The Mzingazi gauging weir and its effects on the fish and macrocrustacean communities of Lake Mzingazi

By

Puleng Cathrine Moloi

Submitted to the Faculty of Science and Agriculture
in partial fulfilment of the requirement for the degree of
Masters Science
in the Department of Zoology
University of Zululand

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

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 Any unpublished information used was duly acknowledged.

P.C. Moloi

2012

DEDICATION

I dedicate this dissertation to my son, who suffered with me to bring about its existence.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr L. Vivier, for giving me the opportunity to conduct research under his supervision and for his guidance, patience and kindness during the entire process of producing this thesis. I would also like to thank Dr Vivier's family for the accommodation provided during field trips.

Many thanks go to my co-supervisor, Professor D.P. Cyrus, for providing literature, advice and constructive criticism of the manuscripts. Thanks to Mr. R. Wilkinson for reviewing my script and for grammar corrections.

Thanks to Zoology staff and postgraduate students who assisted in the field during sampling: My supervisor Dr. L. Vivier, Dr. H. Jerling, Mr. H.M.M. Mzimela, Mr. T.S.W Mahlinza, Mr. B. Zondo, Mr. M. Mhlongo, Mr. N. Ndlovu, Miss Luthada, Miss J.B.B Nhleko and Miss S.G. Ngqulana.

A special word of thanks is extended to Miss D.P. Nyalungu for her help in identification of prawns and Miss Nyawo for her administrative support.

To my parents, brothers, sisters and Lebohang: thank you for your loyal support, interest and encouragement in fulfilling my dream.

I would like to thank the University of Zululand Research Committee for providing financial assistance in the form of a study privilege.

Finally and most importantly, I would like to thank God for His love, blessing and guidance.

ABSTRACT

Lake Mzingazi is a freshwater coastal lake in Richards Bay, KwaZulu-Natal. Because of ongoing industrial and residential developments in the Richards Bay area, the need for potable water increased and led to the construction of a weir across the outlet of Lake Mzingazi. The first weir on this historically estuarine lake was built in 1955, after which it was raised several times to satisfy the increasing demand for water. Due to potential salt-water intrusion via groundwater from the saline Mzingazi River into the lake, another weir, namely the Saltwater Barrier, was built 1.4 km downstream of Lake Mzingazi to limit saltwater intrusion into the lake. The Mzingazi weir largely prevented the migration of fish and crustaceans between the marine/estuarine environment and the freshwater environment. In 2005-2006, the DWA designed and constructed a new and improved gauging crump weir across the lake outlet, which included a pool and weir fishway to allow the migration of fauna in and out of the lake. The fishway was aimed at allowing euryhaline fish species to migrate out to sea to spawn and back to the lake to complete their life cycle since Lake Mzingazi historically served as an important nursery habitat for juveniles of a number of euryhaline fish species. Monitoring of the fishway was required to assess the efficiency of the design, and if necessary, to modify flow conditions to meet the requirements of migrating fauna. This study aimed firstly at monitoring the operation and efficiency of the Mzingazi fishway and secondly, at monitoring its effect on the fish community of Lake Mzingazi.

In order to assess the operation and efficiency of the Mzingazi fishway, the fish and macroinvertebrate fauna were sampled at six locations in the Mzingazi system, i.e at the Saltwater Barrier, in the upper Mzingazi River, at the entrance to the fishway, in the fishway pools, at the fishway exit and in the lake immediately above the fishway. The fishway was sampled over two days on a monthly basis over the period August 2007 to July 2008, using funnel traps, dip nets and a small seine net. In order to monitor the effect of the fishway on the lake fish community, seasonal sampling in the lake was conducted for a period of two years, from August 2007 to June 2009, using seine and gill nets. A total of 3 288 fish, representing 29 species, were recorded throughout the study. Of these 29 species, 20 species were able to locate and enter the fishway. The fishway was found to allow passage for 17 fish species between the estuary and the lake. The dominant species that managed successfully to migrate through the fishway were *Myxus capensis, Glossogobius callidus* and *Eleotris fusca*, making up 77% of the total catch. The fish migrating through the fishway included five marine species, five estuarine resident species, six freshwater species and one unclassified Gobiid larvae sp.

A total of 8 188 macrocrustacea representing eleven species were also recorded in the Mzingazi system, of which seven prawn and one crab species were able to locate and enter the fishway. The fishway provided migratory passage for seven prawn species, these being dominated by *Macrobrachium equidens, Caridina nilotica* and *Caridina indistincta* respectively, together making up 97.6% to the total catch.

This study proved that the fishway was effective and efficient for upstream migration of the target species. The design of the fishway was found to create suitable hydraulic conditions for migration of juvenile and sub-adult fish (10 to < 100 mm SL) and for macrocrustacea (3 to < 26 mm CL). Peak upstream migration of fish through the fishway occurred in August, September, October and December, which coincides with the peak recruitment period of most estuarine and marine spawning species. Peak migration and species abundance of both fish and macrocrustaceans were found to be a natural effect of seasonal recruitment and breeding, which was indirectly driven by seasonal temperature variations.

The fish community of Lake Mzingazi during the study comprised 16 species, which included four marine species, five estuarine resident species and seven freshwater species. The community was dominated by freshwater species such as *Oreochromis mossambicus* and *Tilapia rendalli* and estuarine species such as *Glossogobius callidus* and *Gilchristella aestuaria*. The operation of the Mzingazi fishway was found to be causing a gradual change in the lake fish community by re-introducing euryhaline fish species into the freshwater coastal lake.

The following important recommendations were made. Firstly, further long-term monitoring of the fishway and the lake fish community is required to validate the absence of previously recorded euryhaline species and to determine the long-term effect of the fishway on the fish and macrocrustacean community. Secondly, the operation of the fishway is entirely dependent on water levels in the lake and ongoing water abstraction for domestic and industrial purposes often results in the water level in the lake being drawn below the overflow level of 3.0 masml. For this reason, the Department of Water Affairs should limit abstraction from the lake so that there is sufficient water allocated to allow the fishway to operate. The water level should never be drawn below the minimum level of 3.0 mamsl, at which the fishway can still operate.

TABLE OF CONTENTS

CHAPTER 4

OPERATION AND EFFICIENCY OF THE MZINGAZI FISHWAY FOR MACROCRUSTACEANS

CHAPTER 5

THE EFFECTS OF THE MZINGAZI FISHWAY ON THE FISH COMMUNITY OF LAKE MZINGAZI

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1. INTRODUCTION

1.1.1. Zululand coastal lakes and their importance to fish communities

Lakes Mzingazi, Nsezi, Cubhu, Mangeza and Nhlabane are freshwater coastal lakes in the vicinity of Richards Bay, KwaZulu-Natal (Weerts and Cyrus, 2001). Lake Mzingazi is a relict estuarine coastal lake characterized by marine sand substrata, historically low detrital input and clear waters (Cyrus, 2000). It reaches depths below sea level and the potential for salt-water intrusion via groundwater has been identified as a threat to the sustainable utilization of the resource for potable water (Cyrus *et al*., 1997; van Tonder *et al.,* 1986), although this would only occur at very low lake levels (Weerts and Cyrus, 2001).

Industrial and residential development in the area increased the need for water abstraction which led to the construction of barriers across the outlets of a number of freshwater systems in the Richards Bay area. Barriers which were built to increase the storage capacity of the coastal lakes include those across the outlets of Lake Nhlabane, Lake Mzingazi, Lake Nsezi and Lake Cubhu (Figure 1.1) (Cyrus, 2000). In addition, a Saltwater Barrier was built across the Mzingazi River 1.4 km downstream of Lake Mzingazi to prevent saltwater penetrating into the lake. A weir was also built in the Mhlathuze River from where the Mhlathuze Water Board transfers water to Lake Nsezi from where it is abstracted, purified and distributed as potable water. The barriers changed the historical relict estuarine character of these coastal lakes and prevented the migration of fish and crustaceans between the marine/estuarine environment and the freshwater environment (Cyrus, 2000).

1.1.2. Aquatic Faunal Migration

Feeding, wintering and reproduction are the main reasons for fish to migrate (Kleynhans, 1990; Payne and Crawford, 1989). Of these, feeding and reproduction have been shown to be the most important reasons for fish in the estuarine/freshwater environment found along the Mzingazi River to migrate (Vivier and Cyrus, 1996). Richards Bay Harbour is an important nursery habitat for juveniles of many estuarine dependent marine fish and invertebrate species (Cyrus and Forbes, 1996), including a number of species that need to migrate into freshwater environments (Vivier and Cyrus, 1996).

Historical data show that juveniles of the following euryhaline fish migrated up the Mzingazi River as they have previously been recorded in the freshwater environment of Lake Mzingazi: *Ambassis spp*, *Elops machnata, Megalops cyprinoides*, *Myxus capensis*, *Mugil cephalus*, *Liza alata*, *Acanthopagrus berda*, *Rhabdosargus* spp*, Monodactylus* spp, *Caranx sexfaciatus*, *Croilia mossambica*, *Gilchristella aestuaria*, *Hyporhamphus capensis* and *Glossogobius callidus* (Vivier and Cyrus, 1996).

Most euryhaline marine fish species found in estuaries migrate out to the sea to spawn. Once hatched, the post-larvae and juveniles of these species migrate back into estuarine and freshwater environments because estuaries provide favourable conditions such as warm temperatures, rich food supply, and shelter for juvenile fish (Wallace, 1975; Payne and Crawford, 1989). Catadromous species and freshwater eels spend most of their lives in the freshwater environment and only migrate out to the sea to spawn. The majority of freshwater fish migrate for breeding, feeding and dispersal (Skelton, 1993; Heath *et al.,* 2005), undergoing seasonal migration in accordance with seasonal flood cycles to avoid less favourable conditions and migrate to more favourable areas (Skelton, 1993). Migration in most fish species usually occurs during late winter, spring and early summer.

The majority of freshwater prawns and crabs are also known to migrate between the estuary and fresh water (Bickerton, 1989). At least nine of these species are expected to migrate up and down the rivers along the south and east coasts of South Africa (Bok *et al.*, 2004). Certain freshwater prawns (e.g. *Macrobrachium* spp.) need to migrate into brackish water with a salinity of at least 8 ppt in order to breed and for the purpose of successful larval development. The larvae of these freshwater prawns therefore need access to the saline and brackish reaches of estuaries. After completing their obligate estuarine phase, the juveniles migrate back to the freshwater environment (Hart *et al.,* 2001). Adults also migrate back into fresh water areas after spawning in estuaries (Bok *et al.*, 2004; Heath *et al.*, 2005).

According to Day (1981), an estuary is a semi-enclosed coastal body of water having a free connection with the open sea and within which sea water is measurably diluted with fresh-water run-off. Estuarine systems play a major role in contributing to fisheries (Lamberth and Turpie, 2003), but more importantly, estuaries provide nursery areas for juveniles of numerous species of estuarine and marine fish and macrocrustacea (Blaber and Blaber, 1980; Cyrus and Martin, 1991; Strydom and Whitfield, 2000**;** Forbes and Demetriades, 2005).

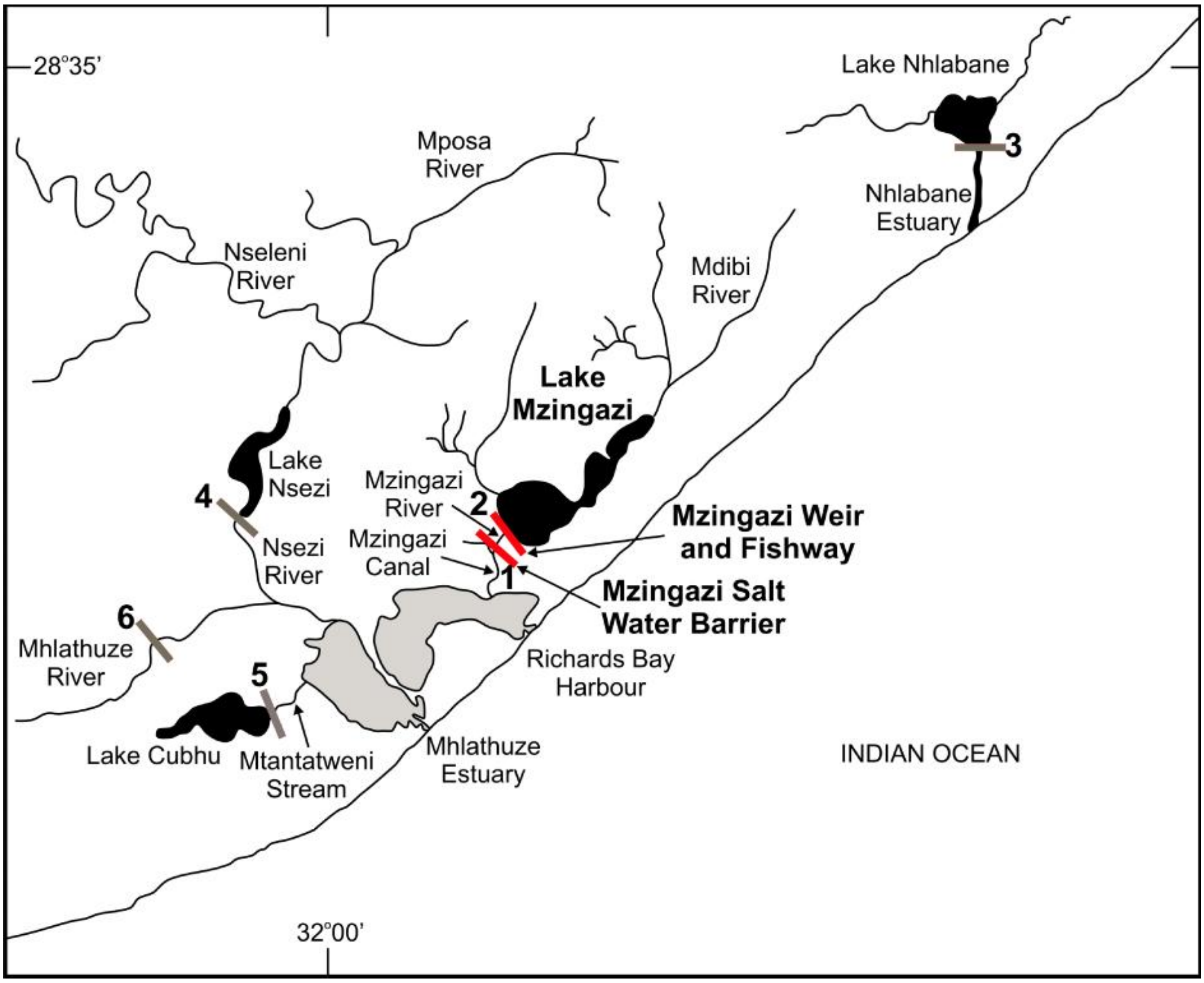

Figure 1.1: A map of Lake Mzingazi, Richards Bay Harbour and the coastal lakes in the Richards Bay area, showing the six barriers constructed on freshwater ecosystems in the area (After Cyrus, 2000).

The important role played by estuaries in the life cycles of many species of fish and crustaceans has led to these species being considered to be estuarine-dependent (Day *et al.,* 1981). Fish species have different degrees of association with estuaries and have been classified into five broad categories of association, which may be further subdivided into nine types (Table 2.1) (Whitfield, 1998). Estuarine resident species (Category I) and Euryhaline marine species of Category IIa are entirely dependent on estuaries, as are Catadromous species (Category V). Euryhaline marine species of Category IIb are largely dependent on estuaries, while Category IIc species are partially dependent on estuaries. Marine species (Category III) are found in estuaries but are not dependent on them. Freshwater species of category IV penetration into estuaries are determined by their salinity tolerance (Whitfield, 1998).

1.1.3. Fishways in South Africa

Obstructions such as dams and weirs on rivers and estuaries have a complex impact on migratory fauna since they form obvious barriers in the passage of fauna up and down these systems (Larinier, 2002a). These obstructions also cause changes to the flow regime, water quality, temperature and turbidity. The impacts of obstructions on fish populations often result in a decrease in the number of species and local extinctions can occur (Porcher and Travate, 2002). This is particularly evident in obligate species that depend on longitudinal migrations for completion of their life-cycles (Skelton, 1990).

Existing legislation (National Environment Management Act, 107 of 1998, the Environment conservation Act, 73 of 1989, the National Water Act, 36 of 1998 and various international treaties and protocols) states that appropriate improvements, such as fishways, are required to prevent barriers from blocking the natural migration of aquatic species. When investigating the potential barrier effect of any man-made in-stream structure, it is important to find out whether it is necessary and possible to ensure free passage of migratory aquatic species past the potential barrier (Bok *et al.*, 2004).

Fishways can be broadly described as natural or artificial devices that enable fish to overcome obstructions in rivers during migration (Klapwijk, 1990). Fishways serve to attract migrants downstream of the obstruction towards the fishway entrance and encourage them to pass upstream. An efficient and effective fishway allows fish to find the entrance and negotiate it without delay, stress or injury that might disturb the success of their upstream migration (Larinier, 2002a).

There are three types of fishways that are considered suitable for South African conditions; these are pool and weir fishways, vertical slot fishways and by-pass canals and fish ramps (Bok *et al.,* 2004). The most commonly used fishway in South Africa on estuarine systems is the pool and weir type fishway (Klapwijk, 1990). The advantage of using this type of fishway is its effectiveness in allowing passage of juveniles and adults of a variety of species at relatively low flows (4 l/s). This fishway can also be modified to operate effectively at low flows to accommodate crawling species and small fish (< 20 mm long). However, pool and weir type fishways cannot accommodate large discharges and tend to accumulate sediment (Bok *et al.,* 2004). Vertical slot fishways are more commonly used on freshwater systems, as they can more easily accommodate large seasonal flooding conditions and are more suitable for the migration of adult fish (Bok, 2004; Klapwijk, 1990,).

Over the last 15 to 20 years, promoting free passage for aquatic organisms in rivers worldwide has been part of the wider goal for researchers so as to restore and conserve aquatic ecosystems (Heath *et al.*, 2005). The main concern was the adults and juveniles of various species that undertake longitudinal movements in a river as part of their life history (Skelton, 1990; Heath *et al.*, 2005). Historically, fishways were designed to cater for strong-swimming adults, but have been found to be ineffective for the passage of juvenile fish. The design limitation of the earlier fishways has resulted in a renewed research effort to develop designs for non-salmonids species, through close cooperation between hydraulic engineers and fish biologists in many countries around the world (Heath *et al.*, 2005).

In 1990, the Department of Water Affairs (DWA) initiated a workshop on fishways in South African rivers and estuaries. The aim of the workshop was to formulate decision and design criteria for the design and construction of fishways and to identify rivers that required fishways in South Africa (Klapwijk, 1990). As limited information was available on in-stream barriers in South Africa, an inventory on all fishways that were constructed in South Africa was developed (Heath *et al.*, 2005). There are about 57 fishways in South Africa, of which 42 are functional to some degree. Most of the functional fishways in South Africa are of the pool and weir (32) and of the vertical slot types (8) (Klapwijk, 1990). The paucity of quantitative data on the performance of the existing fishways in South Africa led to an awareness that monitoring of fishways is needed. The accessibility of data will assist with further design developments and refinements of fishways (Heath *et al.*, 2005).

1.1.4. Mzingazi Fishway

Lake Mzingazi has a long history of impoundment for water abstraction (Botha *et al.,* 2006). In 1943, the first weir was built across its outlet, which was raised in 1955 by the incorporation of a concrete weir into the earthen wall (Cyrus, 2000). In 1984, the weir was raised again (Botha *et al.,* 2006) to satisfy the increasing demand for water for domestic and industrial use because of sustained development in the Richards Bay area. The construction of the Mzingazi weir negatively impacted on migratory fauna as it prevented faunal movement between the marine and freshwater environment (Cyrus, 2000). In 2003, the DWA initiated the feasibility, design and construction processes for a new and improved weir across the outlet of Lake Mzingazi. The new weir across the lake outlet was necessary because the old embankment had been breached three times since 1971 by overtopping caused by flooding (Botha *et al.*, 2006). The new gauging crump weir was to include a pool and weir fishway to allow migration of fauna in and out of the lake (Botha *et al.,* 2006). The construction of the new structure was carried out between August 2005 and August 2006.

The Mzingazi fishway is a double pool and weir type fishway with a central sloping spillway. Each side of the fishway is divided into a series of 25 pools (Figure 1.2). The crest of the weir, at 3 m amsl, is 9 m wide and leads to 2 x 3 m wide fishways providing a range of flow conditions. The slope of the weir is approximately 1:4, the drop between the fishway pools is 150 mm, the pools are 600 mm deep and 300 mm across, while the sloping weirs between the pools are 100 mm thick. Built into each pool weir are 50 mm pipes as well as semicircular orifices at the bottom of each weir to enhance the movement of slow-swimming fauna from one pool to the next (Figure 1.3). The Mzingazi weir embankment and spillway are approximately 500 m long and comprises three sections: an upgraded concrete-lined embankment, the crump weir with its fishway and an emergency spillway. The combined crump gauging weir/fishway incorporated into the weir design was developed by Dr Peter Wessels (DWA), while Dr Anton Bok (Bok and Associates) provided specialist information regarding the biological requirements of the fishway (Vivier, 2007). The fishway hydraulic model was tested and improved to accommodate the migration of specific target species (Botha *et al.*, 2006). Since late spring and early summer is the peak migration period of euryhaline and freshwater organisms that need to migrate into Lake Mzingazi, the new fishway was designed to operate most effectively during this main migratory period (Botha *et al.*, 2006), creating hydraulic conditions suitable for the migration of small (20–80 mm), weakly-swimming fish and climbing species (eels, crabs and prawns). These form the target migratory species that seek to migrate from the estuarine/marine environment of Richards Bay Harbour via the Mzingazi River into Lake Mzingazi (Vivier, 2007).

Figure 1.2: The Mzingazi gauging crump weir with the central spillway and double fishway showing the funnel trap at the fishway exit.

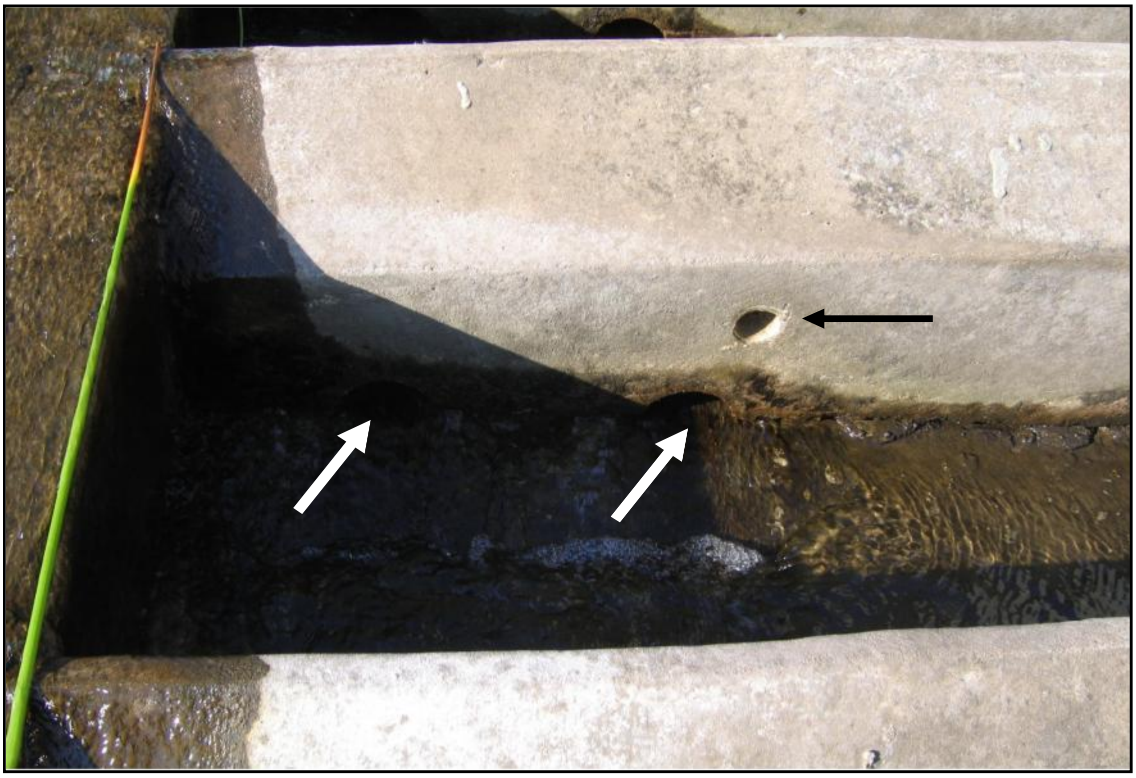

Figure 1.3: A section of a Mzingazi fishway pool showing the pool weirs with fitted pipes (black arrow) and semicircular orifices (white arrows) at the bottom of the weir.

1.1.5. Saltwater Barrier on the Mzingazi River

In 1992, a continued drought and the associated low lake levels led to concerns about saltwater intrusion through groundwater from the tidally influenced Mzingazi River into Lake Mzingazi, which would adversely affect the water quality of the lake and as such render the lake unsuitable as a freshwater supply for the town of Richards Bay. The Borough of Richards Bay took a decision to construct a concrete weir across the Mzingazi River, 1.4 km downstream of the lake, to minimize saltwater penetration into the upper end of the Mzingazi River, thereby preventing saltwater intrusion into the lake (Cyrus *et al.,* 1997; Kelbe *et al*., 2001). In 1996, the weir, commonly called the Saltwater Barrier, was upgraded to a permanent 1.7 m high concrete structure fitted with one-way valves to restrict saltwater intrusion into the Mzingazi River (Cyrus, 2000). Since the Saltwater Barrier was a potential obstacle to upstream migration of estuarine and marine breeding fauna, a tidal gate was incorporated into the design so that some tidal flow bypasses the barrier on rising spring tides (0.8 m amsl), allowing a short period during which fauna could pass through the weir and into the upper Mzingazi River (Weerts *et al.,* 2002).

1.1.6. Monitoring of the fishway

Environmental legislation stipulates that fishways need to be monitored after construction to assess the efficiency of the design, and if necessary, to modify flow conditions to meet the requirements of migrating fauna. A fishway monitoring programme should be designed to provide data on both the effectiveness of the fishway in terms of internal hydraulics (Porcher and Travade, 2002) at various flows, as well as data on migratory behavior and swimming ability of all migrants to move up the river (including prawns, crabs and eels) (Porcher and Travade, 2002; Bok *et al.*, 2004). To determine fishway performance, information is required on the number and size composition of fish species that were migrating, but could not find the fishway entrance, the fish which entered the fishway but were unable to reach the top, as well as the fish that successfully passed through the fishway. Environmental parameters (abiotic and biotic) also need to be monitored to determine what stimulates fish migration (Heath *et al.*, 2005).

In 2007, a preliminary survey on the functioning of the fishway was conducted by Vivier (2007). Eight fish species were recorded, of which seven were found in the fishway, six were recorded below and only one above the fishway. Only three species (*Favonigobius reichei, Glossogobius callidus* and *Oreochromis mossambicus)* were found to successfully pass through the fishway. These results indicated that conditions in the fishway were suitable in allowing juvenile fish (between 30-40mm Standard Length) of certain estuarine and marine associated species to pass through. Carid prawns were also found passing through the fishway and emphasised the importance of creating suitable conditions in the fishway not only for fish, but also for other aquatic fauna (Vivier, 2007). Although Vivier (2007) provided some useful data on the efficiency of the fishway, it was only a once-off survey conducted in April, thus outside the prime migration period of most migrating fish and macrocrustacea. More detailed and long term monitoring of the fishway was necessary, as well as monitoring of the community of the lake to better understand the effect of the fishway on the lake fish community.

1.2. AIM OF THE STUDY

The aims of this study was to monthly monitor the operation and efficiency of the Mzingazi fishway over a one year period for migration of fish and macrocrustacea and to monitor the effect of the fishway on the fish community of Lake Mzingazi over a two year period.

1.3. HYPOTHESIS

The hypotheses that were tested during this study were:

1.3.1. The Mzingazi fishway is efficient in allowing migration of marine, estuarine and freshwater fauna between the Mzingazi River and Lake Mzingazi.

1.3.2. The Mzingazi fishway allows migrating marine spawning fish to reach Lake Mzingazi and thereby causes a change in the fish composition of the lake.

CHAPTER 2

STUDY AREA AND MATERIAL AND METHODS

2.1. STUDY SITE

2.1.1. Lake Mzingazi

Lake Mzingazi and its catchment area are situated in the warm, humid, subtropical Zululand coastal belt. A 2 km wide coastal dune barrier separates the lake from the sea. A marginal remnant of the Mhlathuze floodplain through which the Mzingazi River flows separates the south of the lake from Richards Bay Harbour (Wepener *et al.,* 1995). Lake Mzingazi consists of two main compartments, a rounded southerly deep basin and a narrow northerly section (Figure 1.1). The two sections are separated by a very shallow and narrow section which is exposed during extreme drought conditions (Cyrus, 1993). The southern compartment at its deepest point is approximately 14 m below mean sea level and therefore susceptible to saline water penetration under drought conditions (Kelbe *et al*., 2001). At lake levels below 3.0 mamsl, seawater intrusion is considered possible (van Tonder *et al.,* 1986).

The volume of the system at full supply level is 47.5 x 10^6 m^3 and the surface area is 1216 ha, which gives an overall mean depth of 3.9 m. The shoreline under normal conditions is 19.6 km in length, but this varies considerably due to drought conditions and the shallow littorial zone (Wepener *et al.*, 1995). The catchment area of the lake is approximately 171 km^2 (Botha *et al.*, 2006). The lake is fed by a number of streams; the most important of which are the Mdibi and Mzingazi Rivers (Figure 1.1).

The link between Lake Mzingazi and Richards Bay Harbour comprises a lower tidal section and an upper low salinity section, with the two sections separated by the Saltwater Barrier. The 1.4 km section above the Saltwater Barrier is known as the Mzingazi River, while the lower 2.6 km section is known as the Mzingazi Canal. The Mzingazi Canal is a 5-7 m deep dredged canal with limited mangrove stands and has substratum characterized by fine to medium grained sand (Weerts *et al.,* 2003).

Richards Bay Harbour, despite being a busy port, still contains large areas of natural habitat including intertidal mudflats and mangroves. These natural areas have retained much of their estuarine functioning, contributing importantly as nursery areas for large numbers of estuarine and marine organisms such as crustaceans (Weerts *et al.,* 2003) and estuarine dependent fish (Cyrus and Forbes, 1996). These natural habitats need to be maintained and preserved to retain their important function as nursery area for fish and crustaceans depending on estuaries to complete their life cycle (Harris and Cyrus, 1997). According to Cyrus and Forbes (1996), Richards Bay Harbour is under pressure because of anthropogenic activities and developments along its shoreline, such as shipping, effluent disposal and recreation (Begg, 1978). Despite this, Richards Bay Harbour remains ecologically one of the most important estuaries in South Africa. According to Turpie *et al.* (2002), Richards Bay Harbour was ranked 3rd nationally in terms of its ecological importance for water birds and fish as well as 5th for rarity of habitat types. In addition, in KwaZulu-Natal, Richards Bay Harbour is ranked 6th for overall conservation importance.

2.1.1.1. Climate

The mean annual rainfall in Richards Bay is generally > 1000 mm/year at the coast but decreases to less than 800 mm within 20 km of the coastline (Kelbe *et al.,* 2001), most of which falls in summer months from November to March, with a maximum in the months of January and February (Vivier *et al.,* 2009). Winter rainfall (May to September) is usually associated with frontal weather patterns and typically coincides with cool weather. Abnormal rainfall events typically coincide with cyclones and cutoff low pressure systems which may lead to extensive flooding (Vivier *et al.,* 2009). Richards Bay has a subtropical climate with warm moist summers and moderate dry winters. Average temperature in summer is 26°C and 18°C in winter. Wind direction is typically from the north-east or south-west throughout the year (Kelbe *et al.,* 2001).

2.1.1.2. Vegetation

The vegetation of the Lake Mzingazi catchment was classified as coastal forest and thornveld (Veld Type No.1, Acocks, 1988). This vegetation type has been subdivided into five groups, four of which are found in the immediate vicinity of Lake Mzingazi. These are coastal forest, Zululand palmveld, dune forest and mangrove forest (Wepener *et al.,* 1995). The lake environment favours the development of submerged macrophytes and emergent species which are rooted in shallow water (Hemens *et al.,* 1974, Achibald *et al.,* 1983). Species such as *Phragmites australis, Phragmites mauritianus, Typha capensis, Cyperus papyrus, Cyperus digitalis, Scirpus littoralis, Ficus tricopoda* and *Barringtonia racemosa* represent the dominant emergent macrophytes (Hemens *et al.,* 1974, Achibald *et al.,* 1983).

In 1990-1991 degradation of aquatic plant communities occurred in Lake Mzingazi as a result of increased water salinities caused by saltwater penetration into lake during a drought (Cyrus *et al.,* 1997). According to Burger (2008), species such as *T. capensis, C. papyrus and B. racemosa* recovered after the destruction caused by saltwater intrusion, although a decline in *P. mauritianus* was noted during the survey.

2.2. MATERIAL AND METHODS

This study was divided into two main components, firstly to monitor the operation and efficiency of the Mzingazi Fishway and secondly, to monitor the effects of the fishway on the fish community of Lake Mzingazi. In order to assess the operation and efficiency of the Mzingazi fishway, the fish and macroinvertebrate fauna were sampled at six locations in the Mzingazi system, that is: (i) At the Saltwater Barrier at the downstream end of the Mzingazi River, (ii) in the upper Mzingazi River just downstream of the Mzingazi fishway, (iii) at the fishway entrance, (iv) in the fishway pools, (v) at the fishway exit and (vi) immediately upstream of the fishway (Figure 2.1). In order to study the effect of the fishway on the fish community of Lake Mzingazi, fish sampling was conducted at selected sites throughout the lake (Figure 2.3).

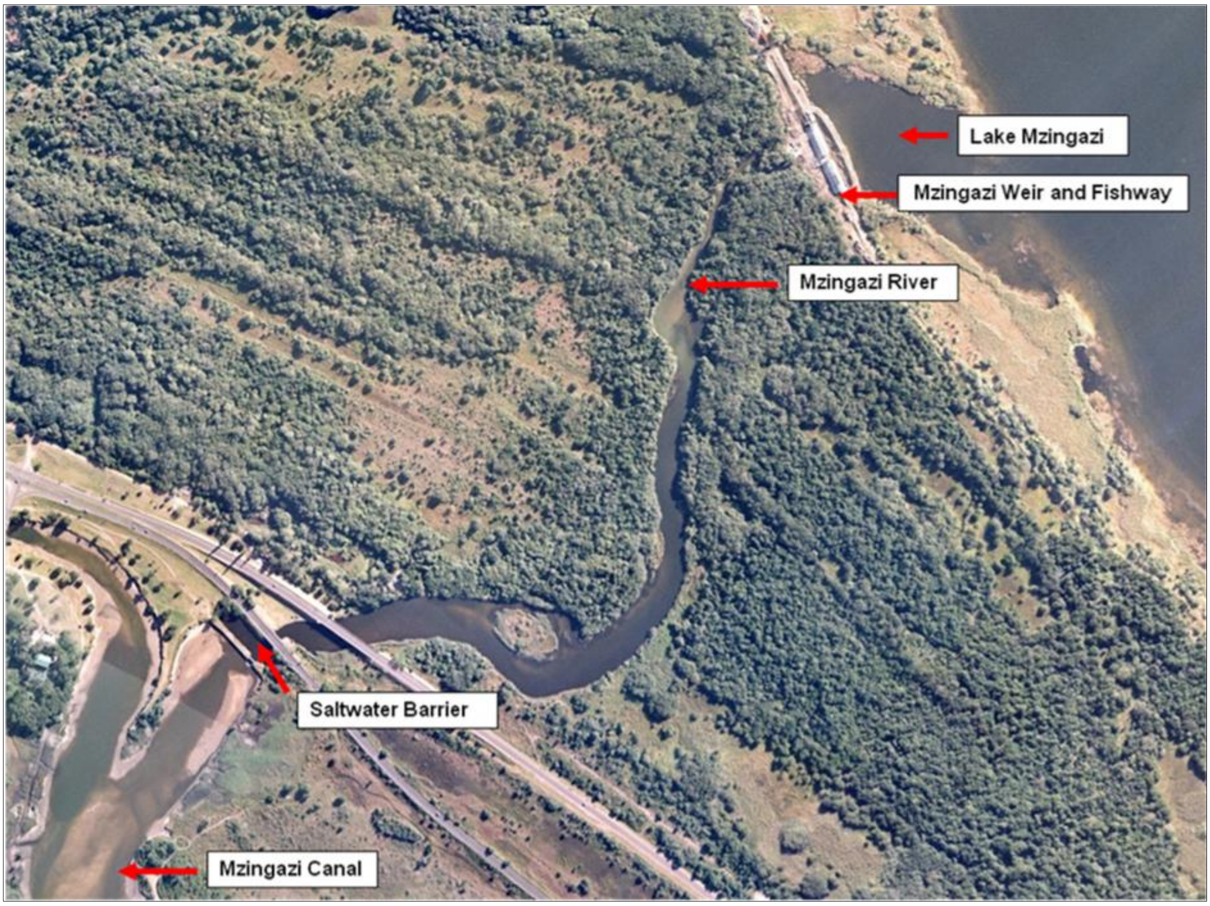

Figure 2.1: Sampling sites in the Mzingazi system (Mzingazi River and Lake Mzingazi).

2.2.1. The operation and efficiency of the Mzingazi Fishway

2.2.1.1. Sampling frequency

A monthly monitoring programme for the operation and efficiency of the Mzingazi fishway over a one-year period was initially planned over the period August 2007-July 2008, but due to low water levels in the lake during certain months, flow conditions in the fishway became unsuitable for sampling and, as such, sampling was done for only eight months instead of twelve. No sampling was done in January, February, March and July 2008. During all months, sampling was conducted once a month for two days.

2.2.1.2. Sampling procedure

Details of fish and invertebrate capture methods as well as the equipment used varied depending on the physical constraints at the site. A variety of sampling equipment was used, including funnel traps, dip nets and seine nets. For sampling of the fishway itself, the left and right sides of the fishway were treated differently (Figure 1.2). In order to monitor the migration of fish through the fishway, the pools on the left-hand side of the fishway were left untouched and a funnel trap was placed at the fishway exit and entrance (see Figure 1.2 and 2.2). In order to monitor the movement of fish within the fishway pools, the pools on the right-hand side of the fishway were sampled with a dip net.

The following gear was used where appropriate:

a) **Funnel trap nets:** These were used to catch fish and macroinvertebrates at the Saltwater Barrier, at the fishway entrance and at the fishway exit (Figures 2.1 and 2.2a,b,c). The fishway exit funnel trap was placed at the crest of the left-hand side of the fishway to trap the fauna that had successfully migrated through the fishway (Figure 2.2a); the fishway entrance funnel trap was placed between the concrete blocks at the downstream end of the fishway to the left-hand side of the fishway to trap all the migrants that had successfully migrated through the entrance of the fishway (Figure 2.2b). The entrance funnel trap and the exit funnel trap were both placed on the left-hand side of the fishway at the same time. The fishway entrance funnel trap was aimed to capture all the migrants that managed to pass through the entrance before the trap was placed, while the exit funnel trap was aimed to capture all migrants that were already in the fishway pools making their way to the lake. The third funnel trap was placed in the concrete lined tidal gate that runs through the Saltwater Barrier (Figure 2.2c). Funnel traps were designed large enough to allow fish and invertebrates to be held without injury (Bok *et al.*, 2004). The 2mm mesh cloth that was used to cover the funnel traps was tested several times during trial sampling and it was found to be appropriate for retaining upstream migrants. The dimensions of the funnel trap for the fishway exit was 1.5 m long, 0.5 m wide, and 0.2 m deep with 2 mm mesh size; for the fishway entrance: 0.5 m long, 0.5 m wide and 0.5 m deep with 2 mm mesh size; for the Saltwater Barrier: 0.5 m long, 0.6 m wide and 0.5 m deep with 2 mm mesh size. Funnel traps at the fishway entrance and exit were deployed for two days per month and checked and emptied at sunset and sunrise. The day and night sampling data was omitted because it was lumped and analyzed as one data; the reason for this is because the day sampling was in most cases interrupted by the local inhabitants and it was not feasible to compare this data.The Saltwater Barrier trap was deployed for 1-2 hrs per day over high tide. Due to the strong tidal current flowing though the concrete channel, this net was checked and emptied regularly during the 1-2 hrs sampling period.

b) **Dip nets:** The fishway pools were sampled using a dip net. All 25 pools on the right-hand side of the fishway were scooped once a day for two days per month. The dip net was inserted at the inner end of each pool and then pulled sideways to capture all fish and invertebrates in the pool. This procedure was repeated three times for each pool. The size of the dip net (0.3 m x 0.3 m with 500 µm mesh size) matched the internal dimensions of the fishway pools to ensure effective operation (Figure 2.2d) (Bok *et al.*, 2004). For ease of analysis, all pools, except pools 1-4 and pool 25, were paired and the catch from the two pools in a pair was combined. Pools 1-4 were always under water and the fauna could freely swim from one pool to the next, so the catch from these four pools were combined. Pool 25, which is the last pool before the fishway exit, was sampled separately as fauna often congregated in this top pool before they attempted to pass over the weir crest and into the lake. Comparisons were made between the fish and prawns sampled in the four quarters of the fishway, with pools 1-8 forming the 1st quarter, pools 9-14 the 2nd quarter, pools 15-20 the 3rd quarter and pools 21-25 the 4th quarter.

c) **Seine nets:** A small seine net (10 m x 1.5 m with 6 mm mesh size) was used to sample the fish and macroinvertebrates at the upper end of the Mzingazi River (just downstream of the fishway) and immediately upstream of the fishway. Two to three seine hauls were pulled at each site.

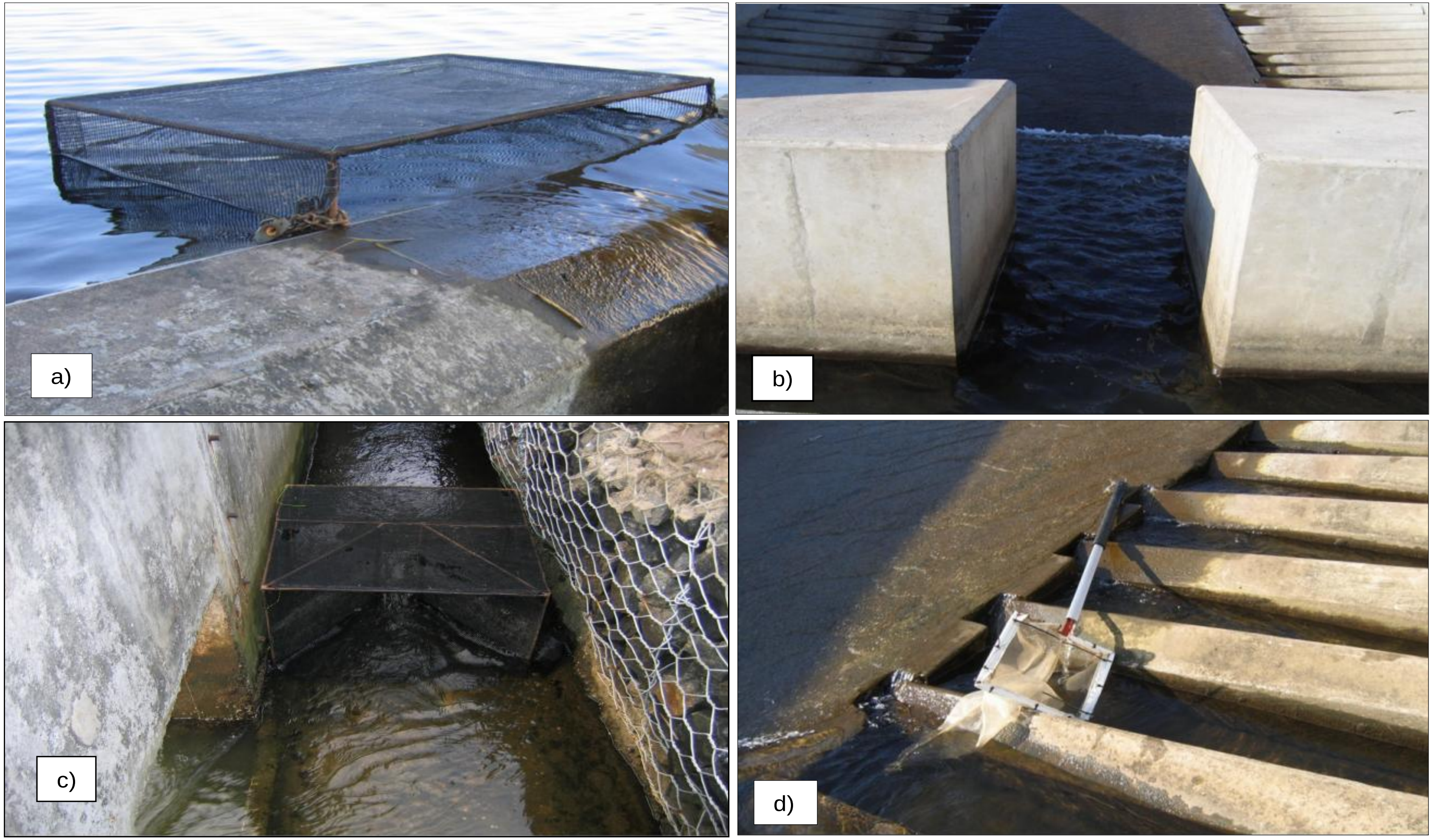

Figure 2.2: The Mzingazi fishway (a) exit and (b) entrance, the (c) Saltwater Barrier and (d) the Mzingazi fishway pools, showing the funnel traps and dip net used during the monitoring period.

