THE ICHTHYOFAUNA AND PISCIVOROUS AVIFAUNA IN A SMALL TEMPORARILY OPEN/CLOSED EASTERN CAPE ESTUARY, SOUTH AFRICA

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Declaration

The work presented in this thesis was conducted in the Department of Zoology and Entomology, Rhodes University, under the supervision of Professor P.W. Froneman. These studies represent original work by the author and have not been submitted in any form to another University.

Abstract

The spatial and temporal patterns in selected components of the ichthyofauna and piscivorous avifauna in the small temporarily open/closed Riet River Estuary located on the eastern seaboard of southern Africa was investigated monthly over the period August 2005 to July 2006. The ichthyofauna within the littoral zone of the estuary was sampled using a 5 m seine net (8 stations) while a 30 m seine net (4 stations) was employed to sample the fish in the channel. Bird counts were made along repeat transects along the length of the estuary.

Total ichthyofaunal abundances and biomass ranged between 1.60 and 8.67 individuals m^{-2} and 0.45 to 21.76 g wwt m^{-2} within the littoral zone, and between 0.08 and 0.44 individuals m^{-2} and 0.58 and 36.52 g wwt m^{-2} in the channel of the estuary. The highest values were generally recorded during the summer months. Results of the numerical analysis indicated that the breaching events recorded over the study period did not lead to a common trend in the ichthyofaunal community. In the absence of a link to the marine environment, the ichthyofaunal community in the littoral zone was numerically dominated by the estuarine resident species, *Gilchristella aestuaria* and to a lesser extent by *Glossogobius callidus,* which collectively accounted for *ca.* 54% of the total ichthyofauna sampled. The establishment of a link to the marine environment coincided with increased numbers of marine breeding species including *Atherina breviceps* and *Rhabdosargus holubi* to total fish counts within the estuary. Hierarchical cluster analysis did not identify any spatial patterns in the community structure of the ichthyofauna in the littoral zone or channel zone of the estuary, which could likely be linked to the absence of any distinct horizontal patterns in salinity and temperature within the system.

A total of thirteen piscivorous bird species was recorded over the study period. Of the recorded species, six species were wading piscivores, four species were aerial divers and the remaining three species were pursuit swimmers. There were no significant correlations between the estimates of the ichthyofaunal abundance and biomass and bird numbers evident during the study (P> 0.05 in both cases). The Reed Cormorant (*Phalacrocorax africanus*) was the dominant species throughout the study, with a mean of 8.25 (SD ± 7.90) individuals per count. Mean values of the Pied Kingfisher (C*eryle rudis*) and Giant Kingfisher (*Megaceryle maximus*) were 3.42 (SD ± 1.20) and 1.17 (SD ± 0.60) individuals per count, respectively. The remaining species revealed mean values < 0.5 individuals per count. The highest bird numbers were recorded in winter reflecting the migration of large numbers of the Reed Cormorant into the system. Breaching events were associated with a decrease in total bird numbers, which was most likely due to loss of potential foraging habitat (littoral zone) for waders resulting from reduced water levels. Monthly food consumption by all piscivorous birds revealed large temporal variability, ranging from 26.35 to 140.58 kg per month. The observed variability could be linked to mouth phase and bird numbers.

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Chapter 1:

Introduction

The South African coastline can, on the basis of mean seawater temperature and rainfall, broadly be divided into three distinct biogeographic zones; the cool and warm temperate zones and the subtropical zone (Figure 1.1) (Whitfield, 1999a; Harrison *et al.*, 2000). The subtropical and warm temperate zones are influenced by the warm Agulhas Current while the Benguela Current influences the cool temperate zone on the west coast of South Africa (Figure 1.1) (Whitfield, 1999a). Within these zones are 258 functional estuaries (Whitfield, 2000). Based on their physiographic, hydrological and salinity gradients, the estuaries can broadly be separated into five distinct estuarine classes (Whitfield, 1992). The five classes are: estuarine bays, river mouths, estuarine lakes, permanently open systems and temporarily open/closed estuaries (Whitfield, 1992). Of the five estuarine classes, temporarily open/closed estuaries account for *ca.* 70% of all estuaries along the South African coastline (Whitfield 1992; 1996).

The catchment size of temporarily open/closed estuaries (TOCE's) is generally < 500 km^2. The low freshwater run-off as well as deposition of sand across the mouth of the estuary leads to the development of a sandbar separating the estuary from the sea (Pritchard, 1967; Whitfield, 2005). This separation from the sea often persists for extended periods of time, thus large biotic and abiotic differences between the larger permanently open systems and the smaller temporarily open/closed systems are observed (Harrison *et al.*, 2000).

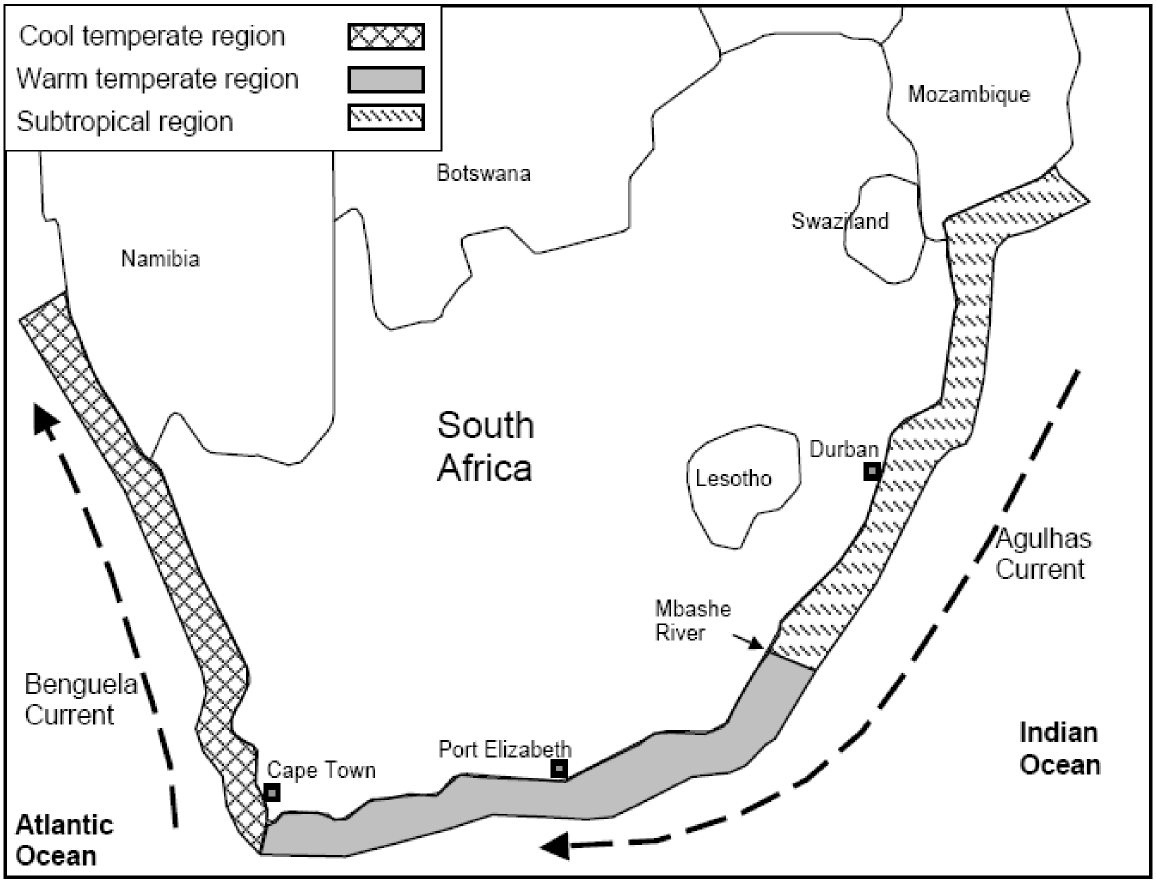

Figure 1.1: Biogeographic regions along the coast of South Africa. (After Whitfield, 1999a).

1.1. Temporarily open/closed estuaries

Temporarily open/closed estuaries account for up to 80% of all estuaries along the Eastern Cape coastline. The numerical dominance of these systems along the South African coastline contributes to these systems representing an important nursery area for a variety of marine breeding invertebrates and vertebrates with an obligate estuarine phase. The numerical dominance of these systems coupled with the increased food availability within these systems contribute to these estuaries representing important foraging grounds for both local and paleartic migrant bird species.

TOCE's in South Africa take on two forms depending on whether the back-barrier water level is higher than that of the open sea tidal levels or whether they are within range of the open sea tidal range (Harrison *et al*., 2000). The difference in elevation is determined by the elevation of the berm crest at the mouth of the estuary. Temporarily open/closed estuaries are therefore characterized as either perched or non-perched estuaries (Harrison *et al*., 2000).

Perched TOCE's are characterised by a high berm at the mouth of the estuary caused by a combination of coarse-grained barrier sediment and low wave action (Day, 1980; Harrison *et al*., 2000). Water in these estuaries is impounded at levels above the levels of most high tides (Figure 1.2). These estuaries are subject to both periods of barrier over washing when the tide exceeds the berm level, and periods of breaching when the inputs of freshwater discharge and barrier over wash exceed outputs from evaporation, seepage and evapotranspiration resulting in a surface channel being cut to permit discharge. Under conditions of breaching, the water levels and surface area of an estuary are reduced within a few hours (Cooper, 1990). The salinity in such systems is typically lowered during the closed phase and can sometimes reach limnetic (0.1 – 0.5 ‰) conditions, depending on the volume and frequency of barrier over wash (Young *et al.,* 1997; Harrison *et al*., 2000; Young and Potter, 2002). Due to existing shore dynamics, perched estuaries predominate along the southern coast of South Africa (Harrison *et al*., 2000).

Non-perched closed estuaries lack a high berm or a surface channel but are impounded either at, or close to the high tide level (Figure 1.3) (Harrison *et al.*, 2000). The beaches associated with this type of system have a dissipative gradient and a wide surf zone (Young *et al.,* 1997). The close proximity of the estuarine mouth to the high tide level means that barrier over-wash is more frequent than in perched systems and thus the waters in non-perched estuaries are typically more saline (Young *et al.,* 1997; Harrison *et al*., 2000). When freshwater inflow increases, a surface connection with the sea is often established and tidal regimes dominate system functioning (Harrison *et al.*, 2000). Non-perched systems exhibit constancy in their water level and surface area, thus providing a more stable habitat than perched systems (Young *et al.,* 1997; Harrison *et al*., 2000).

The closed phase of non-perched temporarily open/closed estuaries generally leads to mesohaline conditions (5-18 ‰) prevailing throughout the system. During periods of high rainfall, however, limnetic conditions prevail, while during periods of drought or high evaporation, hypersaline conditions (>40 ‰) are often observed (Day, 1981; Whitfield, 1992, 1998, 1999a; Young and Potter, 2002).

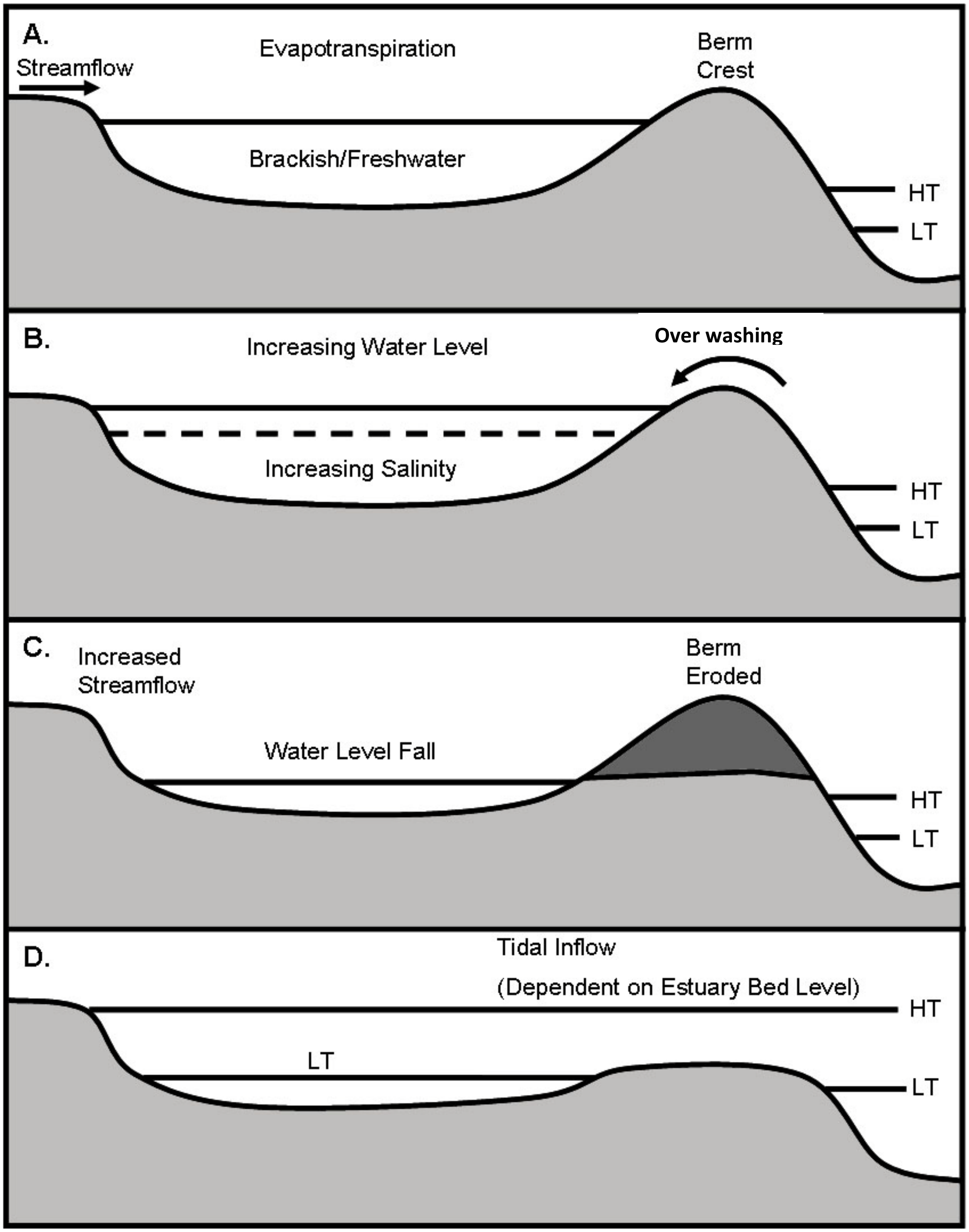

Figure 1.2: Cross-sectional diagram of a perched temporarily open/closed estuary. Under balanced conditions (A), the stream flow is matched by evapotranspiration and seepage. Over washing (B) may elevate water levels and salinity while increased stream flow (C) may promote breaching. When breached (D) the water levels are lowered and tidal flow may take place if the berm level is sufficiently low (After Harrison *et al.*, 2000).

