnection of The river to the St Lucia system, WRC Report No. KV 255/10.
- TURPIE, K. 2004. South African National Spatial Biodiversity Assessment 2004 Technical Report Volume 3: Estuary Component. Pretoria: *South African National Biodiversity Institute*, **3**: 1-31.
- VAN DER ELST, R.P., BIRNIE, S.L. and EVERETT, B.I. 1999. Siyaya catchment demonstration project: an experiment in estuarine rehabilitation. *Oceanographic Research Institute* (Special Publication) **6**:1-99.
- VAN DOLAH, R. F., HYLAND, J. L., HOLLAND, A. F., ROSEN, J.S. and SNOOTS, T. R. 1999. A benthic index of biological integrity for assessing habitat quality in estuaries in estuaries of the South Eastern USA, *Marine Environmental Research*, **48** (4-5):269-283.
- VAN HEERDEN, I. L. 2011. Management concepts for the Mfolozi Flats and estuary as a component of the management of the iSimangaliso Wetland Park, KwaZulu-Natal,

- In:** GC Bate, AK Whitfield & AT Forbes (Eds), A review of studies on the Mfolozi Estuary and associated flood plain, with Emphasis on information required by Management for future reconnection of The river to the St Lucia system, WRC Report No. KV 255/10.
- VIVIER, L. 2011. Macrobenthic community and ecotoxicological status of the Nhlabane Estuary, PhD thesis, University of Zululand, 158pp.
- VIVIER, L. and CYRUS, D.P. 1999, The Zoobenthic Fauna of the Nhlabane Coastal Lake System, KwaZulu-Natal, South Africa, 20 Years After Construction of a Barrage, *Water SA*, **25**(4): 533-542.
- VIVIER, L. and CYRUS, D.P. 2009, Alternative nursery habitat for estuarine associated marine fish during prolonged closure of the St Lucia estuary, South Africa, *Estuarine, Coastal and Shelf Science*, **85**: 118-125.
- VIVIER, L., CYRUS, D. P. AND JERLING H. L. 2010. Fish community structure of the St Lucia Estuarine System under prolonged drought conditions and its potential for recovery after mouth breaching, *Estuarine, Coastal and Shelf Science*, **86**:568-579.
- WHITFIELD, A. K. and HARRISON, T. D. 2003. River flow and fish abundance in a South African estuary, *Journal of Fish Biology*, **62**:1467-1472.
- WHITFIELD, A. K. 1980, A Quantitative Study of the Trophic Relationships Within the Fish Community of the Mhlanga Estuary, South Africa, *Estuarine and Coastal Marine Science*, **10**: 417-435.
- WHITFIELD, A.K. 1989, The Benthic Invertebrate Community of a Southern Cape Estuary: Structure and Possible Food Sources, *Transactions of the Royal Society of South Africa*, **47**(2): 159-179.
- WHITFIELD, A.K. 2000. *Available Scientific Information on Individual South African Estuarine Systems*. Water Research Commission Report No. 577/3/00. Pretoria.

- WHITFIELD, A.K. and TAYLOR, R.H. 2009, Case studies and reviews: A review of the importance of freshwater inflow to the future conservation of Lake St Lucia, *Aquatic Conservation: Marine and Freshwater Ecosystems*, **19**: 838-848.
- WHITFIELD, A.K., 1992, A characterization of southern African estuarine Systems. *Southern African Journal of Aquatic Science*, **12**:89-103.
- WILDSMITH, M.D., ROSE, T.H., POTTER, I.C., WARWICK, R.M., CLARKE, K.R. and VALESINI, F.J. 2009. Changes in the benthic macroinvertebrate fauna of a large microtidal estuary following extreme modifications aimed at reducing eutrophication, *Marine Pollution Bulletin*, **58**:1250-1262.
- WOOLDRIDGE, T.H. and DEYZEL, S.H.P. 2009. The Subtidal Macrozoobenthos of the River-dominated Great Berg Estuary, *Transactions of the Royal Society of South Africa*, **64**(2): 204-218.