2.2.1.3. Physico-chemical parameters

The flow and physico-chemical conditions of the water in the fishway were monitored monthly concurrent with the fishway sampling. Nine flow measuring points were selected in the fishway (see Figure 3.1 for location of flow measuring points). An OTT Z20 flow meter, with propeller number 3-93173, diameter 50 mm and pitch 0.25 was used to measure velocity (V) in the fishway and over the weir baffles during the monitoring period. The formula below was used to calculate velocity with **n** representing the number of revolutions.

$$V = 0.2520\, \mathbf{n} + 0.006$$

A YSI 6920 Sonde multi probe (YSI Incorporated, Yellow Springs, Oklahoma, USA) was used to measure a suite of physico-chemical water quality parameters in the fishway. The physico-chemical parameters measured included temperature, salinity, conductivity, turbidity, dissolved oxygen, percentage oxygen saturation and pH.

2.2.1.4. Sample treatment for fish and macrocrustaceans

All fish collected during the monitoring period were identified to species level according to Smith and Heemstra (1986), Skelton (1993) and Whitfield (1998). Larval fish were identified to the lowest possible taxon, since there is still limited information available on the identification of many species of larval fishes that occur in South African estuaries and near-shore marine environments (Strydom, 2002). Larval fish were identified according to Leis and Trnski (1989), Leis and Carson-Ewart (2002) and Neira *et al.* (1998). The standard length (SL) for all fish caught was recorded. Crustaceans collected during the monitoring period were identified to species level according to Kensley (1972) and Hart *et al.* (2001). The carapace length (CL) of crustaceans was measured using Vernier calipers, from the post-orbital margin to the postero-median margin of the carapace. Fish and macrocrustaceans were returned to the system as soon after capture as possible, unless positive identification in the laboratory was required, in which case the organisms were fixed in 10% formaldehyde on site, labeled and transported back to the laboratory for positive identification. Fish captured in the funnel trap were released upstream of the fishway. Voucher specimens of all species recorded were kept. All fish were also classified according to their Estuarine Dependence Category (EDC) (Whitfield, 1998) (Table 2.1).

2.2.1.5. Data analysis

Fish and prawns were analysed separately using similar procedures as these two components form two separate chapters of this thesis. The total number of individuals recorded per sampling method was converted to catch per unit effort (CPUE), which is equivalent to the total number of fish or prawns recorded per month divided by the number of sampling days. Seine net CPUE was calculated as the number of fish or prawns per haul per day. Stacked and clustered bar graphs were constructed to show the abundance of each species per month, the total number of fish per pool and also to determine the size class of all fish recorded. Single factor analysis of variance (ANOVA) was used to test for significant differences between sampling months and between the catches of paired fishway pools.

2.2.2. The effects of the fishway on the fish community of Lake Mzingazi

2.2.2.1. Sampling frequency

Lake Mzingazi was monitored seasonally for a period of two years, from August 2007 to June 2009. Five seine sites (S1-S5) and three gill net sites (G1-G3) were chosen, as shown on the map (Figure 2.3). Later during the monitoring period a fourth gill net site (G4) was added because of low catches at Site G3. One large seine haul and three small seine hauls were pulled at each seine site, while the gill nets were deployed for 2-3 hours at each gill net site.

2.2.2.2. Sampling procedure

a) **Gill nets:** Lengths of 50 (25 m), 75 (25 m),100 (42 m), 125 (25 m) and 150 mm (25 m) (2“- 6”) stretch mesh size gill nets were deployed in the lake for three hours per site.

b) **Seine nets:** A small seine net (10 m x 1.5 m net with 6 mm mesh size) and a large seine net (70 m x 1.5 m with 10 mm mesh size) were used to sample the inshore fish community as per five selected sites throughout the lake.

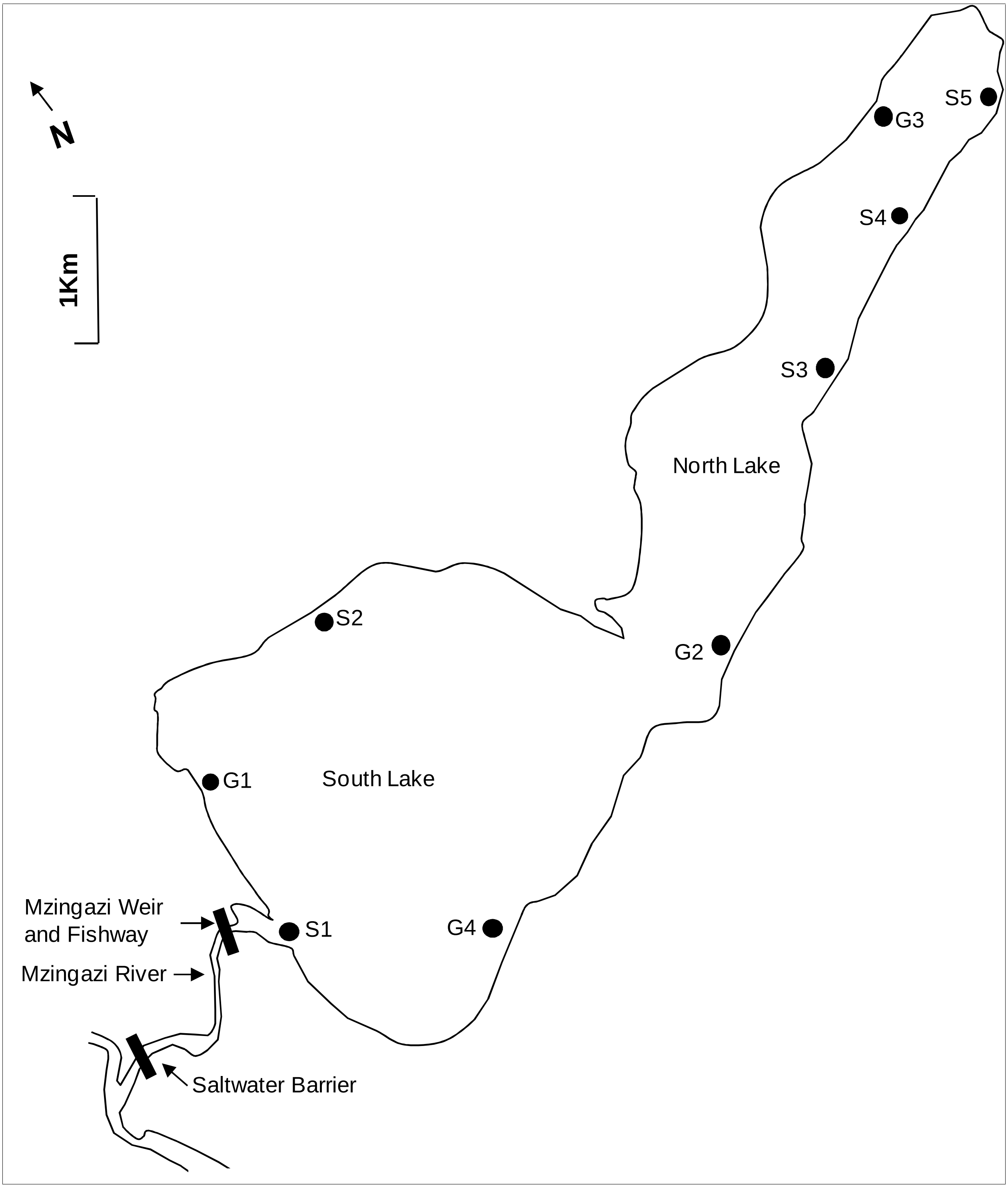

Figure 2.3: Lake Mzingazi showing the sites sampled during the monitoring period, •: indicates sampling sites, G: Gill net sampling sites, S: Seine net sampling sites.

2.2.2.3. Physio-chemical parameters

The physico-chemical conditions of the water in the lake were monitored seasonally concurrent with the fish sampling. A YSI 6920 Sonde multi probe (YSI Incorporated, Yellow Springs, Oklahoma, USA) was used to measure a suite of physico-chemical water quality parameters in the lake, which included temperature, salinity, conductivity, dissolved oxygen, percentage oxygen saturation and pH. The readings were taken in the middle of the lake between the south and the north lake.

2.2.2.4. Sample treatment for fish

All fish collected during the monitoring period were identified to species level according to Smith and Heemstra (1986), Skelton (1993) and Whitfield (1998). The standard length (SL) was recorded for all fish caught. Fish were returned to the system as soon after capture as possible, unless positive identification in the laboratory was required in which case the fish were fixed in 10% formaldehyde on site, labeled and transported back to the laboratory for positive identification. Voucher specimens of all species recorded were kept. All fish were classified according to their Estuarine Dependence Category (EDC) (Whitfield, 1998) (Table 2.1).

2.2.2.5. Data analysis

Multivariate analysis (PRIMER version 6.0) (Clarke & Warwick 2001; Clarke and Gorley, 2006) was used to investigate changes in the Lake Mzingazi fish community structure. The data was 4^{th} root transformed; averaged data was used to determine the Bray-Cutis similarity coefficient, followed by hierarchical clustering and ordination of data through Non-metric multidimensional scaling (MDS). Significant differences between temporal (seasonal) and spatial (sites) changes in the fish community was tested by using Analysis of Similarity (ANOSIM). SIMPER was used to identify the species that were most responsible for the differences in community structure between seasons, years and lake compartments; this means all the species that contributed the most within each group.

Univariate analysis was performed using species diversity indices such as total species number, abundance, Shannon-Wiener diversity (H'), Margalef's species richness (d') and species evenness (J'). The results from these analyses were then used to calculate the means per year, site and season. Single factor analysis (ANOVA) was used to test for temporal and spatial differences between years, sites and seasons.

Table 2.1: Estuarine Dependence Categories describing fish utilisation of South African estuaries (Whitfield, 1998).

Category	Description of categories
I	Estuarine species which breed in Southern African estuaries. Further subdivided into: Ia.Resident species which have not been recorded spawning in marine or freshwater environments. Ib. Resident species which also have marine or freshwater breeding populations.
II	Euryhaline marine species which usually breed at sea with juveniles showing varying degrees of dependence on southern African estuaries. Further divided into: II a. Juveniles dependent on estuaries as nursery areas. II b. Juveniles occur mainly in estuaries but are also found at sea. II c. Juveniles occur in estuaries but are usually more abundant at sea.
III	Marine species which occur in estuaries in small numbers but are not dependent on these systems
IV	Freshwater species whose penetration into estuaries is determined primarily by salinity tolerance. This category includes some species which may breed in both freshwater and estuaries systems.
V	Catadromous species which use estuaries as transit routes between the marine and freshwater environments but may also occupy estuaries in certain regions. Further divided into: V a. Obligate catadromous species which requires freshwater phase in their development. V b. Facultative catadromous which do not require freshwater phase in their development.

CHAPTER 3

OPERATION AND EFFICIENCY OF THE MZINGAZI FISHWAY FOR FISH

3.1. RESULTS

3.1.1. Environmental variables

A table showing the physico-chemical results of water analysed in this study is given in Appendix 1. During monitoring of Mzingazi fishway water quality over the period of August 2007 to July 2008, the water salinity and conductivity, recorded at the fishway entrance, remained relatively constant at 0.2 and 0.45 mS/cm, respectively. Turbidities were very low, ranging from 0.29 to 0.31 NTU, while water temperature ranged from 18.5°C in winter to 31.7°C in summer. The fishway water was well oxygenated throughout the study period, with oxygen saturation ranging between 79 and 131%, and dissolved oxygen between 7.3 and 10.9 mg/l. The highest oxygen concentrations were recorded in September and October.

Lake water level fluctuated considerably during the study period, ranging from a maximum of 3.36 mamsl in November 2007 to a minimum of 2.8 mamsl in January 2008. Low water levels, below 3 mamsl in Lake Mzingazi, caused the fishway to cease flowing for a period of four months during the study, namely from January to March 2008 and during July 2008.

Water flow velocities over the weir crest and down through the fishway were recorded during the study period and are presented in Table 3.1. The localities of the flow measuring points in the fishway are illustrated in Figure 3.1. The highest flow velocity, at the weir crest, was recorded in June followed by December, while the lowest flow velocity was recorded in October. The flow recorded at the weir crest indicates the rate at which the water enters the fishway. The highest velocity (2.27 $m.s^{-1}$) was recorded at the crest of the second pool, while the lowest velocity (0.61 $m.s^{-1}$) was recorded at the fishway entrance.

The accuracy of the flow velocity during low flow cannot be assured because flow velocity was not recorded during low flow and shallow water (depth < 50mm). This is because of the lack of equipment such as propeller that is < 50mm diameter. Juvenile fish (< 20 mm SL) were observed trying to negotiate the point of lowest flow over the crest of the fishway (Figure 3.1) but the propeller of 50mm diameter was used to measure flow at this point.

Table 3.1: Flow velocities ($m.s^{-1}$) recorded at different positions within the fishway between August 2007 and July 2008 (***** indicates that sampling was not done because of low water level in the lake, **X** indicates that the site was often blocked, while **#** indicates water eddies caused by concrete blocks at the fishway entrance were flowing in the opposite direction).

	Months							
Site	Apr	May	Jun	Jul*	Aug*	Oct	Nov	Dec
i. Fishway crest	0.89	1.17	1.44			1.42	1.29	1.42
ii. Weir crest	0.89	0.89	1.54			0.84	1.01	1.09
iii. Point of the lowest flow over crest	0.96	0.99	0.89			1.01	0.99	1.24
iv. Top pool in the fishway	1.54	1.54	1.87			1.69	1.19	1.69
v. Crest of the 2nd pool	1.49	1.42	2.27			1.34	1.8	1.74
vi. Pipe in baffle	1.52	0.81	0.79			1.32	0.76	0.69
vii. Submerged orifice	**x**	**x**	1.29			**x**	0.84	**x**
viii. Fishway entrance	#	#	1.77			#	#	#
ix. Fishway entrance	0.79	0.61	1.82			1.17	2.15	1.32

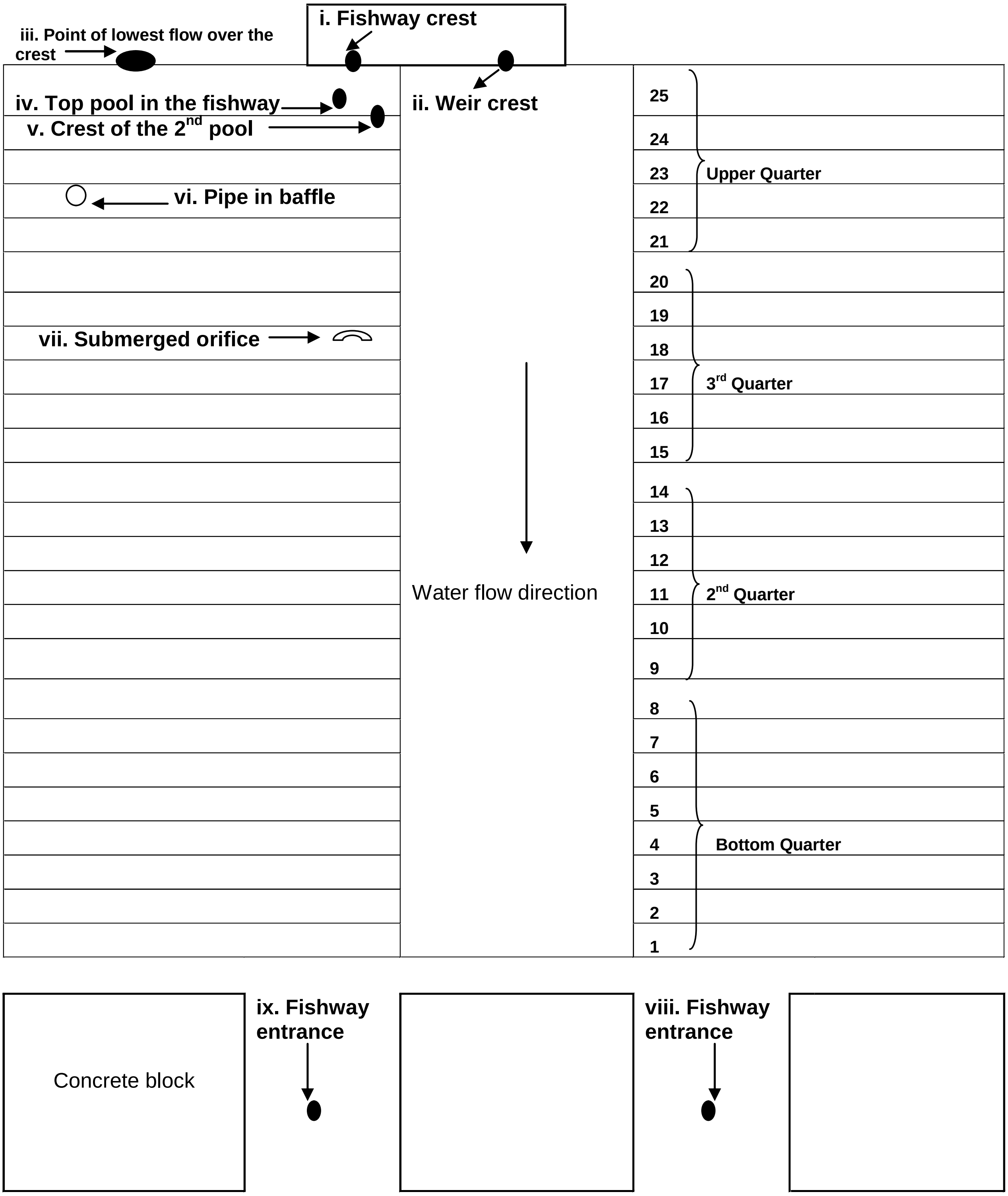

Figure 3.1: Schematic diagram showing locality of the flow measuring points in the fishway (● indicates flow measuring points).

3.1.2. Fish species composition

A total of 3 288 fish, representing 17 families and 29 species, were recorded throughout the study – 1) in the Mzingazi River at the Saltwater Barrier, 2) in the Mzingazi River below the fishway, 3) at the fishway entrance, 4) in the fishway, 5) at the fishway exit, and 6) in the lake immediately above the fishway (Table 3.2, Figure 2.1 and Figure 2.3a, b, c). The dominant fish species recorded were *Myxus capensis, Ambassis natalensis, Mugil cephalus and Glossogobius callidus*, which contributed 72.5% of the total catch (Table 3.2). The remaining 25 species constituted only 27.5% of the total catch. In terms of estuarine association, estuarine spawning species (Category I) were most abundant and constituted 34.8% of the total catch. Categories Ia and Ib contributed 30.8% and 4%, respectively. Euryhaline marine species (Category II) constituted 24% of the total catch with Categories IIa, IIb and IIc contributing 18.9%, 0.1% and 5%, respectively. Marine species (Category III), which are not dependant on estuaries, constituted 0.03% of the total catch, while freshwater (Category IV) and catadromous fish (Category Va and Vb) contributed 8 %, 0.06% and 29%, respectively (Table 3.2). In general, euryhaline marine species abundance (Category II, III and V) contributed 53% of the total catch.

In terms of number of species, freshwater species (Category IV) contributed 21% of the total number of the species caught during the monitoring period. Estuarine resident species (Category Ib) contributed 18%, while Euryhaline marine species (Category IIa and IIb), contributed 21% and 12%, respectively. All category II species contributed up to 36% of the total number of species. Estuarine resident species (Category Ia), marine species (Category III) and catadromous migrant (Category V (b) contributed 15%, 3% and 3%, respectively (Figure 3.2). In general, euryhaline marine species (Category II, III and V) contributed 45% of the total catch.

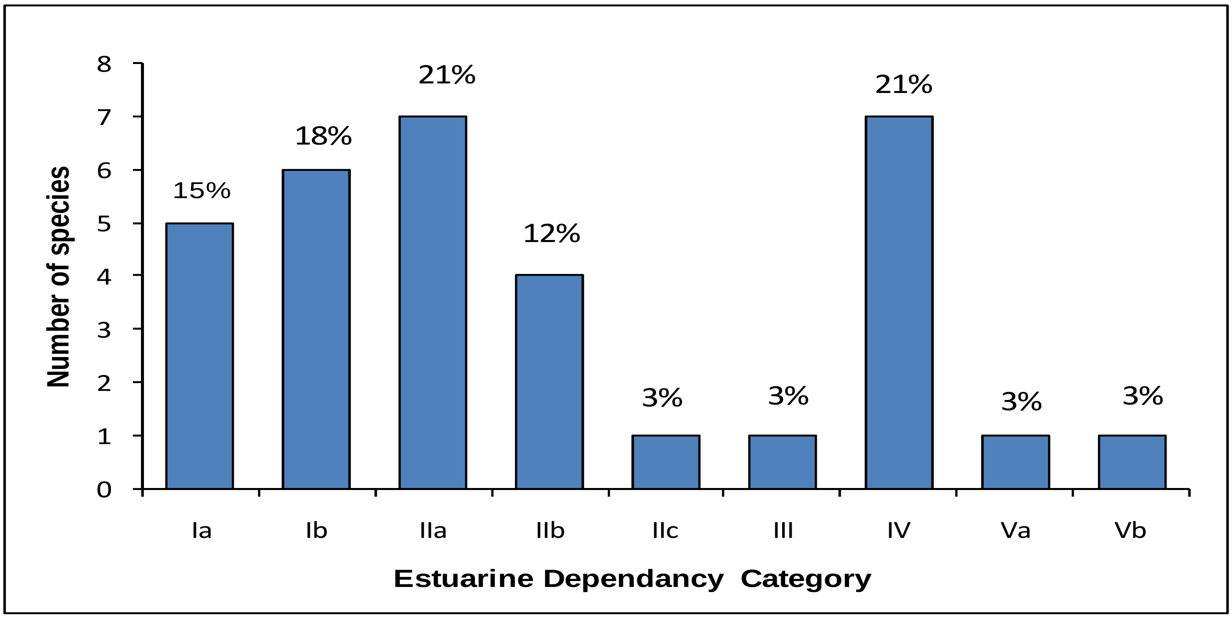

Figure 3.2: The number of fish species recorded per Estuarine Dependence Category of fish at six sites in the study area (Figure 2.1) between August 2007 and July 2008.

3.1.3. Longitudinal Distribution

The number of species recorded in the lower Mzingazi River (at the Saltwater Barrier) was higher (22 species) than in the upper end of the Mzingazi River (16 species). A total of 20 species was recorded at the fishway entrance and 17 species in the fishway exit, while 15 species were recorded at the fishway pools. The lowest number (seven) species was recorded in the lake just upstream of the fishway (Table 3.2). The species composition in different reaches of the Mzingazi system (at the Saltwater Barrier, upper end of the Mzingazi River, fishway entrance, fishway pools, fishway exit and in the lake just upstream of the fishway exit) showed dominance by different species. In terms of abundance, *Lutjanus ruvilatus* was the dominant species at the Saltwater Barrier (24%), *A. natalensis* (39%) at the upper end of the Mzingazi River, and similarly, *A. natalensis* at the fishway entrance (28%). The dominant species for both fishway pools and fishway exit was *M. capensis,* contributing 59% and 43%, respectively. *Oreochromis mossambicus* (30%) was found to be the dominant species in the lake just upstream of the fishway exit (Table 3.2).

In terms of number of species, estuarine spawning species (Category I) were dominant at the Saltwater Barrier, upper end of the Mzingazi River, fishway entrance and fishway pools , contributing 42%, 38%, 47% and 34% respectively (Figure 3.3a, 3.3b, 3.3c and 3.3d). Freshwater species (Category IV) were mostly dominant at the fishway exit and in the lake just upstream of the fishway exit, contributing 38% and 57%, respectively (Figure 3.3e and 3.3f). Euryhaline marine species (Category IIa and IIb) were also dominant at the Saltwater Barrier, at the upper end of the Mzingazi River, and at the fishway entrance and exit, contributing 41%, 32% 26% and 25%, respectively, with only 2% at the fishway pools (Figure 3.3a. 3.3b, 3.3c and 3.3e). Euryhaline marine species (Category IIc) and III) were only recorded at the Saltwater Barrier (Table 3.3a). *Myxus capensis* was the only euryhaline marine species that was recorded in the lake just upstream of the fishway exit (Table 3.11).

Table 3.2: Species list, numbers and percentage contribution per species arranged in decreasing order of abundance and percentage contribution to CPUE in Mzingazi System (at six sites in the study area: Figure 2.1) during the period August 2007 to July 2008. Fish species classified according to Estuarine Dependency Categories in Table 2.1 (Whitfield, 1998); ** indicates endemic to southern Africa (Skelton, 1977).

				Percentage contribution to CPUE in each section					
				Mzingazi River		Mzingazi fishway			Lake Mzingazi
Species	EDC	Total Catch Number recorded	%	Saltwater Barrier	Mzingazi River	Fishway Entrance	Fishway Pools	Fishway Exit	Lake, above fishway exit
*Myxus capensis***	Vb	976	29.60	17.00	8.00	24.00	59.00	43.00	4.10
Ambassis natalensis	Ib	488	14.80	20.40	35.00	28.00	1.40	0.90	
Mugil cephalus	IIa	470	14.20	0.10	39.00	2.90	7.00	0.90	
*Glossogobius callidus***	Ib	460	13.90	0.40	11.00	19.00	19.00	22.00	29.00
Lutjanus rivulatus	IIc	166	5.00	24.00					
*Oreochromis mossambicus***	IV	146	4.40		0.23	2.30	3.70	7.80	30.00
Tilapia rendalli	IV	83	2.50		0.11		0.07	0.90	24.00
Mugilid larvae	IIa,IIb,IIc,Vb	66	2.00	9.90					
*Gilchristella aestuaria***	Ia	53	1.60		1.09	2.90	2.60	1.70	11.00
Valamugil cunnesius	IIa	53	1.60		1.20	5.00	0.07	0.90	
Liza macrolepis	IIa	50	1.50	7.30	0.11				
Eleotris fusca	Ia	38	1.10			2.90	4.40	12.00	
Ambassis gymnocephalus	Ib	35	1.00	4.20	1.09	1.60			
*Croilia mossambica***	Ib	33	1.00	4.00	0.37	0.50	1.40	1.70	
Acanthopagrus berda	IIa	29	0.80	3.70	1.09	0.50			
Monodactylus falciformis	IIa	23	0.60	0.30		0.50	0.20	1.70	
Eleotridid larvae	Ia	20	0.60	2.90					
Ambassis ambassis	Ia	19	0.50	2.00	0.37	1.60			
*Glossogobius giuris***	IV	18	0.50		0.46	2.30	0.70	3.40	
Aplocheilichthys myaposae	IV	12	0.36			1.60		1.70	0.30

Table 3.2 continues...

				Percentage contribution to CPUE in each section					
		Total Catch		Mzingazi River		Mzingazi fishway			Lake Mzingazi
		Number		Saltwater	Mzingazi	Fishway	Fishway	Fishway	Lake, above
Species	EDC	recorded	%	Barrier	River	Entrance	Pools	Exit	fishway exit
Gobiid larvae sp. 1	-	11	0.33	0.50					
Gobiid larvae sp. 2	-	5	0.15	0.40	0.11	0.50		0.90	
Ambassids larvae	I?	4	0.12	0.60					
Barbus viviparus	IV	4	0.12			1.70		0.90	
Elops larvae	IIa	4	0.12	0.60					
Terapon jarbua	IIa	4	0.12			1.70			
Oligolepis acutipennis	Ia	3	0.09	0.30		0.50			
Anguilla sp. 1	Va	2	0.06		0.37				
Pseudocrenilabrus philander	IV	2	0.06						0.90
*Silhouettea sibayi***	Ib	2	0.06			0.50	0.20		
Arothron immaculatus	III	1	0.03	0.10					
Awaous aeneofuscus	IV	1	0.03					0.90	
*Gerres methueni***	IIb	1	0.03					0.90	
Liza alata	IIb	1	0.03		0.28				
Microcanthid larvae	-	1	0.03	0.10					
Monodactylid larvae	II	1	0.03	0.10					
Monodactylus argenteus	IIb	1	0.03	0.10					
*Psammogobius knysnaensis***	Ib	1	0.03				0.07		
Rhabdosargus sarba	IIb	1	0.03				0.07		
Total		3 288							
Number of species		29		22	17	20	15	17	7

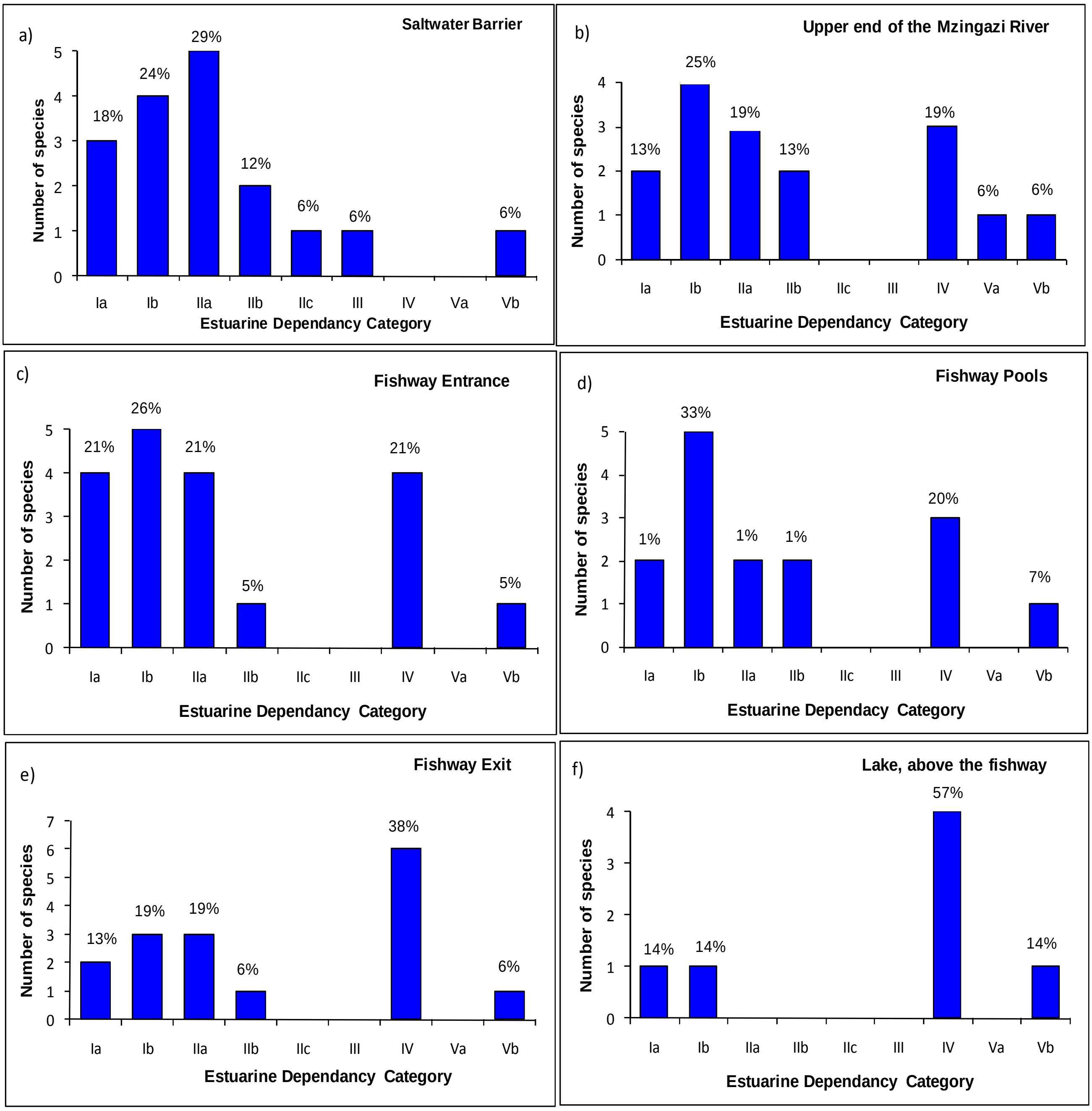

Figure 3.3: Number of fish species per estuarine dependence category recorded at six sites in the study area (Figure 2.1) between August 2007 and July 2008.

3.1.3.1: Fish recruitment into the Mzingazi River (at the Saltwater Barrier)

In April, June and July 2008, the Saltwater Barrier was visited immediately after high tide; because the high tide was missed, no sampling was performed during these months. Only five runs of sampling were carried out at the Saltwater Barrier. The total number of fish that were recorded migrating through the Mzingazi Saltwater Barrier from Richards Bay Harbour via the Mzingazi Canal into the low salinity environment of the Mzingazi River comprised 680 fishes of 22 species, of which 15 could be identified to species level (Table 3.3). The dominant species were *L. rivulatus, A. natalensis* and *M. capensis,* contributing 61.4% of the total catch (Table 3.3). The fish migrating into the Mzingazi River were dominated by euryhaline marine species (Category IIa, IIb and IIc), contributed 47% of the total catch, while marine species (Category III) and catadromous species (Category Vb) contributed 6% each. Estuarine spawning species (Category I) contributed 42%. No freshwater species were recorded at the Saltwater Barrier (Figure 3.3a). A total of 13 species was recorded at the Saltwater Barrier in December, while only two species were recorded there in October (Table 3.3). The highest CPUE was recorded in September followed by December. A marked decrease in abundance occurred in May, when only 17 fish were recorded (Table 3.3). *Myxus capensis* was consistently recorded, while the remaining species were only recorded on one or two occasions during the sampling period. *Ambassis natalensis* and *L. rivulatus* were abundant in September (Table 3.3).

The size of fish recorded at the Saltwater Barrier varied from 5-71 mm SL. The smallest specimens recorded were *Monodactylus* larvae (5 mm SL), and the largest, *A. natalensis* (71 mm SL) (Table 3.3). The size of *Lutjanus rivulatus* ranged from 10-40 mm*, A. natalensis* from 10-71 mm, and *M. capensis* from 10-45 mm SL.

3.1.3.2. Fish composition at the upper end of the Mzingazi River

A total of 835 fish representing 16 species was recorded at the upper end of the Mzingazi River immediately below the fishway (Table 3.4). The dominant species were *A. natalensis, M. cephalus, Glossogobius callidus* and *M. Capensis,* which contributed 93% of the total catch (Table 3.4). A total of 10 species were recorded in August, while in June only one species was recorded. The highest CPUE was recorded in August, followed by October and November. *Mugil cephalus* was consistently recorded, while *A. natalensis* and *G. callidus* were not recorded in April, May and June. *Valamugil cunnesius* occurred in October, November and December. The remaining species were recorded on one occasion only during the sampling period (Table 3.4).

Table 3.3: Species list, Estuarine Dependency Categories, CPUE (Total number/sampling days), months and the size range (mm SL) of fish recorded at the Saltwater Barrier in the Mzingazi Canal between August 2007 and July 2008.

		Months							
		Catch per unit effort					Mean		Size
Species	**EDC**	**Sep**	**Oct**	**Dec**	**Mar**	**May**	**CPUE**	**%**	**range**
Lutjanus rivulatus	IIc	166.0					33.2	24.0	10-40
Ambassis natalensis	Ib	134.0			1.0	2.0	27.4	20.4	10-71
Myxus capensis	Vb	21.0	1.0	56.0	36.0		22.8	17.0	10-45
Mugilids larvae	IIa			20.0	46.0		13.2	9.9	8-12
Liza macrolepis	IIb				49.0		9.8	7.3	21-26
Ambassis gymnocephalus	Ib	29.0					5.8	4.2	15-50
Croilia mossambica	Ib			27.0			5.4	4.0	15-20
Acanthopagrus berda	IIa	21.0	4.0				5.0	3.7	10-40
Eleotridid larvae	Ia			12.0		8.0	4.0	2.9	10-20
Ambassis ambassis	Ia	14.0					2.8	2.0	10-15
Ambassids larvae	I?			3.0		1.0	0.8	0.6	8-12
Elops larvae	IIa			2.0		2.0	0.8	0.6	25-30
Gobiid larvae sp. 1	I?			6.0		4.0	0.8	0.5	14-20
Glossogobius callidus	Ib			3.0			0.6	0.4	10-18
Gobiid larvae sp. 2	I?			3.0			0.6	0.4	10-18
Oligolepis acutipennis	Ia	1.0		1.0			0.4	0.3	20-30
Monodactylus falciformis	IIa			1.0	1.0		0.4	0.3	7-10
Monodactylus argenteus	IIb	1.0					0.2	0.1	30
Arothron immaculatus	III	1.0					0.2	0.1	40
Mugil cephalus	IIa	1.0					0.2	0.1	20
Microcanthid larvae	II			1.0			0.2	0.1	10
Monodactylid larvae	II			1.0			0.2	0.1	5
Total		389.0	5.0	136.0	133.0	17.0	134.8		
Number of species	22	10	2	13	5	5	7		

Estuarine dependency showed that Category Ib was the most dominant component, contributing 25%. Category IIa and Category IV contributed 19% each, while Category IIb and Category Ia contributed 13% each. Category IIc, Category III and the catadromous species were not recorded at the base of the fishway (Figure 3.3b).

The size of the fish recorded at the upper end of the Mzingazi River ranged from 10 to 65 mm SL. This clearly indicates that mainly juveniles, predominantly *M. cephalus*, *G. callidus and M. capensis,* were recorded, while sub-adults and adults for *A. natalensis* were also recorded (Figure 3.4). *Mugil cephalus* ranged from 16-30 mm SL, with the majority of the total catch (33%) between 21-25 mm SL. *Ambassis natalensis* ranged from 19 and 65 mm SL, with the majority (14%) between 36 and 40 mm SL. *Glossogobius callidus* ranged from 25 to 65 mm with the majority (6%) between 36 and 40 mm SL (Figure 3.4.).

Table 3.4: Species list, Estuarine Dependency Categories and the CPUE (Total number/sampling days) for fish sampled downstream of the fishway between August 2007 and July 2008 (*indicates no sampling done due to low water level).

						Months						
						Catch per unit effort						Mean
Species	**EDC**	**Apr**	**May**	**Jun**	**Jul***	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**%**	**CPUE**
Mugil cephalus	IIa		10.00	21.00		21.00		27.00	17.00	12.00	39.00	13.50
Ambassis natalensis	Ib					97.00					35.00	12.10
Glossogobius callidus	Ib					20.00	9.00		1.00		11.00	3.75
Myxus capensis	Vb					17.00	4.00	1.00		1.00	8.00	2.87
Valamugil cunnesius	IIa		1.00					0.30	1.00	1.00	1.20	0.41
Gilchristella aestuaria	Ia								1.00	2.00	1.09	0.38
Ambassis gymnocephalus	Ib					3.00					1.09	0.38
Acanthopagrus berda	IIa					3.00					1.09	0.38
Glossogobius giuris	IV					0.30			1.00		0.46	0.16
Anguilla spp	Va		1.00								0.37	0.13
Ambassis ambassis	Ia									1.00	0.37	0.13
Croillia mossambica	Ib		1.00								0.37	0.13
Liza alata	IIb					0.80					0.28	0.10
Oreochromis mossambicus	IV							0.60			0.23	0.08
Tilapia rendalli	IV					0.30					0.11	0.04
Gobiid larvae sp. 2	-					0.30					0.11	0.04
Liza macrolepis	IIb							0.30			0.11	0.04
Total			13.00	21.00		162.70	13.00	29.20	21.00	17.00		34.58
Number of species	16		4	1		1	2	5	5	5		

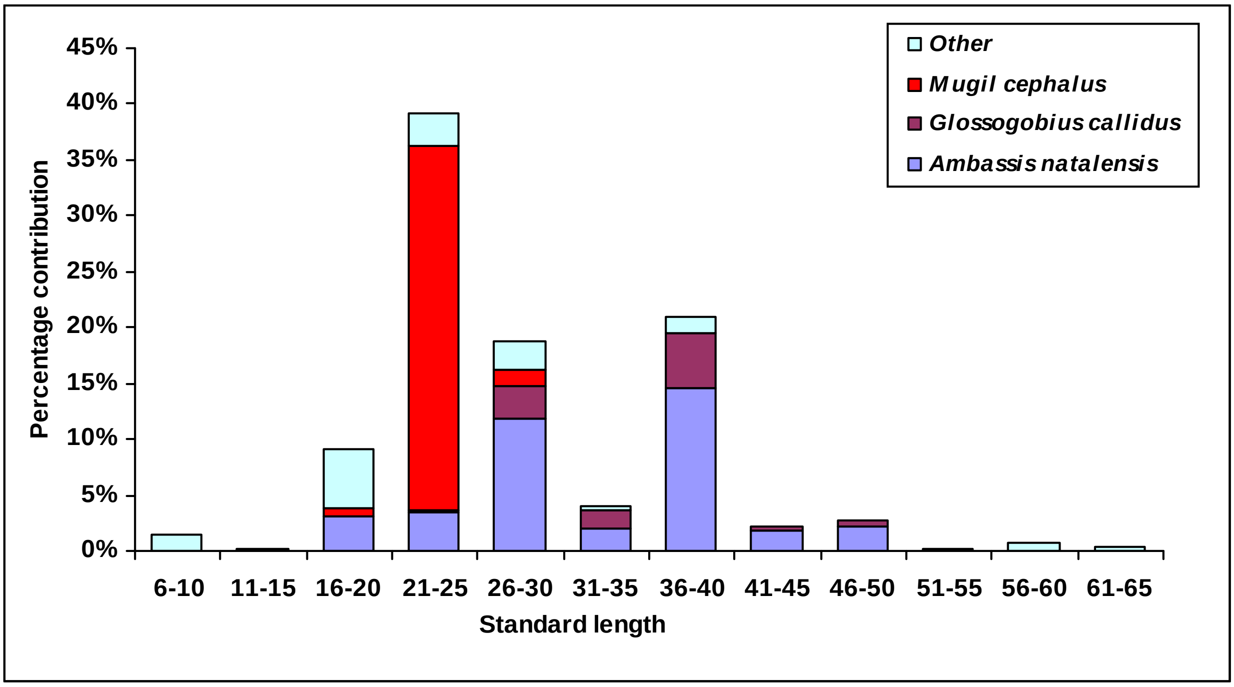

Figure 3.4: Size frequency distribution of fish recorded in the Mzingazi River downstream of the fishway between August 2007 and July 2008.

3.1.3.3. Fish composition of the fishway entrance

A total of 225 fish representing 20 species was recorded at the fishway entrance (Table 3.5). The dominant species made up 71% of the total catch; they were *A. natalensis, M. capensis* and *G. Callidus*, contributing 28%, 24% and 19% of the total catch, respectively (Table 3.5). The remaining 17 species constituted 29% of the total catch (Table 3.5, Table 3.6). The lowest number of two species was recorded in May, while in October, 10 species were recorded. Species such as *G. callidus* and *M. capensis* were consistently abundant during the monitoring period while *A. natalensis* was most abundant during April, August and December (Figure 3.5). *Myxus capensis* numbers exhibited a marked peak from August to October, while *G. callidus* numbers peaked in August and September. Species such as *O. mossambicus* and G. *giuris* were only recorded for a limited period, October to December. The number of species in Category Ia, Category Ib and Category IV, contributed 21%, 26% and 21%, of the total species caught, respectively, while catadromous species (Category Vb) contributed only 5% (Figure 3.3c). Category Vb was represented by *M. capensis,* which was consistently recorded during the monitoring period (Table 3.5).

The size of fish recorded at the fishway entrance varied from 7-170 mm SL with the majority (27%) in size class 26-30 mm (Figure 3.7). The smallest specimen recorded was *M. capensis* and the largest *G. giuris* (Table 3.6, Figure 3.7). The majority of *M. capensis* was 10-15 mm SL juveniles, with this size class comprising 8% of the total CPUE of all species recorded, while the majority of *G. callidus* (14%) recorded was between 26 and 50 mm SL. *Ambassis natalensis* ranged from 20-50 mm, with the majority between 26 and 40 mm SL. This size class comprised 22% of the total CPUE of all species recorded.

Table 3.5: Species list, Estuarine Dependence Categories and CPUE (Total number/sampling days) of fish recorded at the fishway entrance between August 2007 and July 2008 (*indicates no sampling done due to low water level).