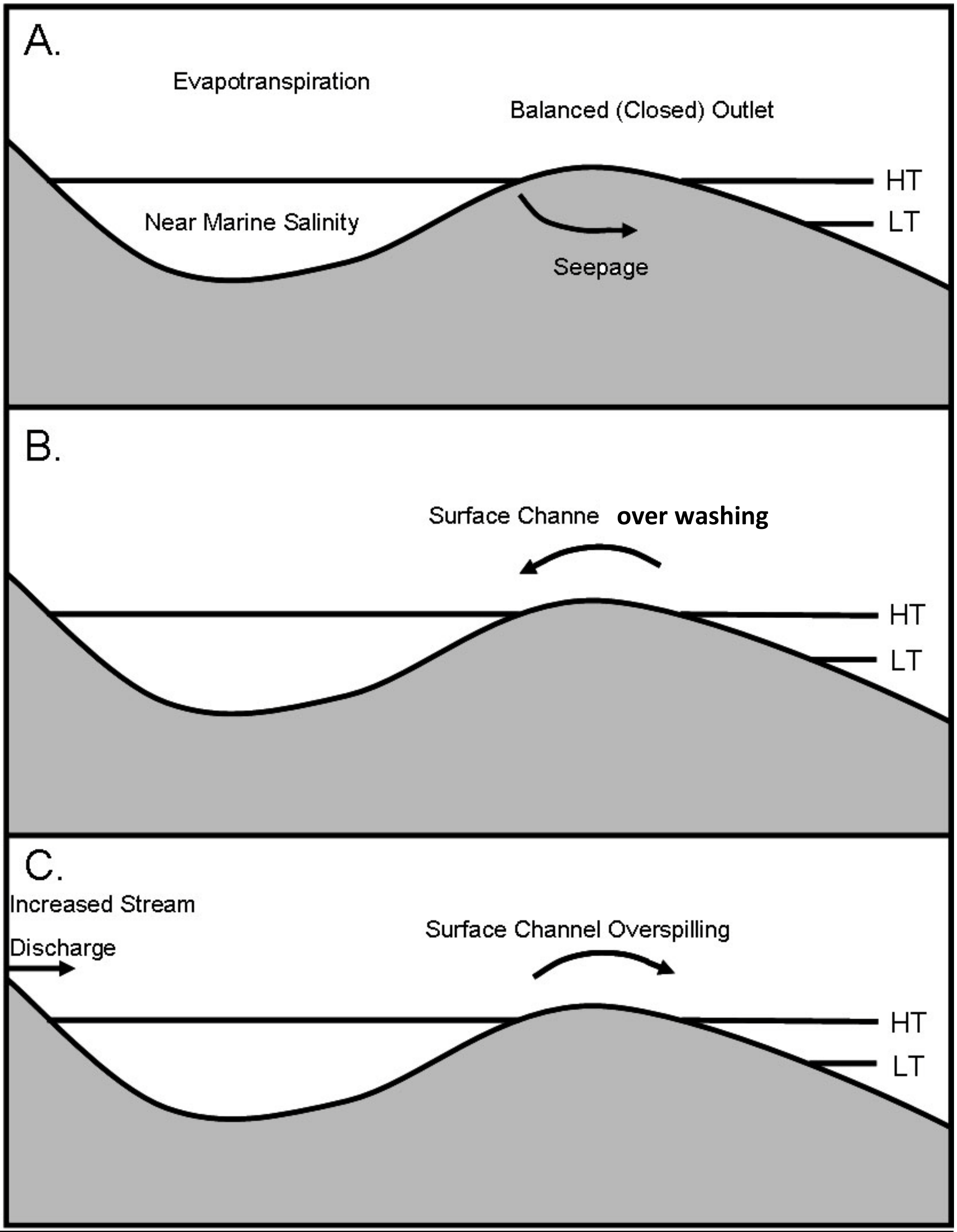

Figure 1.3: Cross-sectional diagram of a non-perched temporarily open/closed estuary. Under balanced conditions (A) stream flow is balanced by losses through evapotranspiration and seepage. Under high wave energy (B) overtopping introduces marine water into the system. Under improved inputs from overtopping (B) and stream flow (C) the system may breach. The depth of the channel is low since the estuary water level is close to sea level (After Harrison *et al.*, 2000).

1.2. Physico-chemical variables

Temporarily open/closed estuaries are characterised by the virtual absence of horizontal salinity or temperature gradients (Day, 1981; Whitfield, 1983; Froneman, 2002a; 2002b). The absence of these gradients is due to reduced freshwater inflow resulting from small catchment size (<500 km^2) and persistent, strong coastal winds which facilitate the vertical and horizontal mixing of the water column (Froneman, 2002a).

1.2.1 Water temperature

Water temperatures in temporarily open/closed estuaries are primarily determined by seasonality and the regional climate (Whitfield, 1992; 1998; 2000). Water temperatures in TOCE's situated in the cool temperate zone vary between 11˚C and 28˚C while in the warm temperate zone, water temperatures range from 19˚C to 32˚C. Finally water temperatures in subtropical zone TOCE's have been shown to range from 18˚C to 32˚C (Day, 1981; Perissinotto *et al*., 2000; 2002).

1.2.2. Turbidity

Turbidity within TOCE's is largely determined by mouth phase and freshwater inflow into the system (Hecht and van der Lingen, 1992; Whitfield, 1998; Perissinotto *et al*., 2000; Froneman, 2002b). During periods of high freshwater inflow, or when the estuary has a link to the marine environment, turbidity values may attain levels of up to 75-90 Nephelometric Turbidity Units (NTU) (Cooper *et al*., 1993; Froneman, 2002b). In contrast, when the estuary is separated from the marine environment turbidity values of <15 NTU are not uncommon (Froneman, 2002a; 2002b).

1.2.3. Sediment

The bottom sediment distribution in temporarily open/closed estuaries is similar to that found in permanently open estuaries (Day, 1981). The sediments found in the middle and upper reaches are generally comprised of mud, clay, silt and organic derived sediments, while coarse to medium marine-derived sediments predominate in the lower reaches of the estuary (Day, 1981).

1.3. Biology

1.3.1. Phytoplankton and microphytobenthic algae

Phytoplankton biomass values in temporarily open / closed estuaries are generally lower than those reported for permanently open estuaries within the same biogeographic region (Adams and Bate, 1999; Perissinotto *et al*. 2000; Nozais *et al*., 2001; Perissinotto *et al*., 2002). Permanently open estuaries exhibit phytoplankton biomass values ranging from 20 mg chl-*a* m^{-3} to 100 chl-*a* m^{-3}, while phytoplankton biomass values of <1 mg chl-*a* m^{-3} to 15.4 mg chl-*a* m^{-3} are common in temporarily open/closed estuaries (Adams and Bate, 1999; Froneman 2002a, 2002b; 2004). Low macronutrient concentrations resulting from reduced freshwater inflow into TOCE's are considered to be the main cause of the low phytoplankton biomass observed in these systems (Adams *et al*., 1999; Froneman 2000; 2002a; 2002b; 2004). On the other hand, concentrations of microphytobenthic algae in TOCE's generally exceed those found in permanently open systems and have been shown to attain levels 2-3 orders of magnitude higher than phytoplankton biomass (Adams and Bate, 1994; Adams *et al.*, 1999; Nozais *et al.*, 2001; Froneman 2002a; 2002b; 2004). The low turbidity, reduced current flow and high macronutrient concentrations in the sediments of TOCE's are the probable factors leading to the high microphytobenthic algal concentrations observed within these systems (Adams and Bate, 1999; Perissinotto *et al.*, 2002). Breaching events in TOCE's are associated with a dramatic decline in the concentrations of both water column phytoplankton and microphytobenthos (Froneman, 2004). The observed decrease can be associated with the export of estuarine water into the marine environment (Froneman, 2004).

1.3.2. Aquatic macrophytes

Mouth condition and the geographic position of the estuary determine the macrophyte distribution and composition in TOCE's (Day, 1981). Macrophytes characteristic of mangroves are absent in TOCE's (Day, 1981). The ability to withstand large variations in salinity is the primary factor influencing composition and abundance of macrophytes in TOCE's (Howard-Williams and Liptrot, 1980). The dominant aquatic and terrestrial macrophyte species present within these systems in the warm temperate zone are *Phragmites australis*, *Ruppia* spp., *Sarcocornia perennis*, *Juncus kraussii*, *Chenolea diffusa* and along the banks, *Acacia karoo* (Lubke and de Moor, 1998).

1.3.3. Zooplankton

The zooplankton community structure in temporarily open / closed estuaries has been studied both in the sub-tropical and warm temperate zones of South Africa (Wooldridge, 1999; Perissinotto *et al*., 2003; Kemp and Froneman, 2004; Froneman 2004). Zooplankton diversity in TOCE's during periods of extended mouth closure is generally lower than in permanently open estuaries. The lower diversity can be linked to the near absence of true estuarine species and the limited recruitment of marine species into the estuary (Froneman, 2004). The zooplankton community structure and biomass have been shown by Froneman (2000 ; 2004) to be determined by the interactive effects of freshwater inflow, water temperature and mouth status. Zooplankton biomass within these systems is highly variable and has been recorded ranging from *ca.* 20 mg Dwt m^{-3} to *ca.* 200 mg Dwt m^{-3} (Froneman, 2003). The highest biomass levels are consistently recorded during summer, while the lowest are found during winter or when breaching occurs (Froneman, 2004).

The zooplankton species community in TOCE's comprises copepods, isopods, mysids and amphipods, although copepods have been shown to dominate numerically while mysid shrimps are often important in terms of biomass (Wooldridge and Bailey, 1982; Wooldridge, 1999; Froneman, 2002a; 2002b; 2004; Kibirige, 2002). Zooplankton biomass and abundances in TOCE's, especially during periods of mouth closure, achieve far greater levels than in permanently open systems due to high microphytobenthic accumulations in these estuaries (Perissinotto *et al*., 2000' Perissinotto *et al*., 2003; Froneman 2004). In these circumstances, copepods have been shown to numerically dominate the zooplankton community, comprising between 72 and 92% of the total zooplankton biomass (Froneman 2004). Overtopping events have been shown to increase zooplankton biomasses and abundances in TOCE's by transporting large quantities of marine larvae into these systems (Kemp and Froneman, 2004).

1.3.4. Ichthyofauna

The fishes frequenting South African estuaries have been classified into five categories according to their estuarine associations (Table 1.1) (Whitfield, 1994; 1998). Category 1 comprises those species that are estuarine spawners, and are thus true estuarine species; Category 2 comprises those species that are marine spawning but whose juveniles utilize estuaries as nursery areas; Category 3 species are marine spawning species whose juveniles or adults may be found in estuaries but are not dependent on estuaries for survival; Category 4 comprises freshwater species whose range extends into estuaries to varying degrees as salinity tolerances allow. Finally, Category 5 species include all species which utilize estuaries as a transition zone between the marine and freshwater environment (Whitfield, 1994; 1998).

In the past, ichthyological research in the Eastern Cape region has mostly been directed towards the larger permanently open systems such as the Kariega (Ter Morshuizen *et al*. 1996; Paterson, 1998), Great Fish (Whitfield *et al*., 1994; Ter Morshuizen *et al*. 1996), Swartkops (Melville-Smith and Baird, 1980; Beckley, 1983; Beckley, 1985; Baird *et al*., 1996); Kromme (Melville Smith, 1981) and Sundays (Harrison and Whitfield, 1990; Baird *et al*., 1996; Whitfield and Harrison, 1996) estuaries. Over the past decade, however, considerable research has been conducted in larger TOCE's within the Eastern Cape (Cowley and Whitfield, 2001b; Vorwerk *et al.*, 2001; Kemp and Froneman, 2004; Tweddle, 2004; Harrison and Whitfield, 2005; Lukey, 2005; Lukey *et.al.,* 2006). The main findings of these studies have shown that TOCE's are characterised by a greater abundance of fish per unit area and a lower diversity than that of permanently open estuaries in the same biogeographic area (Bennett *et al*., 1985; Heydorn and Morant, 1988; Potter *et al*., 1993; Perissinotto *et al*., 2000; Cowley and Whitfield, 2001b; Kemp and Froneman, 2004). The reduced diversity in TOCE's can be linked to several factors including poor representation by freshwater species, limited habitat availability (e.g. beds of submerged macrophytes) and the presence of a sandbar at the mouth that prevents recruitment of marine breeding species into the estuary (Cowley and Whitfield, 2001b; Kemp and Froneman, 2004).

Table 1.1: The five major categories of estuarine-associated fish species in southern African estuaries. (After Whitfield 1998).

	Description of Categories	
I	Estuarine species, which breed in Southern African estuaries. Further subdivided into	
	Ia.	Resident species, which have 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 subdivided into:	
	IIa.	Juveniles dependent on estuaries as nursery areas.
	IIb.	Juveniles occur mainly in estuaries, but also found at sea.
	IIc.	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.	
V	Catadromous species which use estuaries as a transit route between the marine and freshwater environments, but also may occupy estuaries in certain regions.	
	Further subdivided into:	
	Va.	Obligate catadromous species, which require a freshwater phase in their development.
	Vb.	Facultative catadromous species, which do not require a freshwater phase in their development.

Mouth status in TOCE's has been demonstrated to be an important factor in determining species composition and biomass of the ichthyofaunal community within these systems (Cowley, 1998; Vorwerk, 2001; Lukey *et al*., 2006). The establishment of a link with the marine environment through overtopping has the effect of increasing ichthyofaunal diversity within a TOCE as marine-breeding species are able to recruit into the estuary (Bennett, 1989; Griffiths and West 1999; Tweddle, 2004; Lukey, 2005). Conversely, breaching events coincide with a large decline in total ichthyofaunal biomass within these systems as a result of emigration of estuarine fish to the marine environment (Griffiths, 1999).

The main biotic and abiotic factors, which determine the abundance and distribution of fishes in South African estuaries, work synergistically to create a highly dynamic environment, which large numbers of fish species inhabit (Whitfield 1999a). These factors may either gradually change over time or change abruptly, depending on the environmental state at the time (Blaber, 1973; Whitfield, 1999a). The ability to adapt to changes in salinity is the most essential adaptation shown by fish species inhabiting estuaries (Griffiths, 2001). A change in salinity may be gradual, as often occurs in temporarily open/closed estuaries with a constant freshwater flow (Whitfield, 1992; 1998), or sudden, as occurs when a TOCE breaches and is influenced by tidal regimes and wave action from the marine environment (Whitfield, 1992; 1998; Froneman, 2002a; 2002b; Young *et al.,* 2002). The magnitude of change depends on the flow of freshwater into the estuary, the tidal regime of the sea as well as evaporation in the shallow areas of small estuaries (Young *et al.*, 1997; Whitfield, 2005).

Water temperature has been shown by Blaber (1973) and Whitfield (1988) to play an important role in determining the salinity extremes tolerated by freshwater and marine species in estuaries. Fish can move from the littoral zones into the deeper zones of the estuaries when warmer conditions prevail or vice versa when colder conditions prevail. If fish are trapped in shallow areas, or the water level suddenly drops, typical of a large breaching event, large fish kills are often observed (Blaber, 1973; Whitfield, 1988).

Turbidity is a highly dynamic factor influencing fish utilization of estuaries (Harrison and Whitfield, 2005). Turbidity influences light penetration and has been shown to negatively affect fish egg survival, hatching success, feeding efficiency, growth rate and population size (Harrison and Whitfield, 2005). Studies by both Hanekom and Baird (1984) and Whitfield (1986) indicated linkages between the presence of submerged macrophyte beds and the associated ichthyofaunal communities in the Kromme and Swartvlei estuaries. The findings showed that the absence of submerged macrophyte communities did not lead to a subsequent decline in ichthyofaunal diversity, although the density of *Rhabdosargus holubi* and *Monodactylus falciformis* did show a decline when submerged macrophytes were absent (Whitfield, 1986).

Previous studies have shown that the ichthyofaunal community structure in TOCE's is numerically dominated by estuarine resident species (*Gilchristella aestuaria* and *Glossogobius callidus*) but in terms of biomass, marine breeding species including *R. holubi* and Muglidae species dominate the community (Vorwerk *et al*. 2001; Tweddle, 2004; Lukey, 2005). No apparent horizontal patterns in community structure have been observed which has been linked to the absence of horizontal patterns in temperature and salinity within these systems (Tweddle, 2004; Lukey, 2005).

1.3.5. Avifauna in temporarily open/closed estuaries

The majority of the research effort on birds utilizing estuaries over the past 30 years has been centered on the Berg River Estuary, Langebaan Lagoon, Swartkops River Estuary and Lake St Lucia (Hockey and Turpie, 1999). Results of these studies have demonstrated that there is a high avian diversity associated with estuaries; 162 species from 13 orders are regularly found in estuaries in South Africa (Siegfried, 1984; Hockey and Turpie, 1999). The high diversity of avian fauna recorded in estuaries in South Africa reflects the seasonal presence of Palearctic migrants, the wide range of habitats estuaries provide for birds (including mudflats, sand flats, reed beds, open deep water, shallow bank water and salt marshes) as well as increased food availability (vertebrates and invertebrates) (Hockey and Turpie, 1999). It has been estimated that South African estuaries support at least 345 000 non-passerine bird species during summer, with 225

000 of these being Charadriiformes comprising 150 000 waders (Siegfried, 1984; Martin and Baird, 1987; Hockey and Turpie, 1999).

Blaber (1973) demonstrated that piscivorous bird species could exert a considerable influence on fish populations within TOCE's. During a period of mouth closure of the West Kleinemonde Estuary (Eastern Cape), the population of juvenile *R. holubi* decreased by *ca.* 80% over a 5 month period. This relatively high mortality rate was density dependant and thought to be due to predation by piscivorous birds, the numbers of which were related to the density of fish (Blaber 1973). A further study conducted on Lake St Lucia by Whitfield (1978) showed that there was a highly significant correlation between the relative density of fish and piscivorous bird numbers. More recently, a study conducted by Cowley (1998) revealed a mean monthly consumption by all piscivorous birds at the East Kleinemonde Estuary of 142.6 kg month^{-2}. Indeed the large numbers of piscivorous birds observed in the East Kleinemonde Estuary over the study period were believed to be responsible for the decline of up to 70% of fish total abundance within the estuary (Cowley, 1998). These data suggest that piscivorous birds may represent an important source of mortality for fish within TOCE's and may therefore contribute to structuring the fish communities within these systems.

1.4. Thesis aims

Small TOCE's (surface area <5 ha) are the most commonly occurring estuarine systems along the Eastern Cape coastline (Harrison *et al.*, 2000). There is however, little information on these systems as research in the past has largely concentrated on medium size TOCE's (surface area >15 ha), such as the East Kleinemonde (Blaber, 1973; Blaber 1974; Cowley and Whitfield, 2001a; Cowley *et al.*, 2001; Bell *et al.*, 2001) and the Kasouga (Jubb, 1979; Froneman, 2002b; Tweddle, 2004). A notable exception is the recent study by Lukey (2006) which focused on the small (<5 ha) temporarily open / closed Grants River Estuary along the Eastern Cape coastline. The objectives of this study were, as follows:

- To examine spatial and temporal changes in selected components (littoral zone and in the channel) of ichthyofaunal species composition and community structure in a small TOCE.
- To assess the potential ecological role that piscivorous bird species may have on the fish community within the estuary.

The study was conducted in the Riet River Estuary located along the Eastern Cape coastline, South Africa.

Chapter 2:

Study Site

The small temporarily open/closed Riet River Estuary (mouth co-ordinates: 33˚ 34’ S; 27˚ 01’ E) is situated approximately 10 km north-east of Port Alfred on the southern coast of South Africa (Figure 2.1). The main access road (R72) to the system crosses the estuary approximately 800 m from the mouth (Cowley and Danial, 2001). Residential development in the mouth region is restricted to the Riet River share block settlement on the western bank and a small number of houses on the farmland on the eastern bank. The entire share block settlement is fenced off with a high electric fence.

The estuary has a surface area of less than 5 hectares and is ~2 km long and less than 100 meters wide in the lower reach which is the widest portion of the estuary. The estuary is a shallow system with the main channel depth seldom exceeding 1.5 m (Cowley and Danial, 2001). The estuary is characterized by extended periods of mouth closure, which results in the system becoming perched due to extensive sandbar development on the seaward side of the mouth (Cowley and Danial, 2001).

The majority of the catchment area is used for cattle ranching and is relatively undisturbed. The main river feeding the estuary is vegetated by dense valley bushveld. A large reed bed of *Phragmites australis* is found on the western bank just upstream of the public parking lot, which is an indication of fresh water seepage from a marsh area on the western side of the access road. Large salt marshes predominate on the eastern bank in the lower reaches of the system (Cowley and Danial, 2001).

A total of 8 ichthyofaunal sample stations were selected along the length of the estuary during the 12-month study. All 8 stations were sampled with a 5 m seine net while only 4 were sampled with a 30 m seine net when water levels permitted. The co-ordinates and a brief description of the stations sampled during the survey are listed in Table 2.1.

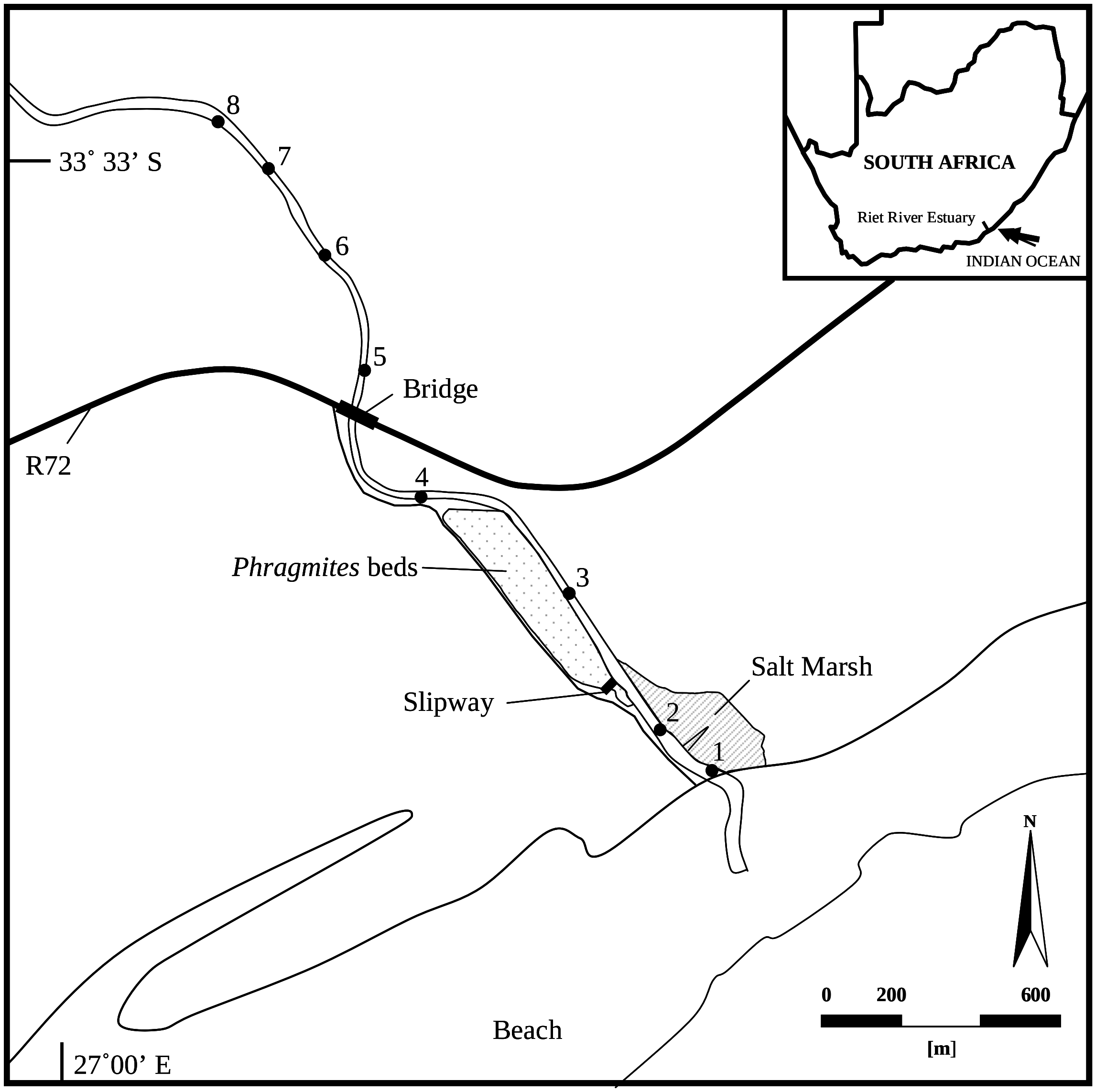

Figure 2.1: Map of the Riet River Estuary, Eastern Cape, South Africa showing the basic form, dominant vegetation types and associated anthropogenic structures. Monthly sampling stations (●)(1-8) are shown. Stations 1 to-8 were sampled with the 5 m seine net, while stations 1, 3, 6 and 8 were sampled with the 30 m seine net over the period August 2005 to July 2006.

Table 2.1: Global positioning co-ordinates for the sample stations for the 5 m seine net, the substrate type and submerged vegetation cover at each station. Vegetation cover was estimated visually in a 1×1 m quadrate. The 30 m seine tows were conducted at stations 1, 3, 6 6and 8.

Station Number	Longitude	Latitude	Substrate	Vegetation
1	33˚ 33’ 38.12”	27˚ 00’ 49.32”	Marine sediments	0%
2	33˚ 33’ 35.76”	27˚ 00’ 46.03”	Muddy Sediments	0%
3	33˚ 33’ 28.63”	27˚ 00’ 39.16”	Muddy Sediments	0%
4	33˚ 33’ 21.09”	27˚ 00’ 25.53”	Muddy Sediments	5%
5	33˚ 33’ 14.27”	27˚ 00’ 22.40”	Muddy Sediments	5%
6	33˚ 33’ 10.74”	27˚ 00’ 22.51”	Muddy Sediments	0%
7	33˚ 33’ 07.72”	27˚ 00’ 20.85”	Muddy Sediments	5%
8	33˚ 33’ 00.16”	27˚ 00’ 14.77”	Muddy Sediments	5%

2.1. Site description

Station 1 at the mouth of the estuary was characterized by coarse marine sand and the absence of aquatic macrophyte vegetation. The water depth at station 1 was always <1 m. A mixture of coarse marine sediment and finer muddy sediments characterized stations 2 and 3. An extensive salt marsh was found on the eastern bank between station 1 and 3 (Figure 2.1). The middle reaches of the estuary (stations 4 through 6) were characterized by finer particle size with infrequent rock outcrops within the channel of the estuary. There was a distinct lack of aquatic macrophytes at these stations with < 5% cover of submerged vegetation evident during the study (pers. observation). Small, isolated outcrops of reed beds, mainly *Phragmites australis* were located along the banks in the middle reaches (Figure 2.1).

A muddy substrate and the presence of large boulders and lack of vegetation within the channel characterised stations 7 and 8 in the upper reaches of the estuary. The channel in the upper reaches was narrow (<10 metres) and did not exceed 1.5 metres in depth. The upper reaches were steep-banked and shaded by milkwood trees (*Sideroxylon inerme*), Acacia (*Acacia karoo*) and *Rhus* species (*Rhus crenata*).

Chapter 3:

Spatial and temporal patterns of selected ichthyofauna within the littoral zone and channel of the temporarily open/closed Riet River Estuary

3.1 Introduction

A number of previous studies conducted in TOCE's within the same geographic region have demonstrated that the mouth phase (open / closed) and the establishment of a link to the marine environment via breaching / overtopping, plays an important role in structuring the plankton and ichthyofaunal communities within these systems (Cowley, 1998; Vorwerk, 2001; Kemp and Froneman, 2004). These studies have, however, largely focussed on medium and large sized TOCE's within the region, or have a limited temporal component. For example, a study by Vorwerk (2001) included only a seasonal study of the ichthyofauna in 5 temporarily open / closed Eastern Cape estuaries. Longer-term studies within small TOCE's are therefore, generally lacking. A notable exception is the study by Lukey (2005) which investigated the ichthyofaunal community within the small temporarily open / closed Grants River Estuary over the period of 14 months.

To date, there has been no quantitative biological research conducted on the Riet River Estuary. Cowley and Danial (2001) published a descriptive report on the state of the estuary based on visual observations. The report stated that the Riet River Estuary is in an "excellent condition" (Cowley and Danial, 2001).

The main aim of this study was to investigate the spatial and temporal patterns in the ichthyofauna within the littoral zone and channel in the temporarily open / closed Riet River Estuary. Changes in the community structure were related to mouth phase and a suite of physico-chemical (temperature, salinity and light attenuation) and biological (total chlorophyll-*a* and zooplankton biomass) variables.

3.2 Materials and methods

3.2.1. Sampling procedure

The spatial and temporal patterns in selected physico-chemical (temperature, salinity, light attenuation, dissolved oxygen) and biological (chlorophyll-*a*, zooplankton and ichthyofauna) variables within the Riet River Estuary were investigated monthly at 8 stations for a period of 1 year (August 2005 – July 2006).

3.2.2. Physico-chemical variables

Surface salinity, surface and bottom dissolved oxygen; surface and bottom temperature and turbidity were measured at each station monthly throughout the sampling period. Only surface salinity measurements were made as a previous study indicated that there were no significant vertical and horizontal patterns in salinity evident within the Riet River estuary ($P<0.05$; Froneman, unpublished data). Surface salinity (‰) was measured with the use of an Atago S-10 hand held refractometer on site. Surface and bottom dissolved oxygen concentrations and temperature (˚C) were measured employing an YSI 550DO dissolved oxygen and temperature meter. Secchi disk readings were taken on site and light attenuation (k) was then determined using the formula:

$$k = 1.7 / D$$

where D is the secchi disk reading in centimetres (Poole and Atkin, 1929).

3.2.3. Depth

Channel depth was determined by lowering a graduated, weighted rope to the estuary floor. Depth was then measured from pre-made markers on the rope.

3.2.4. Chlorophyll-*a* analysis

Water samples (250 ml) were taken from each station (0.5 metre depth) to determine *in situ* chlorophyll-*a* (chl-*a*) concentrations. The water samples collected were transported back to the laboratory and gently filtered (< 5 cm Hg) through a GF/F glass fibre filter (Schleicher and Schuell

Microscience) (vacuum, <5 cm Hg). The filters were then extracted in 8 mL of 90% acetone in the dark at -20˚C for a minimum of 24 hours. Chlorophyll-*a* concentrations were then determined flourometrically (10-AU field flourometer, Turner Designs) according to the method by Holm-Hansen and Riemann (1978). Chl-*a* concentrations were expressed as mg chl-*a* m^{-3}.

3.2.5. Zooplankton

Zooplankton biomass at each station was determined from net tows (n = 3 for each station) that were conducted at night (19:00-21:00) using a WP-2 net (nominal mouth size 0.25 m^2; mesh size 100 µm) towed at the surface (approximately 0.5 metre depth). The net was fitted with a General Oceanics flow meter to determine the amount of water filtered during each tow. Volume filtered during the tows varied between 5.3 and 12.8 m^{-3}. Towing speed varied between 1.5 and 3 knots. The samples collected were immediately fixed in 10% buffered (hexamine) formalin. Total dry weight (Dwt) of the zooplankton was determined after oven drying at 60˚C for 24 h using a Sartorius microbalance. No correction factor for the loss of tissue for the samples preserved with formalin was applied. Data were expressed as mg Dwt m^{-3}.

3.2.6. Aquatic macrophyte cover

At each station, a visual estimation of the percentage cover of aquatic macrophytes was made in a 1 x 1 m quadrant according to the method of Lukey (2005).