						Months Catch per unit effort						Mean
Species	**EDC**	**Apr**	**May**	**Jun**	**Jul***	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	%	**CPUE**
Ambassis natalensis	Ib	25.0				7.3		1.5		5.5	28.0	4.9
Myxus capensis	Vb		0.5	0.7		10.7	11.0	10.5	0.5		24.0	4.2
Glossogobius callidus	Ib	3.0		3.3		10.7	6.0	3.5			19.0	3.3
Valamugil cunnesius	IIa			6.0			1.0				5.0	0.9
Gilchristella aestuaria	Ia					1.3	3.0				2.9	0.5
Eleotris fusca	Ia		1.0	0.7			1.0	0.5	1.0		2.9	0.5
Mugil cephalus	IIa						4.0				2.9	0.5
Oreochromis mossambicus	IV							1.0	1.5	0.5	2.3	0.4
Glossogobius giuris	IV						1.0	0.5	1.5	0.5	2.3	0.4
Barbus viviparus	IV	0.5					2.0				1.7	0.3
Terapon jarbua	IIa	2.0									1.7	0.3
Ambassis gymnocephalus	Ib	0.5						1.0			1.6	0.2
Ambassis ambassis	Ia							0.5		1.0	1.6	0.2
Aplocheilichthys myaposae	IV			0.7				0.5			1.6	0.2
Monodactylus falciformis	IIb					0.7					0.5	0.1
Gobiid larvae sp. 2						0.7					0.5	0.1
Acanthopagrus berda	IIa							0.5			0.5	0.1
Silhouettea sibayi	Ib									0.5	0.5	0.1
Oligolepis acutipennis	Ia								0.5		0.5	0.1
Croilia Mossambica	Ib			0.7							0.5	0.1
Total CPUE		31.0	1.5	12.1		31.4	29.0	20.0	5.0	8.0		17.2
Number of species	19	5	2	6		6	8	1	5	5		5

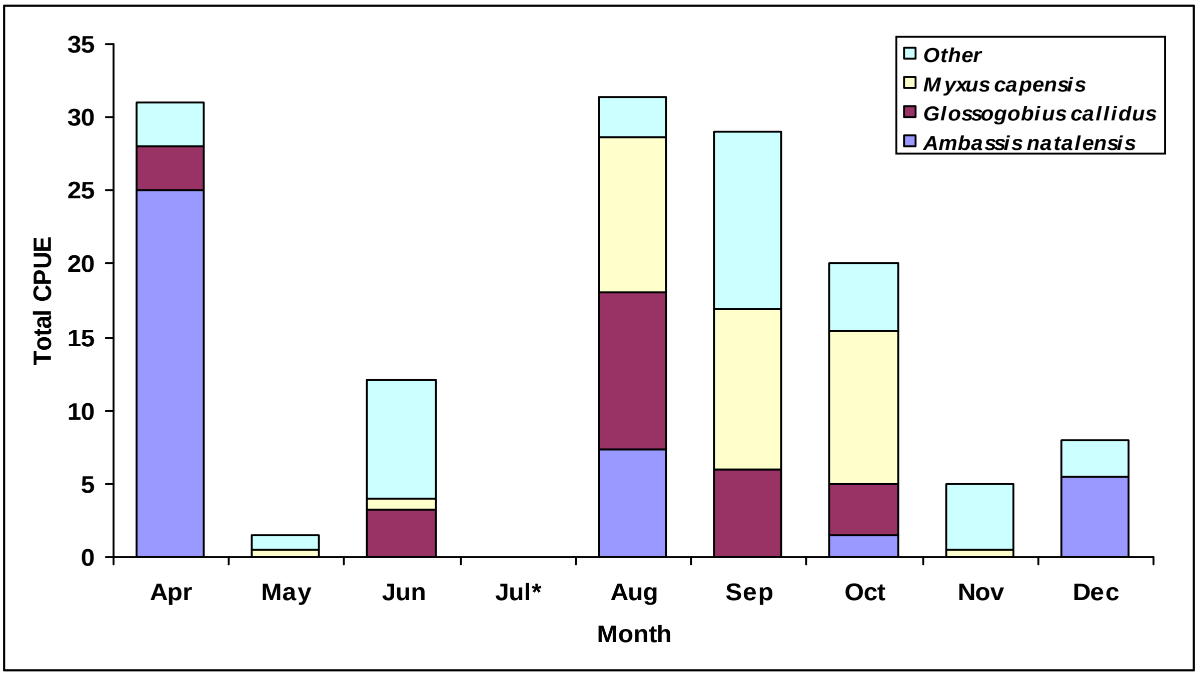

Figure 3.5: Monthly mean abundance of all species recorded at the fishway entrance between August 2007 and July 2008 (* indicates no sampling done due to low water level).

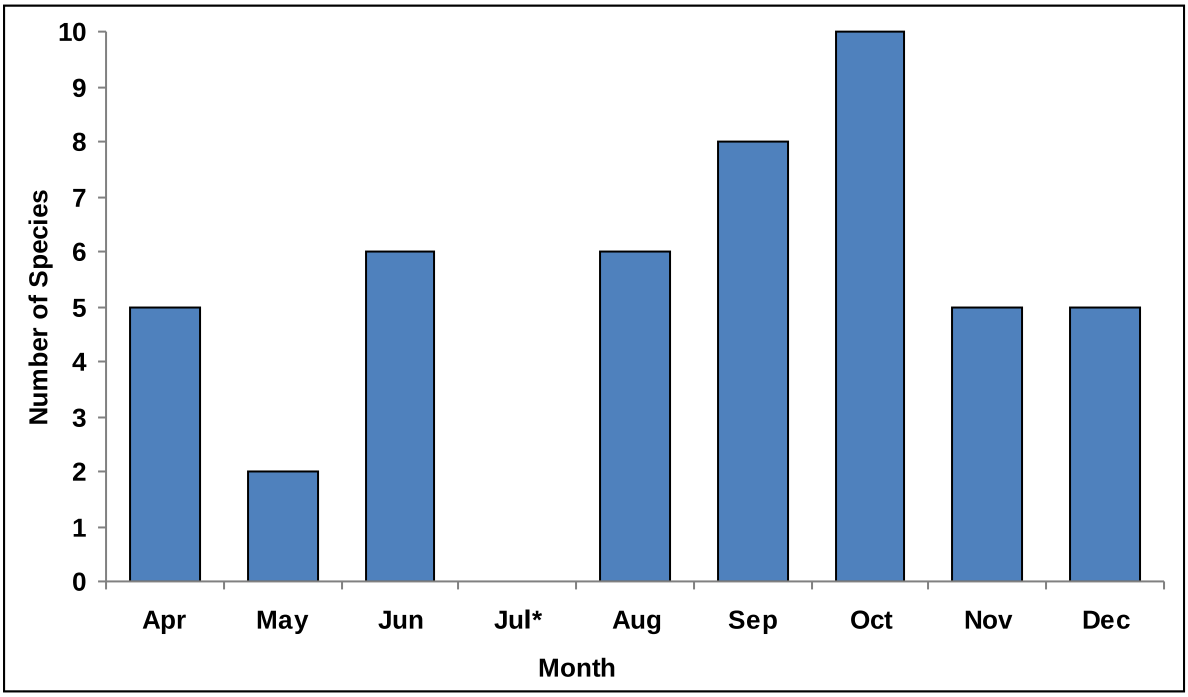

Figure 3.6: Number of species recorded at the fishway entrance per month between August 2007 and July 2008 (* indicates no sampling done due to low water level).

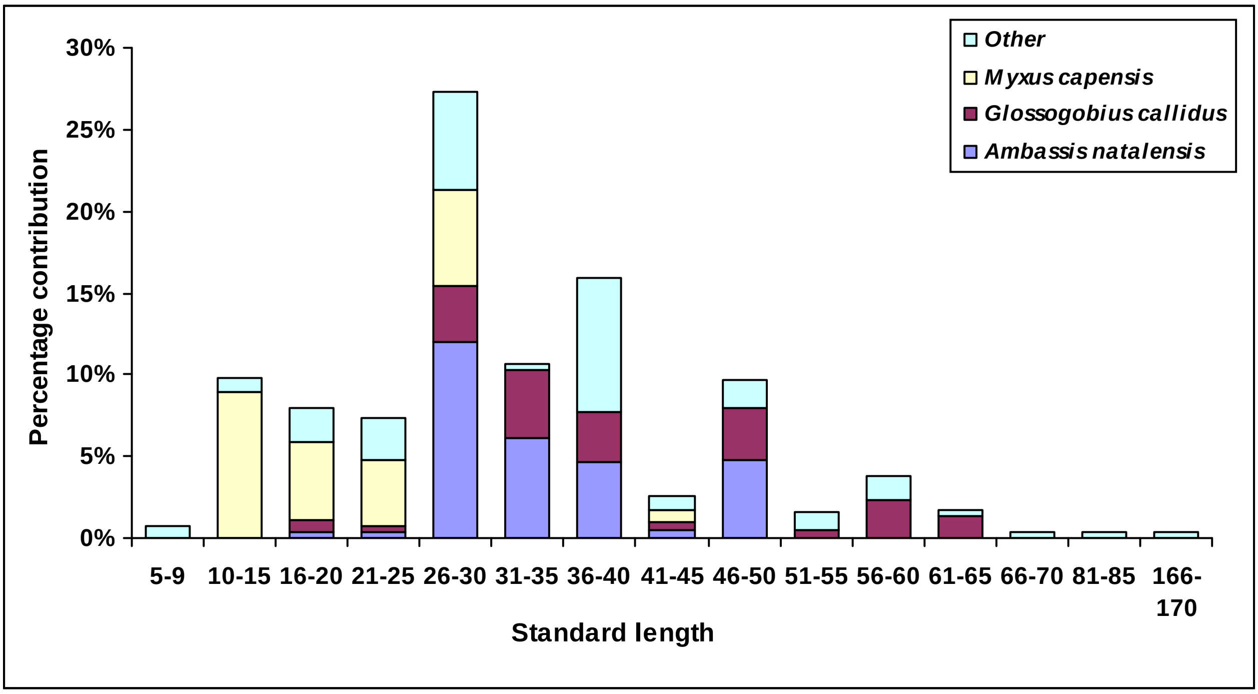

Figure 3.7: Size frequency distribution of fish recorded at the fishway entrance between August 2007 and July 2008.

Table 3.6: The number and the size range of fish recorded in abundances of less than 20 at the fishway entrance.

Species	Number	Size (SL)
Valamugil cunnesius	11	22 -37
Glossogobius giuris	7	30-170
Oreochromis mossambicus	6	Jul-80
Eleotris fusca	6	20-50
Gilchristella aestuaria	5	30
Terapon jarbua	4	35-56
Barbus viviparus	3	30-40
Ambassis gymnocephalus	3	44-50
Ambassis productus	3	45-70
Mugil cephalus	2	25-30
Aplocheilichthys myaposae	2	20-29
Monodactylus falciformis	1	60
Gobiid larvae sp. 2	1	10
Acanthopagrus berda	1	40
Oligolepis acutipennis	1	40
Silhouettea sibayi	1	20
Croilia mossambica	1	40

3.1.3.4. Fish composition in the fishway pools

The fish recorded within the 25 pools of the fishway during the study period are presented in Table 3.7. For ease analysis, the pools were paired, although 1-4 were grouped together in the analysis as these four pools were always under water and fish could move freely between them. Pool 25 was also analysed separately, as this was the highest pool in the fishway and fish often congregated there. The number of fish recorded in the fishway pools contributed 33.5% of the total catch recorded during the monitoring period, with 1 095 fish representing 15 species being recorded (Table 3.7). The dominant species made up 85% of the total catch; they were *Myxus capensis, Glossogobius callidu*s and *Mugil cephalus,* contributing 59%, 19% and 7% of the total catch in the fishway pools, respectively.

The majority of fish were found in the lower 25% of the fishway pools (Pool 1-8), with 71% of the fish recorded in this bottom section of the fishway. There was a gradual but significant decrease in mean fish abundance from the bottom to the top of the fishway ($F = 2.3$, $p = 0.018$), although the mean abundance remained relatively uniform in the upper half of the fishway (Figure 3.8). The highest mean number of species was recorded in the lower quarter of the fishway, while the lowest number of species was found at Pools 11-12 and Pool 25. There was a significant decrease in the number of species from the bottom to the top of the fishway ($F = 2.8$ $p = 0.004$). Pools 5-6 was significantly different from Pools 11-12 ($p = 0.03$) and Pool 25 ($p = 0.03$) (Figure 3.9).

In terms of Estuarine Dependency Category, Category I (Category Ia and Ib) species were the most dominant in the fishway pools, contributing 34% of the total catch, followed by Category II species contributing 2% of the total number of species caught (Figure 3.3d).
A number of species such as *A. natalensis, C. mossambica, R. sarba and V. cunnesius* were only recorded in the lowest quarter of the fishway, while all four species recorded in the upper quarter were also relatively common throughout the fishway. *Myxus capensis* and *G. callidus* were consistently recorded in the fishway pools, but declined in numbers from the first to the last pool (Table 3.7).

The fish recorded in the fish pools during each of the eight sampling months are presented in Table 3.8. *Myxus capensis* exhibited a marked peak from August to October, declined in November but was again abundant in December. The highest abundance of *G. callidus* was recorded from June to September (Table 3.8). *Myxus capensis* was recorded from May to October with the highest abundance being recorded in June. The highest number of species (nine) was recorded in May, while in September only *A. natalensis*, *M. capensis and G. callidus* were recorded (Table 3.8).

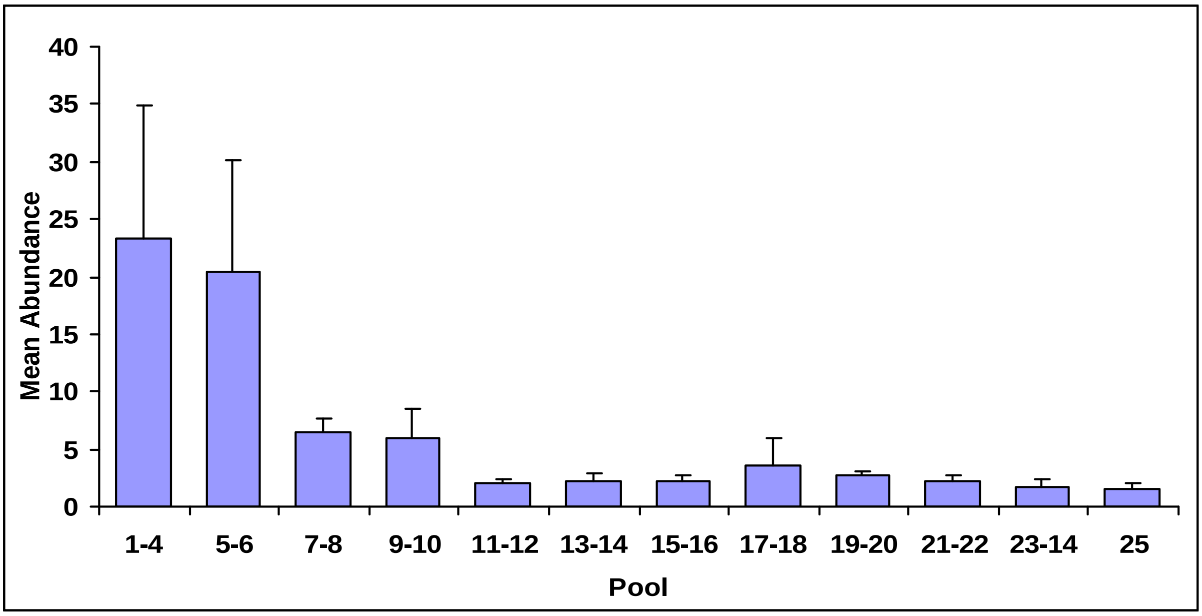

Figure 3.8: The mean abundance (CPUE) of fish recorded at each set of fishway pools between August 2007 and July 2008, $F = 2.28$, $p = 0.018$.

Table 3.7: Species and the mean CPUE (Total number/month/sampling days) of fish in decreasing order of abundance sampled within the fishway pools during the eight sampling months between August 2007 and July 2008.

		Pools Catch per unit effort													
		Lower Quarter			**2nd Quarter**			**3rd Quarter**			**Upper Quarter**				**Total**
Species	EDC	1-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21-22	23-24	25	%	**CPUE**
Myxus capensis	Vb	12.5	17.5	1.8	2.1	0.1	0.6	0.6	2.3	0.4	1.0	0.6	0.8	58.9	40.4
Glossogobius callidus	Ib	1.3	1.8	3.2	1.3	0.8	1.0	0.5	0.8	0.5	0.4	0.6	0.4	18.4	12.6
Mugil cephalus	IIa	3.9	0.5	0.2				0.1						6.9	4.7
Ambassis natalensis	Ib	3.0	0.1											4.5	3.1
Oreochromis mossambicus	IV		0.1	0.1	1.5			0.3	0.1	0.4	0.1			3.8	2.6
Valamugil cunnesius	IIa	1.8												2.6	1.8
Monodactylus falciformis	IIb	0.4			0.3	0.2	0.2			0.1				1.7	1.2
Tilapia rendalli	IV			0.3	0.1	0.2	0.4			0.1				1.6	1.1
Eleotris fusca	Ia		0.1	0.1				0.1			0.1	0.1		0.7	0.5
Glossogobius giuris	IV		0.1							0.1				0.3	0.2
Croilia mossambica	Ib		0.1											0.1	0.1
Gilchristella aestuaria	Ia		0.1											0.1	0.1
Silhouettea sibayi	Ib		0.1											0.1	0.1
Psammogobius knysnaensis	Ib			0.1										0.1	0.1
Rhabdosargus sarba	IIb	0.1												0.1	0.1
Total CPUE		23.0	20.6	5.6	5.3	1.3	2.2	1.6	3.2	1.6	1.7	1.3	1.2		68.6
Number species	15	7	10	7	5	4	4	5	3	6	4	3	2		

Table 3.8: Species list, Estuarine Dependency Categories and monthly CPUE (Total number/sampling days) of fish sampled migrating though the pools between August 2007 and July 2008, (* indicates no sampling done due to low water level).

		Months										
		Catch per unit effort										Mean
Species	**EDC**	**Apr**	**May**	**Jun**	**Jul***	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**%**	**CPUE**
Myxus capensis	Vb	5.5	0.5			106	44	65.5	16	91.5	57	41.1
Glossogobius callidus	Ib	0.5	13.0	25.0		23.5	20.0	10.0	7.0	9.0	18.8	13.5
Mugil cephalus	IIa		2.0	28.0		7.0	0.5	0.5			6.0	4.8
Eleotris fusca	Ia							0.5	2.0	23.0	4.4	3.2
Oreochromis mossambicus	IV		1.0	4.5		0.5		0.5		24.0	5.2	3.8
Gilchristella aestuaria	Ia		24.0	0.5							4.1	3.0
Ambassis natalensis	Ib	2.0						0.5		5.5	1.3	1.0
Croilia mossambica	Ib		0.5	1.0						6.5	1.3	1.0
Glossogobius giuris	IV		0.5	0.5		0.5		1.5	1.0	0.5	0.2	0.2
Silhouettea sibayi	Ib					1.0					0.2	0.2
Monodactylus falciformis	IIb		0.5	0.5							0.1	0.1
Psammogobius knysnaensis	Ib		0.5								0.1	0.1
Tilapia rendalli	IV									0.5	0.1	0.1
Valamugil cunnesius	IIa							0.5			0.1	0.1
Rhabdosargus sarba	IIb	0.5									0.1	0.1
Total CPUE		8.5	42.5	60.0		138.5	64.5	79.5	26.0	160.5		72.0
Number of species	15	4	9	7		6	3	8	4	8		

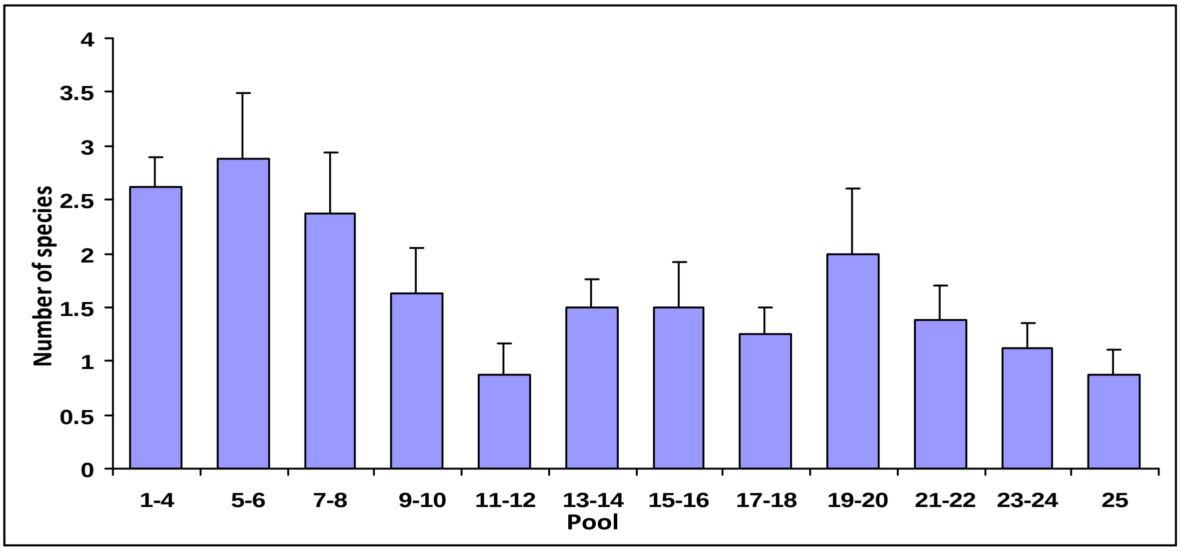

Figure 3.9: Mean number of species recorded at the fishway pools between August 2007 and July 2008 (F = 2.78, p = 0.0039).

3.1.3.5. Composition of fish migrating over the crest of fishway

The efficiency of the Mzingazi fishway is determined by the ability of the fish to migrate over the crest of the fishway and into the freshwater environment of Lake Mzingazi. The 173 fish from 17 species caught at the fishway exit which had successfully migrated over the top of the fishway were dominated by *Myxus capensis, Glossogobius callidus* and *Eleotris fusca*. The percentage contribution of these three dominant species was 43%, 22% and 12%, respectively, making up 77% of the total catch (Table 3.9). Species recorded in small numbers (less than 10) (Table 3.10) contributed only 23% of the total number of fish recorded at the fishway exit (Table 3.9). During the study period, the highest number of fish migrating over the fishway crest was recorded in October (Figure 3.10). *Myxus capensis* were consistently recorded, but peak migration for *M. capensis* occurred in October. Migration of *G. callidus* over the crest of the fishway peaked in September and October. *Eleotris fusca* migration peaked in May and June, whereas this species was not caught in September and October. *Oreochromis mossambicus* was recorded from October to December, with highest abundance in October (Table 3.9, Figure 3.10). The highest number of species migrating over the top of the fishway was recorded in November and April, while the lowest was recorded in September. There was a gradual decline in the number of species from April to September, followed by a sharp increase in October (Figure 3.11).

Five marine spawning species (Categories II and V) were recorded migrating into the lake (Table 3.9). Freshwater species (Category IV) was found to be the most dominant category migrating over the top of the fishway, contributing 38% of the total number of species migrating over the crest of the fishway. Category Ia and Ib contributed 13% and 19%, respectively, while Category IIa and IIb contributed 19% and 6% of the total number of species migrating over the crest of the fishway, respectively. Category Vb contributed 6% of the total species caught migrating over the crest of the fishway (Figure 3.3e). *Myxus capensis* and *Gerres methueni* were the only species representing Category Vb and IIb, respectively. No marine species (Category III) were recorded at the fishway exit (Table 3.9).

Table 3.9: Species list, estuarine dependency categories and CPUE (Total number/sampling days) of fish migrating though the fishway between August 2007 and July 2008 (* indicates no sampling done due to low water level).

		Months Catch per unit effort										Total
Species	**EDC**	**Apr**	**May**	**Jun**	**Jul***	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**%**	**CPUE**
Myxus capensis	Vb	8.5	2.0			0.7		21.0	5.0	2.0	43.0	4.9
Glossogobius callidus	Ib	1.0		3.3			7.0	6.5	2.0		22.0	2.5
Eleotris fusca	Ia	0.5	4.5	4.7		0.7			0.5	0.5	12.0	1.4
Oreochromis mossambicus	IV							6.5	0.5	0.5	7.8	0.9
Glossogobius giuris	IV	1.0		0.7				0.5	1.0		3.4	0.4
Croilia mossambica	Ib		0.5	1.3							1.7	0.2
Aplocheilichthys myaposae	IV							1.5			1.7	0.2
Gilchristella aestuaria	Ia								1.5		1.7	0.2
Monodactylus falciformis	IIa		0.5							1.0	1.7	0.2
Mugil cephalus	IIa			0.7							0.9	0.1
Gobiid larvae sp. 2	-					0.7					0.9	0.1
Awaous aeneofusca	IV							0.5			0.9	0.1
Ambassis natalensis	Ib	0.5									0.9	0.1
Barbus viviparus	IV	0.5									0.9	0.1
Gerres methueni	IIb	0.5									0.9	0.1
Tilapia rendalli	IV								0.5		0.9	0.1
Valamugil cunnesius	IIa								0.5		0.9	0.1
TOTAL CPUE		12.5	7.5	10.7		2.1	7.0	36.5	11.5	4.0		11.5
Number of species	17	7	4	5		3	1	6	8	4		

The size of fish recorded at the fishway exit varied from 10 to 110 mm SL, with the majority fish in the sizes of the 20-50 mm category (Figure 3.12). The smallest specimen recorded was *M. capensis* and the largest *G. giuris* (Table 3.10, Figure 3.12). The size of *Myxus capensis* ranged from 10-70 mm*,* *G. callidus* from 25-68 mm and *E. fusca* from 30-80 mm SL. The fact that the majority of *M. capensis* and *G. callidus* that successfully migrated through the fishway fell within the 20-50 mm size range clearly indicates that the hydraulic conditions in the fishway were suitable for migration of post-larvae and juvenile fish.

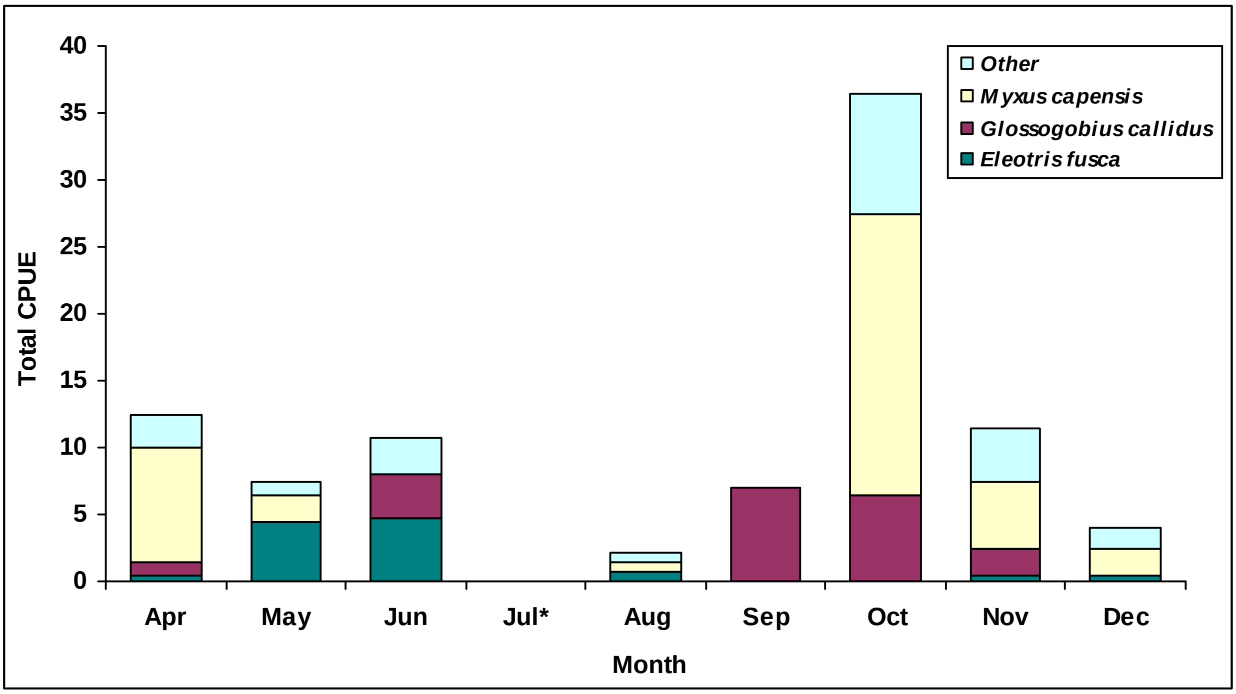

Figure 3.10: Monthly mean abundance of fish recorded at the fishway exit between August 2007 and July 2008 (* indicates no sampling done due to low water level).

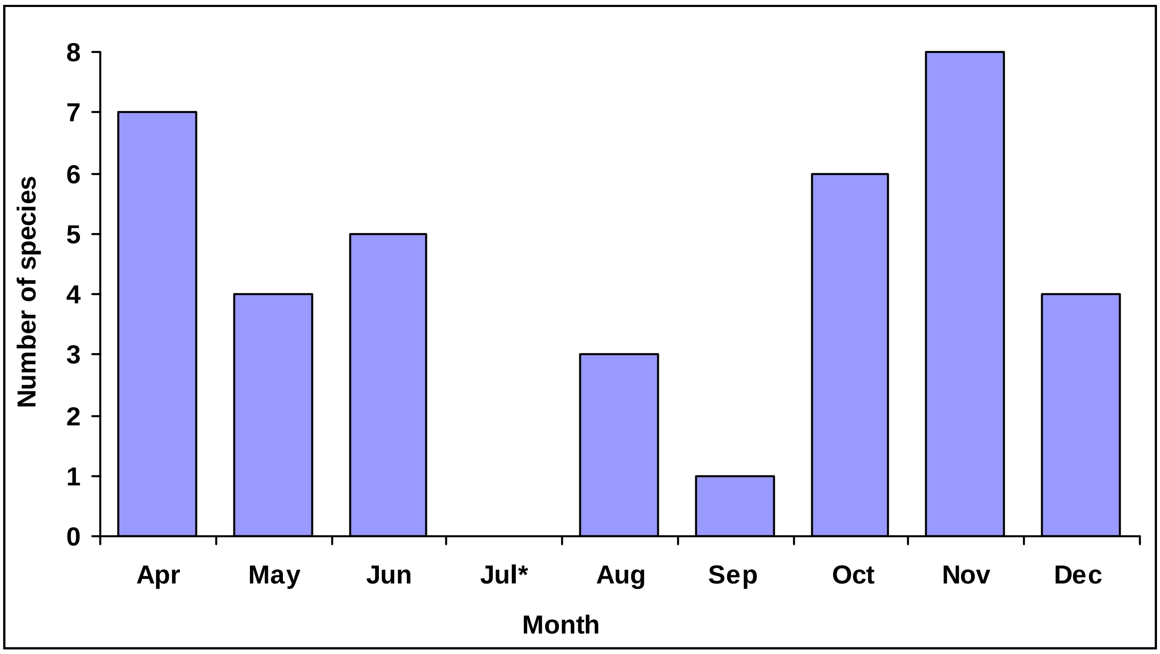

Figure 3.11: Number of species recorded at the fishway exit between August 2007 and July 2008 (* indicates that no sampling was done due to low water level).

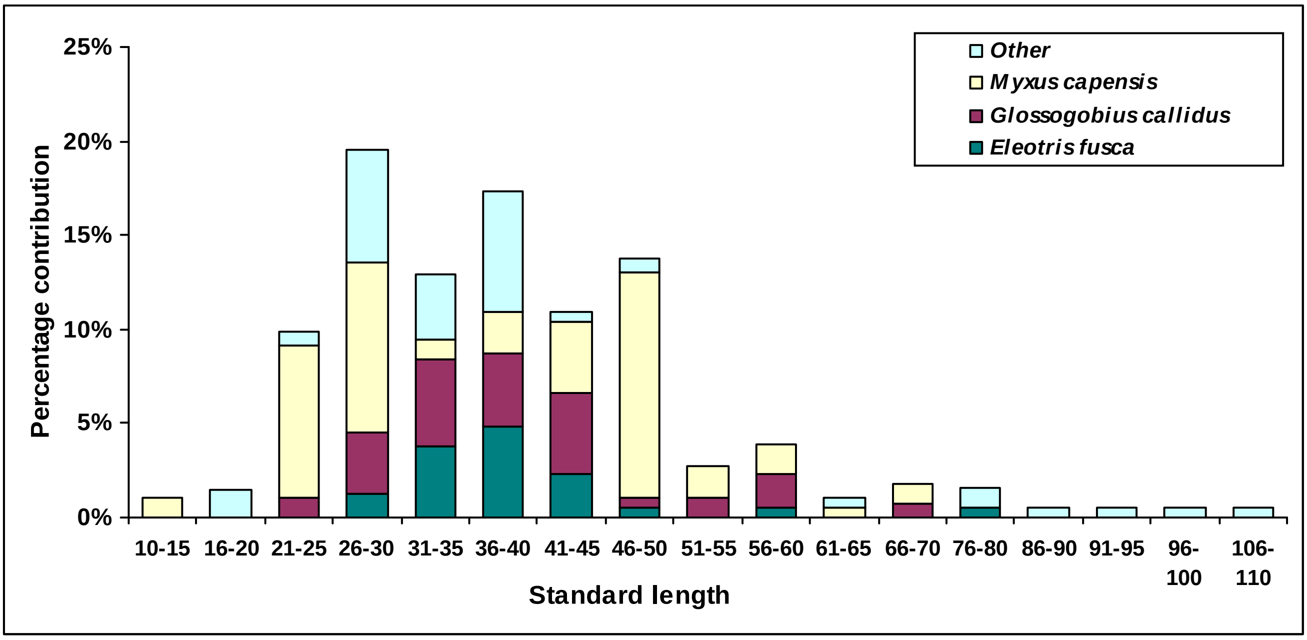

Figure 3.12: Size frequency distribution of fish recorded at the fishway exit between August 2007 and July 2008.

Table 3.10: Fish recorded at the fishway exit in small numbers (less than ten).

Species	Number	Standard length
Glossogobius giuris	6	30-110
Aplocheilichthys myaposae	3	30-35
Gilchristella aestuaria	3	28-30
Monodactylus falciformis	3	30-40
Croilia Mossambica	3	25-35
Tilapia rendalli	1	95
Gobiid larvae sp. 2	1	20
Awaous aeneofuscus	1	100
Valamugil cannesius	1	35
Mugil cephalus	1	20
Gerres methueni	1	40
Ambassis natalensis	1	33
Barbus viviparus	1	33

3.1.3.6. Fish composition in the Lake just upstream of the fishway

A total of 279 fish representing seven species were netted in the lake just upstream of the fishway (Table 3.11). This included four freshwater species and two estuarine species, while only one marine breeding species (*M. capensis)* was recorded. The dominant species made up 83% of total catch. *Oreochromis mossambicus* was the most abundant species, representing 30.4% of the total fish caught in the lake just upstream of the fishway, followed by *G. callidus* (29.3%) and *Tilapia rendalli* (23.8%). The remaining four species comprised only 16.5% of the fish caught. The highest CPUE was recorded in May-June and also in October-November. The highest number of five species was caught in May, while only one species was recorded in September and October.

In terms of estuarine dependence categories, both the abundance and species composition were dominated by freshwater species (Category IV) (Figure 3.3f). *Myxus capensis* was the only marine breeding species recorded in May with only eleven individuals. *Glossogobius callidus, M. capensis* and *Tilapia rendalli* were the only three species that were frequently recorded migrating through the fishway that were again recorded in the lake. *Glossogobius callidus* was consistently recorded in the lake just upstream of the fishway, while *T. rendalli* was recorded in May and October. The size of fish recorded upstream of the fishway varied from 10-80 mm SL with the most dominating size class being 30-50 mm SL (Figure 3.13). The smallest and the largest specimen recorded were *O. mossambicus* (Figure 3.13). The size of *Glossogobius callidus* ranged from 30-70mm and *T. rendalli* from 18-70 mm SL. *Myxus capensis* size ranged from 40-60 mm SL this being indicative of the importance of the fishway for juveniles of marine species migrating into the freshwater environment of Lake Mzingazi.

Table 3.11: Species list, estuarine dependency categories and the CPUE (Total number/sampling days) of fish caught in the lake just upstream of the fishway between August 2007 and July 2008 (* indicates no sampling done due to low water level)

		Months										
		Catch per unit effort										
Species	**EDC**	**Apr**	**May**	**Jun**	**Jul***	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**%**	**Total**
Oreochromis mossambicus	IV		37.0	36.0		5.0			5.0		30.0	10.4
Glossogobius callidus	Ib		3.0	17.0		5.0	18.0		32.0	5.0	29.0	10.0
Tilapia rendalli	IV			25.0				40.0			24.0	8.1
Gilchristella aestuaria	Ia		23.0	3.0					5.0		11.0	3.9
Myxus capensis	Va		11.0								4.1	1.4
Pseudocrenilabrus philander	IV								2.0		0.9	0.3
Aplocheilichthys myaposae	IV		6.0							1.0	0.3	0.1
Total CPUE			80.0	81.0		10.0	18.0	40.0	44.0	6.0		34.8
Number of species	7		5	4		2	1	1	4	2		

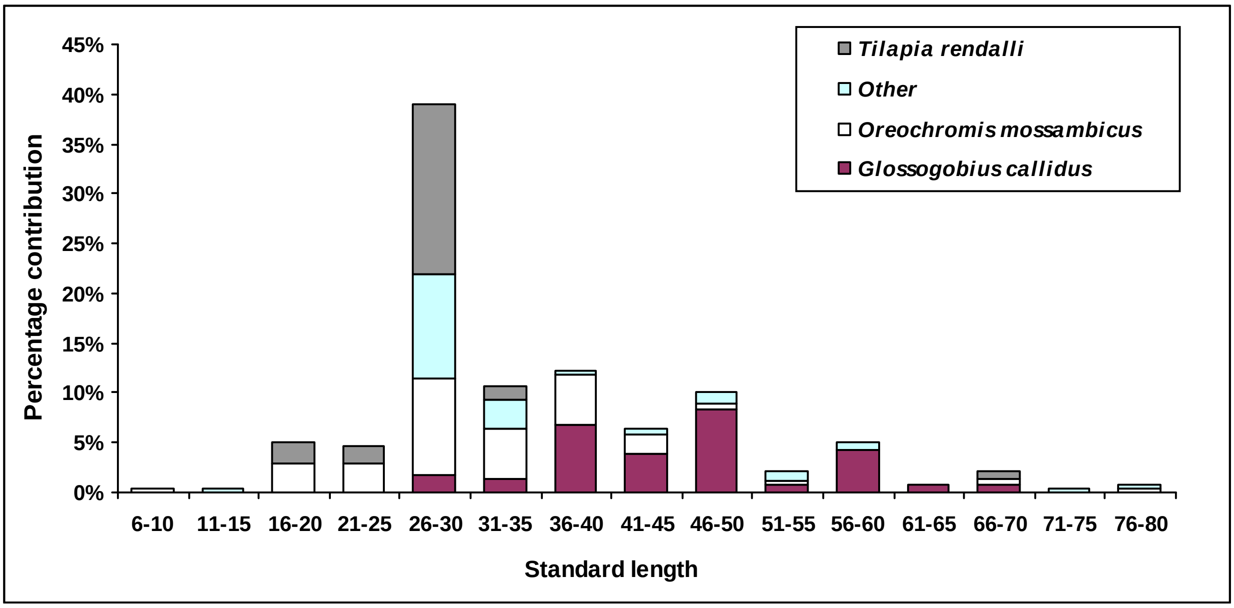

Figure 3.13: Size frequency distribution of fish recorded in Lake Mzingazi upstream of the fishway between August 2007 and July 2008

3.1.4. The correlation between the flow velocity, fish numbers and species

The discharge (Volume of flow) over the crest of the fishway and throughout the fishway was not measured during this study and the effectiveness of the fishway during various discharges was partially observed but this observation cannot be discussed because of the lack of data.

The mean number of fish (CPUE) recorded migrating through the fishway exit showed a weak negative correlation with the flow rate across the crest of the weir (Figure 3.14). The number of species also showed a weak negative correlation with the flow rate across the crest of the weir (Figure 3.15). As a result these correlations were not used to interpret data and discussion. Generally, peak abundance occurred in October at a flow rate of 0.84 $m.s^{-1}$, while the highest number of species was recorded in November at a flow rate of 1.01 $m.s^{-1}$.

The mean monthly CPUE of the three dominant species migrating over the top of the fishway and the water flow in the fishway are illustrated in Figure 3.16. The catch per unit effort of *Myxus capensis* and *Glossogobius callidus* peaked in October, while *Eleotris fusca* was more abundant in June. *Myxus capensis* and *Glossogobius callidus* were more abundant at low flow velocities (0.84 $m.s^{-1}$), while *Eleotris fusca* was more abundant in June at high flow velocities (1.54 $m.s^{-1}$) and decreased in abundance at low flow velocities (0.84 $m.s^{-1}$) in October (Figure 3.16). As shown in Figure 3.17, the number of *M. capensis* migrating over the fishway was negatively correlated with the flow over the crest of the fishway, while that of *E. fusca* was positively correlated with the flow. There was no correlation between *G. callidus* and flow rate, since *G. callidus* migration remained constant at different flow velocities.

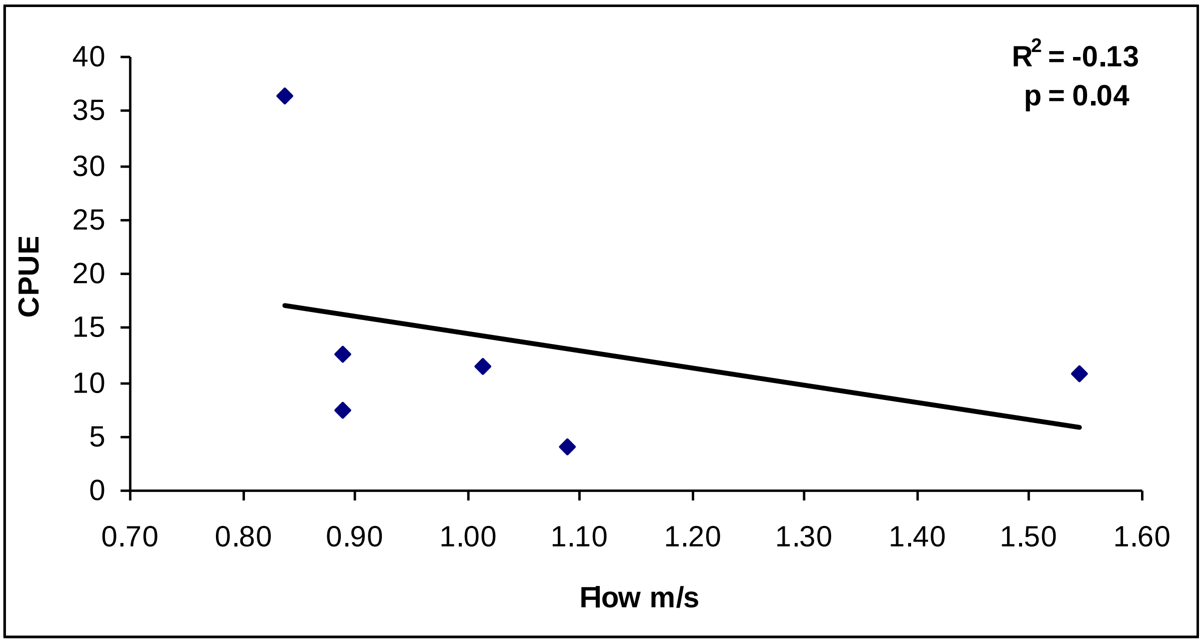

Figure 3.14: Correlation between fish abundance recorded migrating through the Mzingazi fishway exit and water flow velocities

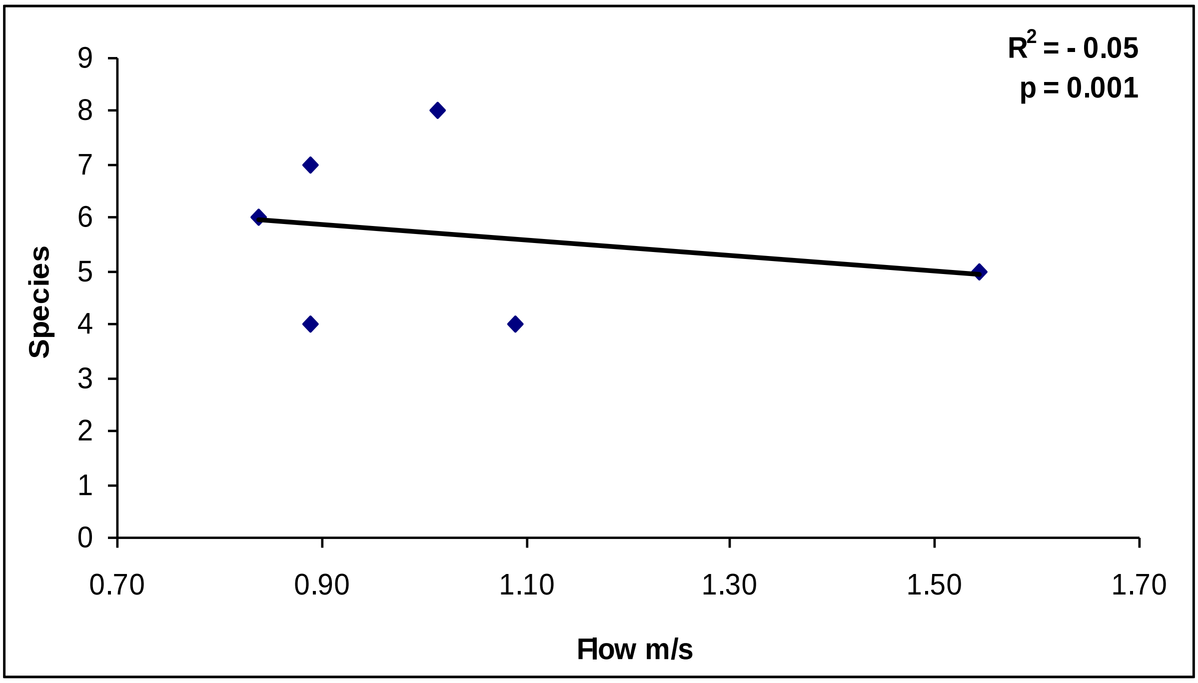

Figure 3.15: Correlation between numbers of species recorded migrating through the Mzingazi fishway exit at different water flow velocities

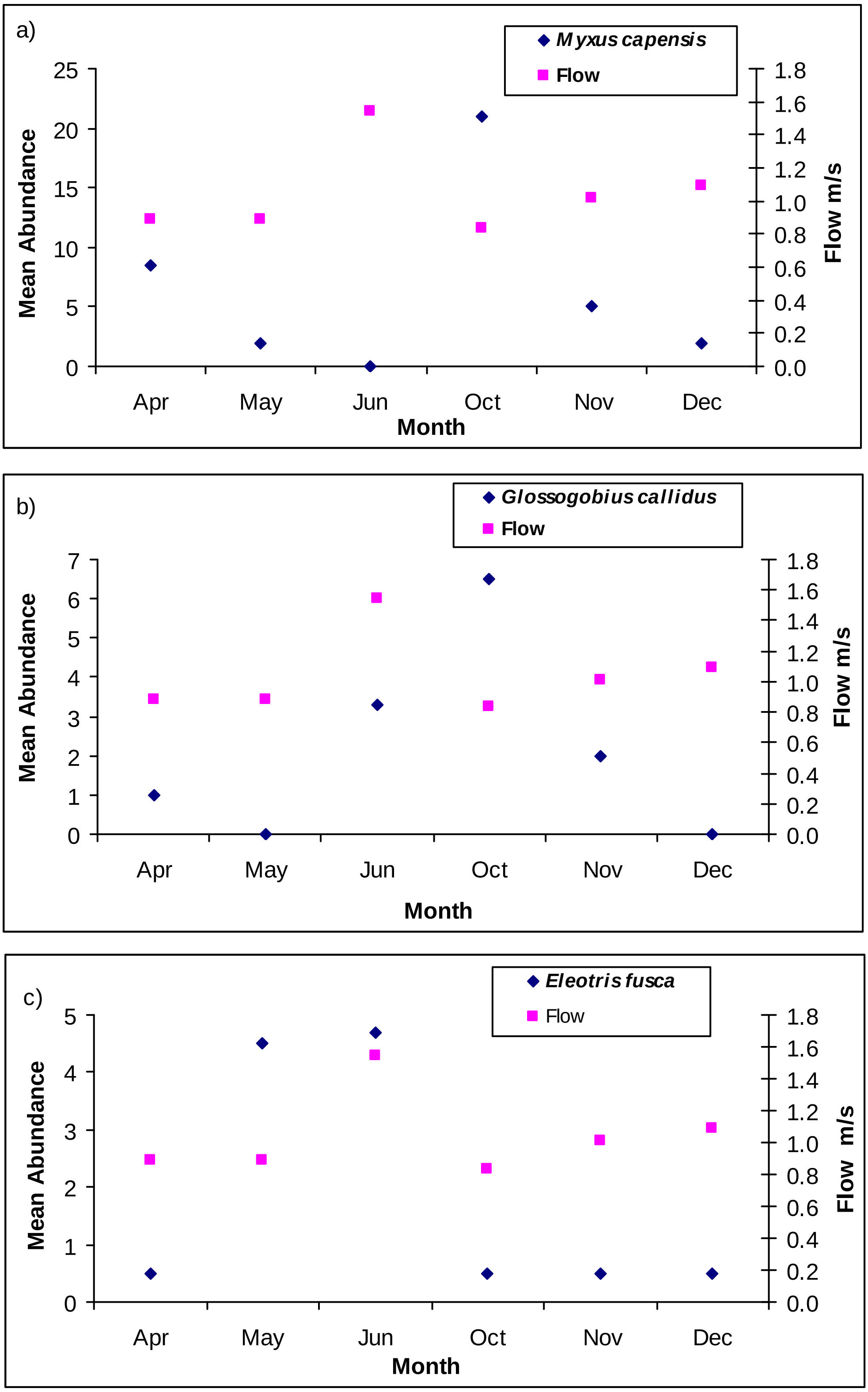

Figure 3.16: Mean abundance of dominant species recorded migrating through the Mzingazi fishway exit and flow velocity down the fishway.