3.3. Ichthyofaunal sampling

The Riet River Estuary may remain closed / separated from the sea for periods of up to 2 years due to a small catchment area and the subsequent infrequency of freshwater pulses scouring the system as well as the development of a large sandbar at the mouth of the estuary (Cowley and Danial, 2001). In light of this fact, it was decided not to employ gill net sampling during the study. Furthermore the large number of obstacles (sunken trees, rock outcrops and boats) and the prevalence of large numbers of submerged rocks within the channel of the estuary precluded the use of an Otter trawl within the system. The sampling of the fish within the Riet River Estuary was therefore undertaken using 5 and 30 m seine nets.

3.3.1. Littoral zone

A 5 m x 1 m seine net with a 500 µm mesh size was used to sample the early developmental stages of the ichthyofauna inhabiting the littoral zone of the Riet River Estuary. A single haul involved two people holding either end of the 5 m seine net. One person would walk out into the estuary while the other would remain on the bank. A chain sewn into the base of the net ensured it was kept along the substrate for the duration of the tow. The net would then be walked up the shore of the estuary for a pre-determined distance of 5 m. The net was then pulled onto the bank and all fish caught were preserved in a 10% buffered (hexamine) formaldehyde solution for later analysis in the laboratory where they were identified to species as per Smith and Heemstra (1991). Standard length (SL) of individuals was measured to the nearest mm with the use of a digital Vernier calliper. Weight of individuals was measured with the use of a standard scale. Fish abundance and biomass data were standardized and expressed as individuals per unit area (ind m^{-2}) or biomass (g wwt m^{-2}), respectively. Identified species were then placed into estuarine association categories according to the classification system of Whitfield (1998) (Table 1.1).

3.3.2. Channel

The larger ichthyofauna in the channel of the estuary was sampled with the use of a 30 metre seine net. The net measured 30 m by 2 m with a 30 mm stretch mesh size and a bunt in the middle of the net composed of 10 mm box mesh. The net was waded out in a semicircle from the bank and then pulled ashore. The 30 m net was retrieved keeping the base of the net intact with the bottom of the estuary. The stations were selected to limit the possibility of snagging of the net during the retrieval process. A single net tow was conducted at each station.

All fish captured were funnelled into the bunt as the net was retrieved and placed into a 50 litre plastic container filled with estuarine water. The fish captured were identified and SL (mm) determined before being released back to the estuary. Fish that could not be identified or were dead were bottled and preserved in a 10% formaldehyde solution and returned to the laboratory for analysis. Fish biomass for select species was estimated according to Harrison (2001) based on standard lengths measured. Fish abundance and biomass data were standardized and expressed as individuals per unit area (m^{-2}) or biomass (g wwt m^{-2}), respectively. Estuarine association categories for the fish species captured during the study were assessed as above.

3.3.3. Numerical analysis

Multivariate statistical analysis of the fish abundance data in the littoral zone and channel was undertaken using the Plymouth Routines in Multivariate Ecological Research (PRIMER) (version 5.2.4. for Windows) statistical package. Data from the two nets employed during the study were analysed separately. The data collected over the study period from each station were analysed to assess the spatial and temporal patterns in the ichthyofaunal community structure within the estuary. Thereafter, the data were combined into months for a temporal comparison and to give an indication of the overall richness and diversity of the ichthyofauna of the Riet River Estuary. Abundance data were logarithm transformed {log(x+1)} to produce the similarity matrix. Hierarchical cluster analysis was conducted with a complete linkage hierarchical sorting strategy to identify groupings. Dendograms and non-metric multidimensional scaling (MDS) were used to determine spatial and temporal relationships. Significant differences between the groups were tested with the Analysis of Similarities (ANOSIM) program. The Similarity Percentage Program (SIMPER) was run to test sources of dissimilarity between identified groups.

The ichthyofaunal richness and diversity during each sampling trip were calculated using the Shannon Weiner's Diversity Index, Simpson's Index and Margalef's Richness Index. These were calculated with the use of the PRIMER (version 5.2.4 for Windows) computer package.

Shannon-Weiner Diversity Index

$$H = \Sigma - p_i \ln p_i$$

where p_i is the proportion of individuals in species i.

Simpson's Index

$$D = 1 - \Sigma p_i^2$$

Margalef's Richness Index

$$R_{Mg} = (S-1) / \ln N$$

Where S is the number of species present, and

N is the total number of fish. This index calculates the number of fish in the sample relative to the number of individuals thus reducing the sample bias (Peet, 1974).

3.3.4. Statistical analysis

Spearman rank order correlation analysis was used to identify possible relationships between the total ichthyofaunal abundance and biomass and the selected physico-chemical (temperature, salinity and turbidity) and biological (total chl-*a* concentration and zooplankton) variables. The analyses were conducted employing the statistical package, Statistica (version 7).

3.4. Results

3.4.1. Physical and chemical environment

The Riet River Estuary breached on 2 occasions over the study period, on December 15, 2005 and on June 22, 2006. These breaching events occurred prior to the sampling being conducted for those months. The December breaching event was of short duration with the establishment of a link to the marine environment lasting *ca.* 1 day. During the June breaching event, the estuary was closed off from the sea within 3 days. An additional breaching event was recorded 2 weeks prior to the commencement of the study. No overtopping events were recorded during the survey. The absence of overtopping events could be ascribed to the presence of a steep bank at the mouth of the estuary throughout the duration of the study (Froneman, unpublished data). There were no significant spatial differences in the biological and physico-chemical variables during each month and as a consequence, data for each month have been pooled (ANOVA) ($P > 0.05$). For the temporal analysis, the months September to November were categorised as “spring”, December to February as “summer”, March to May as “autumn” and “winter” was defined by the months June to August.

3.4.2. Salinity

Salinity values recorded over the study period showed a weak seasonal pattern (Figure 3.1). Mesohaline conditions were observed during the first two months of the study (August and September 2005) with mean salinities ranging between 23.50‰ and 26.85‰. Salinities in the warmer, summer months ranged between 3.50‰ and 30.50‰. The salinity values recorded in the estuary over the remainder of the study period ranged between 0.25‰ and 28.15‰. The low mean salinity recorded in June 2006 coincided with the second breaching event, which resulted in large variations in salinities throughout the length of the estuary (Figure 3.1).

3.4.3. Temperature

Surface and bottom water temperatures exhibited a distinct seasonal pattern with the minimum values recorded in the autumn and winter months (May-July) (mean value 13.59˚C (±2.88) surface and bottom) and the maximum values recorded in the spring and summer months (November-January) (mean value 27.60˚C (±1.59) surface, 25.08˚C (±0.62) bottom) (Figure 3.2).

3.4.4. Turbidity

Light attenuation (k) values during the study period ranged between 0.01 and 0.06 k (Figure 3.3). The highest values were recorded during October (0.04 k) and November (0.06 k) 2005.

3.4.5. Dissolved oxygen

Dissolved oxygen concentrations during the study period ranged between 3.24 and 6.37 mg l^{-1} in the surface waters and between 1.33 and 5.13 mg l^{-1} at the bottom of the water column (Figure 3.4). There were no distinct seasonal patterns in dissolved oxygen concentrations during the study. The highest values were recorded (Surface, 6.36 mg l^{-1}; bottom, 5.13 mg l^{-1}) during the June 2006 breaching period, while the lowest values (Surface, 3.52 mg l^{-1}; bottom, 1.33 mg l^{-1}) were recorded in November 2005.

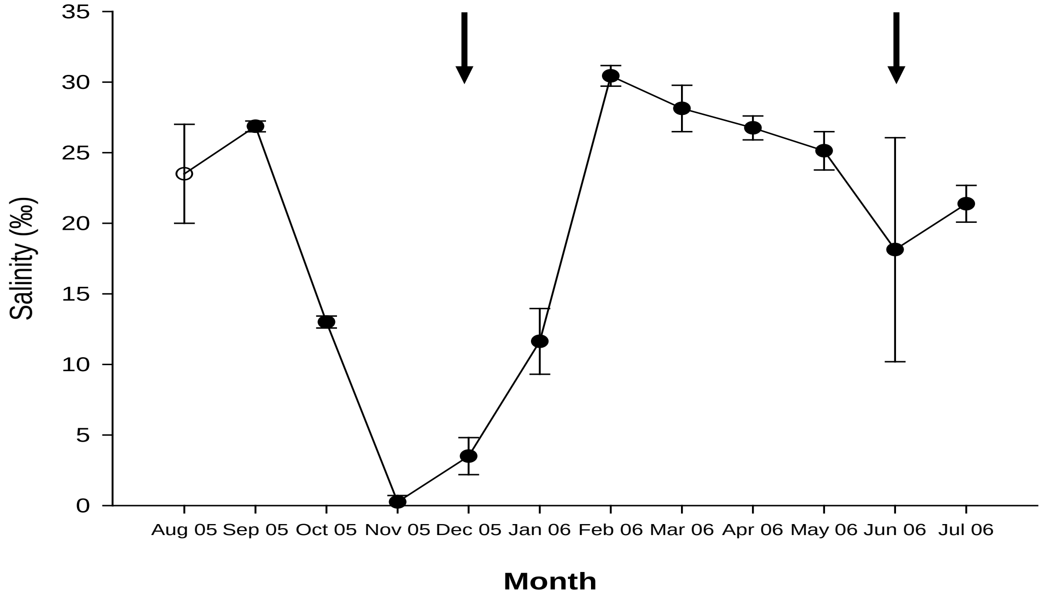

Figure 3.1: Mean monthly surface salinity (± standard deviation) in the Riet River Estuary over the study period, August 2005 to July 2006. Thick arrows indicate periods when breaching occurred.

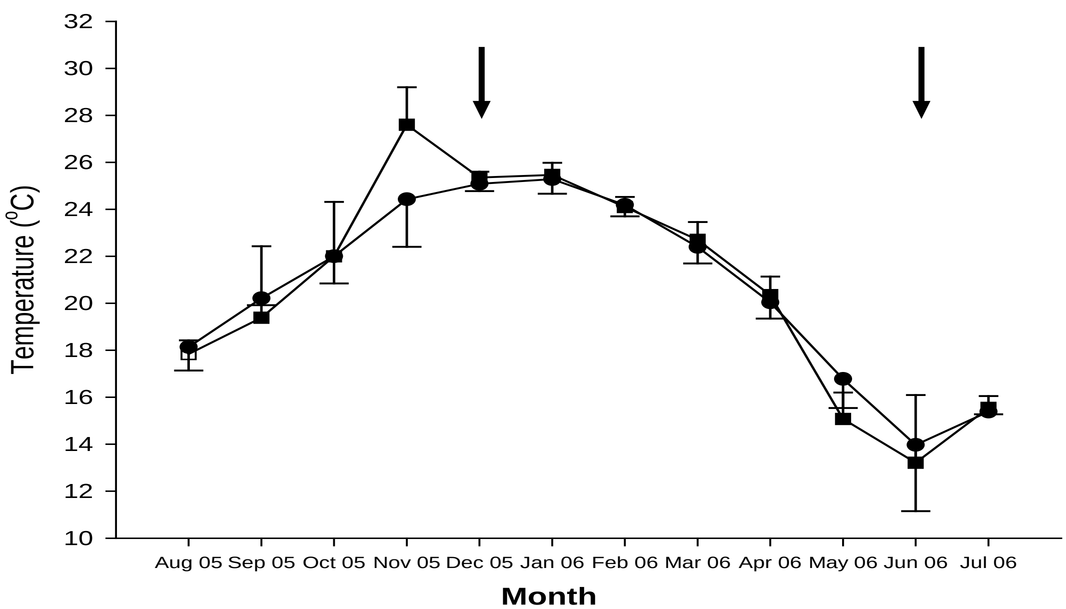

Figure 3.2: Mean monthly surface (■) and bottom (●) water temperatures (˚C) (positive standard deviation for surface temperate and negative standard deviation for bottom water temperature) in the Riet River Estuary over the study period, August 2005 to July 2006. Thick arrows indicate periods when breaching occurred.

3.4.6. Depth

Mean depth of the estuary over the study period ranged between 76.56 and 123.81 cm (Figure 3.5). The shallowest depths (76.56 and 89.38 cm) were observed in the months prior to the recorded breaching events, while the deepest waters (123.81 and 118.88 cm) were associated with those periods when the mouth was closed off from the sea (Mean 106.91 ± 27.00).

3.4.7. Aquatic macrophyte cover

Vegetation cover at the all stations for the entire study period, varied from 0% to 5% of the total surface area. Macrophyte cover showed no increase over the study period and remained at *ca.* <5% of the total area at each sample site. The most common species found in the Riet River Estuary were *Phragmites australis* and inundated *Ruppia cirrohsa* stands in the lower reaches, particularly when freshwater inflow into the estuary was noted. The middle and upper reaches were characterised by isolated *Phragmites australis* stands and stands of *Chenolea diffusa*.

3.4.8. Chlorophyll-*a* (chl-*a*) concentration

The mean total chl-*a* concentration during the study period varied between 0.71 mg chl-*a* m^{-3} and 1.90 mg chl-*a* m^{-3} (Figure 3.6). A weak seasonal trend was observed with the highest chlorophyll-*a* concentrations being recorded in early spring (October 2005) and early autumn (March 2006) (1.90 chl-*a* m^{-3} and 1.79 chl-*a* m^{-3}, respectively). Although variable, the breaching events in December 2005 and June 2006 were associated with a decrease in the total chl-*a* concentration in the estuary. Spearman rank correlation indicated that total chl-*a* concentration was positively correlated to water temperature ($R = 0.4$) and negatively correlated to salinity ($R = -0.4$) ($P < 0.05$ in both cases).

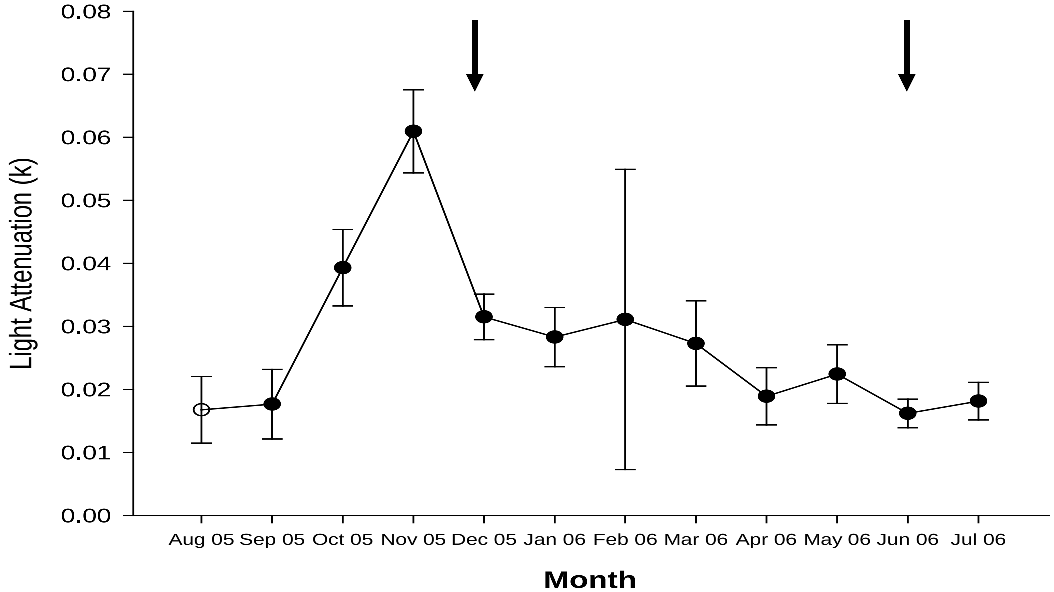

Figure 3.3: Mean light attenuation (± standard deviation) in the Riet River Estuary over the study period, August 2005 to July 2006. Thick, arrows indicate periods when breaching occurred.

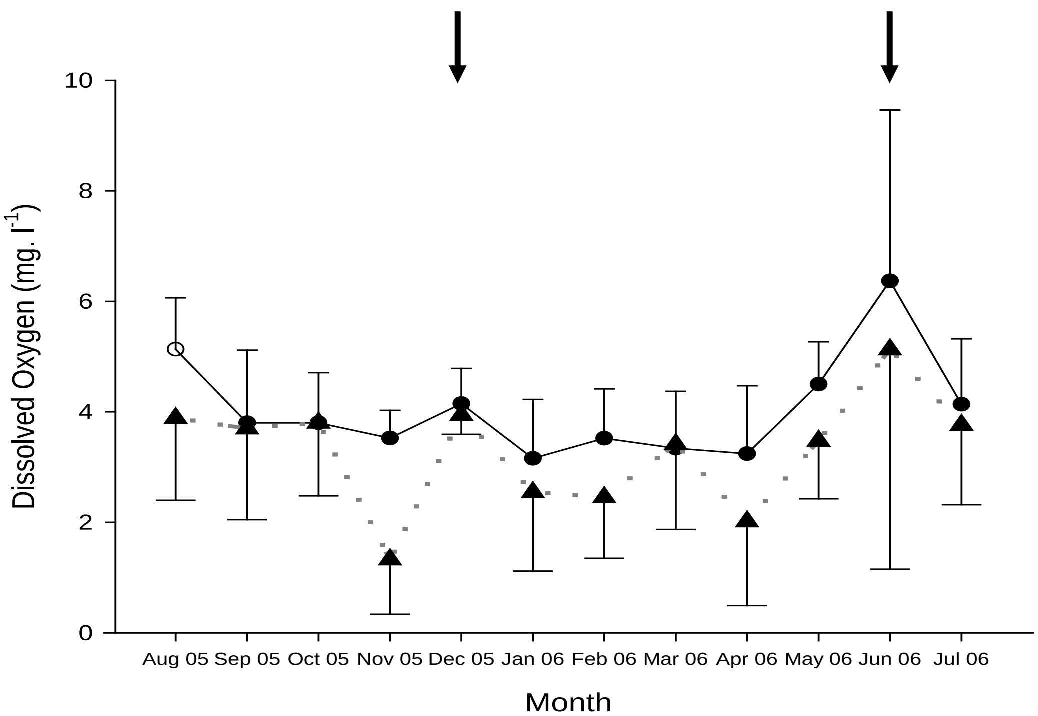

Figure 3.4: Mean surface (circle and solid line) and bottom water (triangle and dotted line) dissolved oxygen concentrations (positive standard deviation for surface dissolved oxygen and negative standard deviation for bottom dissolved oxygen) concentrations in the Riet River Estuary over the study period, August 2005 to July 2006. Thick arrows indicate periods when breaching occurred.

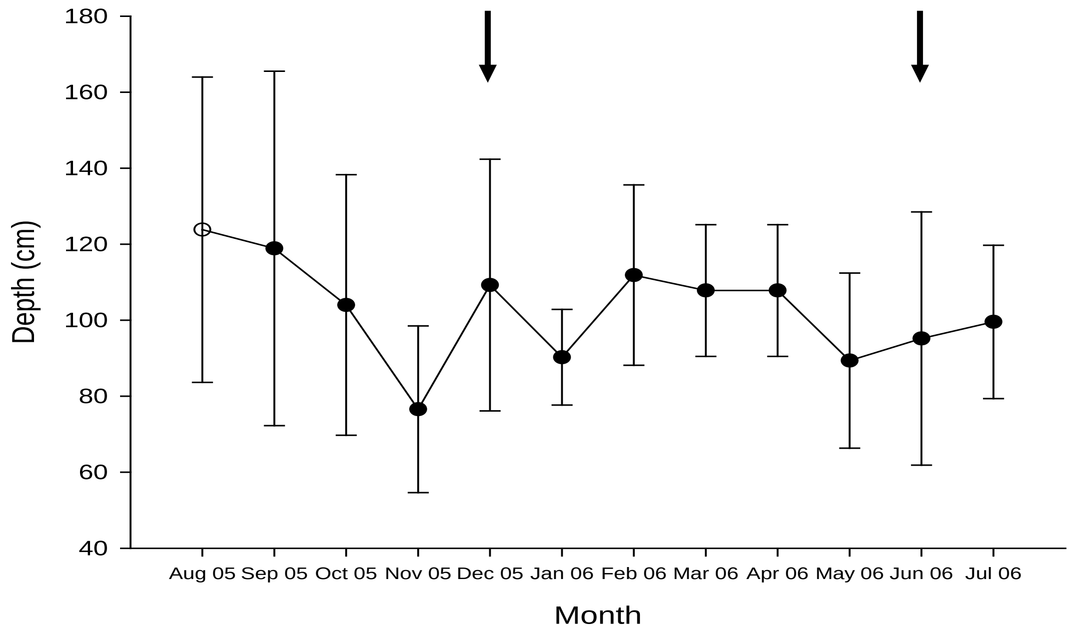

Figure 3.5: Mean depth (cm) (± standard deviation) in the Riet River Estuary over the study period, August 2005 to July 2006. Thick arrows indicate periods when breaching occurred.

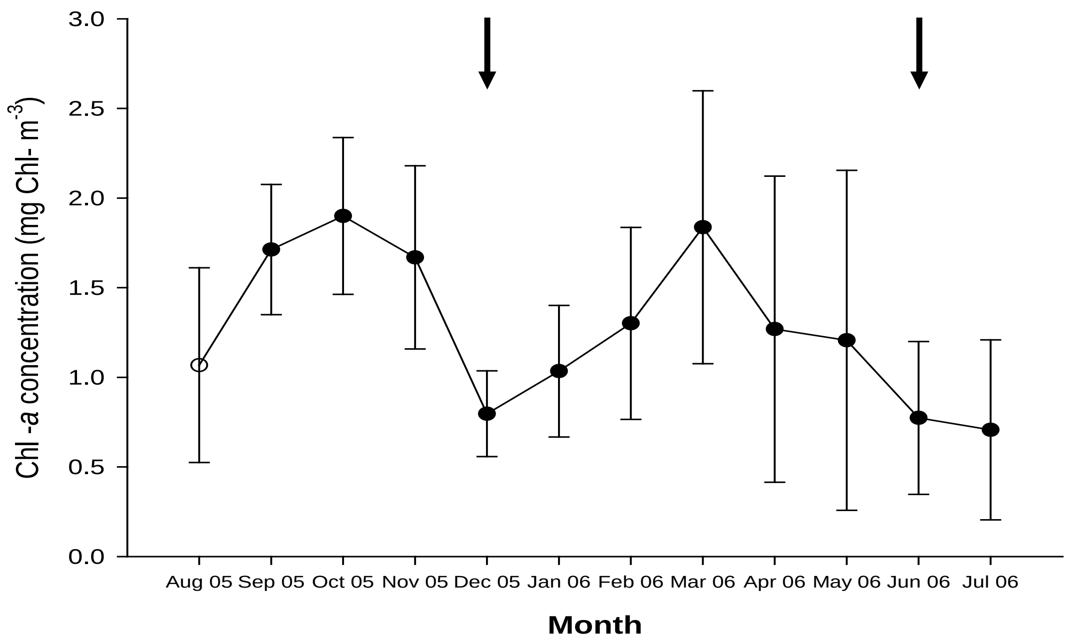

Figure 3.6: Mean Chlorophyll-a concentration (mg chl-*a* m^{-3}) (± standard deviation) in the Riet River Estuary over the study period, August 2005 to July 2006. Thick arrows indicate periods when breaching occurred.

3.4.9. Zooplankton

The mean total zooplankton biomass during the study period ranged from 19.41 mg Dwt m^{-3} to 86.18 mg Dwt m^{-3} and showed a strong temporal pattern (Figure 3.7). The highest biomass values were typically recorded in summer (>40.86 mg Dwt m^{-3}) and the lowest in winter (<30.07 mg Dwt m^{-3}). Intermediate values were recorded in the autumn and spring months (range 29.49 mg Dwt m^{-3} to 49.14 mg Dwt m^{-3}). The breaching event prior to sampling in December 2005 resulted in an increase in zooplankton biomass. A decrease in biomass was observed in the following month (January 2006). The breaching event prior to the June 2006 sampling trip revealed the opposite trend where a decrease in zooplankton biomass was observed followed by an increase in zooplankton biomass the following month (July 2006). Total zooplankton biomass showed no significant correlation to the total chl-*a* concentration for the study period ($R = 0.02$; $P > 0.05$) but significant correlations were observed between zooplankton biomass and salinity ($R = 0.05$; $P < 0.05$) and surface water temperature ($R = 0.07$; $P < 0.05$).

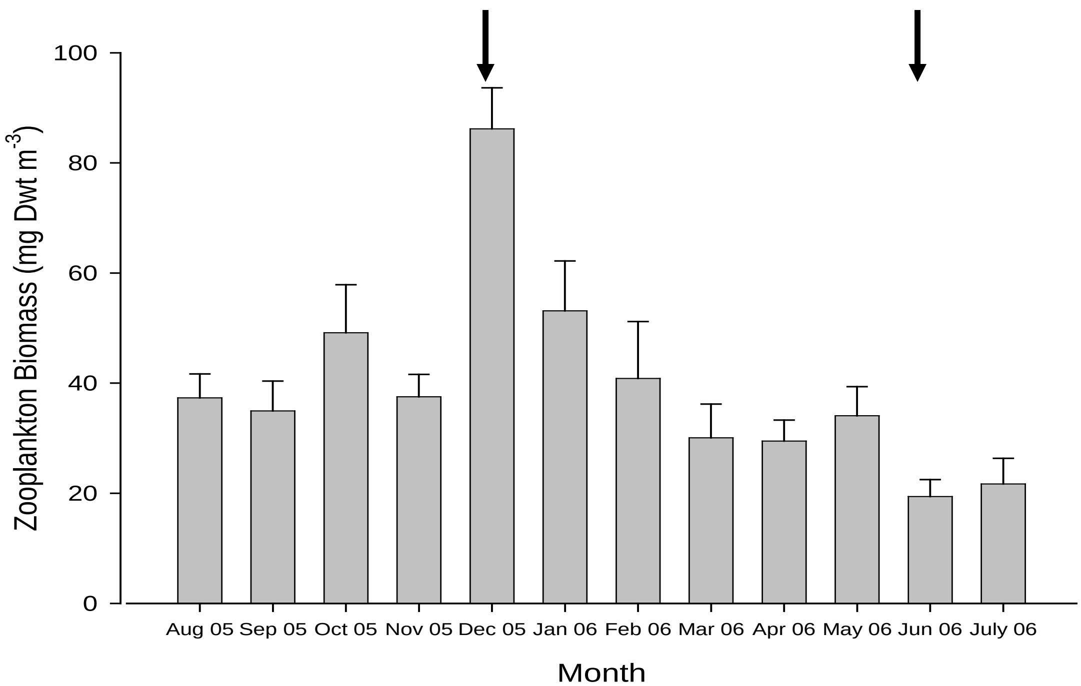

Figure 3.7: Mean monthly zooplankton biomass (mg Dwt m^{-3}) in the Riet River Estuary over the period August 2005 to July 2006. Error bars show standard deviation. Thick arrows indicate periods when breaching occurred.

3.5. Ichthyofauna (Littoral zone)

3.5.1. Abundance and biomass

A total of 8806 fish representing 15 species from 9 families were sampled with the 5 m seine net over the study period, August 2005 to July 2006 (Table 3.1). Mean fish abundance during the study ranged between 1.60 and 8.67 ind m^{-2} (Figure 3.8). The mean fish abundances in the Riet River Estuary showed a weak seasonal pattern with the highest values generally occurring in the summer months (December 2005 – February 2006) (range 4.04 ind m^{-2} to 8.67 ind m^{-2}) while the lowest values recorded in the winter months of August 2005, June 2006 and July 2006 (range 1.60 ind m^{-2} to 2.31 ind m^{-2}). An exception was recorded in September 2005 where the total ichthyofaunal abundance was estimated at 2.13 ind m^{-2} (Figure 3.8). Mean ichthyofaunal abundances decreased after the June 2006 breaching event but increased in December 2005, following the December breaching event. The mean ichthyofaunal biomass in the littoral zone was estimated at 4.20 g wwt m^{-2}, with a high of 21.76 g wwt m^{-2} in September 2005, and a low of 0.45 g wwt m^{-2} in July 2006 (Figure 3.8). Mean ichthyofaunal biomass after the December 2005 breaching event was found to be lower than that of the previous month but an increase in mean biomass was observed associated with the June 2006 breaching event (Figure 3.8).

3.5.2. Statistical analysis

Spearman rank correlation analysis indicated that total ichthyofaunal abundance and biomass within the littoral zone was significantly correlated to turbidity ($R = 0.57$; $R = 0.56$; $P < 0.05$ in both cases) and water temperature ($R = 0.42$; $R = 0.75$; $P < 0.05$ in both cases). There were no significant correlations between total ichthyofaunal abundance and biomass and the total chl-*a* and zooplankton biomass ($P>0.05$ in both cases).

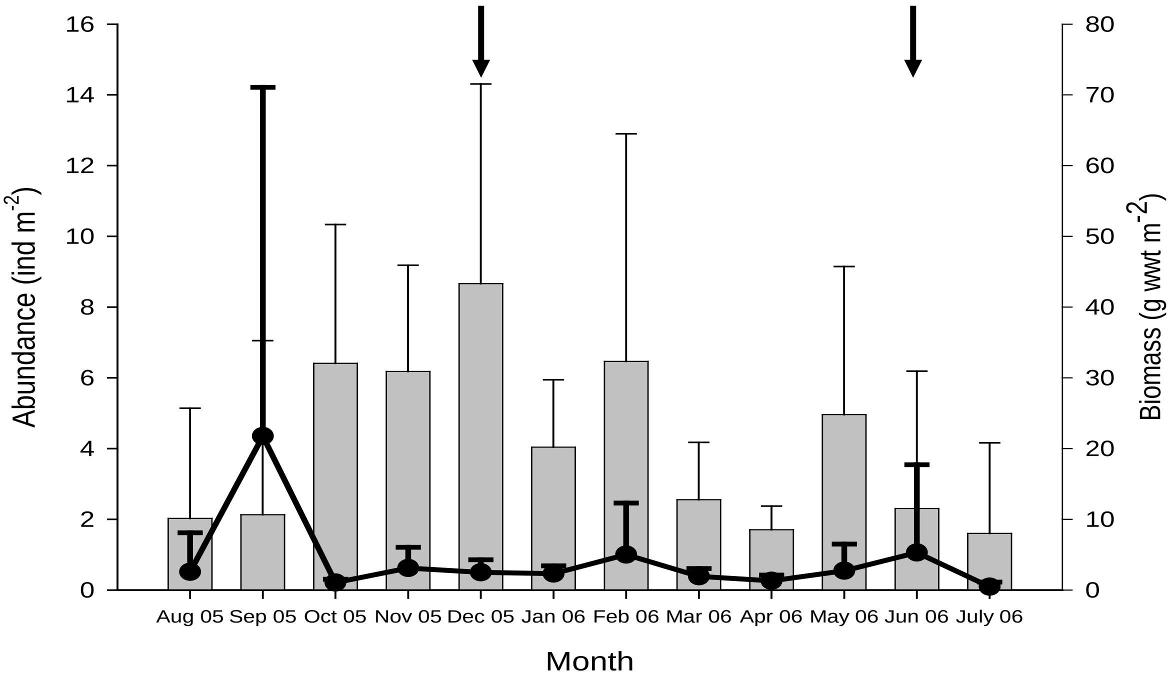

Figure 3.8: Mean monthly ichthyofaunal abundance (bars) and biomass (line) in the Riet River Estuary sampled with the a 5m seine net over the period August 2005 to July 2006. Error bars show standard deviation while thick arrows indicate periods when breaching occurred.