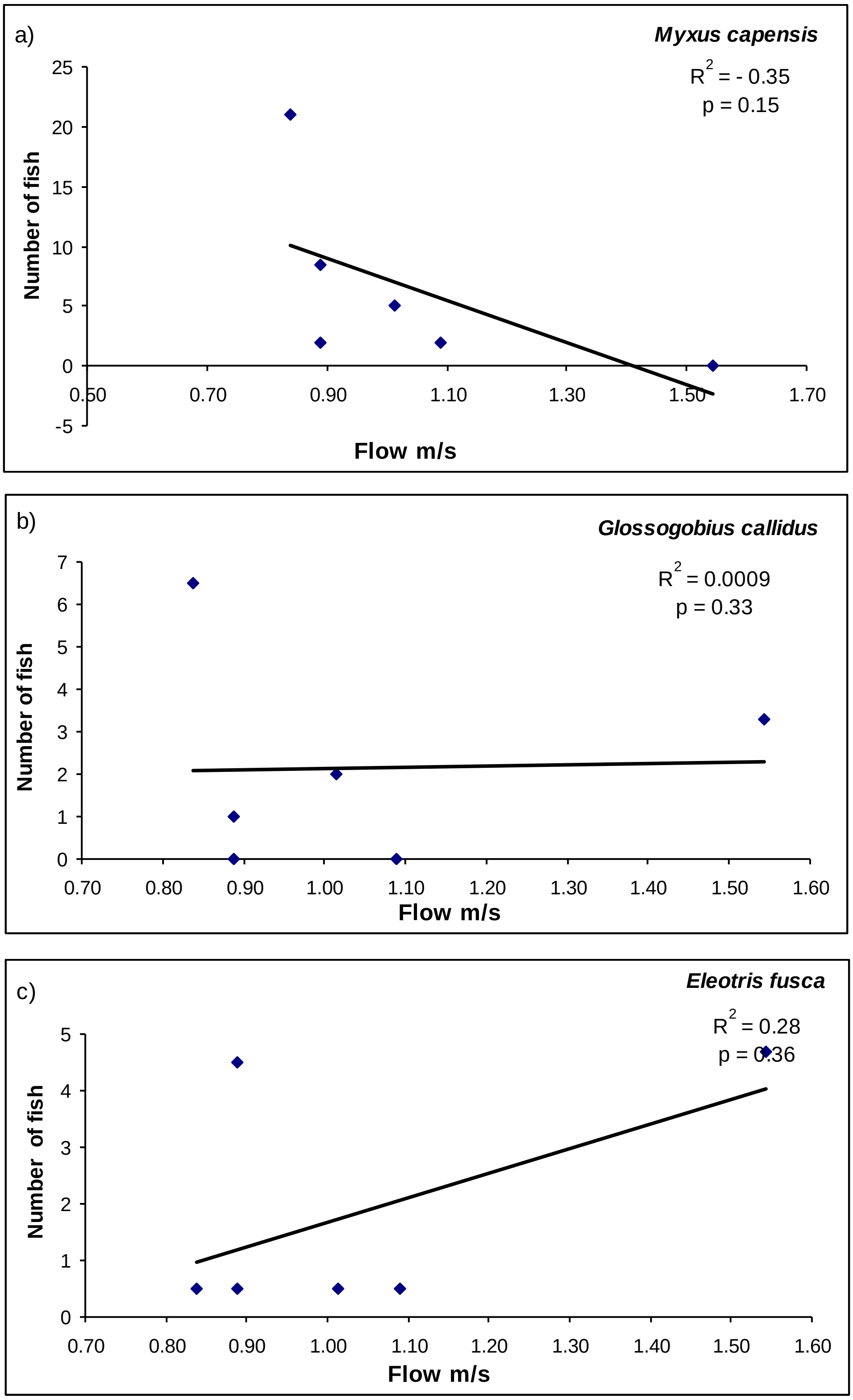

Figure 3.17: Dominant species recorded migrating through the Mzingazi fishway exit at different water flow velocities.

3.2. DISCUSSION

There is limited information available on the composition of fish species in the Mzingazi system with which to compare the current results. The only available information is a list of fishes which have been caught by anglers in Lake Mzingazi (Coke, 1986) and a once-off survey by Cyrus (1993) (Table 3.12). Coke (1986) reported a total of 508 fish, representing 16 species including 131 specimens of seven species large enough to be of value to anglers in the Mzingazi Lake. *Oreochromis mossambicus* was found to be the most abundant species in 1985 (Coke, 1986). Species such as *M. capensi*s and *A. natalensis* were also recorded in Lake Mzingazi (Coke, 1986). Cyrus (1993) recorded a total of 2 401 fish representing 10 species in Lake Mzingazi, with *O. mossambicus* again being the most abundant species, followed by *Pseudocrenilabrus philander* and *Gilchristella aestuaria. Myxus capensis* was the only euryhaline marine species recorded in 1993 (Cyrus, 1993). Weerts *et al.* (2002) recorded a total of 11 species representing five euryhaline and six freshwater species.

There is limited information available in the literature on the fish species composition of the Mzingazi River. Weerts *et al.* (2002) compiled a list of fish species that were recorded in the Mzingazi River in 2002 (Table 3.12), while Vivier and Cyrus (1996) compiled a list of estuarine and marine fish that were expected to migrate up the Mzingazi River, since they were previously recorded in the freshwater environment of Lake Mzingazi. A total of 18 species, representing 15 euryhaline and three freshwater species, were previously recorded in the Mzingazi River (Weerts *et al*., 2002). According to Vivier and Cyrus (1996), the estuarine and marine species expected to migrate up the Mzingazi River include: *Ambassis* species, *Elops machnata, Megalops cyprinoids*, *Myxus capensis*, *Mugil cephalus*, *Liza alata*, *Acanthopagrus berda*, *Rhabdosargus* species*, Monodactylus* species, *Caranx sexfaciatus*, *Croilia mossambica*, *Gilchristella aestuaria*, *Hyporhamphus capensis* and *Glossogobius callidus.*

3.2.1. Species Composition

A total of 3 288 fish, representing 29 species, was recorded in the Mzingazi River, in the Mzingazi fishway and just upstream of the fishway during the monitoring period. This included 15 (45%) marine species (category II, III and V), of which one was the catadromous species *Myxus capensis* (Harrison and Whitfield, 1995; Whitfield, 1998). Estuarine resident species (category Ia and Ib) and freshwater species contributed 34% and 24% of the total number of species caught, respectively. In a study on the efficiency of the Nhlabane fishway, Mastenbroek (2002) recorded a total of 22 species in the Nhlabane fishway, while a further seven species were recorded in the estuary, but not in the fishway. Fourteen species (64%) of euryhaline marine fish and facultative catadromous fish were recorded migrating through the Nhlabane fishway, including one obligate catadromous species (*Anguilla marmorata*). Eight freshwater species were also recorded (Mastenbroek, 2002). The Nhlabane system was dominated by 12 euryhaline marine species in 1992, of which *M. capensis, M. cephalus* and *T. jarbua* were the most dominant species in the fishway (Vivier and Cyrus, 2001). In comparison, a total of 34 species were recorded in Burnett River fishway in South-eastern Queensland Australia; these species included 18 euryhaline species and 16 freshwater species (Stuart and Berghuis, 2002).

Historically, a total number of 17 species (Table 3.12) was recorded in Lake Mzingazi (Coke, 1986; Cyrus, 1993). Vivier and Cyrus (1996) reported that fourteen euryhaline species were expected to migrate up the Mzingazi River since they were previously recorded in Lake Mzingazi. During this study, nine of these species were recorded in the fishway and one in the Mzingazi River, but only three of these migrated through the fishway. The presence of the number of euryhaline species within the fishway would suggest that more species are able to migrate up into the lake (Table 3.12). *Megalops cyrinoides* and *Caranx sexfaciatus* were not recorded but they were expected to migrate through the Mzingazi fishway (Cyrus, 1993). Further sampling would be necessary to validate the absence of these species. However, three estuarine species that were not on the list of expected migratory species were also found in the fishway (Table 3.12), namely *Silhouettea sibayi, Oligolepis acutipennis and Psammogobius knysnaensis. Mugil cephalus* (Table 3.12) was also not recorded previously in Lake Mzingazi (Coke, 1986; Cyrus, 1993; Wepener *et al.,* 1995) but it was among fourteen species that were expected to migrate up the Mzingazi River (Vivier and Cyrus, 1996).

Myxus capensis, Ambassis natalensis and *M. cephalus* were the dominant species in the Mzingazi system during the monitoring period. *Myxus capensis* is a species endemic to southern Africa (Whitfield, 1998), which often spends part of its life in freshwater, with juveniles ascending rivers and returning to the sea to spawn (Smith and Heemstra, 1986; Harrison and Whitfield, 1995). This species tolerates salinities ranging from 0-49 (Whitfield, 1998). *Ambassis natalensis* occurs from KwaZulu-Natal to Algoa Bay (Skelton, 1993). According to Whitfield (1998), *A. natalensis* is an estuarine resident species which is incapable of tolerating salinities above 52 and below 7, but juveniles and adults of this species were present in the Lake Nhlange at salinities below 1 (Blaber and Cyrus, 1981). *Mugil cephalus* occurs in all warm and temperate seas, estuaries and rivers (Smith and Heemstra, 1986), with a wide range of salinities from 0-84 (Whitfield, 1998).

A total of 10 euryhaline species was previously recorded in Lake Mzingazi compared to 12 species in Lake Chubu. Only one euryhaline species was recorded in Lake Nsezi, while three species were recorded in Lake Mangeza. A total of 19 euryhaline species was previously recorded in Lake Nhlabane (Table 3.13) (Vivier, 1998; Weerts and Cyrus, 2001). The difference in species diversity at these coastal lakes might have been influenced by the type of estuary associated with each lake and the conditions at their mouths. Nhlabane estuary is a temporarily closed estuary, while Richards Bay Harbour is an estuarine bay opening directly to the sea (Begg, 1978; Whitfield, 1992). According to Whitfield (1998), estuaries that are closed on a temporary basis are dominated at different periods by different assemblages, while estuarine bays are dominated by euryhaline species. The fish fauna of the temporarily closed estuary is less diverse than that of a permanently open estuary. As a result, marine larvae are well represented in estuarine bays than in temporarily closed estuaries because of sheltered marine conditions in estuarine bays (Whitfield, 1998).

Richards Bay Harbour (Harris and Cyrus 1997) and Mhlathuze estuary (Vivier *et al.,* 2009) in the Richards Bay area are the most important nurseries and feeding grounds for many euryhaline species. Lakes Mzingazi, Chubu and Nsezi were expected to have diverse species compared to Lake Nhlabane, but the historical data (Table 3.13) contrast with the available information on estuarine bays and temporary closed estuaries. This is as a result of human intervention that isolated Lakes Mzingazi, Chubu and Nsezi from the sea years ago, as several weirs had previously been constructed on these coastal lakes and these prevented the recruitment and utilisation of coastal lakes by euryhaline fish. According to Weerts and Cyrus (2001), fishways need to be installed in the existing weirs of Lakes Chubu and Nsezi to enhance the migratory routes of euryhaline species. A total of 12 euryhaline species was recorded migrating through the Mzingazi fishway exit in this study, although only three euryhaline species were recorded upstream of the fishway (Table 3.12). This result clearly indicates the importance of the Mzingazi fishway and possible recovery of euryhaline species within a few years.

3.2.2. Longitudinal distribution

The composition of species in the different reaches of the Mzingazi system indicates a decrease in the number of species from the Saltwater Barrier towards the lake just upstream of the fishway exit, with different species dominating each section. This trend of decreasing species richness and diversity in an upstream direction is similar to that found in Kariega estuary (Whitfield and Paterson, 2003). The species composition in the Mzingazi system was influenced by the presence of the Saltwater Barrier, which allows recruitment of juvenile marine fish to occur, but only during high spring tides. As a result, this must be having some impact on the migration of fish into the Mzingazi River and into to the lake.

Lake Mzingazi is one of four coastal lakes found along the Zululand coast (Cyrus and Wepener, 1993). Historically, this lake had a continuous connection to the sea but became isolated from it due to human intervention 68 year ago. This coastal lake used to have important estuarine fish fauna (Vivier and Cyrus, 1999) and also played a major role in the life cycle of some euryhaline marine fish, such as *M. capensis*. In 1985, Coke (1986) recorded seven euryhaline species, while Cyrus (1993) recorded only five euryhaline species in 1993 – which indicates the importance (but also decreasing role) of Lake Mzingazi as a nursery area for these species since the construction of the first weir across the outlet. The fact that four of the seven euryhaline species recorded in 1985 were not present in 1993 clearly shows a decline in euryhaline species in Lake Mzingazi. The main cause of the decline in migratory species in estuaries is the construction of obstructions that prevent the free movement of fish (Porcher and Travate, 2002). The first weir across the Lake Mzingazi outlet was built in 1943 and its height was raised in 1955 by means of concrete construction and earthworks (Cyrus, 2000). This was done to enlarge the storage capacity of the lake (Reavell and Cyrus, 1989) for domestic and industrial use because of sustained development in the Richards Bay area. This concrete weir on the Lake Mzingazi outlet was raised again in 1984 (Botha *et al.,* 2006). In 1992, a temporary Saltwater Barrier was constructed (Kelbe *et al.,* 2001) and it was upgraded to a more permanent structure in 1996 on the Mzingazi Canal to prevent saltwater intrusion into the lake (Cyrus, 2000). The construction of the Mzingazi weir and Saltwater Barrier negatively impacted on the migration of fauna between marine and freshwater environments. The estuarine fish fauna in Nhlabane changed after the construction of a barrage (Wepener *et al.,* 1995). The construction of the Saltwater Barrier at the Mzingazi River affected the movement of fish, caused a decrease in abundance, and affected the upstream species distribution, especially of the euryhaline and marine species.

Table 3.12: Fish species recorded in the Mzingazi Lake from 1985-2002 (Coke *et al.,* 1986; Cyrus, 1993; Weerts *et al.,* 2002) and in the Mzingazi system (six sites in the study area Figure 2.1) during the present study (SWB: Saltwater Barrier, E: Euryhaline species and F: Freshwater species).

		Historical Data									
		Lake			Mzingazi River	Present study					
Species	Category	1985	1993	2002	2002	SWB	Mzingazi River	Entrance	Pools	Exit	Upstream lake
Acanthopagrus berda	E					*	*	*			
Ambassids larvae	E					*					
Ambassis ambassis	E					*	*	*			
Ambassis gymnocephalus	E				*	*	*	*			
Ambassis natalensis	E	*			*	*	*	*	*	*	
Ambassis productus	E				*						
Anguilla sp.1	E						*				
Aplocheilichthys johnstonii	F		*								
Aplocheilichthys katangae	F	*									
Aplocheilichthys myaposae	F							*		*	*
Athron immaculatus	E					*					
Awaous aeneofuscus	E									*	
Barbus paludinosus	F	*									
Barbus viviparus	F	*		*				*		*	
Caranx sexfasciatus	E	*			*						
Chanos chanos	E				*						
Clarias gariepinus	F	*									
Clarias theodorae	F			*	*						
Croilia mossambica	E		*		*	*	*	*	*	*	
Eleotridid larvae	E					*					
Eleotris fusca	E			*	*			*	*	*	
Elops larvae	E					*					
Elops machnata	E	*									

Table 3.12 continued......

		Historical Data									
		Lake			Mzingazi River	Present study					
Species	Category	1985	1993	2002	2002	SWB	Mzingazi River	Entrance	Pools	Exit	Upstream lake
Gerres methueni	E				*					*	
Gilchristella aestuaria	E	*	*	*		*	*	*	*	*	*
Glossogobius callidus	E		*	*		*	*	*	*	*	*
Glossogobius giuris	E	*			*		*	*	*	*	
Glossogobius kokius	E				*						
Gobiid larvae sp. 1	E					*	*				
Gobiid larvae sp. 2	E					*					
Hyporhamphus capensis	E		*	*							
Liza alata	E				*		*				
Liza macrolepis	E					*	*				
Lutjanus rivulatus	E					*					
Lutjanus argentimaculatus	E				*						
Marcusenius macrolepidotus	E	*									
Megalops cyprinoides	E	*									
Microcanthid larvae	E					*					
Monodactylid larvae	E					*					
Monodactylus argenteus	E					*					
Monodactylus falciformis	E					*		*	*	*	
Mugil cephalus	E					*	*	*	*	*	
Mugilids larvae	E					*					
Myxus capensis	E	*	*	*	*	*	*	*	*	*	*
Oligolepis acutipennis	E							*			
Oreochromis mossambicus	F	*	*	*	*		*	*	*	*	*

Table 3.12 continued......

		Historical Data				Present study					
		Lake			Mzingazi River						
Species	Category	1985	1993	2002	2002	SWB	Mzingazi River	Entrance	Pools	Exit	Upstream lake
Pomadasys olivaceum	E				*						
Psammogobius knysnaensis	E								*		
Pseudocrenilabrus philander	F	*	*	*	*						
Rhabdosargus sarba	E								*		
Silhouettea sibayi	E							*	*		
Solea bleekeri	E				*						
Terapon jarbua	E							*			
Tilapia rendalli	F	*	*	*			*		*	*	*
Tilapia sparrmanii	F	*	*	*							
Valamugil cunnesius	E						*	*	*	*	
Total Number per year		16	10	11	18	22	17	19	15	16	6
Total number in each section		17			18	22	25				

Table 3.13: The occurrence of euryhaline species in the five coastal lakes in the Richards Bay area (Vivier, 1998).

	Historical data				
Species	LM	LN	LC	LMan	LNZ
Ambassis natalensis	x				
Ambassis productus		x			
Ambassis sp.		x			
Anguilla bicolor bicolor			x		
Anguilla marmorata			x		
Anguilla mossambica			x		
Anguilla sp.		x			
Caranx sexfasciatus	x				
Gilchristella aestuaria	x	x	x		
Eleotris fusca		x	x		
Elops machnata	x	x	x		
Awaous aeneofuscus				x	
Croilia mossambica	x		x		
Glossogobius callidus	x	x			
Glossogobius giuris	x	x	x	x	
Redigobius dewaalii				x	
Pomadasys commersonnii		x			
Hyporamphus capensis	x				
Megalops cyprinoides	x	x	x		
Monodactylus falciformis			x		
Monodactylus sp.		x			
Liza macrolepis		x			
Mugil cephalus		x			
Liza alata		x			
Myxus capensis	x	x	x		x
Valamugil robustus		x			
Acanthopagrus holudi					
Acanthopagrus berda		x	x		
Gerres acinaces/ longirostris		x			
Lichia amia		x			
Total number of species	10	19	12	3	1

According to Porcher and Travate (2002), river obstructions are a reason for confinement of certain species to very restricted sections of a river. Since the Saltwater Barrier serves to limit the flow of salt water into the Mzingazi River, the river was completely fresh during the monitoring period and as a result, the species composition changed from marine dominant (Weerts and Cyrus, 2001) to estuarine and freshwater dominant. The transition between estuarine environment of the Mzingazi Canal and the Mzingazi River might lead to a decline in euryhaline marine species in the Mzingazi system. A similar change in species composition was recorded in the Nhlabane estuary by Vivier and Cyrus (2001) during 1992 to 1995, as result of mouth closure and a lack of contact with the marine environment. The recruitment into the estuary is dependant upon the system being in contact with the sea and a decline in numbers of juveniles is indicative of the breakdown in the recruitment process (Kok and Whitfield, 1986).

Due to the construction of the Mzingazi weir in 2006, the change in water level downstream of the fishway with changing flow depended largely on the Lake Mzingazi water levels and the slope of the weir. During low lake water level (2.8 mamsl), water level downstream of the fishway became very shallow, and according to Bok *et al.* (2004) the fishway entrance should be a pool where fish wait for ideal conditions to negotiate the fishway. During the monitoring period, juvenile Mullet were netted next to the fishway entrance. These Mullet spp were netted during the low water level period that lasted three months (in summer), and the pool water level at the fishway entrance decreased. All of the fish in the pool entrance were prone to predation. During high lake water levels or immediately after floods juvenile fish were more abundant in the fishway rather than downstream of the fishway; this clearly indicates that the fishway entrance was more effective immediately after floods or during high flow periods.

Most Southern African estuaries are dominated by euryhaline marine fish species, which spawn in the sea (Marais and Baird, 1980). Egg and the larval development of these species occurs in the sea, followed by a mass migration of postflexion larvae and juveniles (10 mm-60 mm SL) into shallow water of estuaries during spring and early summer (Wallace and Van der Elst, 1975). The high temperatures and food supply in estuaries enhance rapid growth while the estuarine environment offers protection against marine predators (Wallace, 1975; Wallace and Van der Elst, 1975). Estuaries therefore perform an important nursery function for large numbers of juvenile estuarine dependent marine fish (Wallace and Van der Elst, 1975). Harbours are also known to play a major role as nursery areas for juvenile fish, since all estuarine conditions are present in harbours. Euryhaline and marine species dominated the fish community in Richards Bay Harbour, contributing 58.5% and 37.7% of the total catch, respectively, with species such as *Liza dumerilii*, *L. macrolepis* and *A. berda* being dominant (Cyrus and Forbes, 1996). *Myxus capensis, M. cephalus* and *L. alata*, being abundant in Richards Bay Harbour, were expected to migrate into the Mzingazi River (Vivier and Cyrus, 1996). The majority of euryhaline marine species in the Mzingazi River during the monitoring period were Mullet, including species such as *M. capensis, M. cephalus, L. macrolepis, L. alata and V. cunnesius*. The presence of these species in the Mzingazi River indicates the importance of maintaining the estuarine to freshwater link, especially for species such as *M. capensis* that spends most of its life in freshwater.

The majority of mugilids recorded during this study were postlarvae < 7 mm SL and juveniles between 10-60 mm SL. *Myxus capensis* is known to breed from March to November, with the recruitment of 20-50 mm TL juveniles occurring between August and December (Table 3.14) (Wallace and Van der Elst, 1975). In this study *M. capensis* was found to be migrating from April to December and peak migration occurred from August to November. The recruitment of < 30 mm TL *M. cephalus* juveniles into KwaZulu-Natal estuaries occurs between June and October (Wallace and Van der Elst, 1975), but this species was recorded between May and December in the Mzingazi system with its peak migration period occurring in September. *Mugil cephalus* in Knysna (Southern Cape) recruit in August to December (Whitfield and Kok, 1992). *Valamugil cunnesius* was recorded between June and October, while *L. alata* and *L. macrolepis* were recorded on one or two occasions only during the monitoring period. The reason for the lack of *L. alata* and *L. macrolepis* is unclear, since *L. macrolepis* is known to enter estuaries in KwaZulu-Natal between May and September (Table 3.14) (Wallace and Van der Elst, 1975). *Liza alata* juveniles between 20-50 mm TL enter KwaZulu-Natal estuaries over a nine-month period between June and October.

Acanthopagrus berda, T. jarbua, M. falciformis and *M. argenteus* were also found in the Mzingazi system. *Terapon jarbua* was only recorded in April during this study. This species is known to spawn during the summer months in KwaZulu-Natal (Day *et al.,* 1981), and juveniles (10-30 mm TL) enter estuaries between May and November (Wallace and Van der Elst, 1975). *Monodactylus argenteus* was only recorded in September, while *Monodactylus falciformis* was recorded in May and December in this study. The size of *Monodactylus falciformis* ranged between 7 to 40 mm SL. In Swartvlei Bay, recruitment of *M. falciformis* larvae < 10mm TL occurred between February and April (Table 3.14) (Whitfield and Kok, 1992). *Acanthopargus berda* recruitment begins at < 20 mm TL, but the majority of juveniles recruit from July to December at a size range of 30-50 mm TL (Wallace and Van der Elst, 1975). Juveniles of this species were recorded in August and October, with a size range between 10 and 40mm SL in this study. The complete dominance of juvenile euryhaline marine species emphasizes continued recruitment and the extent to which the Mzingazi system acts as a nursery ground for these species. The species composition and abundance was also influenced by temporal variation in the recruitment period, with *M. capensis* and *M. cephalus* being more abundant during the peak recruitment period that occurred between September and December.

3.2.3. The efficiency of the Mzingazi fishway for fish migration

A total of 17 fish species successfully migrated through the Mzingazi fishway (Table 3.15). Six (38%) freshwater species were recorded, followed by five (31%) estuarine resident species, four (25%) euryhaline marine and one (6%) catadromous species (Whitfield, 1998). This shows that a total of ten euryhaline species successfully migrated from the estuarine environment to the freshwater environment of Lake Mzingazi. The dominant euryhaline species that successfully negotiated the fishway were *Myxus capensis* and *Glossogobius callidus.* The results clearly indicate that the Mzingazi fishway plays an important role in the life cycle of the euryhaline species in the area by allowing passage to the freshwater nursery habitat of Lake Mzingazi. During a short-term monitoring programme of the Mzingazi fishway in 2007, only three species of fish successfully passed through the fishway, these being the gobiid species *G. callidus, E. fusca* and *Favonigobius reichei* (Table 3.15) (Vivier, 2007).

At the Nhlabane fishway in 2001, *Oreochromis mossambicus* (45%) was the most abundant species passing through the fishway. Fourteen euryhaline species were recorded migrating through this fishway. These were dominated by *M. capensis* (40%), *M. falciformis* (7%) and *G. callidus* (1.5 %) (Mastenbroek, 2002). A total of 1 011 fish were trapped at the exit of the Kowie fishway. The dominant species were *M. capensis, M. cephalus, M. falciformis* and *G. callidus* (Bok and Cambray, 1995). A total of 52 754 fish representing 34 species were recorded in the pool-and-weir Burnett fishway on a coastal subtropical river in South-eastern Queensland, Australia (Stuart and Berghuis, 2002). Of 34 species recorded in the Burnett fishway, 26 species successfully negotiated the fishway. Eighteen euryhaline species were recorded in the Burnett fishway. These species were dominated by *Aurius graeffei, Mugil cephalus* and *Notesthes robusta*, respectively (Table 3.15) (Stuart and Berghuis, 2002).

During the present study, Catadromous species (*M. capensis*) contributed 43% of the fish caught at the fishway exit, while euryhaline marine species contributed 4.4%. Similar results were recorded in the Nhlabane fishway in 2001-2003, as catadromous species and euryhaline marine species contributed 40.2% and 9.5% of the total catch, respectively. In terms of number of species, euryhaline marine species and catadromous species contributed 27% and 9%, of the total species caught in the Nhlabane fishway, respectively. No marine (Category III) species were recorded migrating through the Nhlabane fishway (Mastenbroek, 2002). The fact that *M. capensis* was dominant at the fishway exit during the present study and was also recorded in the lake just upstream of the fishway indicates the importance of the fishway in the life cycle of this species and suggest that the Mzingazi fishway will lead to rehabilitation of catadromous fish populations in Lake Mzingazi. Species such as *G. callidus*, *A. ambassis*, *G. aestuaria* and *C. mossambica* recorded in the Mzingazi fishway shows that there is a possibility of the recovery of the estuarine fish population in Lake Mzingazi.

The majority of fish migrating through the fishway exit were between 25 and 50 mm SL, while the majority of fish recorded at the fishway entrance ranged from 25 to 40 mm SL. The smallest specimen was *Myxus capensis* (10 mm SL) and the largest was *Glossogobius giuris* (170 mm SL).The majority of *A. natalensis* recorded at the fishway entrance were sub-adults, as this species matures at approximately 35 mm SL (Whitfiled, 1998). The similarity in the relative sizes of fish caught in the top and bottom of the Mzingazi fishway demonstrates that the population that was found in the fishway entrance was able to successfully negotiate the fishway. The dominance of juveniles and sub-adults in the Mzingazi fishway generally indicates that species composition in the Mzingazi fishway was influenced by recruitment especially of the euryhaline marine species. In a similar study in Western Australia, Goodga fishway was found to function not only prior to the spawning period but also during the recruitment of large numbers of juveniles such as *Galaxias maculantus* and *Galaxias truttaceus* (Morgen and Beatty, 2006).

Anguillid eel species larvae (leptocephali) undergo a metamorphosis into glass eel, then change from glass eel to elvers in freshwater and continue to migrate upstream, ascending any artificial and natural barriers (Whitfield, 1998). However, only two specimens of Anguilla sp were recorded at the base of the fishway in this study. Stuart and Berghuis (2002) observed elvers at the bottom of the Burnett river fishway, but few of these ascended above the lower tidally influenced pools. In the Nhlabane fishway study, Anguilla spp were also not recorded (Mastenbroek, 2002; Heath *et al.*, 2005). Anguilla spp were observed at the Kowie fishway unsuccessfully attempting to use the fishway by crawling along the side walls and they negotiated the barrier mainly by crawling over the splash-zone on the edge of the main stream (Bok and Cambray, 1995). McDowall (1996) has indicated that migration of elvers could be improved by increasing the roughness of the fishway using rocks partially embedded in the concrete.

The discharge from the lake during the study period might have influenced Anguillid eel larvae and elvers migration up the fishway, since they rely on freshwater cues to stimulate migration. During low flows eel larvae and elvers were probably unable to negotiate the fishway and were required to swim through the pipes and orifices to reach the upstream pools. This was impossible for them because pipes and orifices were always blocked during this study.

Vertical drops found at low, sharp-crested gauging weir such as Mzingazi fishway can also block eel migration because eel larvae and elvers cannot jump-out of water and vertical steps greater that 60% of their body length, however they have ability to overcome barriers to migration by leaving water and climbing along the edge of the main stream (Bok, 2004).

The fact that only two elvers were recorded at the fishway entrance clearly indicates that elvers could have avoided vertical drops in the fishway pools by leaving water and climbing along the edge of the stream.

Table 3.14: The recruitment period of the euryhaline marine fish into the Mzingazi system (at six sites in the study area, Figure 2.1) and into the selected estuaries along the coast of South Africa

		Recruitment Period along the Coast of South Africa				
Species	Current study	Richards Bay Harbour	Nhlabane Estuary	St Lucia Estuary	Swartvlei Estuary	Knysna Estuary
Myxus capensis	Apr-Dec (10-40mm)	Aug-Dec (20-50mm)	Jan-Dec (20-50mm)	Aug-Dec (20-50mm)	Jan-Jun, Nov-Dec (<30)	Jan-Dec (<30)
Gerres methueni	Apr (40mm)		Nov-Jan (50mm)			
Valamugil cunnesius	Jun-Oct (40mm)	Jan-Mar (20-50mm)		Jan-Mar (20-50mm)		
Rhabdosargus sarba	Apr (30mm)	Aug-Jan (20-30mm)	Nov-Jan (30-50mm)			
Monodactylus falciformis	May-Dec (7-40mm)				Feb-Apr (<10mm)	Feb-May(>10mm)
Mugil cephalus	May-Dec (20-30mm)	Jun-Oct (<30)	Nov-Jan (40mm)	Jun-Oct (<30)	Nov (<30mm)	Aug-Dec (<40mm)
Terapon jarbua	Apr (35-55mm)	Nov-May (10-30mm)	Aug-Jan (20-50mm)			
Acanthopagrus berda	Aug-Oct (10-49mm)	Jul-Dec (20-30mm)	Aug-Jan (20-30mm)	Jul-Dec (20-30mm)		
Monodactylus argenteus	Sep (40mm)					
Liza alata	Aug (25mm)					
Liza Macrolepis	May (20-25mm)	May-Sep (20-40mm)	Nov-Jan (30-40mm)	May-Sep (20-40mm)		
Source		Wallace Van der Elst (1975)	Vivier and Cyrus (2001)	Wallace Van der Elst (1975)	Whitfield and Kok (1992)	Whitfield and Kok (1992)

Table 3.15: The comparative data for pool and weir fishways in South Africa and Queensland Australia, ** information not available.

	Current data	Mzingazi fishway 2007	Nhlabane fishway	Kowie fishway	Bunnet fishway (Queensland Australia)
Total number of individuals	8 288	15	1 396	1 898	52 754
No. of species	29	8	29	**	34
No. of individuals successfully migrated through the fishway	173	6	1 238	1 011	22 873
No. of species successfully migrated through the fishway	17	3	22	4	26
Dominant species at the fishway exit	*Myxus capensis*	*Glossogobius callidus*	*Oreochromis mossambicus*	*Myxus capensis*	*Arius graeffei*
	Eleotris fusca	*Eleotris fusca*	*Myxus capensis*	*Mugil cephalus*	*Mugil cephalus*
	Glossogobius callidus	*Favonigobius reichei*	*Monodactylus falciformis*	*Monodactylus falciformis*	*Notesthes robusta*
	Oreochromis mossambicus		*Glossogobius callidus*	*Glossogobius callidus*	*Anguilla reinhardtii*
Euryhaline marine species	12	3	14	**	15
Estuarine resident species	11	4	5	**	3
Source		Vivier (2007)	Mastenbroek (2002)	Bok and Cambray (1995)	Stuart and Berghuis (2002)

3.2.4. Abiotic factors

Water quality data collected in the Mzingazi River (at the Saltwater Barrier) indicate, historically, the extent to which the physico-chemical characteristics of the water changed after the construction of the Saltwater Barrier from saline (salinity 33) to fresh (Cyrus *et al.,* 1997). The average salinity recorded at the Mzingazi fishway during the study was 0.2. This result clearly shows that the Saltwater Barrier plays a major role in preventing excessive saltwater from entering the Mzingazi River, which was completely fresh during the study period. Fishes in Southern African estuaries are more tolerant to low rather than high salinity condition (Whitfield *et al.,* 2006). This is important as most estuaries are subjected to freshwater flooding (Whitfield, 1996). Euryhaline marine species (salinity tolerance 0-40) such as *M. cephalus, A. berda, M. falciformis* and *M. capensis* recorded at the Saltwater Barrier are capable of surviving under oligohaline conditions (salinity < 5) recorded at the Mzingazi system. For this reason salinity in the Mzingazi system was not considered to influence the euryhaline species distribution. However, the number of euryhaline marine species declined from the Saltwater Barrier to the fishway exit (Table 4.2). *Athron immaculatus* (salinity tolerance 8-38) was the only marine (category III) species recorded in the Mzingazi system during the monitoring period. This species was only recorded in the lower reaches of the Mzingazi River at the Saltwater Barrier, but not in the fishway. In a similar study of the Nhlabane fishway, Mastenbroek (2002) found that marine fish species avoided water salinities below 5 in the Nhlabane fishway despite the fact that the majority of migrants recorded in the fishway were tolerant of low salinities.

The water flowing down the Mzingazi fishway was clear, with an average turbidity of only 0.3 NTU. Laboratory studies and comparison with field data of South-East African estuarine fish (Cyrus and Blaber, 1987) showed that seventeen species were affected by turbidity, of which 10 avoided turbid waters, four avoided clear waters, three showed a preference for waters of intermediate turbidity while only three species were found to be indifferent to turbidity. These results clearly indicate that juvenile fish distribution in estuaries is related to water turbidity (Cyrus and Blaber, 1987). Some species, such as *Monodactylus argenteus* and *L. macrolepis,* in particular, prefer clear water since they were found to be avoiding turbid waters (Cyrus and Blaber, 1987). These species were scarce in the Mzingazi fishway, which suggests that their numbers were not influenced by turbidity and it did not play a major role in their distribution but might have influenced predation pressure in this study. Pisciverous birds, such as Cormorants and Kingfishers, were frequent visitors to the fishway and juvenile fish were exposed to predation due to the clear and shallow water in the fishway pools, although no predation was observed during this study. In conclusion, temperature and turbidity did not play a major role in determining the species distribution and composition of the Mzingazi system in this study.

3.2.4.1. Fishway water flow rate and water level

For a fishway to be considered effective, fish should be able to find the entrance and negotiate it without delay, stress or injury that might prejudice the success of their upstream migration (Larinier, 2000 and 2002a). The attraction of a fishway to migrating fish depends on its location in relation to obstructions and hydraulic conditions such as flow discharge, velocity and flow pattern (Larinier, 2000; Larinier 2002b). It is essential for a fishway entrance to have sufficiently high velocities, but compatible with the swimming capacities of species involved (Larinier 2002c). The velocities at the entrance of the Mzingazi fishway ranged from 0.61m.s^{-1} -2.15 m.s^{-1} (Table 4.1). A minimum of 1 m.s^{-1} was suggested as an optimal normal speed for most species at the fishway entrance (Larinier, 2002c). These results clearly show that the fishway entrance velocities were compatible with the swimming capacity of all the small weakly-swimming migrants that probably used areas of slower velocities (0.61 m.s^{-1}), since 20 species were able to locate and negotiate the entrance.

The majority of *M. capensis* and *G. callidus* recorded ranged in size from 25-50 mm SL. *Myxus capensis* and *G. callidus* were found to migrate at flows of 0.84 m.s^{-1} which was recorded in October, the peak recruitment period for the majority of euryhaline species (Whitfield, 1998). The abundance of fish passing through the fishway exit decreased when the maximum velocity reached 1.01 m.s^{-1} in November. Deep bodied species, such as *M. Falciformis,* preferred to wriggle over a natural in-stream barrier in shallow water, rather than jumping. In a pool and weir fishway, juveniles of many species of fish use a maximum swimming speed to swim through the crest of the pool to the upstream pool (Bok *et al.,* 2004). The maximum swimming speed of *M. falciformis* juveniles (33 mm TL) is 1.2 m.s^{-1} (Bok *et al.,* 2004). *Monodactylus falciformis* juveniles between 30-40 mm SL were netted migrating through the fishway exit in May and December during the present study, and successfully negotiated flows of 0.89 m.s^{-1} and 1.09 m.s^{-1}, respectively. The flow velocities at the fishway exit ranged from 0.84 m.s^{-1}-1.54 m.s^{-1}. The recommended maximum current velocities for small marine and estuarine migrants (20 mm-40 mm in length) is <1.2 m.s^{-1}, for medium size fish (40-100 mm in length) this is <1.5 m.s^{-1} and for larger fish (> 100 mm in length) it is 2.0 m.s^{-1}(Bok *et al.,* 2004). These results indicate that flow conditions in the Mzingazi fishway were suitable to allow all size groups to successfully pass through the fishway exit. Small pipes in the fishway baffles allowed weakly swimming juveniles to migrate upstream, as the lowest velocities (< 0.69 m.s^{-1}) were recorded at these pipes; however they often became clogged and migrants were unable to pass through. Submerged orifices in the pool baffles were also often clogged. During monitoring of the Kowie estuary fishway in the Eastern Cape, *M. capensis* smaller than 45 mm TL were found to be unable to negotiate the fishway. The exclusion of smaller fish was due to high water velocities recorded at the weir (0.9-1.8 m.s^{-1}) and peak migratory periods occurring during decreasing flows after the floods (Bok and Cambray, 1995). The abundance of *Myxus capensis* recorded in Nhlabane fishway was found to increase with an increase in flow rate, but decreased at a flow rate greater than 25 l/s (Mastenbroek, 2002), while in this study, *Myxus capensis* was more abundant at low flow velocities (Figure 4.16a) and the majority of this species found in the Mzingazi fishway were juveniles (< 50 mm SL). According to Bok *et al* (2004) the maximum swimming speed for juveniles (< 50 mm SL) is 1.3 m/s and this could possibly be the reason for a decrease in abundance at flow velocities above 1 m/s (Figure 3.17a).

The fishway entrance, weir crest, the pipes in the baffle and the submerged orifice are the most critical points in the fishway (Larinier, 2002d). The Mzingazi fishway entrance was found to be most effective at a velocity of < 1.1 m.s^{-1} and less effective at a velocity of > 1.1 m.s^{-1}, as the abundance of fish at the fishway entrance declined above these velocities. Hydrodynamics, such as flow pattern and velocity, are used to stimulate and guide the fish towards the entrance. The attractiveness of the fishway entrance depends on the direction of the flow (Larinier, 2002c). Water eddies at the left fishway entrance was found to be flowing in the opposite direction due to the presence of large concrete blocks directing eddies of water down the fishway. This flow pattern had a negative impact on migratory fauna by delaying access to the entrance.

During high water levels in the lake, the weir crest was overflowing and increased flow velocities down the fishway. As a result juveniles were often unable to negotiate the fast flowing water. Juvenile fish often congregated at the top pool of the fishway waiting for the water level to drop. The weir crest was found to be more effective during a decline in water level after the overflow.

Pipes in the baffle and the submerged orifice are the most important fish passage facilities in the fishway (Larinier, 2002d). These were often blocked by foreign material, dumped by local inhabitants, and by floating debris. According to Larinier (2002d), debris results in insufficient water flow in a fishway and obstructs the migratory fauna. The migratory fauna in the Mzingazi fishway often used the crest of the pool and weir crest (Figure 3.1) as their passage facilities during this study.

In conclusion, the fishway was found to allow passage of 17 fish species between the estuary and the lake, indicating that the fishway is effective and efficient for upstream migration of the target species. The design of the fishway creates suitable hydraulic conditions for migration of juvenile and sub-adult fish (10 to < 100 mm SL), while adults fish >100mm SL were found at the entrance and were observed downstream and upstream of the fishway. Peak upstream migration of fish through the fishway occurred in August, September, October and December, which coincides with the peak recruitment period of most estuarine and marine spawning species. Peak migration and species abundance of fish was a natural effect of seasonal recruitment and breeding, which was only indirectly affected by temperature.

The number of fish species and their abundance was affected by water flow rate down the fishway, as they decreased with an increase in flow. The abundance of the two dominant species, *Myxus capensis* and *Glossogobius callidus,* decreased with an increase in water flow rate, while *E. fusca* increased with an increase in flow rate.

The Mzingazi fishway is susceptible to low flows caused by low lake levels (<3 mamsl) due to droughts and continued water abstraction from the lake, since the fishway dried up for approximately four months (January, February, March and July) during the 12 month monitoring period. This clearly has a negative effect on the ability of fish to migrate into the lake.

CHAPTER 4

OPERATION AND EFFICIENCY OF THE MZINGAZI FISHWAY FOR MACROCRUSTACEANS

4.1. RESULTS

4.1.1. Prawn species composition

A total of 7 885 prawns representing ten species were recorded in the Mzingazi system during this study (Table 4.1, Figure 2.1 and Figure 2.3 a, b, c). Overall, eight species of Carid prawns and one species of Penaeid prawn were recorded (Table 4.1). The dominant species were *Caridina nilotica, Macrobrachium equidens* and *Caridina indistincta,* contributing 54%, 26% and 14% of the total catch, respectively. A total of four *Macrobrachium species* was recorded; of these four species three were identified to species level, while the fourth was too small to be identified.

Table 4.1: Species, total numbers and percentage contribution of prawns to the total catch recorded in the Mzingazi system between August 2007 and July 2008.