3.5.3. Estuarine association

The first month of the study (August 2005) was characterised by the numerical dominance of the facultative catadromous Freshwater Mullet (Category Vb), which accounted for 72.10% of the catch while estuarine dependant species (Category I species) accounted for 21.23% of the total catch (Table 3.1 and Figure 3.9). The estuarine dependant species (Category I) *Gilchristella aestuaria*, *Psammogobius knysnaensis*, *Atherina breviceps* and *Glossogobius callidus* contributed < 0.50, < 0.50, 19.25 and 0.99% to the total August 2005 catch respectively. The September, October and November 2005 closed phase was characterised by the numerical dominance of Category I species (mean of 62.55%) with the catch dominated by *Atherina breviceps* and *Glossogobius callidus*. Category II species contributed a high percentage of the total catch in October which can be attributed to the high percentage of *Liza dumerelii* (49.10%) and *Rhabdosargus holubi* (17.92%) caught during that month. This high contribution may be an artefact of the sampling during that period. In essence, a large shoal of these fish may have been sampled on the October sampling trip, which could have skewed results. This theory is supported as the Category II species contribution to the total catches was low prior to and post the October 2005 trip. Category IV (freshwater species whose penetration into estuaries is determined primarily by salinity tolerance) species accounted for 0.00, 0.00 and 2.67% of the total catch over the three months preceding the December breach while *Myxus capensis* (Category Vb) accounted for 15.26, 0.00 and 11.81% of the total catch over the same months. Following the breaching event in December 2005, the catch comprised 62.03% Category I species, 24.52% Category II species 0.40% Category IV species and 13.04% Category Vb species (Figure 3.9).

The closed phase January 2006 to May 2006 again revealed an ichthyofaunal community dominated by Category I species (range of 72.36 to 88.63% of total catch) while Category II and IV species contributed the least to the total catch (range of 1.96 to 24.8% for Category II and 1.87 to 4.96% for category IV). Following the June 2006 breaching event Category I species dominated the catch contributing 59.65% of the total catch. The Category II species contribution was low (3.69%) but an increase in contribution to the total catch was observed in July 2006 where the contribution of Category II species was 64.0%. This increase in contribution by Category II species can be attributed to an increased contribution by *Rhabdosargus holubi* to the total catch (62.81%) (Category IV species contributed 0% to the total ichthyofaunal catch immediately post breaching in June 2006 but the Category IV contribution increased to 27.19% to the total catch in July 2006 (Figure 3.9).

Category III (marine species which occur in estuaries in small numbers, but are not dependant on these systems) species were not caught in the Riet River Estuary using the 5 m seine net for the entire study period (Figures 3.9 and 3.10).

Of the 15 species captured, the 5 most common species, Cape Silverside, *Atherina breviceps*, Estuarine Roundherring, *Gilchristella aestuaria*, River Goby, *Glossogobius callidus*, Freshwater

Mullet, *Myxus capensis* and the Cape Stumpnose, *Rhabdosargus holubi* accounted for 91.68% of the small fish sampled with the 5 m seine net. In particular, *Gilchristella aestuaria*, accounted for 37.13% of the total fish captured and 52.45% of the total fish biomass (Table 3.1). A weak seasonal pattern in the abundance of *G. aestuaria* was observed with the highest values (range 0.79 ind m^{-2} to 4.39 ind m^{-2}) being recorded in summer (December 2005, January 2006 and February 2006) whilst the lowest values (range 0.01 ind m^{-2} to 1.01 ind m^{-2}) were recorded in the winter months. Intermediate values were recorded in spring and autumn. *G. aestuaria* biomass decreased following the December 2006 breaching event while the abundance of *G. aestuaria* increased over the same event. The June 2006 breaching event led to a decrease in *G. aestuaria* abundance with an increase in mean standard length. No *G. aestuaria* were caught in the 5 m seine net in April 2006. Mean standard lengths of *G. aestuaria* over the study period ranged from 19.12 mm to 47.15 mm (Figure 3.11).

The River Goby, *Glossogobius callidus*, contributed 17.74% to the total fish captured and 11.00% of the total fish biomass (Table 3.1). Abundances of *G. callidus* displayed a weak seasonal pattern with the highest values generally recorded in the spring and summer months with the lowest during winter. Total abundances of *G. callidus* ranged from 0.02 ind m^{-2} to 1.65 ind m^{-2}. Mean standard length of *G. callidus* ranged from 21.37 mm to 48.85 mm during the study (Figure 3.12).

The Cape Silverside, *Atherina breviceps* was the second highest contributing species which comprised 16.51% of the total fish captured and 7.67% of the total fish biomass (Table 3.1). Mean abundances of *Atherina breviceps* displayed no distinct seasonal pattern and ranged from 0.07 ind m^{-2} to 1.61 ind m^{-2}. Mean standard lengths over the study period ranged between 15.01 mm and 37.39 mm (Figure 3.13).

The Freshwater Mullet, *Myxus capensis,* contributed 15.27%, in terms of total numbers, and 17.74%, in terms of total biomass (g wwt m^{-2}) (Table 3.1). High abundances were recorded in both the summer (range 0.53 ind m^{-2} to 1.13 ind m^{-2}) and winter (range 0.44 ind m^{-2} to 1.46 ind m^{-2}) months. Intermediate values were recorded in autumn and spring (range 0.01 ind m^{-2} to 0.70 ind m^{-2}). Mean standard lengths of *M. capensis* during the study ranged from 17.59 mm to 66.84 mm (Figure 3.14).

The Cape Stumpnose, *Rhabdosargus holubi,* contributed 5.03% to the total ichthyofaunal catch and 5.55% to the total ichthyofaunal biomass over the entire study period (Table 3.1). The mean monthly abundance of *R. holubi* remained low for the entire study period (range 0.01 ind m^{-2} to 1.23 ind m^{-2}). Two notable exceptions are the abundances in October 2005 and May 2006 when the abundance values measured 1.21 ind m^{-2} and 1.23 ind m^{-2} respectively. Mean standard lengths for *R. holubi* during the study ranged from 11.22 mm to 73.50 mm (Figure 3.15).

Table 3.1: Total abundance and total biomass of selected fish species caught in the 5 m seine net and the subsequent percentage contribution of each species to the total catch for the period August 2005 to July 2006 (data rounded to 2 decimal places).

				Abundance		**Biomass**	
Family	**Species**	**Common Name**	**Estuarine Association Category**	**Total Numbers**	**Percentage Contribution**	**Total Biomass (g wwt)**	**Percentage Contribution**
Atherinidae	*Atherina breviceps*	Cape Silverside	Ib	1454	16.51	754.61	7.67
Cichlidae	*Oreochromis mossambicus*	Mozambique Tilapia	IV	112	1.27	92.39	<1
Clupeidae	*Gilchristella aestuaria*	Estuarine Roundherring	Ia	3270	37.13	5159.55	52.45
Gobiidae	*Glossogobius callidus*	River Goby	Ib	1562	17.74	1082.55	11.00
	Psammogobius knysnaensis	Speckled Sandgoby	Ia	7	0.08	25.43	<1
Monodactylidae	*Monodactylus falciformis*	Oval Moony	IIa	16	0.18	56.69	<1
Muglidae	*Liza dumerilii*	Groovy Mullet	IIb	385	4.37	64.82	<1
	Liza richardsonii	Southern Mullet	IIc	76	0.86	78.62	<1
	Mugil cephalus	Flathead Mullet	IIa	128	1.45	87.67	<1
	Myxus capensis	Freshwater Mullet	Vb	1345	15.27	1745.55	17.74
Soleidae	*Heteromycteris capensis*	Cape Sole	IIb	4	0.05	33.26	<1
	Solea bleekeri	Blackhand Sole	IIb	2	0.02	53.24	<1
Sparidae	*Lithognathus lithognathus*	White Steenbras	IIa	1	0.01	25.44	<1
	Rhabdosargus holubi	Cape Stumpnose	IIa	443	5.03	546.20	5.55
Teraponidae	*Terapon jarbua*	Thornfish	IIa	1	0.01	31.22	<1
			Total	8806	100	9837.24	100

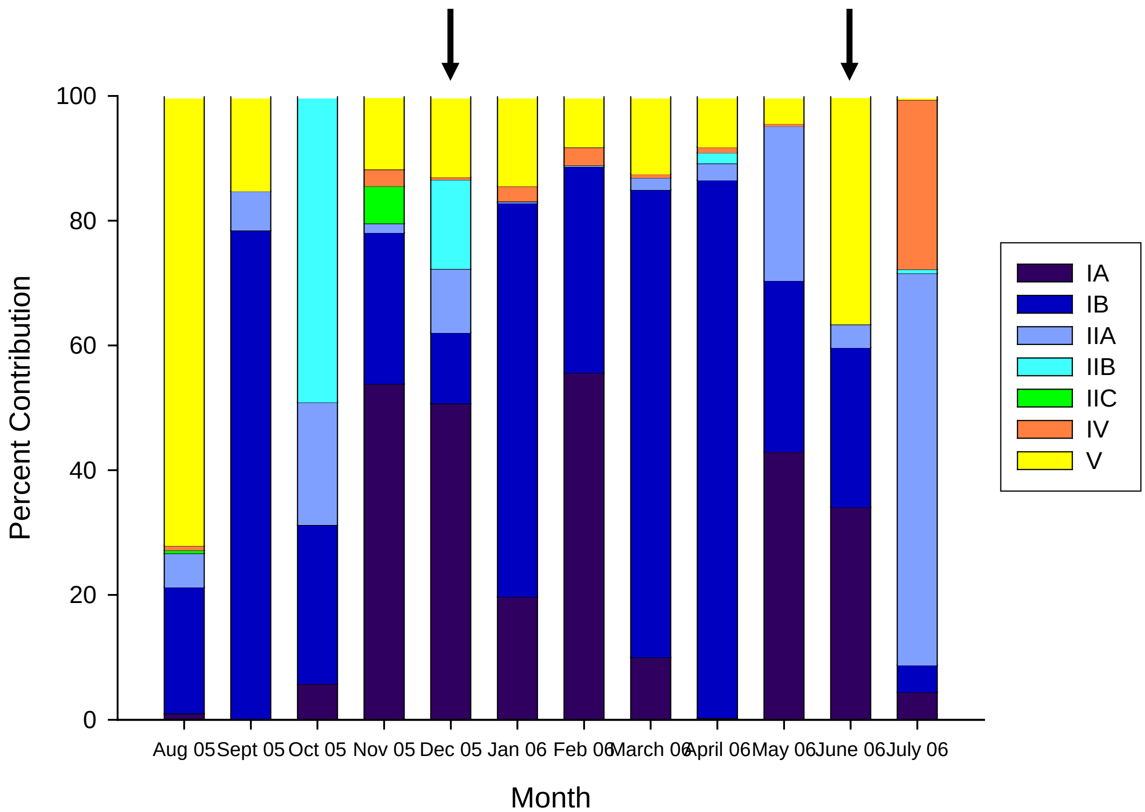

Figure 3.9: Percent contribution of individual fish from different estuarine association categories for each month of the sampling period. Thick arrows indicate periods when breaching occurred. Sampling was conducted with a 5 m seine net.

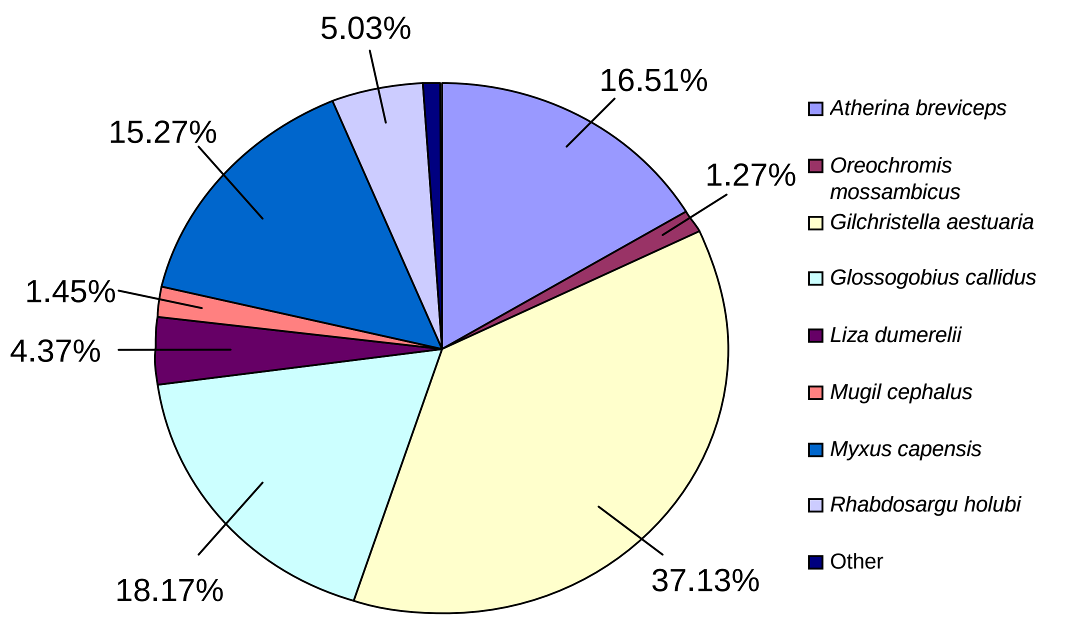

Figure 3.10: Total species contribution to the overall catch of 8806 fish sampled with the 5 m seine net. Other comprises 1.27% of the total catch and is made up of: *Psammogobius knysnaensis, Monodactylus falciformis, Liza richardsonii, Heteromycteris capensis, Solea blekeeri, Lithognathus lithognathus* and *Terapon jarbua* (data rounded to 2 decimal places).

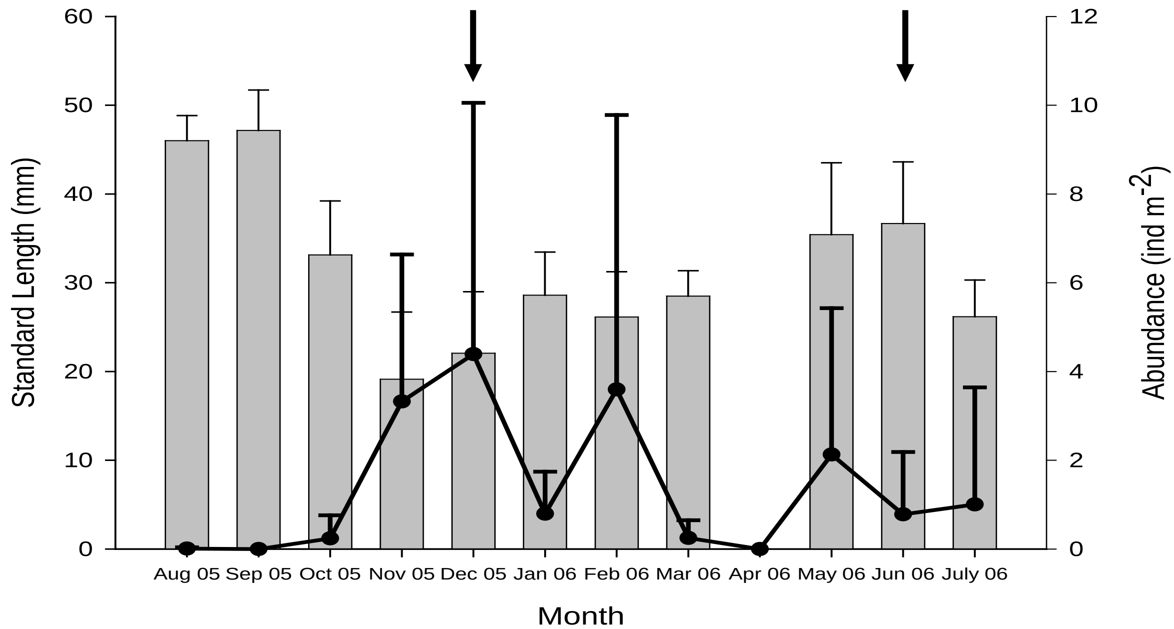

Figure 3.11: Mean monthly standard length (bars) and abundance (line) of *Gilchristella aestuaria* in the Riet River Estuary sampled with the use of a 5m seine net over the period August 2005 to July 2006. Error bars show standard deviation while thick arrows indicate periods when breaching occurred.

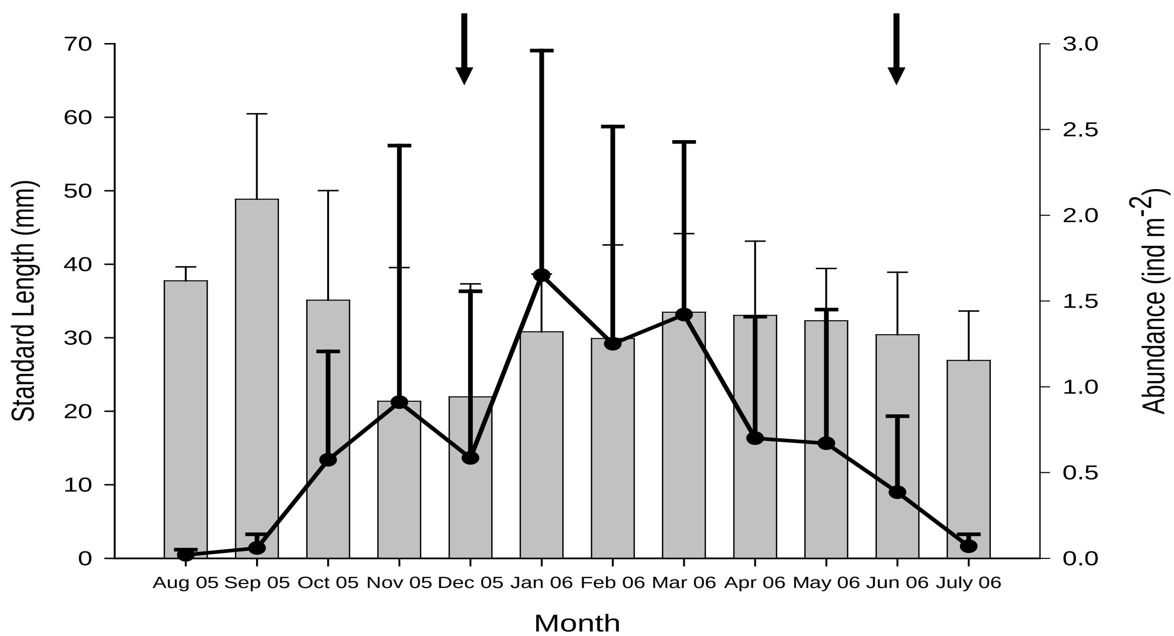

Figure 3.12: Mean monthly standard length (bars) and abundance (line) of *Glossogobius callidus* in the Riet River Estuary sampled with the use of a 5m seine net over the period August 2005 to July 2006. Error bars show standard deviation while thick arrows indicate periods when breaching occurred.

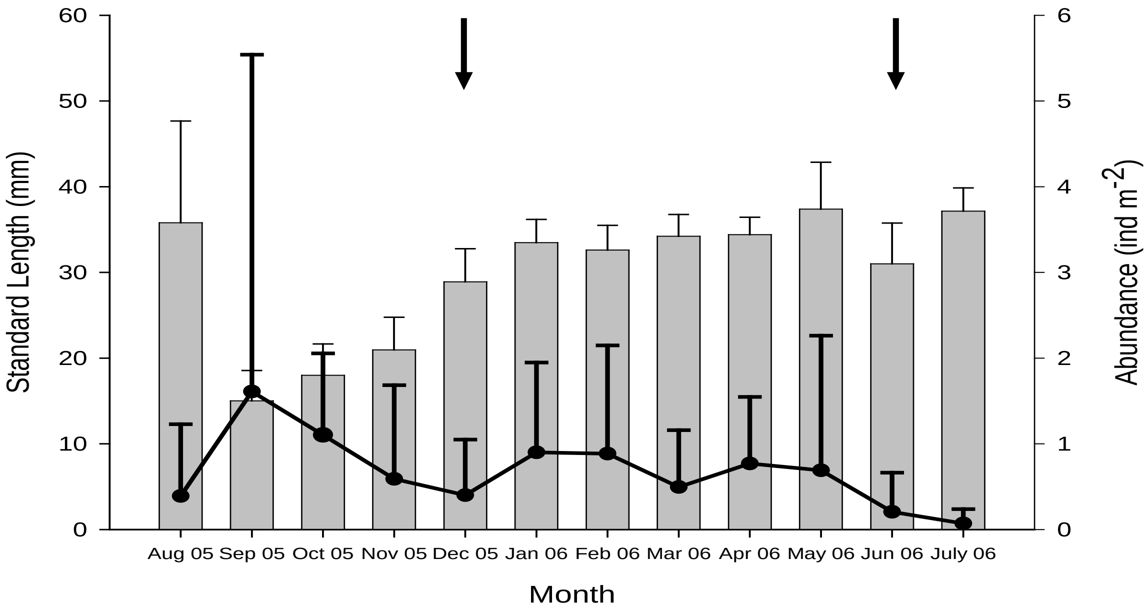

Figure 3.13: Mean monthly standard length (bars) and abundance (line) of *Atherina breviceps* in the Riet River Estuary sampled with the use of a 5m seine net over the period August 2005 to July 2006. Error bars show standard deviation while thick arrows indicate periods when breaching occurred.

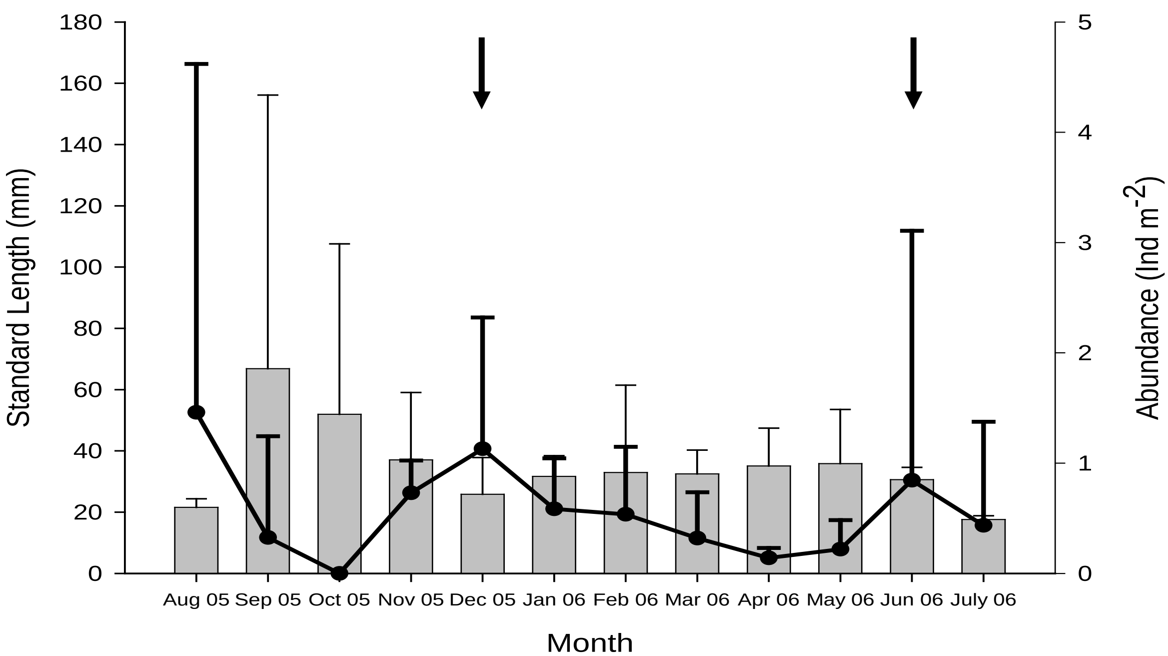

Figure 3.14: Mean monthly standard length (bars) and abundance (line) of *Myxus capensis* in the Riet River Estuary sampled with the use of a 5m seine net over the period August 2005 to July 2006. Error bars show standard deviation while thick arrows indicate periods when breaching occurred.

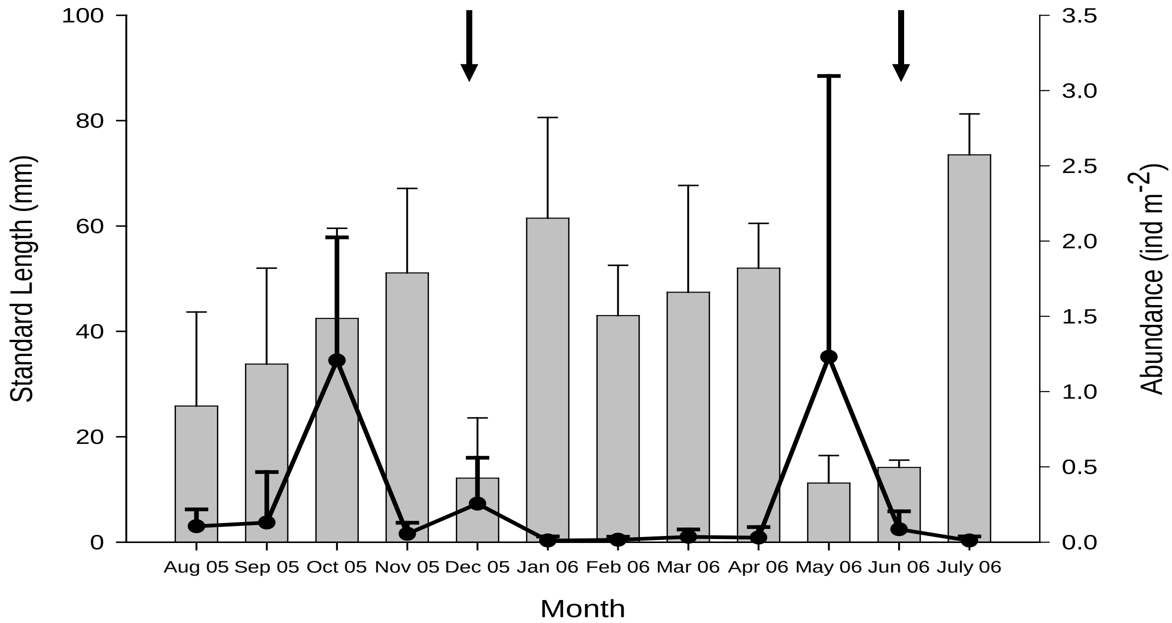

Figure 3.15: Mean monthly standard length (bars) and abundance (line) of *Rhabdosargus holubi* in the Riet River Estuary sampled with the use of a 5m seine net over the period August 2005 to July 2006. Error bars show standard deviation while thick arrows indicate periods when breaching occurred.

3.5.4. Ichthyofaunal diversity

Similar trends in the diversity indices were observed between the number of fish species present and the Shannon-Weiner Heterogeneity Index as well as between Margalef's Richness Index and the Simpson Index (Figure 3.16). The total number of species recorded monthly in the Riet River Estuary over the study period ranged between 5 in September 2005 and 9 in August 2005 and March 2006. The Shannon-Weiner Index produced the lowest heterogeneity values in September 2005 (H = 0.78) with the highest value recorded in December 2005 (H = 1.53). Margalef's Richness Index showed high species richness in August 2005 (R_{MG} = 11.34), April 2006 (R_{MG} = 11.70) and July 2006 (R_{MG} = 10.64) with low species richness values recorded in the remaining months (range R_{MG} = 2.68 to R_{MG} = 8.52). The Simpson Index values were highest in April, June and July 2006 with values of D = 1.50, D = 1.26 and D = 1.4, respectively. The Simpson Index remained low for the remainder of the months in the study period (range D = 0. 81 to D = 1.03) (Figure 3.16). The total number of species did not change in association with either of the breaching events but changes were observed in the diversity indices. Namely, the Shannon-Weiner diversity index showed increased values associated with the first breaching period (December 2005) while Margalef's and Simpson's Indices revealed decreased ichthyofaunal richness associated with the December 2005 breaching periods. The Shannon-Weiner diversity index revealed decreased species richness associated with the June 2006 breaching event while both the Margalef's and Simpson's indices revealed increased diversity over the second breaching period (Figure 3.16).

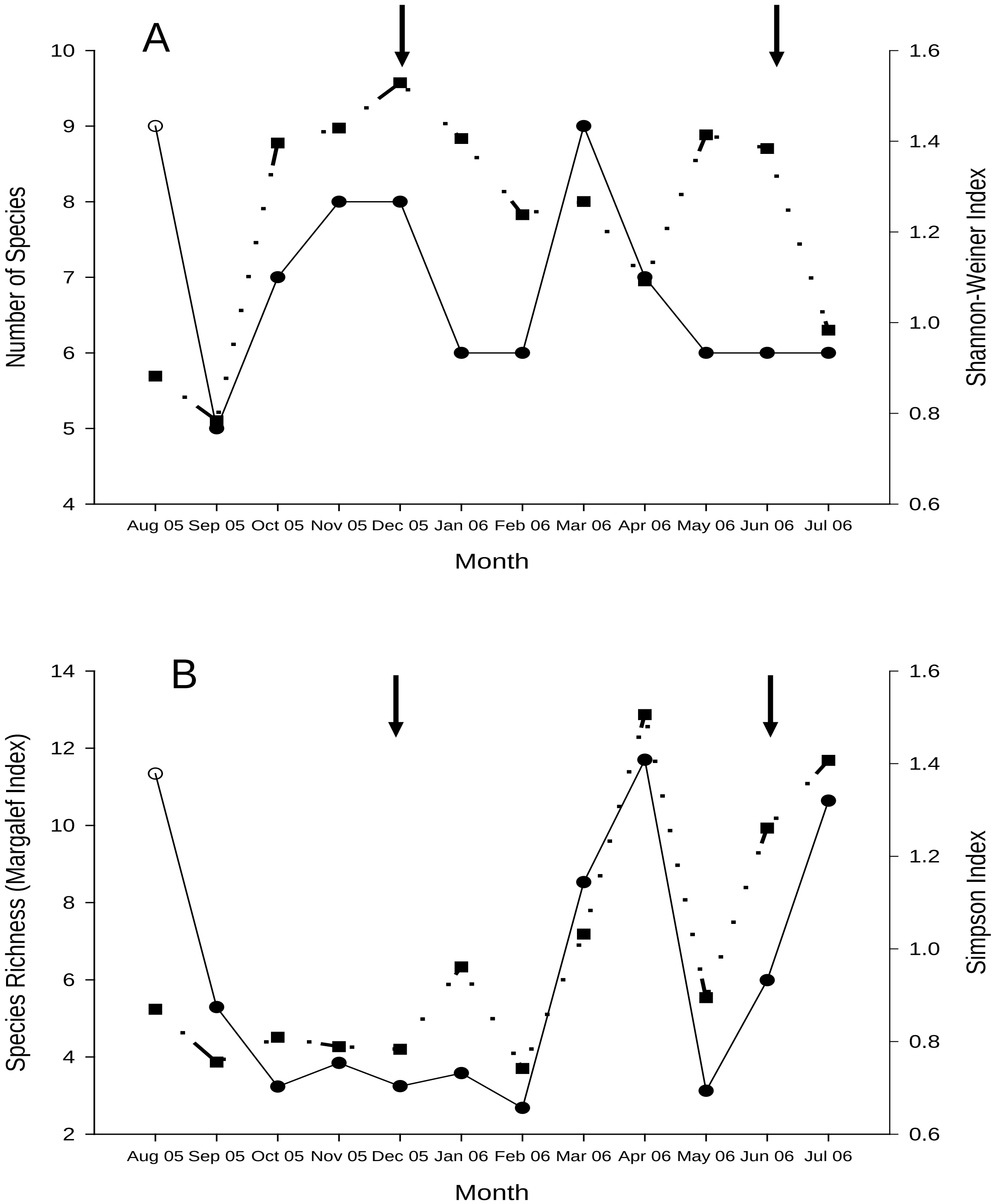

Figure 3.16. Estimates of monthly littoral zone ichthyofaunal diversity in the Riet River Estuary based on:

A: number of fish species present (●) and diversity using the Shannon -Weiner Index (■)

B: fish species richness, using the Margalef Index (●), and the Simpson Index (■).