Species	Total number	Percentage
Caridina nilotica	4,294	54.00%
Macrobrachium equidens	2,074	26.30%
Caridina indistincta	1,089	13.80%
Palaemon concinnus	153	1.90%
Palaemon capensis	100	1.30%
Macrobrachium lepidactylus	95	1.20%
Caridina africana	54	0.70%
Macrobrachium sp. 1	22	0.30%
Fenneropenaeus (Penaeus) indicus	4	<0.1%
Macrobrachium idae	1	<0.1%
Total	7 885	

4.1.2. Longitudinal distribution

4.1.2.1. Prawn recruitment into the Mzingazi River (at the Saltwater Barrier)

The Mzingazi Saltwater Barrier catch comprised 157 prawns of only two species, *Fenneropenaeus indicus* and *Palaemon concinnus* (Table 4.2). The dominant species was *P. concinnus,* contributing 97% of the total catch, while *F. indicus* contributed only 3%. The size of prawns recorded above the Saltwater Barrier varied from 0.9 mm-7.0 mm CL, with the size class of 0.9-1.0 mm CL contributing 53% of the total catch. *Fenneropenaeus indicus* ranged from 4.7 mm-7.0 mm CL, while *P. concinnus* ranged from 0.9-1.5 mm CL (Table 4.2). The highest, *P*. *concinnus* CPUE, was recorded in December, whereas a marked decrease in abundance of this species occurred in March, when only three individuals were recorded. Only four individuals of *F. indicus* were recorded in December.

Table 4.2: Species, total numbers in decreasing order of abundance and size frequency of prawns recorded in the Mzingazi River at the Saltwater Barrier.

Species	Total number	Carapace Length
Palaemon concinnus	39	1.0 mm
Palaemon concinnus	30	0.9 mm
Palaemon concinnus	30	1.3 mm
Palaemon concinnus	24	1.1 mm
Palaemon concinnus	15	1.5 mm
Palaemon concinnus	13	1.0 mm
Palaemon concinnus	1	1.5 mm
Palaemon concinnus	1	0.9 mm
Fenneropenaeus indicus	1	4.7 mm
Fenneropenaeus indicus	1	7.0 mm
Fenneropenaeus indicus	1	4.9 mm
Fenneropenaeus indicus	1	6.2 mm
Total	157	

4.1.2.2. Prawn composition at the fishway entrance.

A total of 634 Carid prawns of seven species were trapped using a funnel net at the fishway entrance, with no Penaeid prawns being recorded (Table 4.3). The dominant species were *M. equidens*, *C. nilotica* and *C. indistincta,* contributing 71%, 19% and 8% to the total catch, respectively (Table 4.3). The remaining four species contributed only 1.7% of the total catch. *Macrobrachium equidens* was mostly recorded in the winter and spring months, with its peak migration occurring in June (Figure 4.1). *Macrobrachium lepidactylus* and *M. idae* were only recorded in April (Table 4.3). *Caridina nilotica* was recorded from June to December, while *C. indistincta* was present from May to September. The numbers of both *C. nilotica* and *C. indistincta* peaked in September. The lowest number of species (one) was recorded in December, while the highest number of species (four) was recorded in June (Figure 4.2). No prawns were recorded in November. A total of nine individuals of *M. equidens* were also recorded during seine netting in the upper Mzingazi River. These individuals were only present in October and November.

The size frequency distribution of the three dominant prawns species recorded at the fishway entrance is presented in Figures 4.3, 4.4 and 4.5. The size of *M. equidens* recorded at the fishway entrance ranged from 5.2 to 25.1 mm CL, with the majority (86%) between 6.0-8.9 mm CL (Figure 4.3). *Caridina indistincta* ranged from < 3 to 7.2 mm CL, with the majority (74%) between 5 to 5.9 mm CL (Figure 4.4). The size of *C. nilotica* ranged from 2.8 to 7.8 mm CL, with the majority (82%) measuring between 4.0 to 6.9 mm CL (Figure 4.5). Peak recruitment of *M. equidens* juveniles occurred in June, while *C. indistincta* and *C. nilotica* peaked in September (Figure 4.1).

Table 4.3: Species, CPUE (Total number/sampling days) and percentage contribution of prawns recorded at the fishway entrance between August 2007 and July 2008 (*indicates no sampling done due to low water level).

	Catch per unit effort									Mean	
Species	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	CPUE	%
Macrobrachium equidens	11.5	20.5	184.0			13.0	57.5			35.8	71.0
Caridina nilotica			20.0		15.3	22.0	20.0		0.5	9.7	19.0
Caridina indistincta		0.5	10.0		6.0	17.0				4.2	8.3
Palaemon capensis			0.6		2.0		0.5			0.3	0.8
Macrobrachium lepidactylus	0.5									0.1	0.1
Macrobrachium idae	0.5									0.1	0.1
Macrobrachium sp. 1		0.5								0.1	0.1
Total mean	12.5	21.5	214.6		23.3	52.0	78.0	0.0	0.5	50.2	
Number of species	3	3	4		3	3	3	0	1	7	

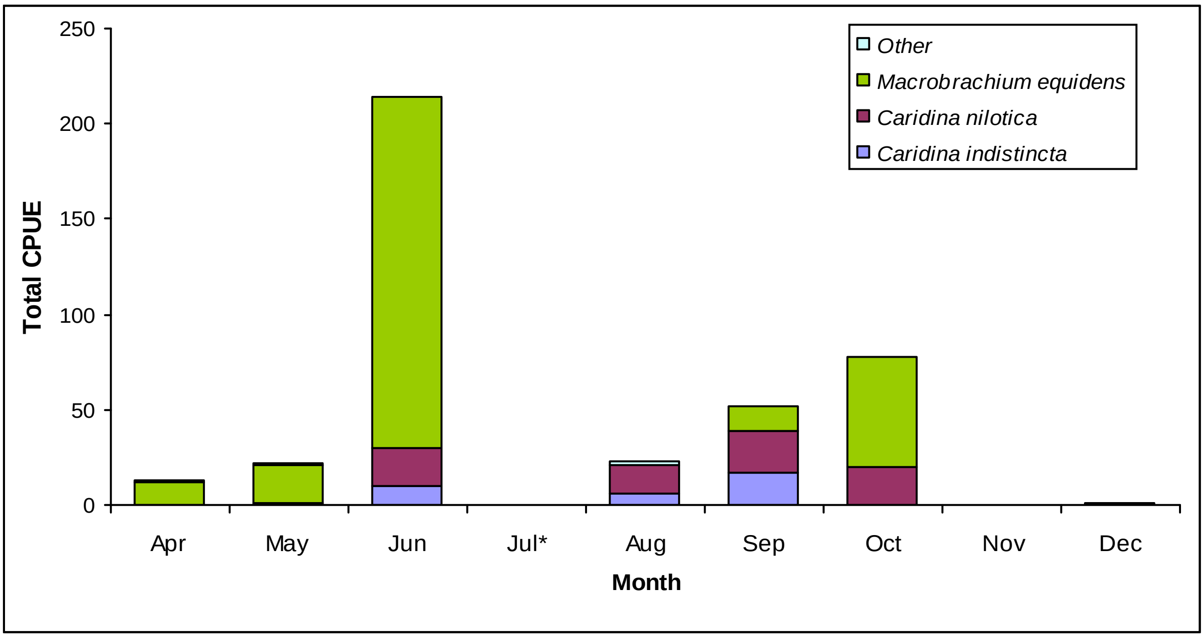

Figure 4.1: Monthly total CPUE of prawns recorded at the fishway entrance between August 2007 and July 2008 (*indicates no sampling done due to low water level).

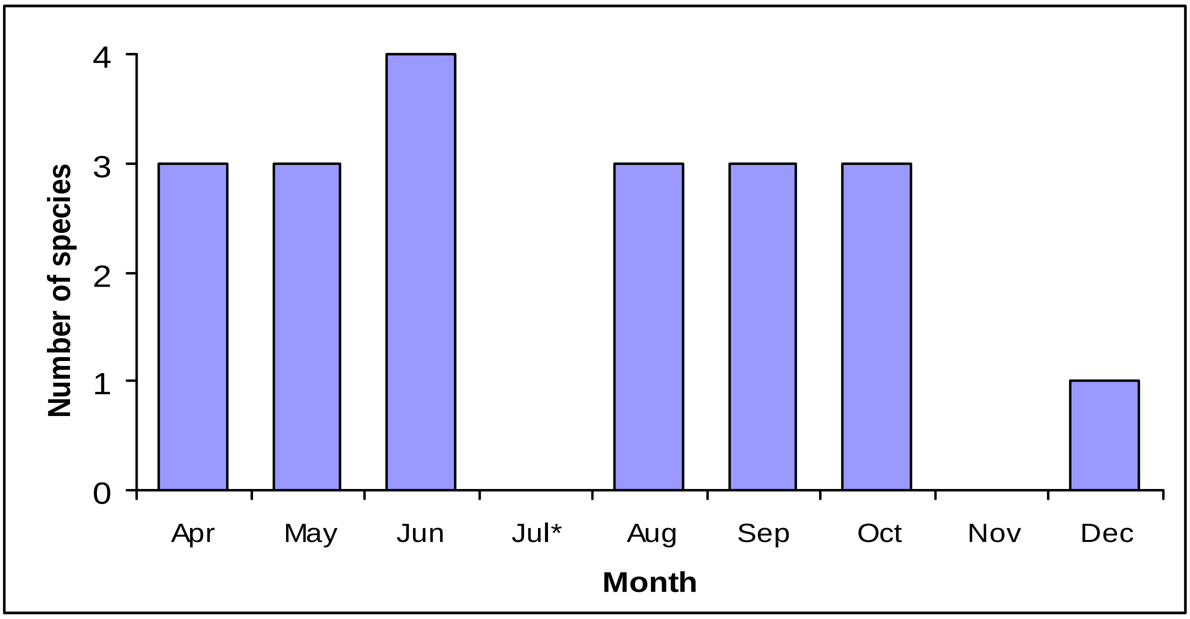

Figure 4.2: Number of prawn species recorded at the fishway entrance per month between August 2007 and July 2008 (*indicates no sampling done due to low water level).

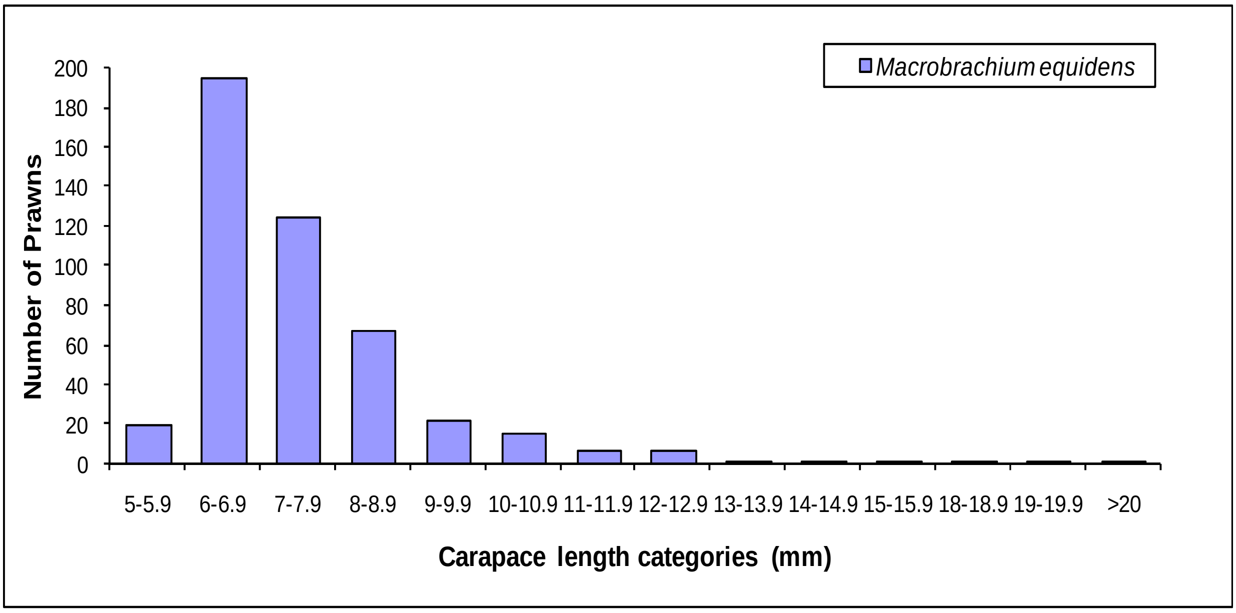

Figure 4.3: Size frequency distribution of *Macrobrachium equidens* recorded at the fishway entrance between August 2007 and July 2008.

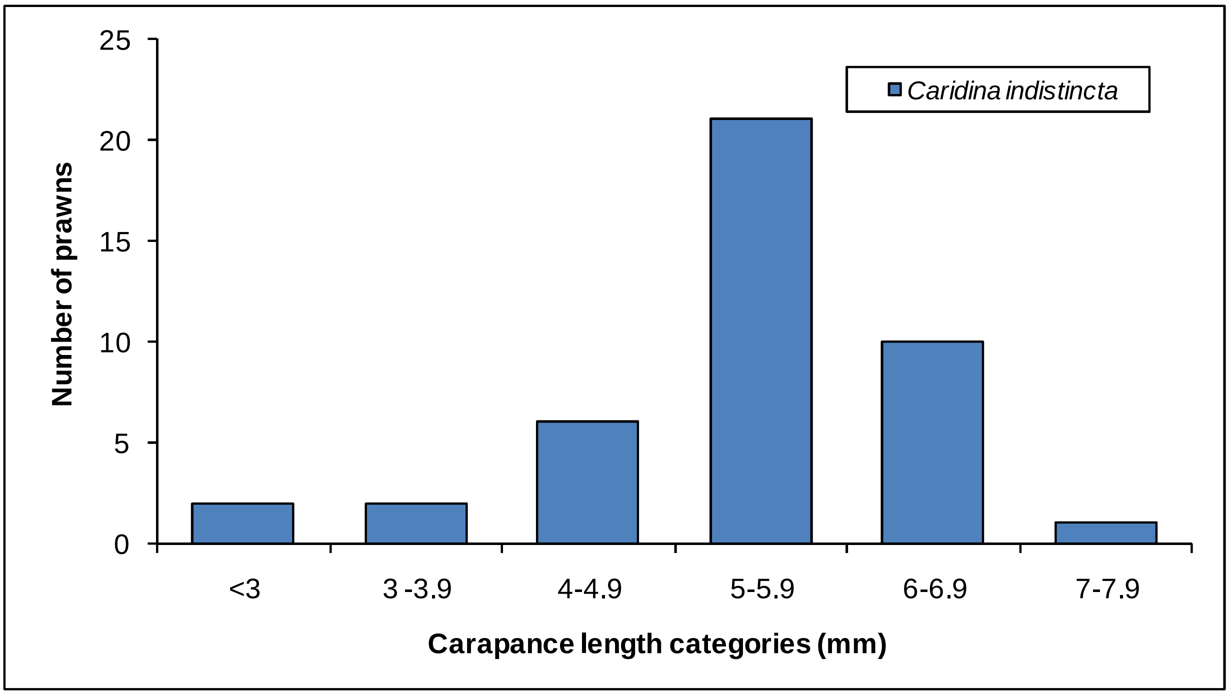

Figure 4.4: Size frequency distribution of *Caridina indistincta* recorded at the fishway entrance between August 2007 and July 2008

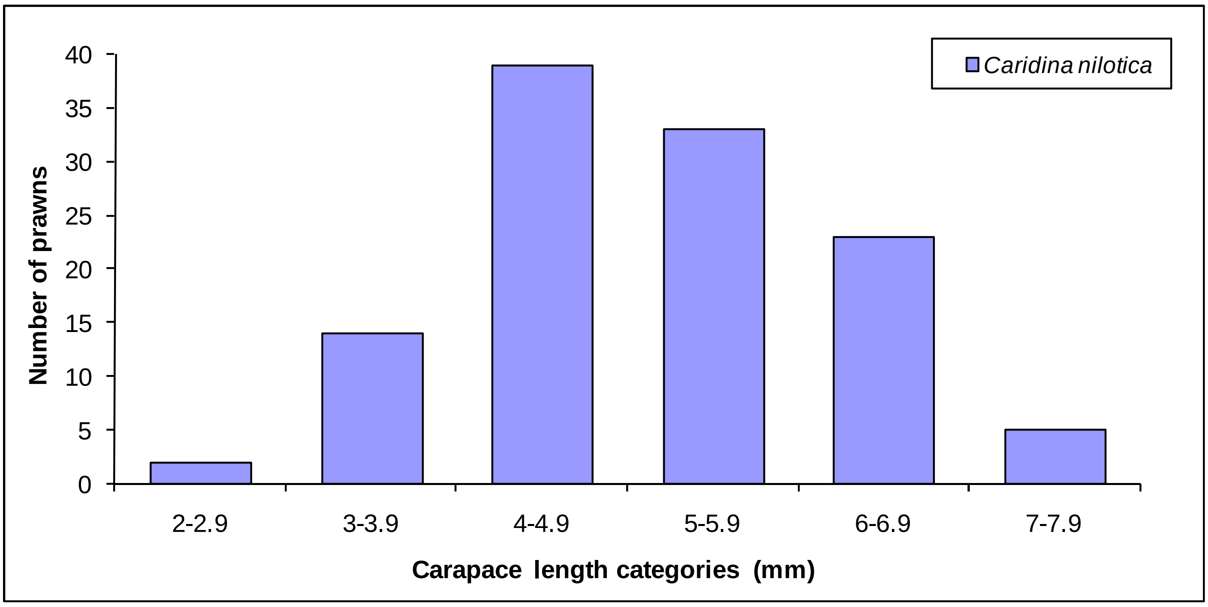

Figure 4.5: Size frequency distribution of *Caridina nilotica* recorded at the fishway entrance between August 2007 and July 2008

4.1.2.3. Prawn composition in the fishway pools

The species and the CPUE of prawns recorded within the 25 pools of the fishway during the study period are presented in Table 4.4. For ease of analysis, the catch in the pools were paired, except for pools 1-4 which were grouped (Figure 3.1). These four pools were always under water and prawns could freely move between them. Pool 25 was also analysed separately as this was the highest pool in the fishway and prawns often congregated there before attempting to pass over the crest of the weir. A total number of 6 657 prawns, representing seven species, were recorded in the fishway pools. The number of individuals caught in the fishway pools contributed 84% of the total catch in the Mzingazi system (Figure 2.1). The numerically dominant species were similar to those recorded at the fishway entrance, although *C. nilotica* (62%) was the most dominant species, followed by *M. equidens* (18%) and *C. indistincta* (15%). The prawns recorded within the fishway pools during each of the eight sampling months are presented in Table 4.5. Generally, peak abundance (CPUE) occurred between June and September and again in December (Table 4.5). The highest number of species was recorded in May-September and in December. The three dominant species (*C. nilotica*, *M. equidens* and *C. indistincta*) were consistently recorded during the monitoring period (Table 4.5). The lowest numbers of these three dominant species were recorded in November. The abundance (CPUE) of *C. nilotica* peaked in December, *M. equidens* in May, while *C. indistincta* abundance peaked in June (Table 4.5).

There was a significant increase in the number of species recorded, from the bottom to the top of the fishway ($F = 2.4$, $p = 0.01$) (Figure 4.6, Table 4.4). There was also a significant increase in mean prawn abundance from the bottom to the top of the fishway ($F = 3.3$, $p < 0.001$) (Figure 4.7), with highest abundance in pools 23-24. The mean abundance remained relatively constant in the lower section of the fishway up to pools 13-14, after which it gradually increased to form a marked peak in pools 23-24 (Figure 4.7).

The significant difference was used to show the difference in terms of abundance and number species between the fishway pools. The fact that the mean abundance at the bottom pools was less compare to the top pools indicates that there were no obstructions in the fishway pools and all the juveniles that successfully completed their obligate estuarine phase were able to migrate back to the freshwater environment and the fishway allowed them to pass through into the lake. The difference between the fishway pools shows how many numbers of species were able to migrate up the fishway without encountering any obstacles. The fact that the pools were significantly different clearly shows that migratory species were able to enter and migrate up the fishway.

The species dominance in the four quarters of the fishway is shown in Figure 4.8. The three most dominant species (*C. nilotica*, *M. equidens* and *C. indistincta*) were consistently recorded throughout the fishway pools (Table 4.4, Figure 4.8). There was a distinct shift in species composition down the fishway, with the mean abundance of *M. equidens* decreasing from the bottom to the top of the fishway, while the abundance of *C. nilotica* and *C. indistincta* increased from the bottom to the top (Figure 4.8).

Table 4.4: Species and CPUE (Total number/month/sampling days) of prawns in decreasing order of abundance, as recorded in the fishway pools, grouped into four quarters during the eight sampling months between August 2007 and July 2008

	Pools Catch per unit effort													
	Lower Quarter			**2nd Quarter**			**3rd Quarter**			**Upper Quarter**				
Species	1-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21-22	23-24	25	Total	%
Caridina nilotica	0.8	5.8	1.6	7.3	11.7	6.4	19.5	15.2	25.3	48.9	83.3	32.9	258.5	62.2
Macrobrachium equidens	3.7	8.8	6.5	7.4	6.4	7.8	5.8	6.9	10.1	4.8	4.3	4	76.5	18.4
Caridina indistincta	0.1	0.3	0.4	3.2	2.5	2.7	5.8	4.4	5.9	13.8	12.6	13.3	64.8	15.6
Palaemon capensis		0.4	0.1	0.1		1	2	1.1	0.2	0.8	0.3		5.9	1.4
Macrobachium lepidactylus	0.1	0.4		0.4	0.3	0.2	0.7	1.4	0.3	0.6	0.8	0.3	5.3	1.3
Caridina africana		0.1		0.3		0.2	0.1	0.3	0.4	1.1	0.4	0.4	3.2	0.8
Macrobrachium sp. 1			0.1		0.2	0.2	0.1	0.1	0.3	0.1	0.2		1.2	0.4
Total mean	4.6	15.7	8.6	18.6	21	18.4	33.9	29.4	42.4	70.1	101.7	50.8	415.4	
Number of species	4	6	5	6	5	7	7	7	7	7	7	5	7	

Table 4.5: Species, CPUE (Total number/sampling days) and percentage contribution in decreasing order of prawns recorded in the fishway pools between August 2007 and July 2008 (* indicates no sampling done due to low water level).

	Months										
	Catch per unit effort									Mean	
Species	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	CPUE	%
Caridina nilotica	15.0	9.5	400.5		387.0	391.0	163.0	21.0	686.5	259.2	60.0
Macrobrachium equidens	126.0	229.0	56.5		2.0	23.5	106.0	3.5	65.5	76.5	17.8
Caridina indistincta	2.0	1.5	232.0		140.0	147.0	32.5	3.0	73.0	78.9	18.3
Palaemon capensis		0.5			46.0	0.5				5.9	1.1
Macrobrachium lepidactylus	12.5	13.5	15.5						3.5	5.6	1.3
Caridina africana			1.0		5.0	7.5	4.0		8.5	3.3	0.8
Macrobrachium sp. 1	0.5	2.0	2.5		1.5	1.0	0.5		2.0	1.3	0.3
Total mean	156.0	256.0	708.0		581.5	570.5	306.0	27.5	839.0	430.7	
Number of species	5	6	6		6	6	5	3	6	7	

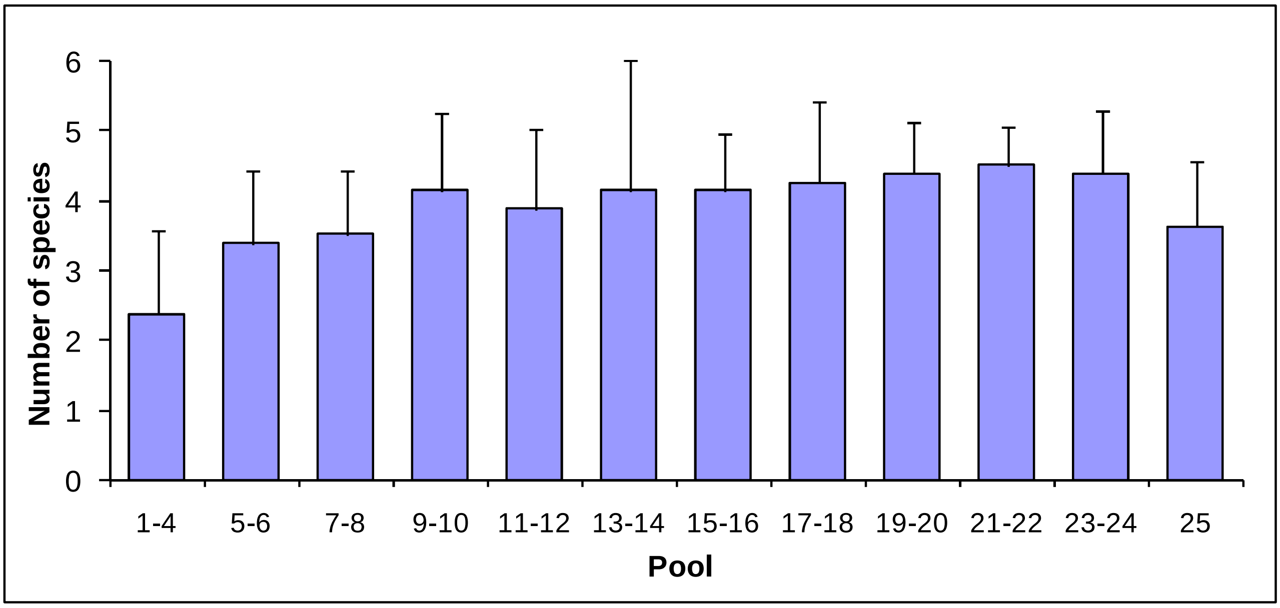

Figure 4.6: Mean number of prawn species in the fishway pools recorded between August 2007 and April 2008, (F = 2.4, p = 0.01).

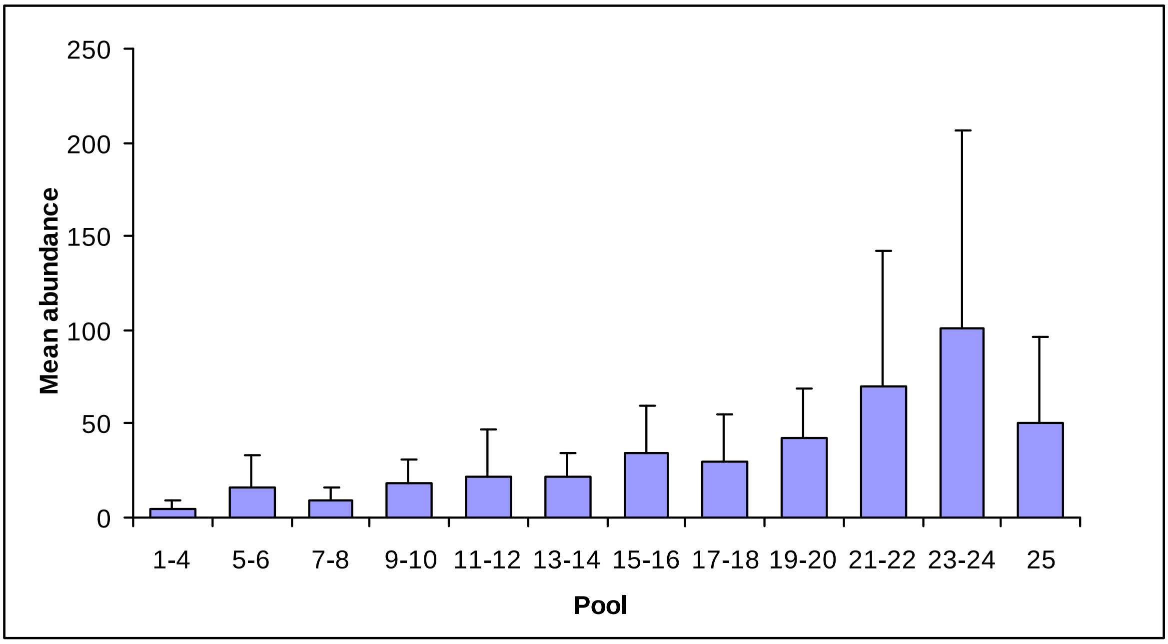

Figure 4.7: Mean abundance of prawns in the fishway pools recorded between August 2007 and April 2008 (F = 3.3, $p < 0.001$).

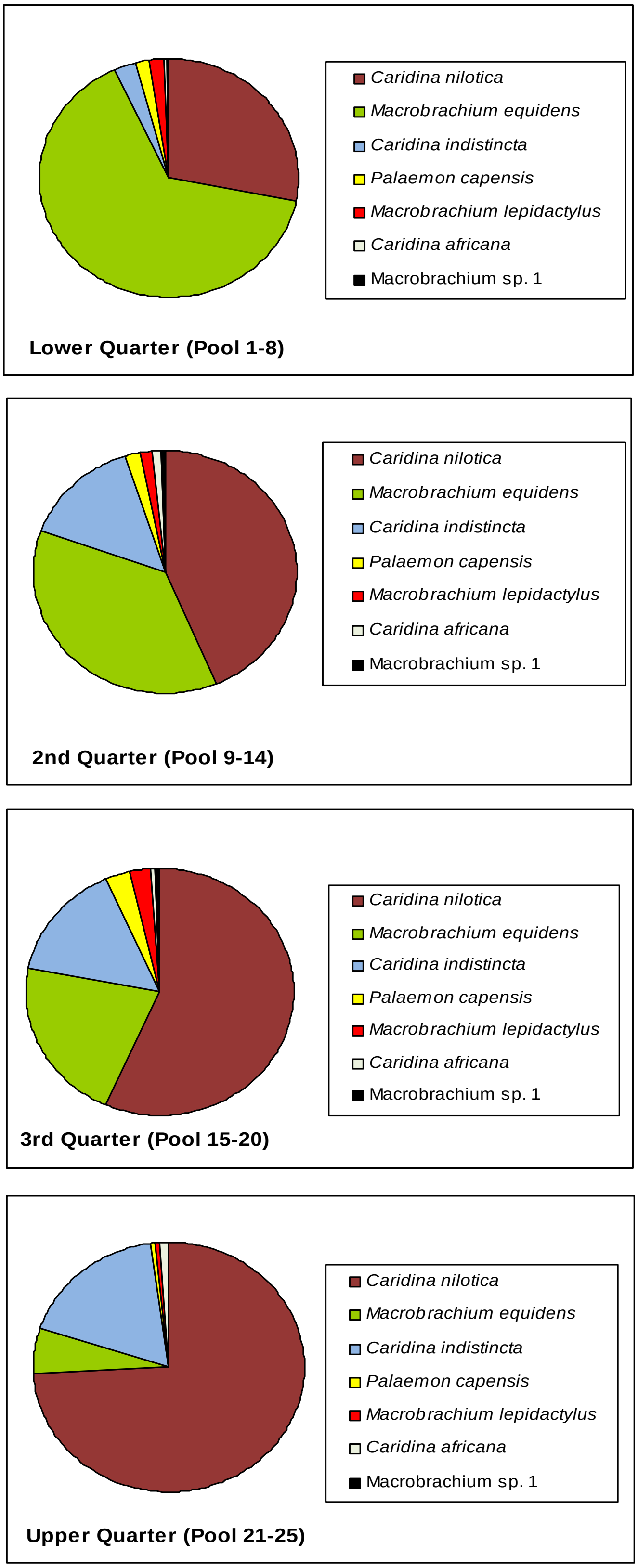

Figure 4.8: Species dominance recorded in the fishway pools between August 2007 and April 2008.

4.1.2.4. Composition of prawns migrating over the crest of fishway

A total of 425 prawns, representing seven Carid prawn species, were trapped in a funnel net as they successfully migrated over the crest of the fishway (Table 4.6). The dominant species were *M. equidens, C. nilotica* and *C. indistincta*, contributing 86%, 7.7% and 3.9% to the total catch, respectively (Table 4.6). Peak abundance (CPUE) occurred in April, May and October. These peaks were marked by very high numbers of *M. equidens* recorded during these months. Peak abundance (CPUE) for both *C. nilotica* and *C. indistincta* occurred in November (Figure 4.9). The remaining species were recorded only once or twice during the monitoring period and contributed less than 2% of the total catch (Table 4.6). The lowest number of species was recorded in April and December, while the highest number of species was recorded in November (Figure 4.10). No prawns were recorded at the fishway exit in September (Table 4.6 and Figure 4.10), which was surprising given the high numbers recorded in October and November. The prawn composition immediately upstream of the fishway was also monitored during the study period, but only four individuals of *M. equidens* were recorded.

Table 4.6: Species, CPUE (total number/sampling days) and percentage contribution in decreasing order of abundance of prawns migrating over the crest of the fishway between August 2007 and July 2008 (* indicates no sampling done due to low water level).

	Months Catch per unit effort									Mean	
Species	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	CPUE	%
Macrobrachium equidens	62.0	58.5	4.6				54.5	7.5	0.5	23.5	86.3
Caridina nilotica			2.5		3.3		1.0	10.0		2.1	7.7
Caridina indistincta			4.0		0.6			4.0		1.1	3.9
Macrobrachium lepidactylus		1.5								0.2	0.7
Caridina africana			0.7					0.5		0.2	0.6
Palaemon capensis							1.0			0.1	0.5
Macrobrachium sp. 1								0.5		0.1	0.2
Total CPUE	62.0	60.0	11.8		3.9	0	56.5	22.5	0.5	27.2	
Number of species	1	2	4		2	0	3	5	1	7	

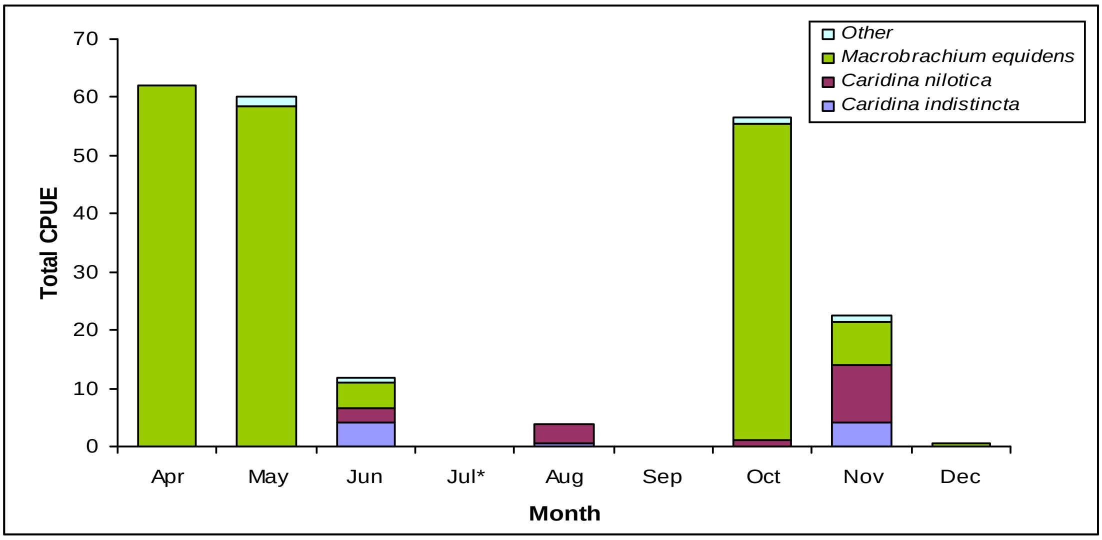

Figure 4.9: Monthly mean abundance of prawns recorded at the fishway exit between August 2007 and July 2008 (* indicates no sampling done due to low water level).

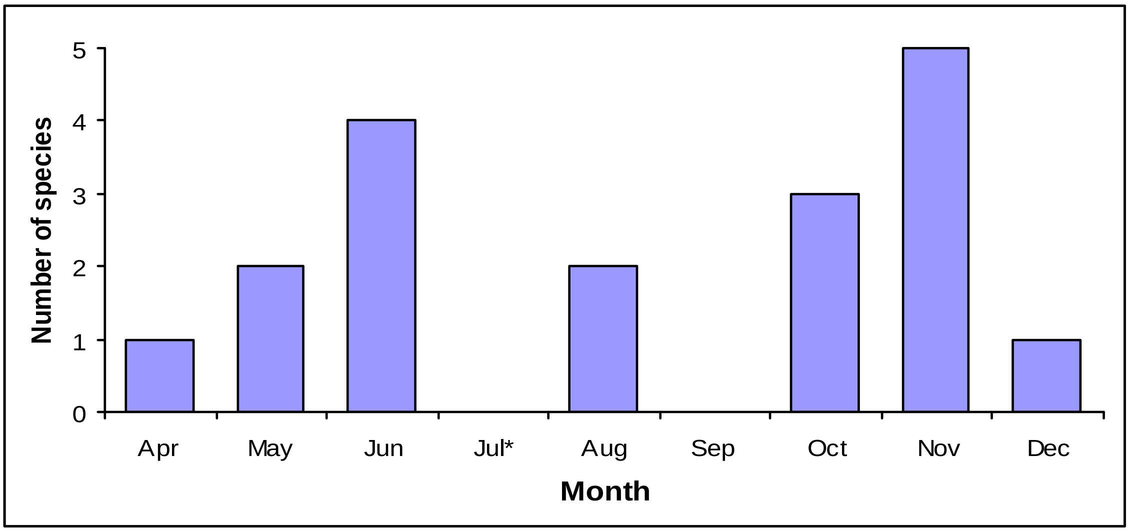

Figure 4.10: Number of species recorded at the fishway exit between August 2007 and July 2008 (* indicates no sampling done due to low water level).

The size of *M. equidens* recorded at the fishway exit ranged from 5.0 to 25.9 mm CL, with the majority (84%) found in the size class 6.0 to 11.9 mm CL (Figure 4.11). *Caridina indistincta* varied from 3.6 to 7.0 mm CL, with the majority (80%) being between 3.6 and 6.0 mm CL (Figure 4.12). The size of *C. nilotica* ranged from 3.1 to 7.5 mm CL, with the majority (80%) between 4.1 and 5.0 mm CL (Figure 4.13). The fact that the majority of *M. equidens* measured between the 6.0 and 11.9 mm CL, is indicative of the extent to which juveniles of this species migrate from the estuarine environment through the fishway into the lake, given that *M. equidens* larvae require brackish environments for successful larval development. The fact that the majority of *C. nilotica* were between 4.1 and 5.0 mm CL, indicates that mainly adults of this species migrate up the fishway.

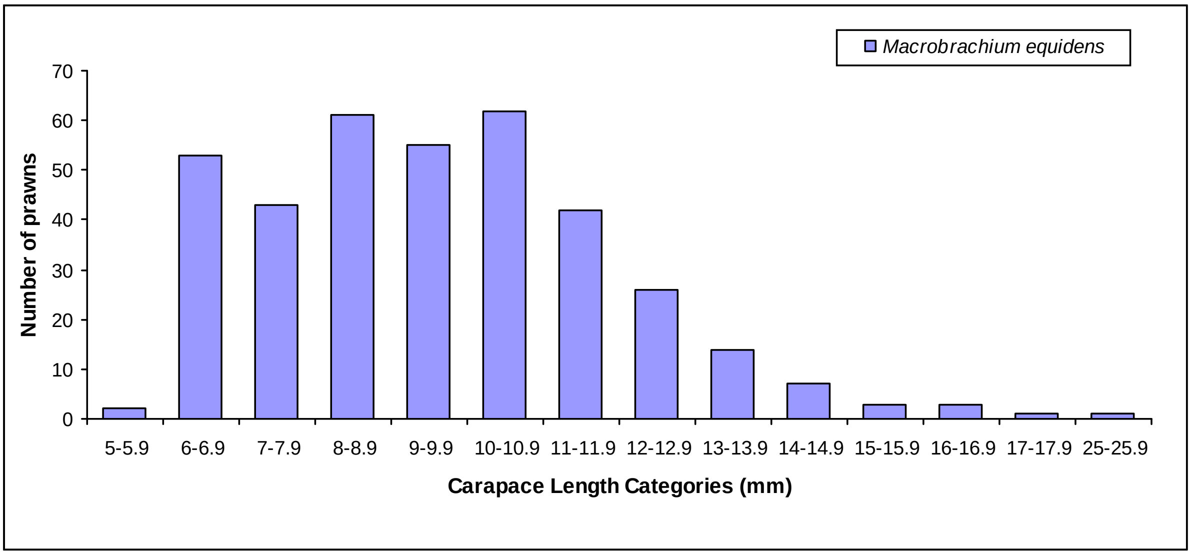

Figure 4.11: Size frequency distribution of *Macrobrachium equidens* recorded at the fishway exit during the period August 2007-July 2008.

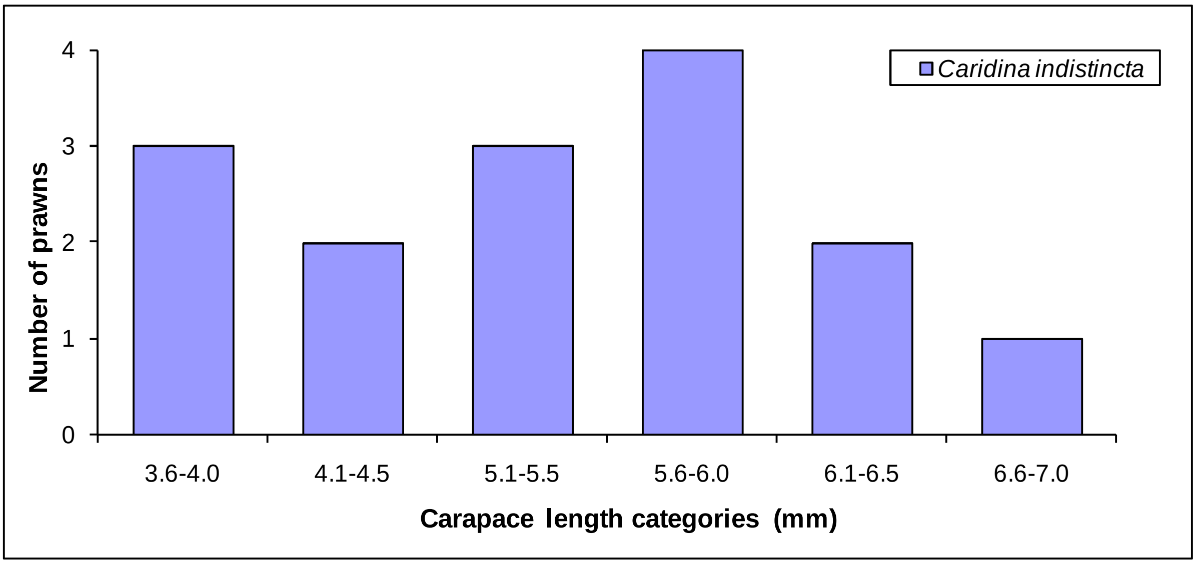

Figure 4.12: Size frequency distribution of *Caridina indinstincta* recorded at the fishway exit during the period August 2007-July 2008.

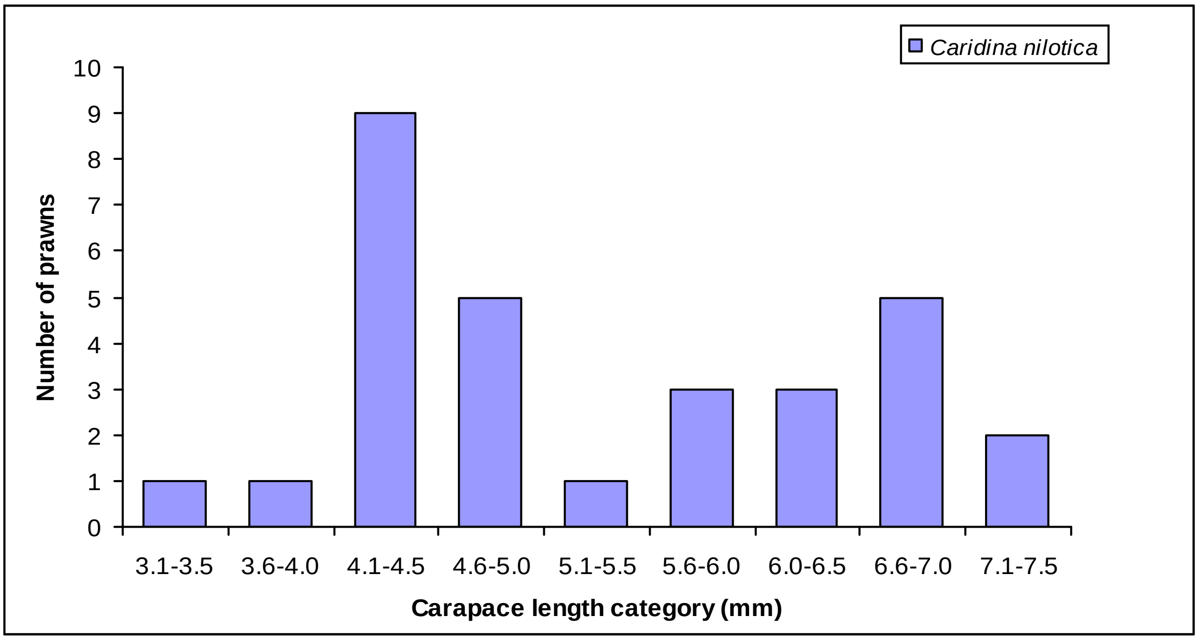

Figure 4.13: Size frequency distribution of *Caridina nilotica* recorded at the fishway exit during the period August 2007-July 2008.

4.1.3. *Varuna litterata* migration through the fishway.

A total of 303 *Varuna litterata* megalopae, of the family Grapsidae, were recorded migrating up the Mzingazi fishway. This data includes the total numbers of *V. literatta* megalopae caught in the funnel traps and in the dip net, and it excludes all the *V. litterata* megalopae and adults that were observed crawling up the wetted splash zones. The reason for excluding this data is because they were too many to count (Figure 4.14). Seventeen individuals were recorded at the fishway exit while the remainders were recorded in the fishway pools and the Saltwater Barrier. These crabs were found to be migrating from August 2007 to June 2008. Peak recruitment occurred during June and August with the highest numbers migrating during spring tides. Although *Varuna* were caught in the traps, most were observed crawling along the moist rocky and concrete surfaces just above the water level (Figure 4.14). The size ranged between 2.9 to 3.6 mm CL.

Figure 4.14: *Varuna litterata* megalopae crawling along the moist splash zone on the pool baffles and on the edge of the flow in the Mzingazi fishway between August 2007 and July 2008

4.1.4. Prawn movement and Fishway water flow velocity

The mean number of prawns (CPUE) recorded migrating through the fishway exit showed a significant negative correlation with the flow rate across the crest of the weir (Figure 4.15a), while the number of species showed a significant positive correlation with the flow velocity (Figure 4.15b). Generally, peak abundance occurred in October at a flow rate of 0.84 $m.s^{-1}$, while the highest number of species was recorded in November at a flow rate of 1.01 $m.s^{-1}$.

The mean monthly CPUE of the three dominant species migrating over the top of the fishway and the water flow in the fishway are illustrated in Figure 4.16. The catch per unit effort of *M. equidens* peaked in May and October, while *C. nilotica* was more abundant in November (Figure 4.16a and b). *Macrobrachium equidens was* more abundant at low flow velocities (0.84 $m.s^{-1}$) (Figure 4.16a). *Caridina indistincta* peaked in June and November at flow velocities of 1.54 $m.s^{-1}$ and 1.01 $m.s^{-1}$, respectively (Figure 4.16c). As shown in Figure 4.17, the number of *M. equidens* migrating over the fishway was negatively correlated with the flow, while that of *C. nilotica and C. indistincta* were positively correlated with the flow.

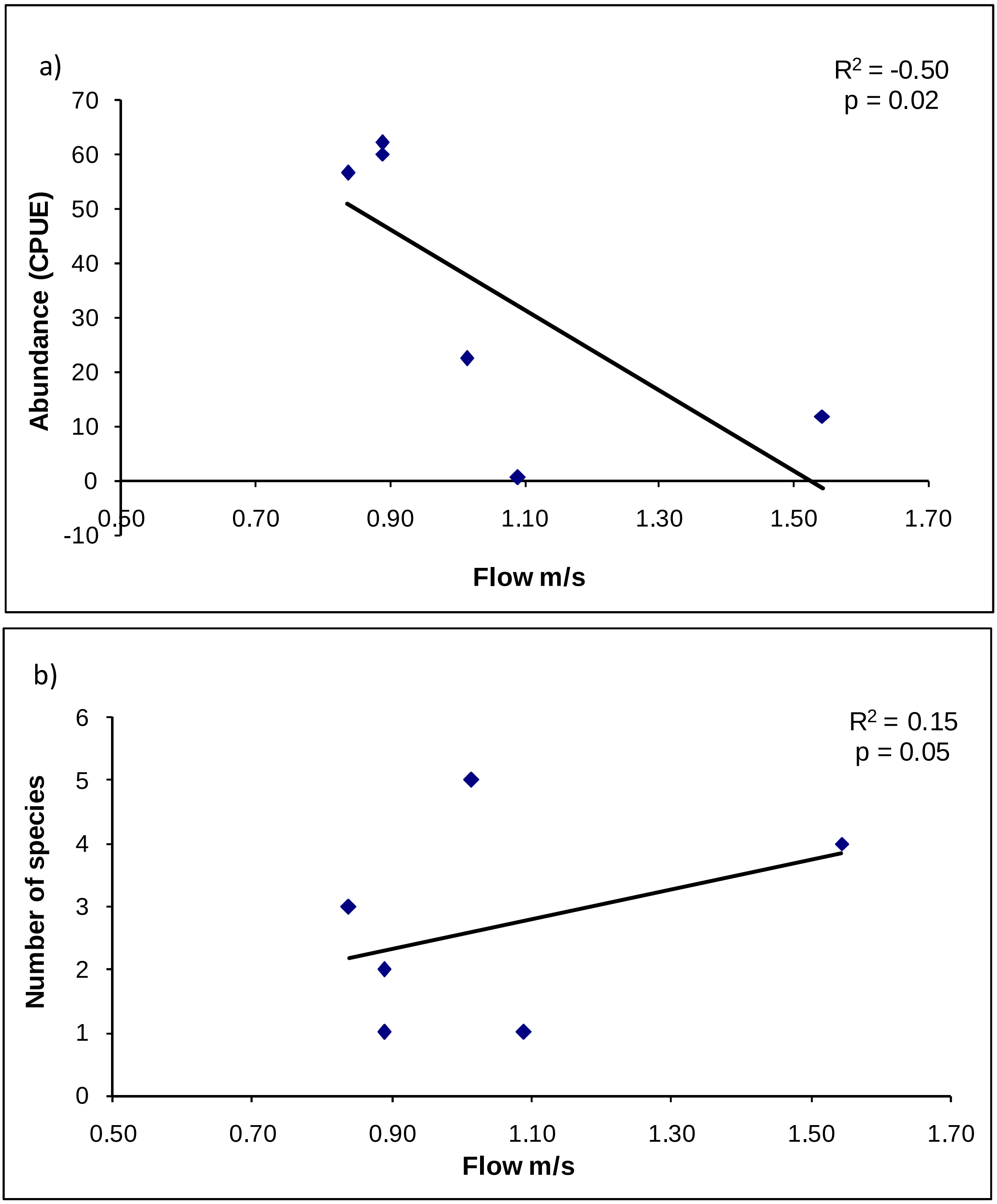

Figure 4.15: Correlation between water flow velocity and (a) abundance and (b) numbers of species recorded migrating through the Mzingazi fishway exit.

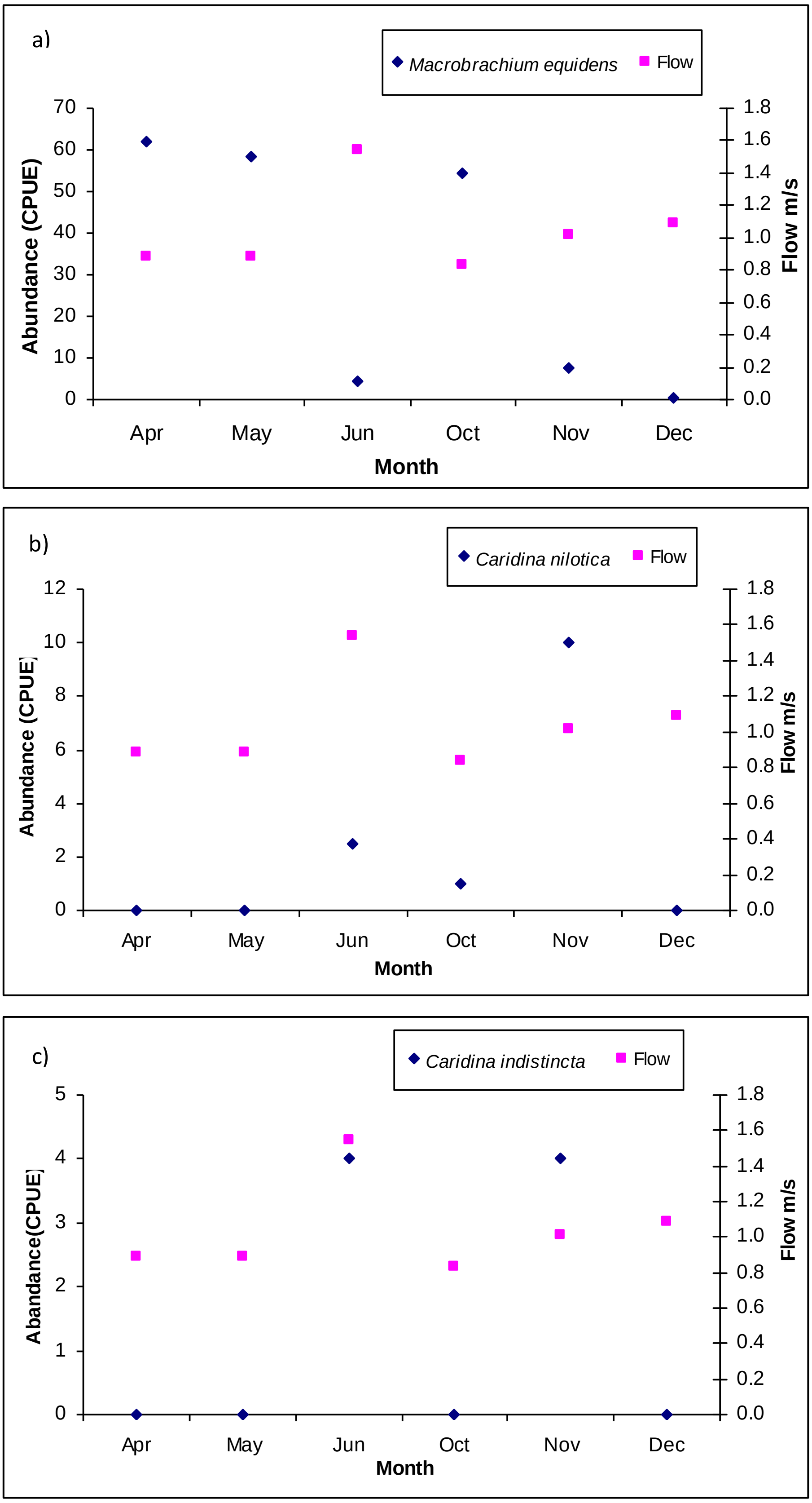

Figure 4.16: Mean abundance of dominant species recorded migrating through the Mzingazi fishway exit and water flow velocity in the fishway.

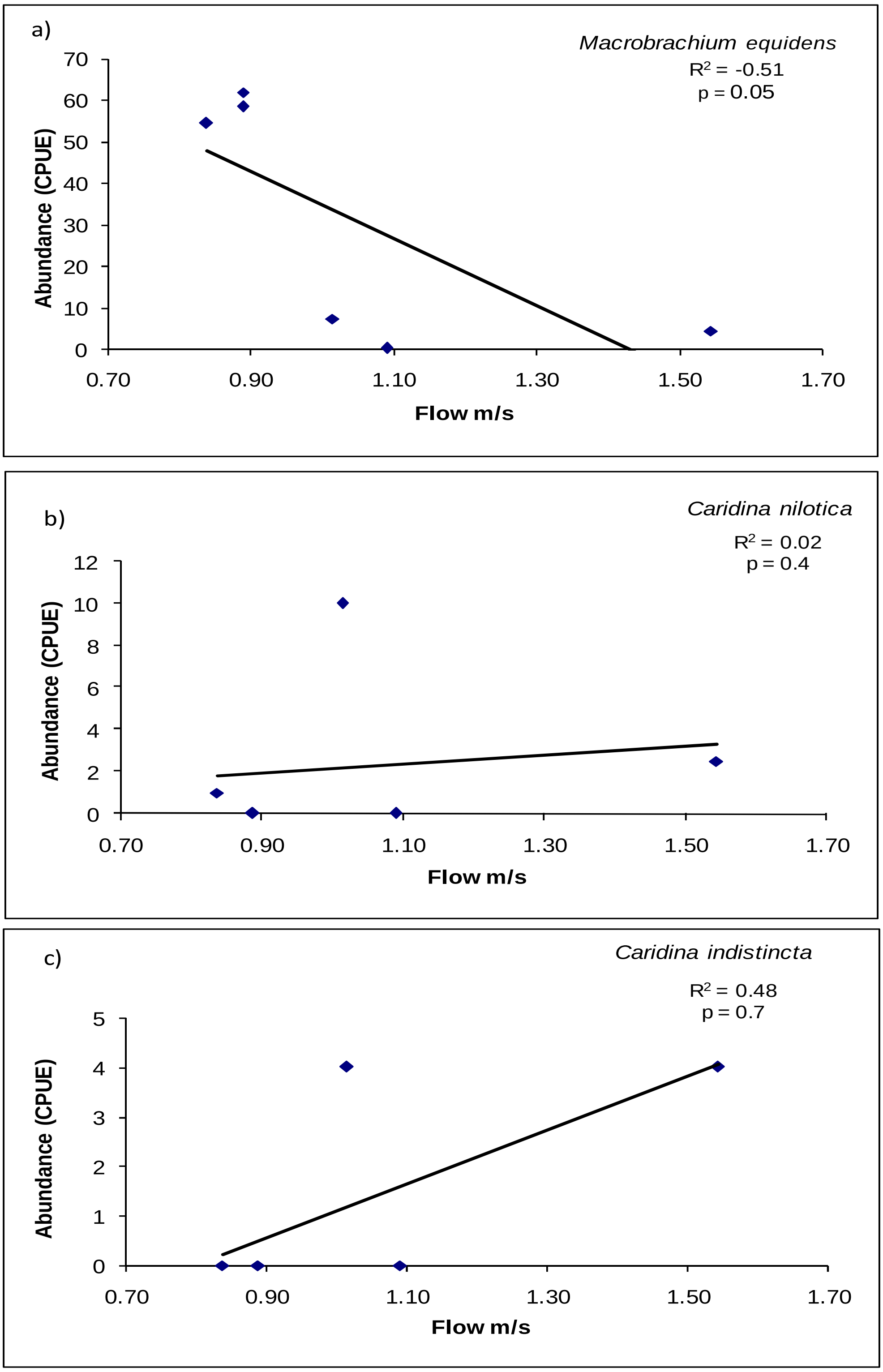

Figure 4.17: Correlation between the abundance of dominant prawn species recorded migrating through the Mzingazi fishway exit with water flow velocity.

4.2. DISCUSSION

There is limited information on the species composition, distribution and abundance of prawns in the Mzingazi River and in Lake Mzingazi with which to compare the current results, except for some unpublished data by Weerts *et al.* (2002), while Vivier (2007) provided some data concerning the Mzingazi fishway. A total of 11 prawn species was recorded in the Mzingazi River previously and the dominant species were *P. concinnus, M. idae* and *C. nilotica,* contributing an average of 58%,19% and 12% to the total catch, respectively (Table 4.7) (Weerts *et al.,* 2002). Weerts *et al.* (2002) also recorded a total of nine prawn species in Lake Mzingazi, with *C. nilotica, C. indistincta and M. lepidactylus* each contributing an average of 61%, 10% and 10% to the total catch, respectively (Table 4.7) (Weerts *et al.,* 2002). A total of three prawn species was recorded in the fishway in 2007, compared to nine species recorded in this present study. The most common species in the Mzingazi fishway during 2007, *C. nilotica* and *M. equidens,* contributed 70% and 25% of the prawns netted, while *P. concinnus* contributed only 5% of the total catch (Vivier, 2007). Prawns were also observed to crawl up and over the sloping baffles during 2007, as well as through the semi-circular holes in the baffles. A number of very large female *M. equidens* carrying eggs were also found in the pools (Vivier, 2007). In the present study, the dominant species recorded at the fishway exit were *M. equidens, C. nilotica and C. indistincta*. These prawns were abundant throughout the fishway, indicating the importance of the fishway in terms of their migration requirements. Other freshwater species, such as *M. lepidactylus, C. indistincta, C. africana* and *Palaemon capensis,* were also recorded in the Mzingazi system during this study (Table 4.7).

Cyrus *et al.* (1996) found three *Macrobrachium* species, *M. equidens, M. rude* and *M. Lepidactylus,* as well as two *Palaemon* species, *P. concinnus* and *P. debilis* in the Nhlabane system. Mastenbroek (2002) recorded a total of 307 macroinvertebrate specimens migrating upstream through the Nhlabane fishway into the lake; consisting of 303 megalopae of the crab *V. litterata* and only four *Macrobrachium* spp prawns. Two freshwater prawns, *C. nilotica* and *M. equidens* and one estuarine prawn, *P. concinnus,* were found to be the most dominant species in the Nsezi stream, a freshwater stream in Richards Bay which is estuarine influenced in its lower reaches (Vivier *et al*., 2009). *Caridina nilotica* was also found to be very common on *Eichornia crassipes* stands in Lakes Nsezi and Cubhu (Cyrus *et al.,* 1999). Cort (1983) found five *Macrobrachium* species, *Macrobrachium scabriculum,* *Macrobrachium petersii, Macrobrachium australe, Macrobrachium rude, and M. lepidactylus* in Lake Chubu on the Mhlatuze river flood plain. These five species are known to occur in freshwater streams linked to coastal lakes in the Mhlatuze system such as Lake Mzingazi (Vivier *et al.,* 2009).

There is also limited work available with regard to the distribution of marine and freshwater prawns in Richards Bay Harbour (Weerts *et al.,* 2002; Weerts *et al.,* 2003; Forbes and Demetriades, 2005). Overall dominance of prawns in Richards Bay Harbour in 1996-1997 was as follows: *Acetes erythraeus, Palaemon peringueyi* and *Metapenaeus monoceros,* contributing 67%, 7% and 4% of the total catch, respectively (Weerts et al., 2003). In 1996-1997, the tidally influenced Mzingazi Canal below the Saltwater Barrier was dominated by *Acetes erythraeus, Marsupenaeus japonicus*, and *Macropetasma africana,* each contributing 53%, 24% and 2% of the total prawn catch, respectively. *Macrobrachium* spp were also recorded in the Mzingazi canal below the Saltwater Barrier, but contributed only 2% of the total prawn catch (Weerts *et al.,* 2003). During a survey in 2005, Forbes and Demetriades (2005) found that Richards Bay Harbour was dominated by marine penaeid prawns, with *F. indicus, M. monoceros and P. monodon* contributing 86%, 10% and 3.7% of the total catch during 2005, respectively. Although the Mzingazi Canal below the Saltwater Barrier was not sampled during the present study, samples collected at the Saltwater Barrier showed that the lower Mzingazi River was dominated by *P. concinnus,* contributing 97% of the total catch, while *F. indicus* contributed only 3% of the total catch (Table 4.7). This is suggested to be related to the difference in salinity between the two sections, with the Mzingazi River showing relatively low salinities, while the Mzingazi canal has a strong marine influence.

According to Weerts *et al.* (2002), the number of crustacean species in the Mzingazi system decreased from the estuarine environment in the Mzingazi canal to the freshwater environment in the lake. Also, marine spawning species decreased in abundance from the Mzingazi canal towards the lake (Weerts *et al.,* 2002). In 2002, the Mzingazi canal (below the Saltwater Barrier) was dominated by *F. indicus and M. japonicus*, while *P. concinnus and M. equidens* dominated the Mzingazi River (above the Saltwater Barrier) (Table 4.7). These results show the difference in species composition between the Mzingazi canal (below the Saltwater Barrier) and the Mzingazi River (above the Saltwater Barrier). This is as a result of the marine character of the Mzingazi canal (below the Saltwater Barrier) with its dominant tidal fluctuations, while the Mzingazi River is often fresh (as the Saltwater Barrier restricts saltwater intrusion into the river). Although the Saltwater Barrier restricts the saltwater intrusion, penetration of seawater during spring high tides ensures that the salinity varies between 0-10.

4.2.1. Species distribution and composition

There are at least nine species of macrocrustacea (*Macrobrachium* spp and crabs) that are known to migrate between the estuary and freshwater reaches of rivers along the south and east coasts of South Africa (Bickerton, 1989). Seven species of the genus *Macrobrachium* occurs within the subtropical zone of KwaZulu-Natal, of which five, *M. scabriculum, M. petersii, M. australe, M. rude and M. lepidactylus* were recorded in Lake Chubu (Cort, 1983; Schoonbee *et al.,* 1989; de Villiers *et al.,* 1999).

Berried females of the genus *Macrobrachium* migrate from freshwater to estuarine areas to spawn because their eggs and larvae require brackish water with a salinity of at least 8 for hatching and early development (Bickerton, 1989; Cyrus *et al*., 1999). The larvae of these freshwater prawns therefore require access to brackish reaches of estuaries. Once their obligate estuarine phase is completed, the juveniles migrate back to the freshwater environment (Hart *et al.,* 2001). Adults also migrate back into freshwater after spawning in estuaries (Heath *et al.,* 2005). If there is an obstacle preventing adults and juveniles from migrating between freshwater and estuarine areas, their life cycle will be disrupted and these macrocrustacea may perish (Bickerton, 1989; Bok *et al.,* 2004 and Heath *et al.,* 2005). Prior to the construction of the Mzingazi fishway, prawns were to a large extent prevented from migrating from the lake into the estuarine environment to breed, even though some adults might have succeeded in crawling over the previous weir (Cyrus, 2000; Botha *et al.*, 2006). Although freshwater macrocrustacea can overcome instream barriers by leaving the water and crawling over and around the obstruction in the wetted area on the edge of the main flow (Mastenbroek, 2002), their migration would remain restricted, unless a fishway is incorporated into the obstacle.

Table 4.7: Prawn species recorded in the Mzingazi Canal, Mzingazi River and Mzingazi Lake from 1996 -2007 (Weerts *et al.,* 2002; Vivier, 2007) and in the present study. Data represent the averaged % contribution of each species to the total catch reported for each section; see Weerts *et al.* (2002). (* indicates that no sampling was done).

	Mzingazi Canal (below Saltwater Barrier)				Mzingazi River (above the Saltwater barrier)				Lake Mzingazi (Mzingazi fishway)			
	1996 - 1997	2002	2007*	This study*	1996 - 1997*	2002	2007*	This study	1996 - 1997*	2002	2007	This study
Acetes erythraeus	49.3											
Alpheus hippothoe	0.7											
Caridea sp.		0.4										
Caridina africana										0.4		0.6
Caridina indistincta						0.1				10.0		3.9
Caridina nilotica						12.7				61.5	70.0	7.7
Caridina typus						0.5						
Fenneropenaeus indicus		96.5						3.0				
Macrobrachuim equidens						19.0				1.3	25.0	86.3
Macrobrachuim idea						0.1				1.7		0.7
Macrobrachuim lepidactylus										10.3		
Macrobrachuim rude						1.2				0.4		
Macrobrachuim scabricilum						3.5				7.6		
Macrobrachuim sp.	2.2											
Macrobrachuim spp.						2.4				6.5		0.2
Macropetasma africana	2.2											
Marsupenaeus japonicus	23.6	1.2										
Metapenaeus monoceros	17.0					0.5						
Paleamon capensis												0.5
Paleamon concinnus						58.9		97.0			5.0	
Paleamon peringueyi	1.4											
Panaeid spp.		0.6										
Penaeus monodon						0.2						
Number of species	7	4	0	0		11	0	2	0	9	3	7

The continued existence of *Macrobrachium* prawns in an aquatic ecosystem depends on their ability to migrate between the freshwater and estuarine environments, but they spend most of their life in freshwater (Bickerton, 1989). A major breeding peak of *M. equidens* usually occurs in spring and early summer (September to December) (Bickerton, 1989), although ovigerous females were found to occur continuously over a period of nine months in St Lucia while being absent during the winter months (June, July and August). The migration of 5 mm CL juveniles back towards the freshwater environment generally occurs during the winter months and extends to spring (Bickerton, 1989). Male and female *M. equidens* grow up to 23 mm CL and 21 mm CL, respectively, with female *M. equidens* reaching sexual maturity at 9 mm CL (Bickerton, 1989). The majority of the specimens recorded at the Mzingazi fishway exit in this study were between 6 to 12 mm CL, which indicates that the majority of *M. equidens* recorded migrating up the Mzingazi fishway were juveniles and early adults. Also, the fact that some juveniles recorded at the Mzingazi fishway entrance and exit were between 5 and 5.9 mm CL clearly indicates that juveniles initiate their migration back to the freshwater environment immediately after they have completed their obligate estuarine phase.

Caridina nilotica dominated the prawn catch in the Mzingazi system (Mzingazi River, in the fishway and above the fishway) (Figure 2.1) during the present study. *Caridina nilotica* occurs in rivers and standing waters of KwaZulu-Natal, the Free-State and in the Northern Cape (Cambray, 1984). In KwaZulu-Natal *C. nilotica* was recorded in Lake Nhlabane, Nsezi and Chubu (Mastenbroek, 2002, Cyrus *et al.,* 1999). Two *Caridina* spp, *C. indistincta and C. africana* were also recorded in the Mzingazi system.

Caridina nilotica eggs hatch within 12 and 72 hours and moult for 6 to 48 hours in fresh water. The larvae reach 0.8 mm CL in 5 to 10 days at 18 to 30°C (Hart, 1980), while juveniles reach 2.5 mm CL (Hart, 1980) within 12 to 40 days, at 18°C (Hart, 1983, Hart *et al.,* 2001). The females reach sexual maturity within five weeks of hatching at around 3.6 mm CL, while they are classified as adults at 4.0 mm CL (Hart, 2001). This species reaches 6.1 mm CL in less than six months (Hart, 2001). The majority of *C. nilotica* specimens recorded at the Mzingazi fishway entrance was between 4 and 6.9 mm CL, and between 4 and 5.0 mm CL at the fishway exit. This clearly indicates that mainly adults were found migrating through the fishway, with the majority migrating within the freshwater environment for feeding and dispersal. Since there is a penetration of saline water that occurs occasionally into the lower Mzingazi River, *C. nilotica* might have avoided this brackish water and dispersed up the Mzingazi fishway during this period. However, some juveniles of < 3 mm CL were also recorded migrating through the fishway. *Caridina nilotica* breeding occurs throughout the year (Hart, 1981; Hart *et al.,* 2001), with peak density of berried females occurring in summer (Hart, 1981). The abundance of *C. nilotica* in the Mzingazi fishway peaked in winter (May and June) and again in spring (September and October). The abundance of *C. nilotica* in Lake Sibaya peaked in winter (May and June in 1975) (Hart, 1981). *Caridina nilotica* has been known to utilize a fishway as a habitat rather than a migratory route (Heath *et al.,* 2005). The fact that consistently high numbers of *C. nilotica* were recorded in the fishway during this study suggests that the species utilize the Mzingazi fishway as a habitat in which they reside and also as migratory route since they were recorded in the fishway exit.

Two *Palaemon* species, *Palaemon concinnus and Palaemon capensis,* were also recorded in the Mzingazi system. There is limited information available on the migratory movements of *P. capensis* and *P. concinnus,* with existing information available dealing with their distribution and their environmental preferences, as provided by Coetzee (1988), Coetzee (1989) and de Villiers *et al.* (1999). *Palaemon capensis* is a freshwater species and mainly occurs in coastal rivers of the Southern and Eastern Cape (Coetzee, 1988), although it has also been recorded in Lake Sibaya, in Northern KwaZulu-Natal (Coetzee, 1988). Juveniles of *P. capensis* require brackish water for growth and development (Coetzee, 1989), this being regarded as the reason why they were also recorded in Richards Bay Harbour (Weerts *et al.,* 2003).

Palaemon concinnus is a brackish water prawn that usually occupies low salinity regions and freshwater heads of estuaries (Quinn, 2000; Hart *et al.,* 2001) and completes its life-cycle within the estuarine or freshwater environment (de Villiers *et al.,* 1999). Maximum abundance of this species occurs at the points of freshwater inflow (de Villiers *et al.,* 1999). In this study *P. concinnus* was recorded at the Saltwater Barrier in the Mzingazi River, which is the transition zone from tidal conditions downstream to freshwater dominated conditions upstream. The Saltwater Barrier largely prevents saltwater from entering the Mzingazi River. Weerts *et al.* (2002) also recorded this species in the Mzingazi Canal (below the Saltwater Barrier) in 2002. *Palaemon concinnus* was previously found to migrate up the Mzingazi River through the Mzingazi fishway into Lake Mzingazi in large numbers (Vivier, 2007). *Palaemon* *concinnus* was therefore also expected to migrate through the fishway in the present study, but this species was found to be restricted to the brackish Mzingazi River which is still a favorable freshwater environment for species. The reason for their absence in the fishway during the present study is not clear.

Palaemon peringueyi is a marine species with a juvenile phase that can be completed in estuarine or marine environments (Emmerson, 1985a, Bernard and Froneman, 2005). This species is widely distributed along the South African coast, occurring from Walvis Bay on the west coast to Kosi Bay on the east coast (de Villiers *et al.,* 1999). Spawning and larval development of *P. peringueyi* occurs offshore (Emmerson, 1983); the post-larvae then enter an estuary, after which the sub-adults migrate back offshore to spawn and complete the reproductive cycle (Emmerson, 1985b). Laboratory study shows that *P. peringueyi* eggs hatch within 30 days at 20°C. An average of 0.14 mm TL is reached in one day, while 4.2 mm TL is reached in one month (Emmerson, 1985b). Individuals > 8 mm TL are classified as juveniles and individuals at 47 mm TL are classified as adults. Females start to reproduce at > 41mm TL (Emmerson, 1985b). Berried females occur in winter (July) and their abundance peaks between August and November (de Villiers *et al.,* 1999). According to Bernard and Froneman (2005), *P. peringuey*i abundance decreased with change from marine to estuarine environment since this species was found to be restricted to the lower and the middle reaches of West Kleinemonde Estuary, except for one individual found in the upper reaches (Bernard and Froneman, 2005). *Palaemon peringueyi* was the second most dominant species recorded in the Richards Bay Harbour but contributed only 1% of the total catch in Mzingazi Canal (below the Saltwater Barrier) (Weerts *et al.,* 2003). The absence of *P. peringueyi* in the Mzingazi River is probably as a result of low salinity (< 5) above the Saltwater Barrier.

Fenneropenaeus indicus was the only marine penaeid prawn recorded in the Mzingazi system during the monitoring period. It was only recorded in the lower reaches of the Mzingazi River at the Saltwater Barrier and not in the fishway. This species is common in the western Indian Ocean and usually abundant in the subtropical estuaries of KwaZulu-Natal and declines in abundance in the more temperate waters of the Eastern and Western Cape (de Villiers *et al.*, 1999). *Fenneropenaeus indicus* is a marine species that is entirely dependent on estuarine habitats to successfully complete its life cycle (Forbes and Cyrus, 1991). Weerts *et al.* (2003) also recorded *F. indicus* in Richards Bay Harbour. This species recruit into the rich feeding grounds in estuaries as early juveniles and mature before migrating out to the sea to spawn (Forbes and Demetriades, 2005).

Prawns form an essential link in marine, estuarine and freshwater ecosystems, as they are consumers of phytoplankton, debris and zooplankton. They are also common prey for fish, birds and mammals (Goudswaards *et al.,* 2006; Sahrhage, 1989). The family Atyidae, especially the *Caridina* species, feed on debris and the leaves of submerged macrophytes. They also enhance macrophyte photosynthesis and the recycling of organic matter (Flyer, 1960). *Macrobrachium equidens* are known to be omnivorous benthic feeders (Bickerton, 1989). The large numbers of freshwater prawns recorded in the fishway during this study confirm the importance of the Mzingazi fishway in enhancing the biotic composition of the lake, where prawns play an important role in the ecological functioning and nutrient cycling.

Freshwater prawns undertake longitudinal movement from lakes/rivers to estuaries as part of their life history. The weir that was built across the outlet of Lake Mzingazi in 1943 (Cyrus 2000) prevented this migration from the lake to the estuarine environment of Richards Bay Harbour (Cyrus, 2000). As a result, the life cycle of these prawns was disturbed as this barrier prevented their migration from freshwater to estuarine areas to spawn (Cyrus *et al*., 1999). In 2005, a new and improved weir with a fishway was built to promote free passage for aquatic organisms (Botha *et al.,* 2006). The weir fishway has been shown during this study to be very important to these freshwater prawns since it allows completion of their life cycle in the Mzingazi system. Barriers were also built across the outlets of Lake Nhlabane, Lake Nsezi and Lake Cubhu to increase the storage capacity of these coastal lakes (Cyrus, 2000). Nhlabane fishway was underutilized by *Macrobrachium* species, since only four individuals were recorded but large numbers of *C. nilotica* and *V. litterata* were present in the fishway throughout the study period (Mastenbroek, 2002). These results clearly show the need for fishways in other coastal lakes with barriers such as those in Lake Chubu and Nsezi to enhance the migratory route between the estuarine and freshwater environment. Weerts and Cyrus (2001) emphasised the low species richness in both Lake Chubu and Nsezi and suggested the construction of a fishway at the existing weir to improve upstream migration.

4.2.2. Longitudinal distribution

Unlike fish species, that decreased in numbers in an upstream direction from the Saltwater Barrier towards the fishway, the number of prawn species recorded increased from the Saltwater Barrier towards the fishway, with the highest number of species being recorded in the fishway itself. Similar results were recorded in St Lucia, where *Macrobrachium* abundance and species numbers increased with decreasing salinity, while penaeid prawns species numbers decreased with decreased salinities (de Villiers *et al.*, 1999).

Richards Bay Harbour plays a vital role in the life cycle of numerous marine prawn species such as *F. indicus, P. monodon, M. japonicus* and *M. monoceros* (Weerts *et al.,* 2003). Although these species were expected in the lower reaches of the Mzingazi River above the Saltwater Barrier, as they were previously recorded by Weerts *et al* (2002), the low salinities (0.5) in the Mzingazi River during this study probably prevented their migration into the upper reaches of the system. Salinities < 10 are generally unfavourable for most penaeid prawns (Forbes and Demetriades 2005). The Mzingazi River (above the Saltwater Barrier) was dominated by juveniles of only *F. indicus and P. concinnus* between 0.9 mm and 1.5 mm CL, which clearly indicates that these species use the Mzingazi Canal and Mzingazi River as a nursery area. The Bhizolo and Mzingazi Canals in Richards Bay Harbour have similar estuarine characteristics, but the Bhizolo Canal is more productive than the Mzingazi Canal (Weerts *et al.,* 2003). The Mzingazi Canal substrate consists predominantly of fine to medium grained sand (Weerts *et al.,* 2003), while the Bhizolo Canal is a mangrove-lined canal with muddy substratum (Weerts *et al.,* 2003). *Fenneropenaeus indicus*, *P. monodon* and *M. monoceros* prefer turbid, muddy areas within mangrove swamps, while *M. japonicus* usually occurs on intertidal flats of sandy mud to muddy sand (Weerts *et al.,* 2003). Mangrove areas are also known to provide important feeding and nursery habitats for many invertebrates (Weerts *et al.,* 2003). The sandy substrate combined with the absence of mangroves along the Mzingazi Canal is therefore expected to contribute to the lower prawn productivity of this area compared to the Bhizolo Canal.

The penaeid species distribution within estuaries is expected to be influenced by salinity, and to some extent temperature, although penaeid prawns, and particularly their juveniles, show relatively broad tolerances to both temperature and salinity (de Villiers *et al.,* 1999). The abundance of *F. indicus* declines at salinities below 10 (de Villiers *et al.,* 1999). This could perhaps explain why only one species of penaeid prawn was caught above the Saltwater Barrier, since the salinity above the Saltwater Barrier was only 0.5. *Palaemon concinnus* is an estuarine species and is known to occur in freshwater, although the consistently low salinities upstream of the Saltwater Barrier during this study probably also prevented higher numbers of this species from inhabiting this area.

4.4.3*.* *Varuna litterata* migration

Varuna litterata has an obligatory marine phase. Adults emigrate to the sea to spawn; larval development is also completed in the sea, followed by recruitment of megalopae into estuaries/rivers (Mackay *et al.,* 1999). During this study, *Varuna litterata* megalopae were observed in June and August migrating up the Mzingazi system at night during high tide. According to Mackay *et al.* (1999), larval recruitment of this species is generally influenced by lunar cycle and tides. Numbers of *V. litterata* megalopae in the Thukela estuary were found to increase during new moon in comparison to full moon. Recruitment into the estuary occurred mainly on the incoming tide, decline as peak flow is attained and decrease dramatically in the ebb tide (Mackay *et al.,* 1999). This coincides with the observed mass migration of this species at night during high tide in the Mzingazi system.

The fact that the majority of *V. litterata* in the Mzingazi system were 2.9 - 3.6 mm CL megalopae, indicates that they were migrating through the estuarine environment of the Mzingazi canal up to the freshwater environment of the Mzingazi River and Lake to complete their life cycle. No *V. litterata* adults were observed migrating downstream on route to the sea to spawn. In 2002, the majority of *V. litterata* individuals recorded above the Saltwater Barrier were adults. According to Weerts *et al.* (2002), recruitment of these crabs into the lake was almost certainly limited by the weir, although this does not explain the absence of megalopae during this study as they can crawl along the wetted weir (Vivier, 2007). The fact that Weerts *et al.* (2002) did not state during which part of the lunar cycle sampling was done indicates that they could have missed their migration, which coincided with high tides. After the construction of the fishway in 2006, *V. litterata* magalopae were expected to again migrate into the lake through the fishway and complete their life cycle, while adults were expected to migrate back to the sea to spawn. Downstream migration (day and night during high tides) throughout the Mzingazi system was not intensively monitored – which could explain the absence of adults in the catch.

Migration of *V. litterata* megalopae was observed in the Mzingazi system in June and August. Historical data shows that mass migration occurs during April and May on the east coast of Southern Africa; however, in June it is regarded as delayed recruitment (Mackay *et al.,* 1999). In the Nhlabane system (Lake, estuary and in the fishway) *V. litterata* megalopae were observed migrating throughout the year (Mastenbroek, 2002).

4.2.4. The efficiency of the fishway

The Mzingazi fishway provided passage for juveniles and adults of seven freshwater prawn species, representing the families Atyidae and Palaemonidae, and one crab species (family Grapsidae, species *Varuna litterata*), which successfully migrated through the fishway. This emphasises the importance of the Mzingazi fishway as a passage for freshwater prawns (*Macrobrachium* spp) and crabs in their migration between Lake Mzingazi and the Mzingazi River and the role the fishway will continue to play in the life cycles of these species. The fact that these carid prawns use the fishway extensively as a migratory passage to the freshwater environment of Lake Mzingazi also emphasises the importance of creating suitable hydraulic conditions in the fishway, not only for fish, but also for other aquatic fauna such as prawns and crabs (*V. litterata*). Since the survival of most freshwater prawn species rely on their ability to migrate between the freshwater and estuarine components, the importance of freshwater baseflow down the fishway cannot be over-emphasized. It is likewise important to ensure that the fishway continues to operate throughout the migratory period of the species in order to maintain the river-estuary link for the life cycle of these taxa.

Macrobrachium spp larvae and *P. capensis* larvae require brackish water for growth and development (Cyrus *et al*., 1999; Coetzee, 1989). In addition, *C. nilotica* move within the freshwater environment for feeding (Flyer, 1960) and for dispersion. The lower Mzingazi River occasionally becomes brackish as a result of random saltwater penetration into the river and *C. nilotica* disperse up the fishway to avoid this saltwater. Habitat competition within the Mzingazi River might also be the reason for this species to migrate up the fishway since it was underutilised and they colonized.

The high numbers of *Macrobrachium* prawns caught during this study contrasts with what was found in the Nhlabane fishway during 2001, when only four *Macrobrachium* specimens were recorded during the entire year of sampling (Heath *et al*., 2005). This serves to indicate the importance of the Lake Mzingazi system as a prawn habitat and nursery area, and of the fishway as a migratory route for these prawns. A total of five *Macrobrachium* species have been recorded in Lake Chubu (Cort, 1989), while *M. equidens* was found in high numbers in the Nsezi stream, a freshwater stream in Richards Bay (Vivier *et al*., 2009). This emphasises the importance of these freshwater environments for prawn species to complete their life-cycle. Lakes Chubu and Nsezi currently do not have fishways across their outlets and data from the Mzingazi fishway strongly suggest that efforts should be made to have fishways built on these lakes.

The similarity in the relative sizes of prawns caught at the fishway entrance and at the top of the fishway serves to indicate that the majority of prawns that entered the fishway were able to successfully negotiate the fishway. The majority of *M. equidens* (86%) migrating through the Mzingazi fishway entrance were between 6.0-8.9 mm CL (Figure 4.3), while at the fishway exit the majority (84%) were between 6.0 and 11.9 mm CL. The majority of *C. indistincta* (74%) at the fishway entrance were between 5 to 5.9 mm CL (Figure 4.4), while at the fishway exit the majority (80%) was between 3.6 and 6.0 mm CL (Figure 4.12). The majority of *C. nilotica* (82%) at the fishway entrance was between 4.0 to 6.9 mm CL (Figure 4.5), while the majority (80%) *C. nilotica* at the fishway exit were between 4.1 and 5.0 mm CL (Figure 4.13).

4.2.5. Abiotic factors

4.2.5.1. Temperature and seasonal migration

Caridina nilotica tolerates temperatures between 10°C and 30°C (Hart, 1983; Hart *et al.,* 2001), while *Macrobrachium* spp tolerate temperatures between 15°C and 30°C (Bickerton, 1989). The water temperatures recorded in the fishway during this study were well within these limits, thus water temperature in the subtropical environment of the Mzingazi system is not expected to influence the distribution of prawns associated with the fishway. Water temperatures in the fishway ranged from 18.5°C in winter to 31.7°C in summer. Prawn migration in the system can therefore be regarded as a natural seasonal effect of recruitment and breeding, which is only indirectly affected by temperature.

The abundance of prawns in the fishway peaked during warmer months, which are September, October, and December and again during the cool months in May, June and

August. *Caridina nilotica* abundance peaked in June, August, October and December. Highest densities of berried *C. nilotica* females are known to occur in summer although they breed throughout the year (Hart, 1981). *Macrobrachium equidens* abundance in the fishway peaked in April, May and again in October. In St Lucia, recruitment was not well defined, although *M. equidens* juveniles (< 9mm CL) were most abundant in winter. The proportion of larger *M. equidens* ovigerous females (≥ 13mm CL) peaked in autumn, spring and summer in St lucia (Bickerton, 1989). The breeding peak of ovigerous females ≥ 9 mm CL occurred in early summer, although ovigerous females were recorded throughout the year except in winter (Bickerton, 1989). The peak migration period of *M. equidens* in the Mzingazi system coincided with the peak winter recruitment period and peak summer breeding period in the St Lucia system.

4.2.5.2. Water flow velocity in the fishway

The number of prawn species recorded in the fishway showed a positive correlation with water flow velocity, while abundance showed a negative correlation with water flow velocity. This implies that more species migrate under higher flows, but in lower numbers. More *Macrobrachium* species were expected during high flows that usually occur in spring and summer, which is their peak breeding period for this Genus, since peak spring and summer rainfall enhances the chances of larvae to find brackish water for growth and development (Read, 1985).

According to Mastenbroek (2002), *Macrobrachium* prawns have a limited swimming ability and tend to avoid the strong currents usually associated with most formal fishway designs. However, prawns make use of the wetted splash zones on the pool baffles and on the edges of the flow (Mastenbroek, 2002). This provides a rough moist surface, shallow water and low velocity to accommodate the climbing behaviour of these invertebrates. In the Nhlabane fishway, *Macrobrachium* prawns were trapped at low water flow volumes (2.75-4.25 l/s). During strong flows, however, there were still enough splash zones to enable prawns to crawl up the Mzingazi fishway. This could possibly be the reason for *C. nilotica* and *C. indistincta* being abundant in the fishway even during high flow velocities.
Megalopae of the freshwater crab (*Varuna litterata*) are intolerant of strong currents and avoid the strong currents linked with most fishway designs. *Varuna litterata* uses wetted splash zones on the pool baffles and on the edges of the flow to crawl up fishways

(Mastenbroek, 2002). This migration behaviour was clearly observed during the present study and by Vivier (2007), with large numbers of *V. litterata* megalopae crawling along the wetted concrete sides of the fishway (Figure 5. 14). In the Nhlabane fishway, *V. litterata* megalopae were also trapped at low water flow volumes (2.75-4.25 l/s) (Mastenbroek, 2002). During a mass upstream migration of *V. litterata* megalopae in the Hughli River, India, juveniles moved in water velocities of < 0.4 $m.s^{-1}$. At a speed of 0.5 $m.s^{-1}$ larvae left the water and travelled over damp stream side banks and stones (Ryan and Choy, 1990). The flows recorded in the Mzingazi fishway were found to be between 0.61-2.27 $m.s^{-1}$. Migration of *V. litterata* was observed in the Mzingazi system in June and August during high tide. The high flow velocities recorded in the fishway in June and August did not seem to have any negative effect on the migration of *V. litterata* in the fishway, which confirms that *V. litterata* juveniles probably used the splash zone to crawl up the fishway during high flows. According to Ryan and Choy (1990), *V. litterata* megalopae prefers calm water (< 0.4 $m.s^{-1}$) since they were found to move rapidly in slow flowing sections (0.14 $m.s^{-1}$) in the Hughli River, India.

In conclusion, the Mzingazi fishway provided migratory passage to seven prawn species between the brackish Mzingazi River and the freshwater Lake Mzingazi. These included three *Macrobrachium* species, two *Caridina* species and one *Palaemon* species. The most dominant species that were found to migrate over the crest of the fishway were *M. equidens*, *C. nilotica* and *C. indistincta*. *Macrobrachium equidens* was dominated by juveniles that have recently completed their obligate estuarine phase and were migrating back to a freshwater environment to complete their life cycle. A number of adults that were migrating back to the freshwater environment after spawning in estuaries were also found migrating through the fishway. The abundance of *M. equidens* in the Mzingazi system was as a result of the seasonal effect of recruitment and breeding that occurred in winter and spring, respectively. The majority of *C. nilotica* recorded in the fishway were adults migrating up and down the fishway for feeding and dispersion. This species used the fishway primarily as habitat and to a lesser degree as a migratory route.

CHAPTER 5

THE EFFECTS OF THE MZINGAZI FISHWAY ON THE FISH COMMUNITY OF LAKE MZINGAZI

5.1. RESULTS

5.1.1. Water physical parameters

Lake Mzingazi was monitored seasonally for a period of two years, from August 2007 to June 2009. The water salinity and conductivity recorded in the lake remained relatively constant at < 0.3 and 0.5 mS/cm, respectively, reflecting the freshwater nature of the lake. Turbidities were also very low, with an average of 0.3 NTU, which reflected the clear oligotrophic conditions in the system. Water temperature showed typical seasonal differences ranging from 21°C in winter to 29°C in summer. Lake Mzingazi was well oxygenated throughout the monitoring period, with oxygen saturation ranging between 55 to 122%, and with dissolved oxygen between 4.6 to 10 mg/l. The lowest oxygen levels were recorded in August, while the highest was recorded in June.

5.1.2. Fish community

A total of 8 821 fish, representing 16 species, was recorded in Lake Mzingazi during the monitoring period (Table 5.1 and Table 5.2). These were caught by using both seine and gill nets. The Lake fish community was dominated by the freshwater species *Glossogobius callidus, Gilchristella aestuaria* and *Tilapia rendalli* contributing 25%, 23% and 21% of the total catch, respectively (Table 5.1). The highest total catch per unit effort (CPUE) was recorded at site 1 just upstream of the fishway, while the lowest was recorded at site 2 (Table 5.1, Figure 2.3). The total number of species caught per site ranged from seven to 12, at site 5 and site 2, respectively. The highest total CPUE was recorded in spring 2008, while the lowest was recorded during winter 2009. A total of only five species was recorded during spring 2007, while 11 species were recorded during autumn 2009.

Of the 16 species recorded, only four were marine spawning species, these being the mullets *Liza macrolepis*, *Valamugil cunnesius* and *Myxus capensis* and the gerred *Gerres methueni*. These four species represent the first records of marine species in Lake Mzingazi that have successfully migrated in after completion of the Mzingazi fishway.

The majority of fish were caught by seine netting, while a total of only 25 fish representing six species were caught in the gill nets during the entire monitoring period. The gill net catches were dominated by *Clarias gariepinus, Awaous aeneofuscus* and *Oreochromis mossambicus,* which contributed 36%, 24% and 16% of the gill net catch, respectively (Table 5.2). *Valamugil cunnesius* was the only large marine fish (160 mm SL) recorded in the system, which indicates that both juvenile and adult marine fish can migrate through the fishway into the lake.

Due to the low catches in the gill nets throughout the study period, only seine net data was used for analysis of the fish community structure. There was little spatial variation in species composition between sampling sites, but more pronounced temporal variation between the eight sampling seasons. There were no significant differences between seine sampling sites with regard to mean species number (S), abundance (CPUE) (N), species richness (d), evenness (J') and diversity (H') (Table 5.3, Figure 5.1). The highest mean values in all indices (total number of species, abundance, species richness, evenness and diversity) were recorded at site 1, site 4 and site 5 (Figure 5.1, Figure 2.3), while the lowest, with the exception of evenness, were recorded at site 3 (Figure 5.1d).

In contrast, there were significant differences between sampling years (2007, 2008 and 2009) with regard to mean species richness, evenness and diversity (Table 5.3, Figure 5.2). The lowest mean values in all indices were recorded in 2007. There was an increase in the mean number of species, abundance and diversity in 2008, followed by a slight decrease in 2009 (Figure 5.2a, 5.2b and 5.2e), while mean species richness and evenness remained relatively uniform throughout the three sampling years (2007-2008) (Figure 5.2c and 5.2d).

Significant differences were also observed between the eight sampling seasons with regard to the mean number of species, abundance and species diversity, again emphasizing the strong temporal variation in species composition (Table 5.3). There was an increase in the number of species from spring 2007 to autumn 2008, followed by a slight decrease in winter 2008 and summer 2009 (Table 5.1). During winter 2009, the number of species decreased substantially. The abundance (CPUE) increased from spring 2007 to spring 2008, although there was a slight decrease in autumn 2008. In summer 2009 to winter 2009, a sharp decrease in abundance occurred (Table 5.1). The lowest values in all indices (total number of species, abundance, species richness, evenness and diversity) were recorded in spring 2007 and in winter 2009. Species richness remained uniform throughout the sampling season, except in spring 2007. The highest evenness value was in winter 2008, while the highest value for diversity was recorded in summer 2008.

The fish composition during each of the eight sampling seasons from seine netting is illustrated in Figure 5.3. The first four seasons (spring 2007- winter 2008) were dominated by different fish species. During spring 2007, *G. callidus* dominated the catch (Figure 5.3a);

summer 2008 was dominated by *Oreochromis mossambicus* (Figure 5.3b); autumn 2008 was dominated by *G. callidus* (Figure 3c), while winter 2008 was dominated by *Gilchristella aestuaria* (Figure 5.3d). From spring 2008 to winter 2009, *G. aestuaria* became the dominant species (Figure 5.3e, 5.3f, 5.3g and 5.3h). *Glossogobius callidus* was abundant throughout the monitoring period, while *H. capensis* was abundant in summer 2008 and winter 2008 (Figure 5.3b and 5.3d). *Aplocheilichthys myaposae* was scarce, although it was recorded throughout the monitoring period.

The species composition recorded at sites 1-5 (Figure 2.3) during the study period is illustrated in Figure 5.4. There were marked differences in the catch between different sites sampled (Table 5.1). Site 1 was dominated *by T. rendalli*, followed by *O. mossambicus* and *G. callidus* (Figure 5.4a). Site 2 was dominated by *G. aestuaria*, *T. rendalli* and *O. mossambicus* (Figure 5.4b). *Glossogobius callidus* increased at Site 3, replacing *O. mossambicus* as one of three dominant species. Sites 4 and 5 were both dominated by *G. callidus*. The second dominant species at site 4 was *O. mossambicus* followed by *T. rendalli* (Figure 5.4d). *Gilchristella aestuaria* was still among the dominant species at site 5, while *A. myaposae* replaced *T. rendalli* at this site (Figure 5.4e).

Table 5.1: Species list, CPUE per site and per season (Total catch per unit effort) and percentage contribution of the fish species recorded using seine netting in Lake Mzingazi during the period spring (August) 2007 to winter (June) 2009.

	Sites					**Seasons**									%
Species	S1	S2	S3	S4	S5	Spr'07	Sum'08	Aut'08	Win'08	Spr '08	Sum '09	Aut '09	Win'09	Total	Contribution
Glossogobius callidus	22.7	4.2	16.8	42.2	49.4	11.5	17.7	8.5	27.9	53.4	10.1	4.1	2.2	135.2	25.4
Gilchristella aestuaria	19.9	37.5	49.8	2.9	15.0	4.3	2.3	25.7	18.1	43.8	16.1	8.1	6.8	125.0	23.4
Tilapia rendalli	38.6	24.8	27.1	17.5	4.3		3.9	7.1	26.6	39.3	20.1	11.5	3.9	112.3	21.1
Oreochromis mossambicus	27.3	7.9	7.4	20.6	12.0	14.3	41.2	5.5	4.4	8.4	1.4	0.4		75.6	14.2
Aplocheilichthys myaposae	8.6	0.2	0.4	4.3	17.3	1.9	3.8	1.1	2.1	17.1	4.1	0.6	0.1	30.7	5.8
Pseudocrenilabrus philander	9.5	0.3	1.9	4.9	9.1	3.0	7.9	1.1	0.6	3.9	5.5	3.6	0.2	25.6	4.8
Hyporhamphus capensis		5.6	6.1	2.5			8.4	4.8	0.2	0.6	0.2			14.1	2.6
Barbus viviparus	0.1	0.1	1.0	7.8	3.8		3.6	2.3	2.5	4.1	0.2	0.1		12.8	2.4
Awaous aeneofuscus	0.4	0.1	0.1								0.4	0.1	0.1	0.5	0.1
Glossogobius giuris		0.3										0.3		0.3	0.1
Liza macrolepis	0.6									0.6				0.6	0.1
Myxus capensis	0.4		<0.1					0.2	<0.1	0.2				0.4	0.1
Clarias gariepinus				0.1				0.1						0.1	<0.1
Gerres methueni		0.1										0.1		0.1	<0.1
Croilia mossambica		<0.1										<0.1		<0.1	<0.1
Total	128.4	80.9	110.5	102.6	110.9	35.0	88.7	56.2	82.4	171.3	58.0	28.7	13.1	533.3	
Number of species	8	12	10	9	7	5	8	10	9	10	9	11	6	15	

Table 5.2: Species list, total number and percentage contribution of the fish species recorded in Mzingazi Lake during the period spring (August) 2007 to winter (June) 2009 using gill nets.

Species	Sites G1	G2	G3	G4	Total	% contribution
Clarias gariepinus	4	2	3		9	36
Awaous aeneofuscus				6	6	24
Oreochromis mossambicus		3	1		4	16
Tilapia rendalli				3	3	12
Glossogobius giuris	1			1	2	8
Valamugil cunnesius				1	1	4
Total	5	5	4	11	25	

Table 5.3: Summary statistics (ANOVA) for total species, abundance (CPUE), species richness, evenness and diversity within sites, years and seasons sampled during the period spring (August) 2007 to winter (June) 2009 in Lake Mzingazi.

	Sites			Years			Seasons		
	F	*P-value*	Significance	*F*	*P-value*	Significance	*F*	*P-value*	Significance
Total species(S)	0.27	0.89	**ns**	31.78	< 0.001	*	3.72	0.005	*
Abundance (N)	0.12	0.97	**ns**	38.33	< 0.001	*	7.43	< 0.001	*
Species richness (d)	0.28	0.89	**ns**	22.26	< 0.001	*	0.43	0.874	**ns**
Evenness (J')	0.80	0.53	**ns**	22.57	< 0.001	*	0.96	0.474	**ns**
Diversity (H')	0.12	0.98	**ns**	35.84	< 0.001	*	4.06	< 0.002	*

ns : not significant
* : significant

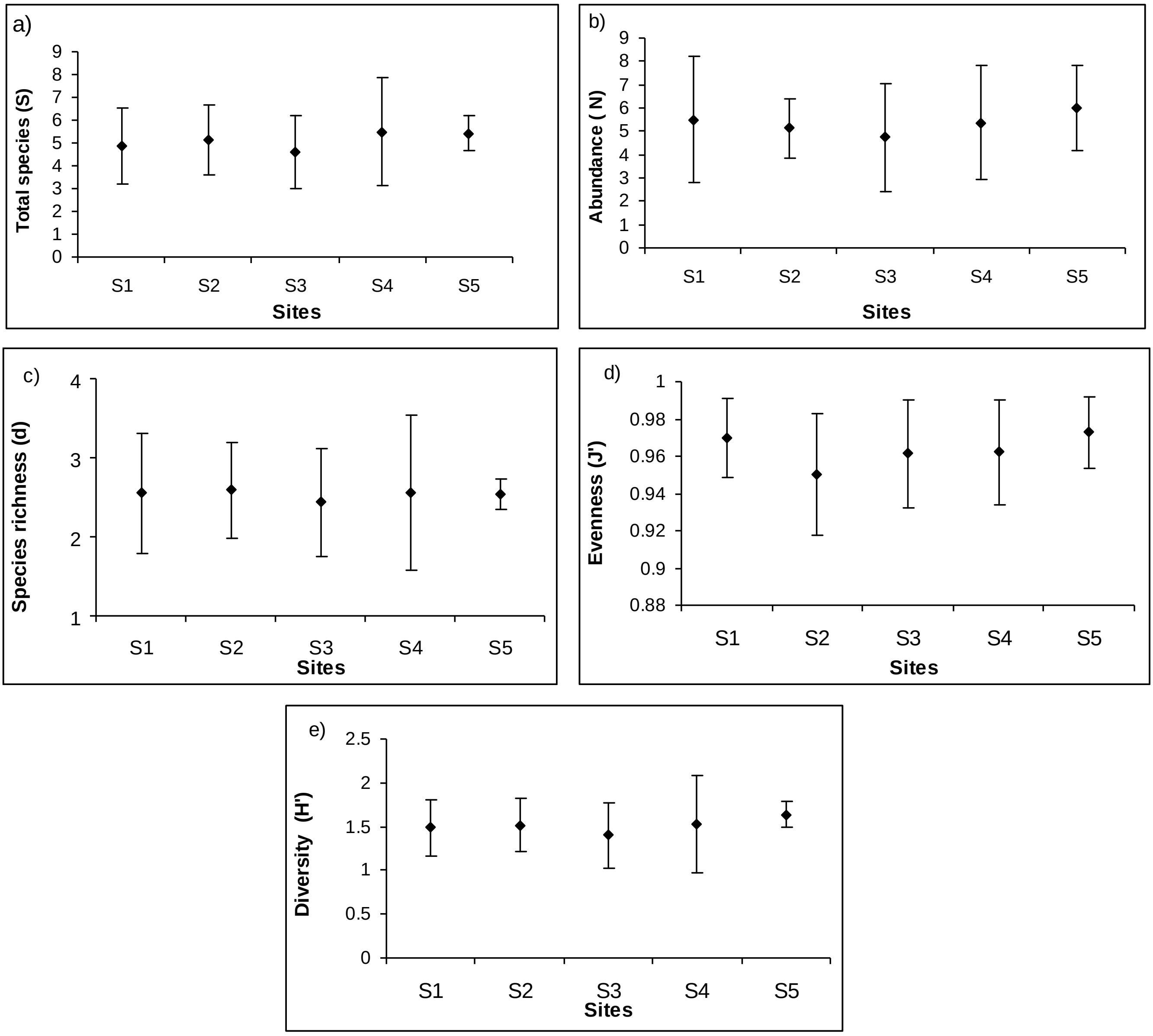

Figure 5.1: Mean (± SD) number of fish species, abundance, species richness, evenness and diversity recorded at different sites (S1-S5) in Lake Mzingazi.

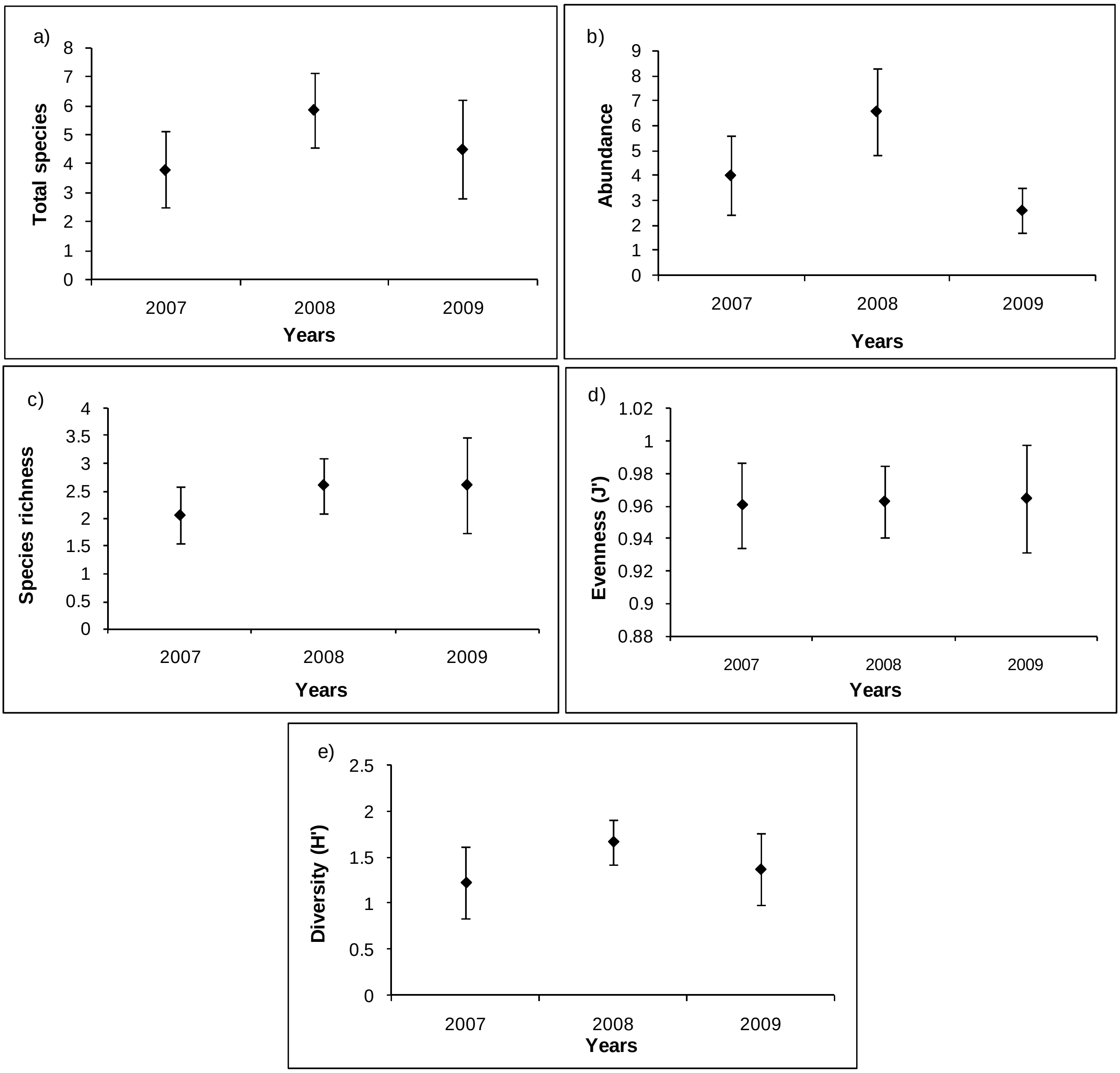

Figure 5.2: Mean (± SD) number of fish species, abundance, species richness, evenness and diversity recorded during the three sampling years (2007-2009) in Lake Mzingazi.

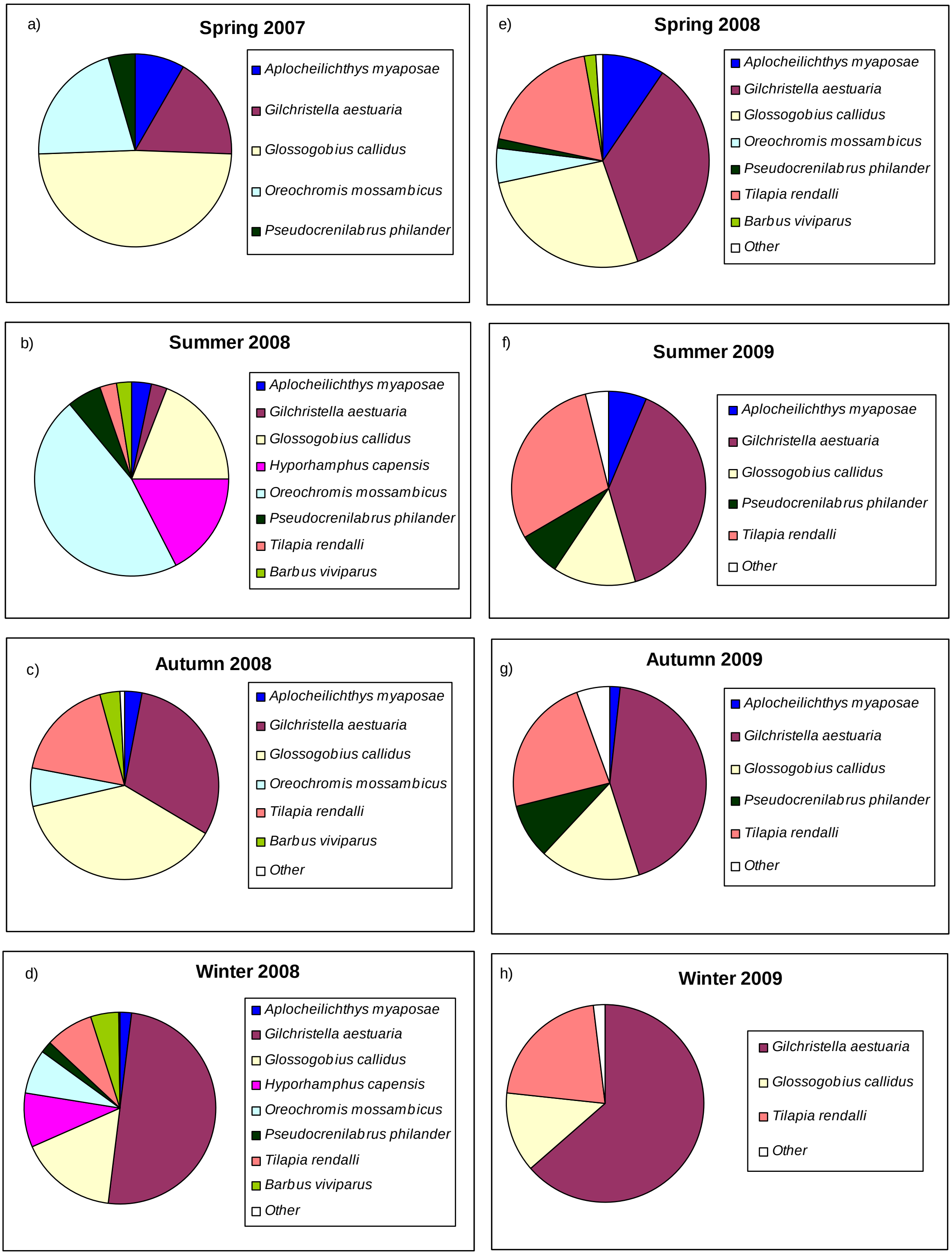

Figure 5.3: Seasonal species dominance recorded in Lake Mzingazi between August 2007 and April 2009.

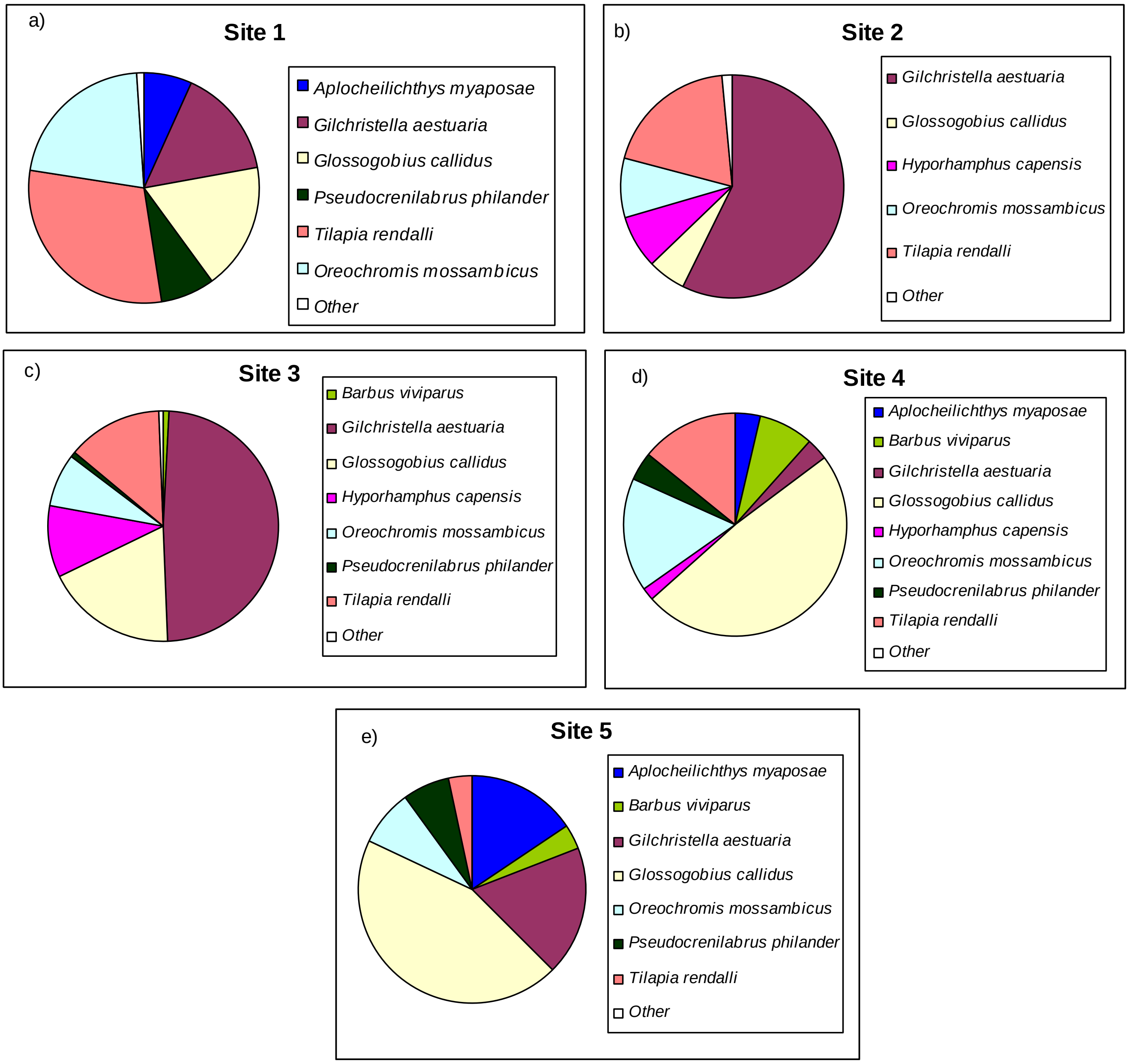

Figure 5.4: Species composition recorded at sites 1-5 in Lake Mzingazi between August 2007 and June 2009.

Analysis of similarity (ANOSIM) revealed that there were significant temporal changes in the fish community of Lake Mzingazi. There were significant differences between sampling years ($R = 0.30$, $p = 0{,}001$), but there were no significant inter-seasonal differences ($R = 0.041$, $p = 0.144$). There were also significant differences between sampling sites ($R = 0{,}18$, $p = 0{,}003$), as well as between the assemblage in South Lake and North Lake ($R = 0.11$, $p = 0.01$).

In Figure 5.5a, which is a MDS plot showing the fish composition recorded per season, there was no meaningful separation between seasons. In contrast, when coded for sampling years, the same MDS plot showed clear separation in the community structure between sampling years (Figure 5.5b), suggesting a strong temporal shift in the community between sampling years. In order to better understand the temporal shift in the fish community over the eight sampling seasons, the fish data were averaged across sampling sites (Figure 5.6). The subsequent Bray-Curtis cluster analysis showed four distinct groups at a similarity at 70%, which reflected a strong but gradual temporal shift in the species composition across the eight sampling seasons (Figure 5.6). In order to obtain a better understanding of spatial differences across sampling sites in the lake and in view of the strong temporal trend in the data, the seasonal samples were averaged out. The analysis revealed a distinct spatial gradient from the bottom of South Lake towards the top of North Lake (Figure 2.3), with three groups being formed in the community (Figure 5.7). There was no clear separation between the South (site 1-2) and the North lake (sites 3-5), mainly because site 3 was grouped with South Lake even though it was located in the North Lake. The site 1 community was separated from the group formed by sites 2 and 3 (Figure 5.7), while sites 4 and 5 formed a third group.

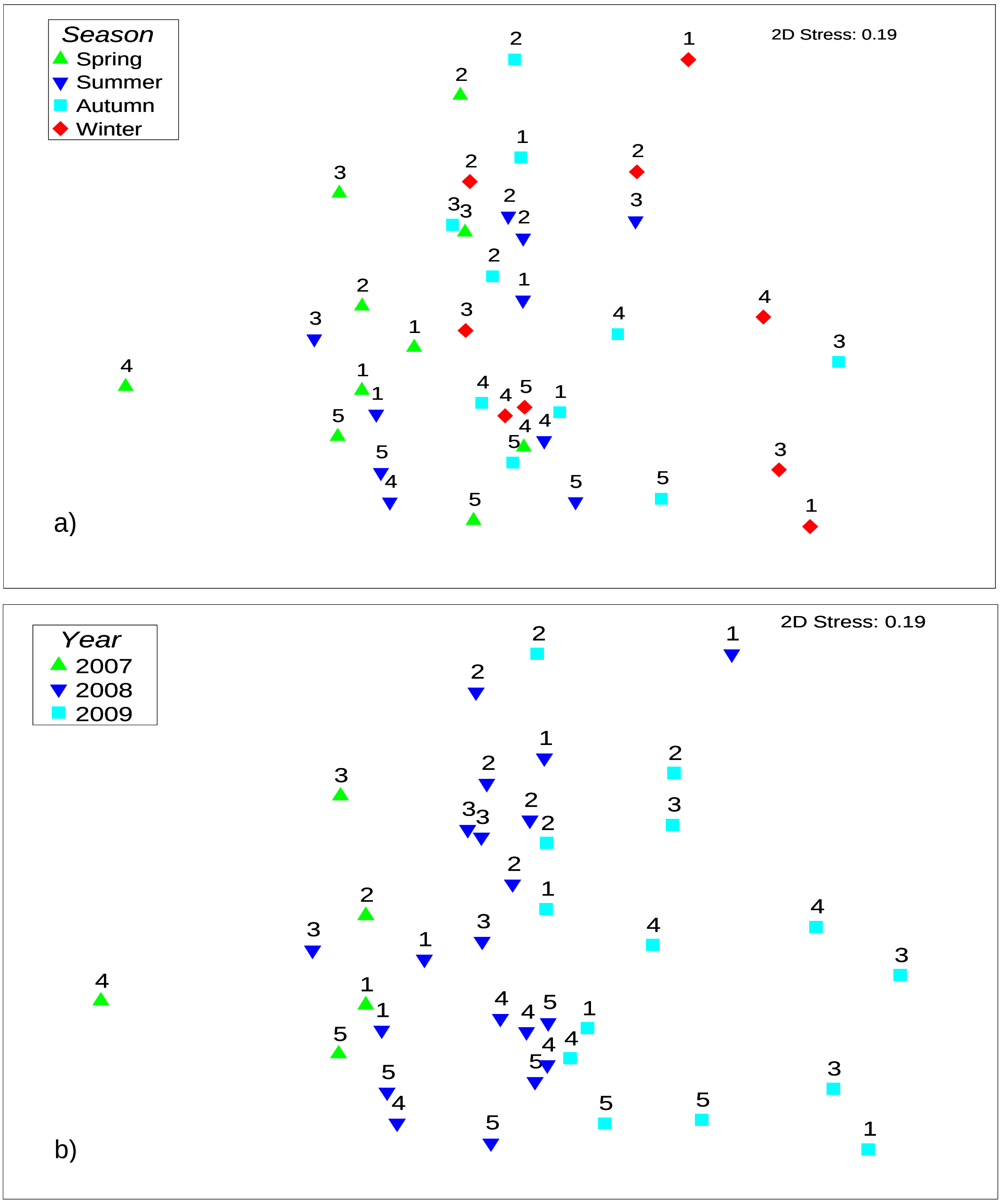

Figure 5.5: MDS ordination constructed from Bray-Curtis similarities showing the differences in community structure between (a) seasons and sites and (b) abundance between sites and years of sampling at Lake Mzingazi. Numbers indicate sampling sites.

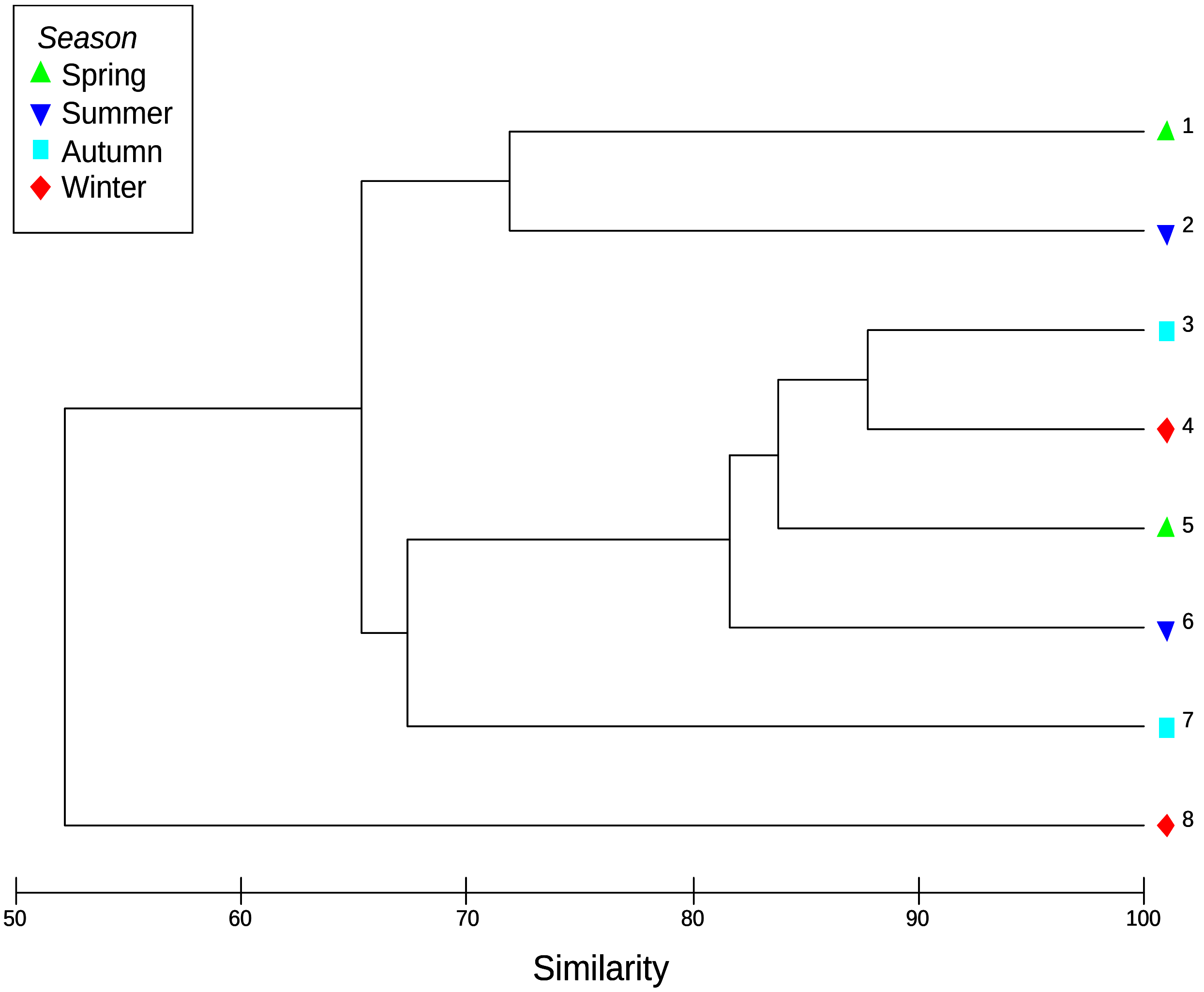

Figure 5.6: Classification constructed from Bray-Curtis similarities showing differences in the community structure between the eight sampling seasons in Lake Mzingazi. The numbers indicate the eight seasonal sampling periods, from August 2007 to June 2009.

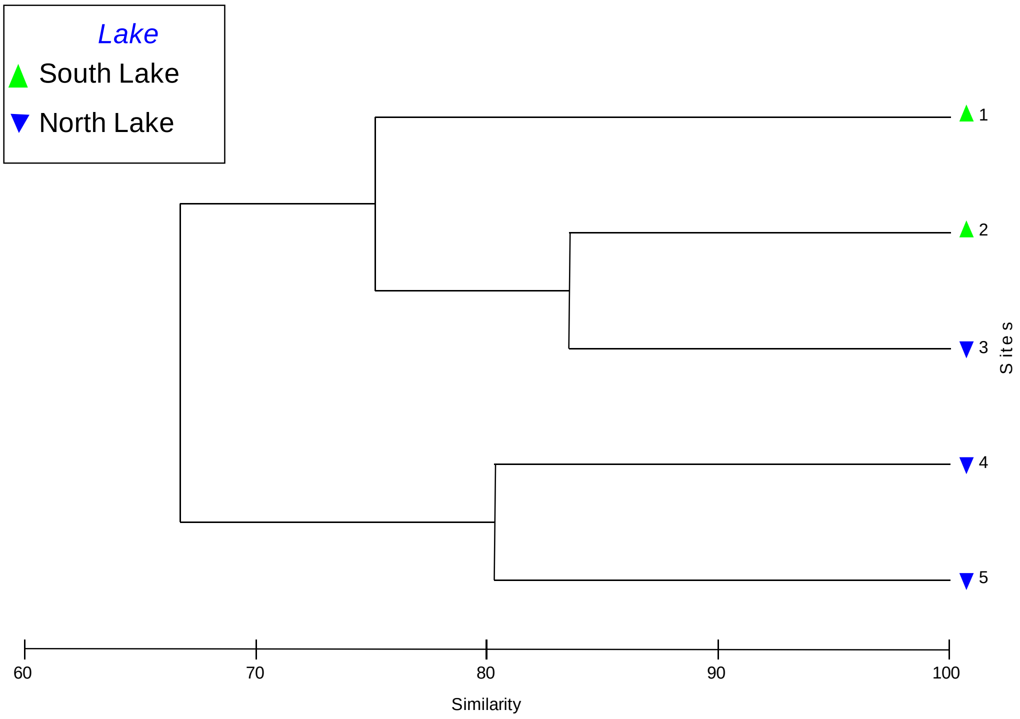

Figure 5.7: Classification constructed from Bray-Curtis similarities showing differences in the community structure and abundance between sampling sites in Lake Mzingazi.

The mean similarity within the year, season and lake compartment community groups and all the species that are most responsible for structuring these community groups are presented in decreasing order of importance in Tables 5.4, 5.5 and 5.6, respectively. *Oreochromis mossambicus, G. callidus* and *G. aestuaria* were most responsible for structuring the fish communities of Lake Mzingazi across sampling years. In 2008 and 2009, *T. rendalli* was among the three dominant species replacing *O. mossambicus* in 2007, while *P. philander* replaced *G. aestuaria* in 2009 (Table 5.4). Within seasons, *G. aestuaria, G. callidus* and *O. mossambicus* were again responsible for structuring the fish communities of Lake Mzingazi. *Tilapia rendalli* replaced *O. mossambicus* in summer, autumn and in winter because it was among the three dominant species (Table 5.5). *Gilchristella aestuaria, T. rendalli* and *O. mossambicus* were responsible for structuring fish communities of South and North Lake (Table 5.6). *Oreochromis mossambicus* was replaced by *P. philander* as the second most important species.

Table 5.4: The species, mean similary and percentage contribution of dominant fish species recorded in Lake Mzingazi between sampling years (2007-2009).

Species	Mean similarity	Contribution%
2007 mean similarity within group : 59.81		
Oreochromis mossambicus	1.15	38.86
Glossogobius callidus	0.99	24.89
Gilchristella aestuaria	0.74	18.19
Pseudocrenilabrus philander	0.65	15.89
2008 mean similarity within group : 57.06		
Gilchristella aestuaria	1.16	21.94
Glossogobius callidus	1.21	20.98
Tilapia rendalli	1.03	18.83
Oreochromis mossambicus	0.96	16.95
Pseudocrenilabrus philander	0.57	7.08
Aplocheilichthys myaposae	0.59	6.15
2009 mean similarity within group : 51.19		
Tilapia rendalli	1.11	43.04
Glossogobius callidus	0.79	26.02
Pseudocrenilabrus philander	0.58	13.36
Gilchristella aestuaria	0.70	11.55
Mean dissimilarity between 2007 & 2008 = 50.35		
Mean dissimilarity between 2007 & 2009 = 61.96		
Mean dissimilarity between 2008 & 2009 = 52.08		

Table 5.5: The species, mean similarity and percentage contribution of dominant fish species recorded in Lake Mzingazi between seasons.

Species	Mean similarity	Contribution %
Spring mean similarity within group : 50.70		
Gilchristella aestuaria	1.15	26.64
Glossogobius callidus	1.23	24.69
Oreochromis mossambicus	0.93	23.48
Pseudocrenilabrus philander	0.64	11.88
Aplocheilichthys myaposae	0.68	7.20
Summer mean similarity within group: 56.31		
Glossogobius callidus	1.16	27.00
Tilapia rendalli	0.93	17.95
Gilchristella aestuaria	0.83	15.14
Oreochromis mossambicus	0.99	14.38
Pseudocrenilabrus philander	0.79	12.94
Aplocheilichthys myaposae	0.50	4.80
Autumn mean similarity within group: 51.78		
Tilapia rendalli	1.18	36.20
Gilchristella aestuaria	0.95	19.99
Glossogobius callidus	0.87	16.41
Pseudocrenilabrus philander	0.56	13.81
Oreochromis mossambicus	0.47	6.51
Winter mean similarity within group: 45.09		
Tilapia rendalli	0.93	41.11
Glossogobius callidus	0.83	30.68
Gilchristella aestuaria	0.81	13.07
Oreochromis mossambicus	0.45	5.96
Mean dissimilarity between Summer & Winter = 50.91		
Mean dissimilarity between Spring & Winter = 57.25		
Mean dissimilarity between Autumn & Winter = 50.07		
Mean dissimilarity between Spring & Summer = 46.60		
Mean dissimilarity between Spring & Autumn = 51.20		
Mean dissimilarity between Summer & Autumn = 46.07		

Table 5.6: The species, mean similarity and percentage contribution of dominant fish species recorded in Lake Mzingazi between South and North Lake.

Species	Mean similarity	Contribution%
South Lake mean similarity within group: 52.08%		
Gilchristella aestuaria	1.14	29.35
Tilapia rendalli	1.05	24.42
Oreochromis mossambicus	0.94	21.43
Glossogobius callidus	0.78	16.35
North Lake mean similarity within group: 51.38%		
Glossogobius callidus	1.20	30.07
Tilapia rendalli	0.85	19.46
Pseudocrenilabrus philander	0.68	16.05
Gilchristella aestuaria	0.80	13.11
Aplocheilichthys myaposae	0.59	8.43
Oreochromis mossambicus	0.57	6.99
Mean dissimilarity between Groups = 51.38		

5.2. DISCUSSION

Lake Mzingazi is one of four freshwater coastal lakes in the vicinity of Richards Bay, KwaZulu-Natal (Cyrus and Wepener, 1993). Historically, the Lake Mzingazi fish fauna was characterised by a combination of freshwater and estuarine/marine associated components (Cyrus 1993; Wepener *et al.,* 1995). During a 1985 survey, Coke (1986) recorded a total of 508 fish in the Lake, representing sixteen species, of which eight were euryhaline species, while in 1993, Cyrus (1993) recorded a total of 2 401 fish representing 11 species, which included five euryhaline species. The most dominant species in both studies was the freshwater tilapia, *Oreochromis mossambicus*, even though the overall species composition was different between the two sampling periods (Coke 1986; Cyrus 1993). *Oreochromis mossambicus*, *Aplocheilichthys katangae* and *G. aestuaria* contributed 21.1%, 18.9% and 18.9% of the total catch in 1985, respectively, while the three most dominant species in 1993 were *O. mossambicus*, *P. philander* and *G. aestuaria,* contributing 34.9%, 28.6% and 17.0% of the total catch, respectively (Coke, 1986, Cyrus 1993). A total of 11 species representing four euryhaline and seven freshwater species were recorded in Lake Mzingazi in 2002 (Weerts *et al.,* 2002). The most dominant species in 2002 were *G. aestuaria, E. fusca,* and *G. callidus* contributing an average of 35%, 14% and 11%, respectively.

A total of 8 821 fish, representing 16 species, was recorded during this study. The most abundant species recorded throughout Lake Mzingazi were *T. rendalli*, *O. mossambicus, G. aestuaria* and *G. callidus. Tilapia rendalli* is a freshwater species occurring in East Coast rivers and lakes, south of the Phongolo River (Skelton, 1993). *Oreochromis mossambicus* occurs in South African coastal rivers and lakes, from the Zambezi system south to the Bushman system (Skelton, 1993, Whitfield, 1998). *Gilchristella aestuaria* occurs on the east coast from Kosi Bay and as far as the Olifants River on the west coast (Skelton, 1993). *Glossogobius callidus* is an endemic species in coastal plain rivers and estuaries in South Africa (Whitfield 1998).

Of the 16 species recorded during this study, 10 were euryhaline species, of which four were marine spawning species (Table 5.7 and Table 5.2). These euryhaline species were dominated by the estuarine resident species, *G. aestuaria, G. callidus* and *H. capensis*, contributing 25%, 23% and 2.6% of the total catch, respectively. These are all estuarine species that can breed in freshwater (Whitfield, 1998) and for this reason they are capable of proliferating in Lake Mzingazi. Of the 10 euryhaline species recorded, four were marine species that breed in the sea (Whitfield, 1998); these were *M. capensis, L. macrolepis, V.*

cunnesius and *G. methueni*. These marine species were expected to be abundant in Lake Mzingazi since they spend most of their life in the fresh headwaters of estuaries and only migrate out to sea to spawn (Whitfield, 1998).

Vivier and Cyrus (1996) reported that juveniles of 22 estuarine associated species could be expected to migrate up the Mzingazi River to Lake Mzingazi since they were previously recorded in the lake. These included four *Ambassis* species, *Elops machnata, Megalops cyprinoids*, *Myxus capensis*, *Mugil cephalus*, *Liza alata*, *Acanthopagrus berda*, three *Rhabdosargus* species, two *Monodactylus* species, *Caranx sexfaciatus*, *Croilia mossambica*, *Gilchristella aestuaria*, *Hyporhamphus capensis* and *Glossogobius callidus* (Table 5.7). Of these, only seven euryhaline species were recorded in this study (Table 5.7). It was expected that the number of euryhaline species in the lake would increase after the construction of the Mzingazi fishway in 2006. This was found to be the case, as five euryhaline species not recorded during 1993 were recorded during the present study. These were *Awaous aeneofuscus*, *G. methueni*, *G. giurus*, *Liza alata and V. cunnesius.* However, 15 of the euryhaline species expected to occur in the lake were not recorded during the present study. The absence of some of these euryhaline species, such as *Acanthopagrus berda* that was previously recorded and *Rhabdosargus sarba* that was never recorded in Lake Mzingazi even though it was among the expected list of species, could be related to the freshwater nature of the lake, as they might have been unable to tolerate totally fresh water for long periods of time. Species such as *Monodactylus argenteus* and *M. falciformis* are, however, known to enter freshwater systems (Mastenbroek 2002) and as such they were expected to utilize the fishway and migrate up into Lake Mzingazi during this study; nevertheless, they have, so far, not been recorded in the lake.

A total of five species that was previously recorded in the lake by Coke (1986) and Cyrus (1993) was absent during this study. Of these, three were euryhaline marine species (*Megalops cyrinoides, Caranx sexfaciatus* and *Elops machnata*). *Elops machnata* and *M. cyrinoides* leptocephali larvae enter the KwaZulu-Natal estuaries at between 20 and 40 mm SL and migrate to the freshwater environment, while *C. sexfaciatus* juveniles between 60 and 70 mm SL are also known to migrate to freshwater above ebb and flow of estuaries (Whitfield, 1998). *Elops* larvae were present above the Saltwater Barrier but not in the fishway, while *M. cyrinoides and C. sexfaciatus* were not recorded at the Saltwater Barrier or in the Mzingazi fishway (Table 3.12, Figure 2.1). The absence of these species in the Mzingazi system (Figure 2.1) could probably be as a result of them being unable to locate the fishway entrance and migrate upstream. Further sampling would be necessary to validate the absence of these species. The swimming abilities and migration of these species over the fishway need to be monitored. However, three estuarine species that were not on the list of expected migratory species were also found in the fishway (Table 3.12), these being *Silhouettea sibayi Oligolepis acutipennis* and *Psammogobius knysnaensis. Silhouettea sibayi* is an estuarine species that breeds both in freshwater and in estuarine environments. *Oligolepis acutipennis is an* estuarine species that breeds only in estuaries, while *Psammogobius knysnaensis is* an estuarine species that breeds in estuaries, but larvae between 20 - 30 mm SL can survive in a salinity range of 2-35. *Mugil cephalus* (Table 3.12) was also not previously recorded in Lake Mzingazi (Coke, 1986; Cyrus, 1993; Wepener *et al.,* 1995) but it was among the 22 species that were expected to migrate up the Mzingazi River (Vivier and Cyrus, 1996). The presence of these species in the fishway indicates that more species can utilize the fishway as a migratory passage and are being introduced into the lake.

Historically, a total of 27 species was found in Lake Nhlabane (Vivier, 1998), another relict estuarine lake 15 km north of Lake Mzingazi. Of these 27 species, 18 were euryhaline, while the remaining were freshwater species. The euryhaline species included category I, II and V species but the most dominant category was category II (Table 5.8). Category II species that were historically present in this lake were *Elops machnata, Acanthopagrus berda, Gerres acinaces, Lichia amia, P. commersonni, M. cephalus, V. robustus, L. alata* and *L. macrolepis* (Vivier, 1998). According to Wepener *et al.* (1995), the species composition of Lake Nhlabane changed from being euryhaline dominant to freshwater dominant after the construction of the Nhlabane weir in 1978, which prevented any further migration of euryhaline fish into the lake. The disappearance of most euryhaline species from the lake led to the dominance of cichlids such as *O. mossambicus, T. sparmanii* and *P. philander.* Following the construction of the Nhlabane fishway in 2002, 14 euryhaline species and six freshwater species were recorded migrating upstream from the estuary into the lake (Mastenbroek, 2002).

A total of 21 species was previously recorded in Lake Cubhu (Vivier, 1998); this included 11 euryhaline species belonging to category I, II and V (Whitfield, 1998). The euryhaline component was dominated by catadromous species such as A*. bicolor bicolor, A. mormorata, A. mossambica, M. cyprinoides* and *M. capensis*, while estuarine species that can breed in freshwater were represented by *E. fusca, G. aestuaria* and *C. mossambica*

(Table 5.8). Only nine species were previously recorded in Lake Mangeza, a small freshwater lake about 15 km up the Mhlathuze River, which included eight freshwater and only one euryhaline species, *Redigobius dewaalii* (Table 5.8) (Vivier, 1998).

Richards Bay Harbour, like the Mhlathuze estuary, is classified as an estuarine bay. The estuary type and its mouth condition are known to influence the species diversity of adjacent coastal lakes (Whitfield, 1998). Estuarine bays are dominated by euryhaline species because of their sheltered marine environment (Whitfield, 1998). It is known that Lake Mzingazi was therefore historically also dominated by euryhaline species. As a result of human intervention, however, that caused Lakes Mzingazi, Cubhu, Nhlabane and Nsezi to become isolated from the sea years ago through the construction of weirs across their outlets (Cyrus, 2000), the faunal communities of these lakes have become freshwater dominated. The construction of weirs on these coastal lakes changed their species diversity (which was dominated by euryhaline fish species) by preventing the recruitment of these species into the coastal lakes.

As shown in Chapter 3, the Mzingazi fishway proved to be effective by providing passage for 17 fish species during this study; these included seven (38%) freshwater species, five (31%) estuarine resident, four (25%) euryhaline marine and one (6%) catadroumous species. *Myxus capensis, E. fusca and M. falciformis* were expected to be relatively abundant in the lake; since they were the three most dominant species recorded migrating through the fishway exit (see chapter 3 for details). The reason for the low CPUE of *Myxus capensis* and the absence of *E. fusca and M. falciformis* in the fish catches of the lake is probably related to colonization of species that appear to be taking a long period to occur, and this causes a delay in dispersion throughout the lake. Only five sites were sampled across the entire lake and these few sites in the system might have caused them to be missed during sampling. This does, however, indicate that the abundance of these species in Lake Mzingazi is expected to increase over the next few years, given that the water levels in the lake are sufficiently high so that the fishway remains operational. It also emphasises the importance of long-term monitoring of the lake fish community to assess how the community changes over time due to migration of euryhaline fish through the fishway.

Table 5.7: Fish species recorded in the Mzingazi Lake from 1985-2009 (Coke *et al.,* 1986; Cyrus, 1993; Vivier and Cyrus 1996; Weerts *et al.,* 2002) [(E: Euryhaline species F: Freshwater species, *: Species recorded and ¤: Expected euryhaline taxa) - (Vivier and Cyrus, 1996; Vivier, 1998)].

Species	Category	Expected euryhaline species	Historical data			Present Study
			1985	1993	2002	2007-2009
Acanthopagrus berda	E	¤				
Ambassis gymnocephalus	E	¤				
Ambassis natalensis	E	¤	*			
Ambassis productus	E	¤				
Aplocheilichthys johnstonii	F			*		
Aplocheilichthys katangae	F		*			
Aplocheilichthys myaposae	F					*
Awaous aeneofuscus	E					*
Barbus paludinosus	F		*			
Barbus viviparus	F		*		*	*
Caranx sexfasciatus	E	¤	*			
Chanos chanos	E					
Clarias gariepinus	F		*			*
Clarias theodorae	F				*	
Croilia mossambica	E	¤		*		*
Eleotris fusca	E				*	
Elops machnata	E	¤	*			
Gerres methueni	E	¤				*
Gilchristella aestuaria	E	¤	*	*	*	*
Glossogobius callidus	E	¤		*	*	*
Glossogobius giuris	E		*			*
Hyporhamphus capensis	E	¤		*	*	*
Liza alata	E	¤				*
Marcusenius macrolepidotus	F		*			
Megalops cyprinoides	E	¤	*			
Monodactylus argenteus	E	¤				
Monodactylus falciformis	E	¤				
Mugil cephalus	E	¤				
Myxus capensis	E	¤	*	*	*	*
Oreochromis mossambicus	F		*	*	*	*
Pseudocrenilabrus philander	F		*	*	*	*
Rhabdosargus holubi	E	¤				
Rhabdosargus thorpei	E	¤				
Rhabdosargus sarba	E	¤				
Tilapia rendalli	F		*	*	*	*
Tilapia sparrmanii	F		*	*	*	
Valamugil cunnesius	E	¤				*
Total Number		21	16	10	11	16

There was little spatial variation noted in the Lake Mzingazi fish species composition, as opposed to the more pronounced temporal variation. Species composition in Lake Mzingazi was clearly dominated by freshwater species and by estuarine species that can breed in the freshwater environment (Whitfield, 1998), with these groups forming the dominant component throughout the system. The spatial variation in species composition of Lake Mzingazi was negligibly influenced by euryhaline species such as *L. macrolepis, M. capensis, G. methueni* which recruited through the fishway and which were only recorded at sites 1 and 2 at the bottom end of the lake.

There was also limited spatial separation in species composition between South (sites 1-2) and North Lake sites (sites 3-5). The Mzingazi Lake is characterised by submerged and emergent macrophytes which are rooted in shallow water (Hemens *et al.,* 1974), such as *Phragmites mauritianus, Scirpus littoralis, Ficus tricopoda*, *Barringtonia racemosa, Cyperus digitalis, Cyperus papyrus* and *Typha capensis.* The shallow, protected area, such as North Lake, provides a suitable habitat for submerged vegetation (Hemens *et al.,* 1974, Archibald *et al.,* 1983), while South Lake is ideal for emergent vegetation. Lake Mzingazi is also characterised by both sand and muddy substrata (Cyrus, 2000), with sites 4 and 5 in North Lake being muddy and sites 2 and 3 in South Lake having sandy beaches. Of the most abundant species recorded throughout the lake, *T. rendalli and O. mossambicus* prefer shallow water (Whitfield, 1998) and their breeding occurs in littoral vegetation (Skelton, 1993). *Pseudocrenilabrus philander* also favours shallow vegetated zones (Skelton, 1993). According to Cyrus (1993), many freshwater and estuarine fish species are dependent on emergent fringing vegetation for shelter. The abundance of these cichlids, such as *O. mossambicus, T. rendalli* and *P. philander,* is therefore as a result of favorable shelter and breeding conditions found in the lake. Although South Lake and North Lake are slightly different in terms of vegetation and substrata, the abundance of *O. mossambicus, T. rendalli* and *P. philander* throughout the system shows that these species were able to proliferate in all of the shallow areas throughout the lake.

Glossogobius callidus, T. rendalli, *O. mossambicus* and *G. aestuaria* were abundant throughout all sampling seasons. *Glossogobius callidus* is known to breed mainly in spring and peak densities occur in November and gradually decrease in summer (Harris, 1996; Whitfield, 1998). *Oreochromis mossambicus* starts breeding in spring and late summer (Bruton and Boltt, 1975). *Tilapia rendalli* breeds in spring (Whitfield, 1998) and broods are raised in summer (Skelton, 1993). *Gilchristella aestuaria* breeds throughout the year with peak breeding occurring in spring and summer (Cyrus *at al.,* 1996). The larvae of *G. aestuaria* were found to be the most abundant in spring and autumn (Harris, 1996). In the present study, *G. callidus* was found to be most abundant in spring, while *T. rendalli*, *O. mossambicus* and *G. aestuaria* were most abundant in spring and summer.

Table 5.8: Historical data of fish species recorded in Zululand coastal lakes (LM = Lake Mzingazi, LN = Lake Nhlabane, LC = Lake Cubhu, LMan = Lake Mangeza and LNz = Lake Nsezi) (Vivier, 1998). All fish were classified according to their estuarine dependence categories (Whitfield, 1998).

Family	Species	Common Name	EDC	LM	LN	LC	LMan	LNz
Ambassidae	*Ambassis natalensis*	Slender glassy	Ib	x				
	Ambassis productus	Longspine glassy	Ia		x			
	Ambassis sp.				x			
Anguillidae	*Anguilla bicolor bicolor*	Short fin eel	Va			x		
	Anguilla marmorata	Madagascar mottled eel	Va			x		
	Anguilla mossambica	Long fin eel	Va			x		
	Anguilla sp.				x			
Carangidae	*Caranx sexfasciatus*	Biyeye king fish	IIb	x				
	Lichia amia	Leerfish	IIa		x			
Clupeidae	*Gilchristella aestuaria*	Estuarine round-herring	Ia	x	x	x		
Eleotridae	*Eleotris fusca*	Dusky sleeper	Ia	x	x	x		
Elopidae	*Elops machnata*	Springer	IIa	x	x	x		
Gobiidae	*Awaous aeneofuscus*	Freshwater goby	IV	x			x	
	Croilia mossambica	Naked goby	Ib	x		x		
	Glossogobius callidus	River goby	Ib	x	x			
	Glossogobius giuris	Tank goby	IV	x	x	x	x	x
	Redigobius dewaalii	Checked goby	Ib				x	
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa		x			
Hemiramphidae	*Hyporamphus capensis*	Knysna halfbeak	Ia	x				
Megalopidae	*Megalops cyprinoides*	Oxeye tarpon	Vb	x	x	x		
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa			x		
	Monodactylus sp.				x			
Mugilidae	*Liza macrolepis*	Large scale mullet	IIa		x			
	Mugil cephalus	Flathead mullet	IIa		x			
	Liza alata	Diamond mullet	IIb	x	x			

Table 5.8 continued.....

Family	Species	Common Name	EDC	LM	LN	LC	LMan	LNz
Mugilidae	*Myxus capensis*	Freshwater mullet	Vb	x	x	x		x
	Valamugil cunnesius	Longarm mullet	IIa	x				
	Valamugil robustus	Robust mullet	IIa		x			
Sparidae	*Acanthopagrus berda*	River bream	IIa		x	x		
Cichlidae	*Orechromis mossambicus*	Mozambique tilapia	IV	x	x	x	x	x
	Psedocrenilabrus philander	Southern mouthbrooder	IV	x	x	x	x	x
	Tilapia rendalli	Redbreast tilapia	IV	x		x	x	
	Tilapia sparmanii	Banded tilapia	IV	x	x	x	x	
Clariidae	*Clarias gariepinnus*	Sahrptooth catfish	VI	x	x	x		x
	Clarias theodorae	Snake catfish	IV	x		x		x
Cyprinidae	*Barbus natalensis*	Scaly	VI					x
	Barbus paludinosus	Straightfin barb	VI	x	x		x	
	Barbus viviparus	Bowsripe barb	VI	x	x	x		
	Barbus sp.				x			
Cyprinodontidae	*Aplocheilichthys johnstoni*	Jonston's topminnow	VI	x				
	Aplocheilichthys katangae	Striped topminnow	VI	x		x		x
	Aplocheilichthys myaposae	Natal topminnow	VI	x	x			
	Aplocheilichthys sp.						x	
Mormyridae	*Marcusenius macrolepidotus*	Bulldog	VI	x		x		
Gerreidae	*Gerres acinaces*	Smallscale pursemouth	IIb		x			
	Gerres methueni	Evenfin pursemouth	IIb	x				
Total number				27	27	21	9	8

Multivariate analysis revealed a marked temporal shift in the fish community over the sampling period (see Figure 5.6), which was not evident in the inter-seasonal composition but rather reflected a gradual change over the entire sampling period, from the first sampling through to the last sampling session. This strongly suggests that the fish composition in the lake was gradually changing, which could be as a result of the gradual introduction of euryhaline species into the system through the fishway. Four marine spawning species were recorded in the system during this study, namely the mullets *Liza macrolepis*, *Valamugil cunnesius* and *Myxus capensis* and the gerred *Gerres methueni*. These four species represent the first records of marine species in Lake Mzingazi that have successfully migrated into the lake after completion of the Mzingazi fishway. Although these species were only recorded at low numbers, their presence in the system does suggest that, with time, their numbers will increase. It also suggests that more euryhaline species could potentially re-colonize in the lake. It is therefore suggested that the temporal variation recorded in the fish composition of Lake Mzingazi is not caused by seasonal reproductive activities of the different species, but rather occurred as a result of the migration of euryhaline species through the fishway. Sampling during this study ended during 2009, which is within 3 years after the fishway became operational. Although recruitment of euryhaline fish into the lake was therefore slower than anticipated, it should also be taken into account that low lake levels often caused the fishway to stop working for months, which would have prevented any migration into the lake.

A total of only 25 individuals, representing five species, were caught by gill nets during eight sampling sessions in this study, which suggests that gill netting is largely ineffective as fish generally avoid the deeper areas of open clear water away from emergent vegetation. *Clarias gariepinus, Awaous aeneofuscus* and *O. mossambicus* dominated the gill net catches, with the majority of fish in the gill nets measuring between 90 and 600 mm SL. Coke (1986) recorded a total of 131 large fish representing seven species using trammel and gill nets; these were *C. gariepinus, T. rendalli, T. sparrmanii M. capensis C. sexfasciatus*, *M. cyprinoides* and *O. mossambicus. Tilapia sparrmanii, M. capensis C. sexfasciatus* and *M. cyprinoides* were not recorded in the gill nets in this study. Cyrus (1993) did however report high fishing pressure in the lake in 1993. Anglers and abandoned gill nets were frequently spotted along the shore line of the lake suggesting that illegal gill-netting might contribute to the low gill net catches during the present study.

In conclusion, there was an increase in the overall abundance of euryhaline species compared to historical data (Coke, 1986; Cyrus, 1993). The fish compositon in Lake Mzingazi is gradually changing due to the migration of euryhaline species into the lake via the fishway. The fact that there is an increase in overall fish abundance in the lake and a return of historically recorded euryhaline species resulting in a gradual temporal change in species composition in the lake, indicates that the fishway is effective in allowing migration of euryhaline fish into the lake. It can therefore be concluded that the efficient operation of the Mzingazi fishway is causing a gradual change in the fish population of the lake by re-introducing euryhaline fish species into the freshwater coastal lake. Although re-colonization of euryhaline species appears to occur very slowly, it is expected that more euryhaline species will migrate into the lake and increase in abundance with time. The Mzingazi lake species composition is expected to improve towards its original state with time.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

- Twenty nine species of fish were able to locate and enter the Mzingazi fishway, which indicates that the fishway entrance is well placed and accessible for migrating fauna. The fishway was found to allow passage of 17 fish species between the estuary and the lake, indicating that the fishway is effective and efficient for upstream migration of the target species.

- Nine species of prawns and one crab species were also able to locate and enter the fishway, which indicates that the fishway entrance is accessible not only for fish species but also for macrocrustaceans. The Mzingazi fishway provided a migratory passage to seven prawn species between the brackish lower Mzingazi River and the lake. Although *C. nilotica* and *C. indistincta* were found migrating through the fishway exit into the lake, no individuals were found in the lake. This means that they use the fishway as habitat and to a lesser degree as a migratory route to the lake.

- Peak upstream migration of fish through the fishway occurred in August, September, October and December, which coincides with the peak recruitment period of most estuarine and marine spawning species. Peak migration and species abundance of both fish and macrocrustaceans were found to be a natural effect of seasonal recruitment and breeding, which was only indirectly affected by temperature.

- The number of fish species and their abundance was affected by water flow velocity down the fishway, as they decreased with an increase in flow. The abundance of the two dominant species, *Myxus capensis* and *Glossogobius callidus,* decreased with an increase in water flow velocity, while *E. fusca* increased with an increase in flow velocity.

- Unlike fish species, the number of prawn species was generally enhanced by flow as it increased with an increase in flow. The abundance of the two dominant species *C. nilotica* and *C. indistincta* increased with an increase in flow, while *M. equidens* decreased with flow.

- The design of the fishway was found to create suitable hydraulic conditions for the migration of juvenile and sub-adult fish (10 to < 100 mm SL) and macrocrustacea (3 to < 26 mm CL). Adults fish >100mm SL were found at the entrance and were observed downstream and upstream of the fishway.

- The Mzingazi fishway is susceptible to low flows caused by low lake levels (<3 mamsl) due to droughts and continued water abstraction from the lake, since the fishway dried up for approximately four months (January, February, March and July) during the 12 month monitoring period. This clearly has a negative effect on the ability of fish and macrocrustaceans to migrate into the lake.

- The efficient operation of the Mzingazi fishway is causing a gradual change in the fish population of the lake by re-introducing euryhaline fish species back into the freshwater coastal lake. Although re-colonization of euryhaline species appears to occur very slowly, it is expected that more euryhaline species will migrate into the lake and increase in abundance with time. The fishway is also allowing breeding migration of freshwater prawns into brackish waters and is therefore expected to cause an increase in the prawn community.

- The aims of this study were to monitor the operation and efficiency of the Mzingazi fishway and to monitor the effect of the fishway on the fish community of Lake Mzingazi. The hypothesis states that the Mzingazi fishway is efficient in allowing migration of marine, estuarine and freshwater fauna between the Mzingazi River and Lake Mzingazi, and the Mzingazi fishway allows migrating marine spawning fish to reach Lake Mzingazi and thereby causes a change in the fish composition of the lake. Because both fish (marine / estuarine and freshwater) and macrocrustaceans (estuarine and freshwater) were able to locate, enter and migrate through the fishway, the Mzingazi fishway was found to be causing a gradual change in the fish population of the lake by re-introducing euryhaline fish species back into the freshwater coastal lake. Both hypothese are therefore accepted.

6.2. RECOMMENDATIONS

- The operation of the fishway is entirely dependent on water levels in the lake. With ongoing water abstraction for domestic and industrial purposes, the water level in the lake is often drawn below the overflow level of 3.0 masml. The Department of Water Affairs should limit abstraction from the lake so that sufficient water can be allocated to allow the fishway to operate. The water level should never be drawn below the minimum level of 3.0 mamsl at which the fishway can still operate.

- Further long-term monitoring of the fishway is required to determine the swimming abilities and behavioural characteristics of migrating fishes with respect to the hydraulic conditions in the fishway.

- In future, the fishway should be monitored daily for a longer period of time (e.g. a month) during a high flow period to provide more detailed information on the effectiveness of the fishway during various flow regimes and hydraulic conditions, immediately after floods with flow being recorded daily and not once a month, as in this study.

- Further long-term monitoring of the fishway and the lake fish community is required to validate the absence of previously recorded euryhaline species and to determine the long-term effect of the fishway on the fish community.

- The link between upstream and downstream migration of fauna through the fishway should be carefully determined, since downstream migration fell beyond the scope of this study and because it would provide important additional information on the frequency and timing of migration of fish and macrocrustacea into the estuarine environment.

- Submerged orifices under the fishway pool weirs should be enlarged to allow fish easier passage between pools. The existing holes/orifices are too small and frequently become clogged by debris. The flow over the sloping weir between the fishway pools should be taken in consideration during the reconstruction of orifices because it may be too high and negatively affect the migration of crawling and climbing species. It is recommended that the flow should be suitable or be able to accommodate crawling and climbing species.

- The effects of weather conditions, predator avoidance and time of day on fish migration need to be considered.

- The sustainable utilization of the lake fish community should be assessed through long-term monitoring, and a local fishery could be started to benefit the local population.

CHAPTER 7

REFERENCES

7.1. REFERENCES

ACHIBALD, C.G.M., FOWLES, B.K., MULLER, M.S. and WARWICK, R.J.1983. *Nutrients survey on Lake Mzingazi*. Final Report to Steering Committee for Limnological Research and water Treatment CSIR/NWIR Project 620/97548.

ACOCKS, J.P.H. 1988. Veld types of South Africa. 3rd Edition. *Memoirs of the Botanical Survey of South Africa* **57:**1-146.

BERNARD, A.T.F. and FRONEMAN, P.W. 2005. Population dynamics of the caridean shrimp *Palaemon peringueyi* in a temperate temporarily open/closed Southern African estuary. *Estuarine Coastal and shelf Science* **63:** 73-81.

BICKERTON, I.B. 1989. *Aspects of the biology of the genus Macrobrachium (Decapoda: Claridea: Palaemonidae) in the St Lucia system*. CSIR Research Report No. 684.1-199. Stellenbosch, South Africa.

BLABER, S.J.M. and BLABER, T.G. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *Journal of Fish Biology* **17**: 143-162.

BLABER, J.S.M and CYRUS, D.P. 1981. A revised checklist and further notes on the fishes of the Kosi system. *Lammergeyer* **31**: 5-14.

BEGG, G.W. 1978. *The Estuaries of Natal*. Natal Town and Regional Planning Report **41**: 1-657.

BOK, A.H. and CAMBRAY, J.A.1995. Kowie ebb and flow fishway: monitoring of fish movement during January and February 1995.In: Bok, A.H (ed), *Fishway criteria workshop: Proceedings of a workshop to evaluate fishway monitoring results and to formulate guidelines for demining the necessity for and design of fishway in South Africa*, D'Nyala Nature Reserve, South Africa, 2-5 May 1995, DWA Report.

BOK, A., ROSSOUW, J. and ROOSEBOOM, J. 2004. *Guideline for the planning, design and operation of fishways in South Africa*: 1st Edition WRC Report No.1270/2/04.1-87

BOTHA, D., BADENHORST, D. and MULLER, I. 2006. Fishway first of its kind in South Africa. I-civil engineering. *South African Institution of Civil Engineering* **14** (10): 4-5.

BRUTON M. N. and BOLTT R. E, 1975. Aspects of the biology of *Tilapia mossambia* Peters (Pisces: Cichlidae) in a natural freshwater lake (Lake Sibaya, South Africa). *Journal of fish Biology* **7:** 423-445.

BURGER, J. 2008. Vegetation of Richards Bay municipal area, KwaZulu-Natal, South Africa, with specific reference to wetlands. M.Sc thesis, University of Pretoria, Pretoria, South Africa.

CAMBRAY, J.A. 1984. Fish populations in the middle and lower Orange River, with special reference to the effects of stream regulation. *Journal of the Limnological Society of Southern Africa* ***10***(2):37-49.

CLARKE, K.R and GORLEY, R.N. 2006. Primer *V*6: Manual user/ Tutorial. Primer-E Ltd. Plymouth Marine Lab, United Kingdom. 190pp.

CLARKE, K.R. AND WARWICK, R.M. 2001. *Changes in living communities: An approach to statistical analysis and interpretation.* 2nd edition Primer-E, Plymouth Marine Lab, United Kingdom. 160pp.

COETZEE, D.J. 1988. Collection of freshwater shrimps along the Southern coast of South Africa. *South African Journal of Zoology*. **23**(1):59-63.

COETZEE, D.J. 1989. The effect of salinity on egg hatching and early larval development in Cpa river shrimp. *South African Journal of Wildlife Research*. **19** (3): 107-111.

COKE, M.M .1986. Description and status of the population. In: Walmsley, R.D. and Grobler, J.H. (eds) *An evaluation of the impact of urban and recreational development on the ecology and usage of Lake Mzingazi* 1986, Occasional Report series No.**6**. Ecosystems Programmes, FRD, CSIR, Pretoria.

CORT, M.P.1983. Development of hatchery facilities for the breeding and larvae rearing of selected *Macrobrachium* species. M.Sc Thesis. Rand Afrikaans University, Johannesburg, South Africa.

CYRUS, D.P. 1993. *The potential impact of decreasing water levels on the fauna and flora of the Lake Mzingazi, Richards Bay*. Unpublished Costal Research Unit Zululand Report: 20pp.

CYRUS, D.P. 2000. A preliminary assessment of impacts on estuarine associated fauna resulting from an inter-basin transfer and freshwater abstraction from aquatic systems in Richards Bay area of KwaZulu-Natal, South Africa. *African Journal of Aquatic Science* **26:** 115-120.

CYRUS, D.P. 2001. The state of Knowledge of water quality and major biotic components of the Richards Bay coastal lakes. *African journal of Aquatic Science* **26**: 75-76.

CYRUS, D.P. and BLABER, S.J.M. 1987. The influence of turbidity on juvenile marine fish in the estuaries of Natal, South Africa. *Continental Shelf Research* **7**(11-12):1411-1416.

CYRUS, D.P. and FORBES, A.T. 1991. Recruitment and the origin of Penaeid prawn postlarvae in two south east Africa estuaries. *Estuarine, Coastal and Shelf Science* **33:**281-289.

CYRUS, D.P. and FORBES, A.T. 1996. Preliminary results on the role of KwaZulu-Natal harbours as nursery grounds for juveniles of selected marine organisms which utilize estuaries. *South African Journal of Wildlife Research* **26**(1): 26-34.

CYRUS, D.P. and MARTIN, T. 1988. Distribution and abundance of the benthos in the sediments of Lake Cubhu: a freshwater lake in Zululand, South Africa. *Journal of the Limnological Society of Southern Africa* **14:** 93-101.

CYRUS, D.P. and MARTIN, T.J. 1991. The importance of estuaries in life histories of flatfish species on the southern coast of Africa. *Netherlands Journal of Sea Research* **27**: 255-260.

CYRUS, D.P. and WEPENER, V. 1993. *Assessment of the potential impact of decreasing water level on fauna and flora of Lake Mzingazi, Richards Bay*. CRUZ investigational Report **13**: 1-27.

CYRUS, D.P., VIVIER, L., JERLING H.J. and CILLERS G.J. 1996. *Effect of dredger crossing on the fauna of the Nhlabane estuary*: Final report to Richards Bay minerals.

CYRUS, D.P., MARTIN T.J. and REAVELL, P.E. 1997. Salt water intrusion from Mzingazi River and its effects of adjacent swamp forest at Richards Bay, Zululand, South Africa. *Water South Africa* **23**:101-108.

CYRUS, D.P., WEPENER, V., MACKAY, C. F., CILLIERS, P. M., WEERTS, S.P and VILJOEN, A.1999. *The effects of inter-basin transfer on the hydrochemistry, benthic invertebrates and ichtyofauna of the Mhlatuze estuary and Lake Nsezi*. Report prepared for the WRC.

DAY, J.H.1981. Nature, origin and classification of estuaries. In: Day, J.H. (ed), *Estuarine ecology with particular with particular reference to South Africa*, A. A. Balkema, Cape Town. Pp 411

DAY, J.H., BLABER, S.J.M. and WALLACE, J.H. 1981. Estuarine fishes. In: Day, J.H. (ed), *Estuarine Ecology with particular reference to South Africa,* A. A. Balkema, Cape Town. pp 197-221.

DE VILLIERS, C.J., HODGSON, A.T. and FORBES, A.T. 1999. Studies on estuarine macroinveterbrates. In: Allanson, B.R. and Baird D. (eds) *Estuaries of South Africa,* Cambridge University Press, New York pp. 167-208,

EMMERSON, W.D. 1983. Tidal exchange of two decapod larvae *Palaemon pacijicus* (Caridea) and *Upogebia africana* (Thalassinidae) between the Swartkops River estuary and adjacent coastal waters. *South African Journal Zoology* 18**:** 326 - 330.

EMMERSON, W.D. 1985a. Seasonal abundance, growth and production of *Palaemon pacijicus* (Stimpson) in Eastern Cape tidal Pools. South African Journal Zoology **20**(4): 221 – 231.

EMMERSON, W.D.1985b. Fecundity, larval rearing and laboratory growth of *Palaemon pacijicus* (Stimpson) (Decapoda, Palaemonidae). *Crustaceana* **49** (3):277-289.

FLYER, 1960. The feeding mechanism of some atyid prawns of the genus *Caridina*. *Transaction of the Royal society of Edinburgh* **64**: 217-244.

FORBES, A.T and CYRUS, D.P .1991. Recruitment and origin of penaeid prawn postlarvae in two South-east African estuaries. *Estuarine, Coastal and Shelf Science* **33:**281-289.

FORBES, A.T and DEMETRIADES, N.T. 2005. *A review of the commercial, shallow water penaeid prawn resource of South Africa: Status, fisheries aquaculture and management.* University of KwaZulu-Natal, Marine and estuarine research. Report prepared for Ezemvelo KZN wildlife.1-65.

GOUDSWAARDS, P.C. WITTE, F. and WANINK, J.H. 2006 The shrimp *Caridina nilotica* in Lake Victoria(East Africa), before and after the Nile perch increase. *Hydrobiologia* **563**:31-44.

HARRIS, S.A. 1996. Larval fish assemblages of selected estuarine and coastal systems in KwaZulu-Natal, South Africa. PHD thesis, University of Zululand, KwaDlangezwa.

HARRIS S.A. and CYRUS D.P. 1997. Composition, abundance and seasonality of larval fish in Richards Bay Harbour, KwaZulu-Natal, South Africa. *Southern African Journal of Aquatic Science* **23**(1): 56-78.

HARRISON, T.D. and WHITFIELD, A.K. 1995. Fish community structure three temporarily open/closed on the Natal coast. *Ichthyological bulletin J.H.B Smith Institute of Ichthyology* **64**:21-22.

HART, R.C. 1980. Embroyonic duration and post-embryonic growth rates of the tropical freshwater shrimp *Caridina nilotica* (Decapoda: Atyidae) under laboratory and experimental field conditions. *Freshwater Biology* **10**: 207-315.

HART, R.C. 1981. Population dynamics and production of the tropical freshwater shrimp *Caridina nilotica* (Decapoda: Atyidae) in the littoral of Lake Sibaya. *Freshwater Biology* **11**: 531-547.

HART, R.C. 1983. Temperature tolerances and Southern African distribution of a tropical freshwater shrimps *Caridina nilotica* (Decapoda atyidae). *South Africa Journal of Zoology* **18**(2): 67-70.

HART, R.C. 2001. Rapid estimation of the situ growth rates of *Caridina nilorica* (Crustacea: Decapoda) in Lake Victoria: Description and pilot application of a simple, field-compatible technique. *American Society of the Limnology and Oceanography*. 692-697.

HART, R.C, STEWART, B.A. and BICKERTON, I.B. 2001. DECAPODA. In: DAY J.A., STEWART B.A, DE MOOR I.J AND LOUW A.E 2001(eds). *Guide to the freshwater invertebrates of South Africa*. Volume 4. Crustacea III. pp 87-120.

HEATH, R., BOK, A. and FOUCHE, P.S.O. 2005. *Development of criteria for the design of fishways for South African rivers and estuaries*. WRC Report No.1310/1/05. pp 3.1-3.3.

HEMENS, J. ACHIBALD, C.G.M., SIMPSON, D.E and WARWICK, R.J. 1974. *Protection of water quality in Natal impountment and Lakes Mzingazi and its catchment area*. NTRPC Natal Rivers Research Report No. 41. pp 25-38.

KELBE, B., GERMISHUYSE, T. and FOURIE, N.S.I. 2001. *Geohydrological studies of the primary coastal aquifer in Zululand*. WRC report No.720/1/01. pp 51-59.

KENSLEY, B. 1972. *Shrimps and Prawns of Southern Africa*. South African Museum. Cape Town.

KENSELY, B.1981. On the zoogeography of Southern African decapod Crustacea, with a distributional checklist of the species. *Smithsonian Contributions to Zoology* **338**:1-64.

KLAPWIJK, C. and ASSOCIATES. 1990. *Fishways in South Africa: proceeding of a workshop on the rationale and procedures for the evaluation of the necessary for fishway in South African rivers*. DWA Report No. V/EF01.142.

KLEYNHANS, C. J. 1990. Fish species that migrate and why. pp 54-59. In: *Fishways in South-Africa*. *Proceedings of a Workshop on the rationale and procedures for the evaluation of the necessity for fishway in South African rivers*. DWA Report No. V/EF01.

KOK, H.M. and WHITFIELD, A.K. 1986. The influence of open and closed mouth phrases on the marine fish fauna of the Swartvlei Estuary. *South African Journal of Zoology* **21**:309-315.

LAMBERTH, S.J. and TURPIE, J.K. 2003. The role of estuaries in South African fisheries: Economic importance and management implications. *African Journal of Marine Science* **25**:131-157.

LARINIER, M. 2000. Dams and Fish Migration contributing paper. World commission on Dams, environmental issues final draft.1-26

LARINIER, M. 2002a. Fishway General Considerations, In: Larinier, M., Travate, F. and Porcher, J. P. (eds). *Fishway: Biological basis, design criteria and monitoring*. pp 21-27. *Bulletin Francais de la Peche et al Pisciculture., 364 Supplement.*

LARINIER, M. 2002b. Biological factors to be taken into account in design of the fishways, the concept of obstruction to upstream migration, In: Larinier M., Travate, F and Porcher,J.P(eds). *Fishways: biological basis, design criteria and monitoring*, pp 28-38. *Bulletin Francais de la peche et al la pisciculture., 364 supplement.*

LARINIER, M. 2002c. Location of the fishway, *In*: Larinier M., Travate, F and Porcher,J.P (eds). *Fishways: biological basis, design criteria and monitoring*, pp 39-53. *Bulletin Francais de la peche et al la pisciculture., 364 supplement.*

LARINIER, M. 2002d. Pool fishways, Pre-barrages and natural bypass channels. In: Larinier M., Travate, F and Porcher, J.P (eds). *Fishways: biological basis, design criteria and monitoring*, pp 54-82. *Bulletin Francais de la peche et al la pisciculture., 364 supplement.*

LEIS, J.M. and CARSON-EWART, B.M. 2002. The larvae of Indo-Pacific Shore Fishes. Identification guide to marine fish larvae. Fauna Malesiana handbook. Boston. pp 162-611.

LEIS, J.M. and TRNSKI, T. 1989. The Larvae of Indo-Pacific Shore Fishes. Honolulu; University of Hawaii Press. 244 pp.

MACKAY, C.F., CYRUS, D.P. and NEWMAN, B.K. 1999. *Recruitment of Varuna litterata megalopae into the Thukela estuary and the implication of reduced river runoff.* CRUZ investigational Report No. **82:** 1-27.

MARAIS, J.F.K and BAIRD, D. 1980. Seasonal abundance, distribution and catch per unit effort of fishes in Swartkops Estuary. *South African Journal of Zoology* **15**:66-71.

MASTENBROEK, W.K .2002. Fish and Macro-inverterbrate migrating through a fishway on the Nhlabane estuary in Kwazulu-Natal, South Africa. Unpl. M.Sc Thesis. University of Natal.

MCDOWALL, R.M. 1996. Freshwater fishes of Southern-Eastern Australia. Sydney: Reed Books 257pp.

MORGEN D.L and BEATTY S.J. 2006. Use of vertical slot fishway by galaxiids in Western Australia. *Ecology of Freshwater Fish* **15**:500-509.

NEIRA, F.J., MISKIEWICZ, A.G. and TRNSKI, T. 1998. Larvae of temperate Australian fishes.Laboratory Guide for larval fish identification. University of Western Australia Press,Nedlands. 24-422pp.

PAYNE, A.I.L and CRAWFORD R.J.M. 1989. *Oceans of life of Southern Africa*. Vlaeberg, Cape Town.

PORCHER, J.P. and TRAVADE, F. 2002. Fishway Basis, Limits and Legal considerations. *In*: Larinier, M., Travate, F. and Porcher, J.P. (eds). *Fishway: Biological basis, design criteria and monitoring*. pp 9-20. *Bulletin Francais de la Peche et la Pisciculture., 364 Supplement.*

QUINN, N. 2000. *Mhlatuze system ecological reserve study: Report on Estuary, Freshwater Requirements Mhlatuze Estuary*. DWA Main Report W120-00-1499.

READ, G.H.L.1985. Factors affecting the distribution and abundance of *Macrobrachium petersi* (Hilgendorf) in the Keiskamma River and Estuary, South Africa. *Estuarine, Coastal and shelf Science* **21**:313-324.

REAVELL P.E and CYRUS D.P. 1989. Obervations on macrocrustacea of coastal lakes in the vicinity of Richards Bay, Zululand, South Africa. *South African Journal of Aquatic Sciences* 15: 103-128.

RYAN, P.A. and CHOY, S.C.1990. Observations on the mass upstream migration of *Varuna litterata* (fabricius) megalopae (Decapoda,Brachyura,Grapsidae) in Fiji. *Crustaceana* **58**(3): 40-41.

SAHRHAGE, D. 1989. Antartic Krill fisheries: potential resources and ecological concerns. In: Caddy. J.F. (eds) Marine invertebrates fisheries: their assessment and management. Wiley, New York. 13-33.

SCHOONBEE H.J, CORT M, FERREIRA, J.T. and VISSER, J.G.J .1989. Species records of the river prawn *Macrobrachium* (Decapoda,Natantia,Palaemonidae) from Lake Cubhu, Zululand, Natal. *Water South Africa* 15: 49-51.

SELLESLAGH, J. and AMARA, R. 2008. Environmental factors structuring fish composition and assemblages in a small macrotidal estuary (eastern English Channel). *Estuarine, Coastal and Shelf Science* **79**: 507-517.

SKELTON, P.H.1977. *South African red databook*. South African National Scientific Programmes Report No. **14**: 34-36

SKELTON, P.H.1990. Importance of fishways in South African rivers from conservation perspective. In: Klapwijk, C. and Associate. (eds), *Fishways in South Africa: Proceeding of a workshop on the rationale and procedures for the valuation of the necessary for fishway in South African rivers*. DWA Report No. V/EF01. pp 76-81.

SKELTON, P.H.1993. A complete guide to the Freshwater fishes of Southern Africa. 1St edition. Southern publishes. Halfway house. pp 81-368.

SMITH, M.M. and HEEMSTRA, P.C.1986. Smith' Sea Fishes. Macmillan South Africa, Johannesburg, STUART, I.G AND BERGHUIS, A.P. 2002 Upstream passage of fish through a vertical-slot fishway in Australian subtropical river. *Fisheries Management and Ecology* **9:** 111-222.

STRYDOM, N. A. 2002. Dynamics of early stage fishes associated with selected warm temperate estuaries in South Africa. PhD Thesis. Rhodes University.

STRYDOM, N. A. and WHITFIELD, A. K. 2000. The effects of a single freshwater release intothe Kromme Estuary. 4: Larval fish response. *J.L.B Smith Institute of Ichthyology* **26**: (3)319-328.

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 South Africa* 28**(2)**: 191-206.

VAN TONDER, G.J., BOTHA, J.F AND MULLER, J.L.1986. The problem of sea water intrusion near Lake Mzingazi at Richards Bay. *Water South Africa* **12**(2): 83-88.

VIVIER, L. 1998. Mhlathuze Ecological (Quantity) reserve study, Lake Water requirements (LWR). Institution for Water Research Report.7.31-7.3.23.

VIVIER, L. 2007. *Lake Mzingazi gauging weir fishway: report on short-term monitoring programme*. Unpublished CRUZ Report. 9pp.

VIVIER, L. and CYRUS, D.P. 1996. *Design a Fishway for the Mzingazi River Saltwater Barrier.* CRUZ Report No. **33**: 1-12.

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 damage. *Water South Africa* **25**(4):533- 542

VIVIER, L. and CYRUS, D.P.2001. Juvenile fish recruitment through wave-overtopping into a closed subtropical estuary. *African Journal of aquatic Science* **26**:109-113.

VIVIER, L., CYRUS D.P., JERLING, H.L. and CILLIERS, G.J.1998*. Effect of the dredger crossing on the Nhlabane Estuary*. CRUZ Investigational Report No. 57.

VIVIER, L., CYRUS, D.P. AND OWEN, R.K. 2009. *Ecological Status of the Nsezi Stream*. CRUZ Investigational Report No. 128: 1-29.

WALLACE, J.H.1975. *The estuarine fishes of the east Coast of South Africa. Part III.Reproduction* Oceanographic Research Institute Invesigational Report **41**: 5-15.

WALLACE, J.H. and VAN DER ELST, R.P.1975. *The estuarine fishes of east coast of South Africa. Part IV. Occurrence of juveniles in estuaries. Part V. Ecology, estuarine dependence and status.* Oceanographic Research Institute Investigational Report **42**: 5-13.

WEERTS, S.P. and CYRUS, D.P. 2001. The Ichthyofauna of the Mhlathuze coastal lakes some preliminary results. *African Journal of Aquatic Science* **26**: 99-107.

WEERTS, S. P., MACKAY C.F., BUTHELEZI, P.P. AND CYRUS, D.P. 2002. *Investigation of the necessity for a fishway between Lake Mzingazi and the marine environment.* CRUZ Report 96:8-38.

WEERTS, S. P., CILLIERS, G. and CYRUS, D. P. 2003. Estuarine macrocrustacea of Richards Bay Harbour, South Africa, with particular reference to the penaeid prawns. *African Zoology* **38**(2): 285-296.

WEPENER, V., FLEISCHER, L. and VIVIER, L. 1995. *Biomonitoring: A literature survey*. Unpublished CRUZ Report for Richards Bay Minerals. 66pp.

WHITFIELD, A.K.1992. A characterization of Southern African estuaries systems. *Southern African Journal of Aquatic Science* **18** (1/2). 89-109.

WHITFIELD, A.K.1996. A review of factors influencing fish utilization of South African estuaries. *Transactions of the Royal Society of South Africa* **51**: 115-137.

WHITFIELD, A.K. 1998. Biology and Ecology of fishes in South Africa Estuaries. *Ichythological monographs of the J. H. B Smith Institute of Ichthyology* **2**: 167-182.

WHITFIELD, A. K. and KOK, H.M.1992. Recruitment of juvenile marine fishes in to permanently open and seasonally open estuarine system on the southern coast of South Africa. *Ichythological monographs of the J. H. B Smith Institute of Ichthyology* **57:** 7-9.

WHITFIELD, A. K. and PATERSON, A.W. 2003. Distribution of fishes in a freshwater deprived Eastern Cape estuary, with particular emphasis on geographical headwater region. *Water South Africa* **29**(1):61-67.

WHITFIELD, A.K., TAYLOR R.H., FOX, C. and CYRUS, D.P.2006. Fishes and salinities in the St Lucia estuarine system-a review. *Reviews in Fish Biology and Fisheries*.1-20.

CHAPTER 8

APPENDIX

8.1. APPENDIX 1

	Temperature	Conductivity	Turbidity	Salinity	Dissolved Oxygen	% Oxygen
August	18.50	0.45	0.29	0.20	7.40	79.00
September	19.50	0.40	0.30	0.20	10.90	131.00
October	23.50	0.50	0.30	0.20	9.40	113.00
April	31.70	0.45	0.30	0.20	7.30	82.80
May	22.20	0.48	0.31	0.20	7.60	87.30
Avarage	23.08	0.46	0.30	0.20	8.52	98.62