Thick arrows indicate periods when breaching occurred.

3.5.5. Community analysis

Numerical analysis of the ichthyofaunal abundance data revealed no significant spatial patterns in the community structure and as such data for each month were pooled (data not shown). Spatial and/or temporal patterns may have been masked by extreme variability in biomass and abundance of the early developmental stages of ichthyofauna inhabiting the littoral zone of the estuary during the period of study.

Three distinct groupings, designated Groups 1 to 3, were identified with the hierarchical cluster analysis (Figure 3.17). ANOSIM indicated that the three groupings were significantly different from one another ($P<0.05$). Group 1 comprised the months of August and September 2005, Group 2, the June and July 2006 samples and finally; Group 3 comprised the remainder of the months. SIMPER analysis indicated that the distinction of the three groupings could largely be ascribed to changes in the numerical dominance in the estuarine associations of fish within each group. The five most numerically dominant species accounting for up to *ca.* 96% of similarity within each grouping are indicated in Table 3.2. Group 1 (comprising months August and September 2005) was numerically dominated by the estuarine dependant species *G. callidus* and *A. breviceps.* Group 2 comprised a combination of estuarine species (*A. breviceps*), the facultative catadromous species, *M. capensis,* as well as the marine breeding species (*R. holubi*). Finally, Group 3 was numerically dominated by estuarine dependant species mainly *G. aestuaria, G. callidus* and *A. breviceps*, which collectively contributed 77.39% of the similarity within the group. The facultative catadromous species *M. capensis* contributed 15.75% of the similarity to group 3. The MDS plot (Figure 3.18) also identified 3 distinct groupings of ichthyofauna, which correspond to groups identified with the hierarchical cluster analysis.

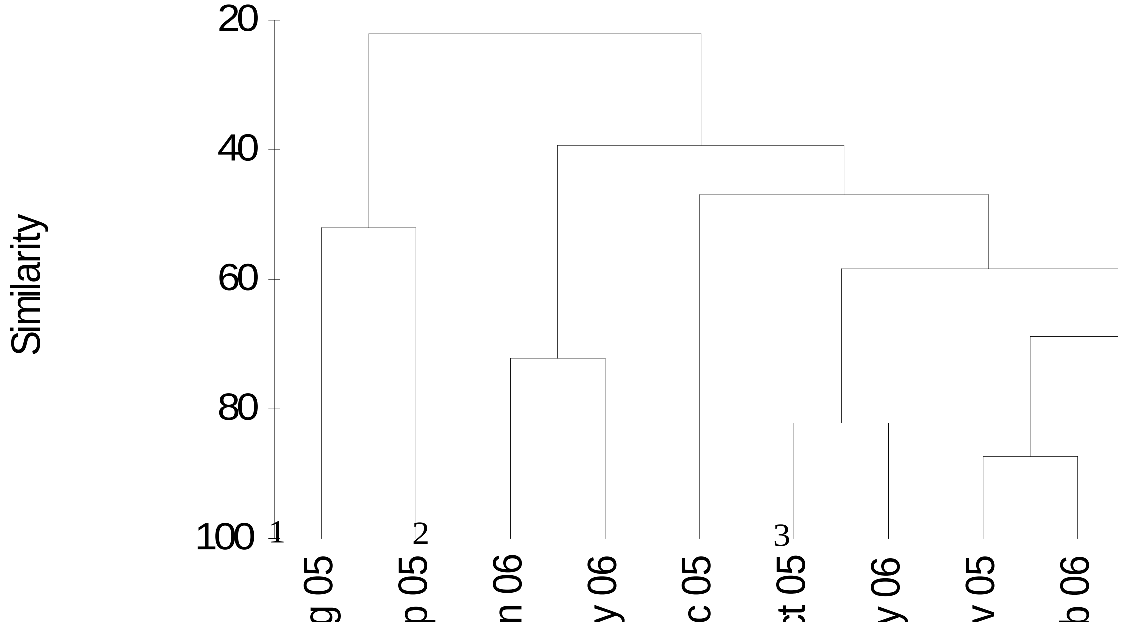

Figure 3.17: Similarity dendogram of the littoral zone ichthyofaunal community data for the Riet River Estuary using Bray-Curtis hierarchical cluster analysis. Data were collected with the 5 m seine net.

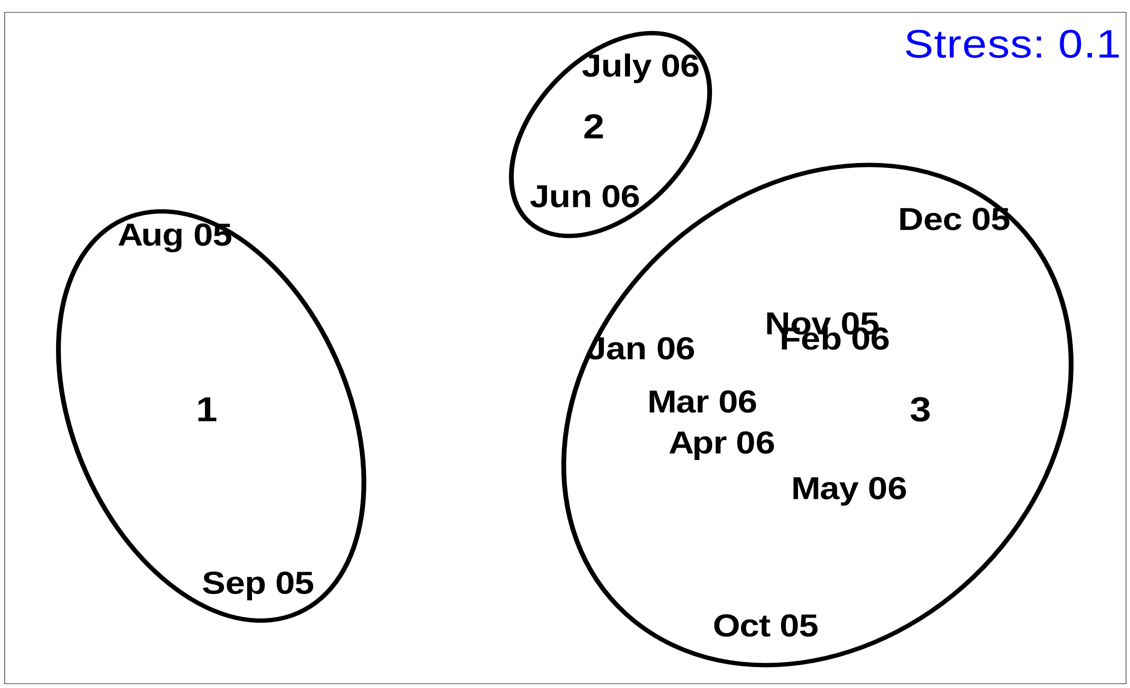

Figure 3.18: Multidimensional scaling plot of the littoral zone ichthyofaunal community data for the Riet River Estuary using Bray-Curtis hierarchical cluster analysis. Data were collected with the 5 m seine net.

Table 3.2: Species contributing up to *ca.* 93% of the similarity within the three groupings (1, 2 and 3) identified with the SIMPER analysis. Data collected with the 5 m seine net.

Group 1 (93.24%)			**Group 2** (96.63%)			**Group 3** (93.14%)		
Species	Mean Abundance (ind m^{-2})	Percent Contribution %	Species	Mean Abundance (ind m^{-2})	Percent Contribution %	Species	Mean Abundance (ind m^{-2})	Percent Contribution %
Glossogobius callidus	1.26	46.67	*A. breviceps*	1.00	44.78	*Gilchristella aestuaria*	2.35	46.87
Atherina breviceps	0.72	33.82	*M. capensis*	0.89	38.27	*G. callidus*	0.63	16.74
Myxus capensis	0.35	12.75	*Rhabdosargus holubi*	0.12	13.58	*M. capensis*	0.56	15.75
						A. breviceps	0.56	13.78

3.6. Ichthyofauna (Channel)

3.6.1. Abundance and Biomass

A total of 12157 fish representing 17 species from 10 families (Table 3.3) were sampled with the 30 m seine net over the study period. The mean total ichthyofaunal abundances within the channel of the estuary ranged from 0.08 to 0.44 ind m^{-2} and demonstrated no distinct seasonal pattern (Figure 3.19). Mean biomass of ichthyofauna within the Riet River estuary varied from 0.58 to 36.52 g wwt m^{-2} (Figure 3.19). A decrease in abundance was observed associated with the December 2005 breaching event while an increase in abundance was observed associated with the June 2006 breaching event (Figure 3.19). There appeared to be no apparent relationship between mouth phase and the estimated fish biomass over the study period. A weak seasonal trend was observed however, with higher values generally recorded during late spring (October and November 2005) and summer (December 2005, , January 2006 and February 2006). Total biomass did decrease following the December 2005 breaching event (Figure 3.19).

3.6.2. Estuarine association

Category I (estuarine resident) species dominated the total 30 m seine net catch contributing a mean of *ca*. 53.39% of all ichthyofauna sampled, while Category II (euryhaline marine species which usually breed at sea with juveniles showing varying degrees of dependence on southern African estuaries) species contributed a mean of *ca.* 44.95% (Figure 3.20). The remainder of the total catch comprised Category IV (freshwater breeding species) and Category Vb species (Facultative catadromous species), which contributed 0.05 and 1.61% of the total catch, respectively.

Changes in the percentage distribution of the estuarine association group were associated with breaching events although changes in percentage contributions of estuarine association groups were observed over periods when there were no breaching events. Following the pre-survey breaching event in August 2005, Category IA species were absent, whilst the majority (69.14%)

of the catch was dominated by Category IB species, (estuarine resident species which also have marine or freshwater breeding species). The remainder of the catch comprised Category II (28.40%) and Category V (2.47%) species (Figure 3.20). The breaching event in December 2005 revealed contributions of 26.11% for Category I species, 72.09% for Category II species, 0.49% of Category IV species and 1.31% of Category V species. The June 2006 breaching revealed contributions of 96.27% (Category I), 3.73% (Category II) while contributions in July 2006 showing decreased contributions of Category 1 species (67.73%) with increased contributions of Category II species (32.27%). The Category I contribution in July 2006 was dominated by Category IB species which again are estuarine resident species which also have marine or freshwater breeding species (Figure 3.20).

The Sparid, *Rhabdosargus holubi* was identified as the single most abundant channel zone species contributing, on average, 25.92% to the total catch (range 1.66% to 58.71%). Of the total monthly catch, *R. holubi* contributed 44.19% (SD ± 16.10) to the total biomass over the study period (Table 3.3). The biomass of *R. holubi* ranged from 0.25 g wwt m^{-2} (August 2005) to 18.48 g wwt m^{-2} (October 2005) (Figure 3.21). *Glossogobius callidus* contributed an average of 5.52% to the total ichthyofaunal catch, while contributing 4.08% to the total biomass over the study period (Table 3.3). *G. callidus* abundances ranged between <0.10 ind m^{-2} (August 2005) and 0.41 ind m^{-2} (November 2005) while the biomass ranged between <0.10 g wwt m^{-2} (July 2006) and 23.82 g wwt m^{-2} (November 2005) (Figure 3.22). *Myxus capensis* contributed 4.33% to the total catch and 12.76% to the total biomass over the study period (Table 3.3). *Myxus capensis* monthly biomasses ranged between 0.00 g wwt m^{-2} (August 2005) and 6.42 g wwt m^{-2} (February 2006), and monthly abundances ranged from 0.00 ind m^{-2} (August 2005) to 2.51 ind m^{-2} (November 2005) (Figure 3.23).

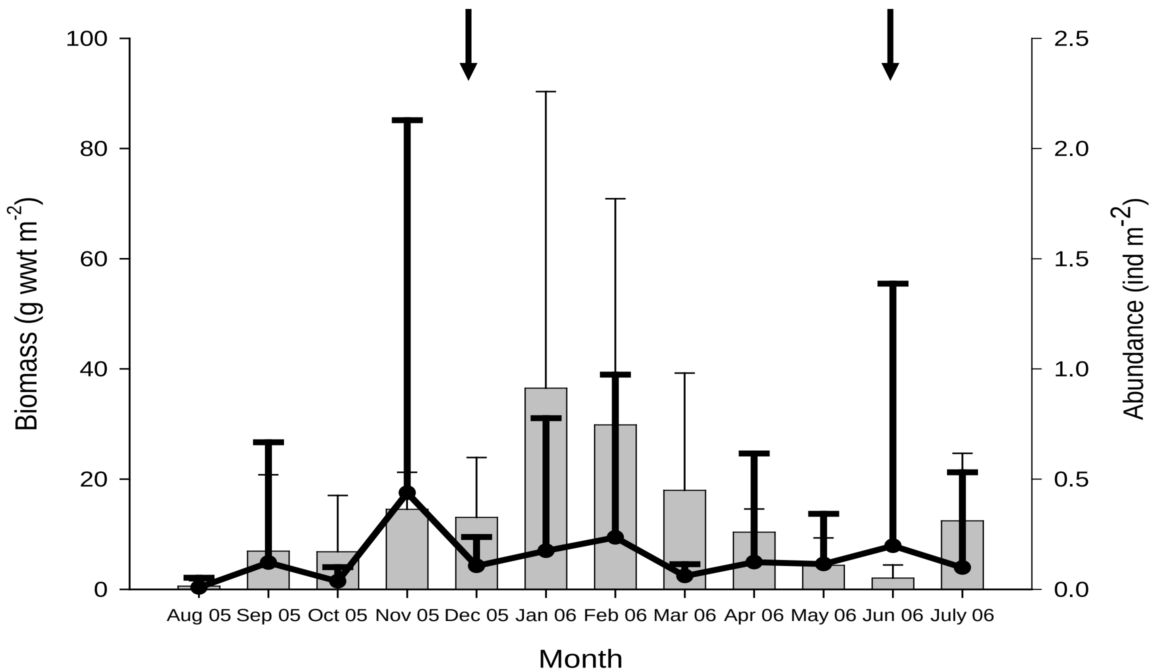

Figure 3.19: Mean monthly biomass (bars) and abundance (line) of fish caught with the 30 m seine net in the Riet River Estuary over the period August 2005 to July 2006. Error bars show standard deviation while thick arrows indicate periods when breaching occurred.

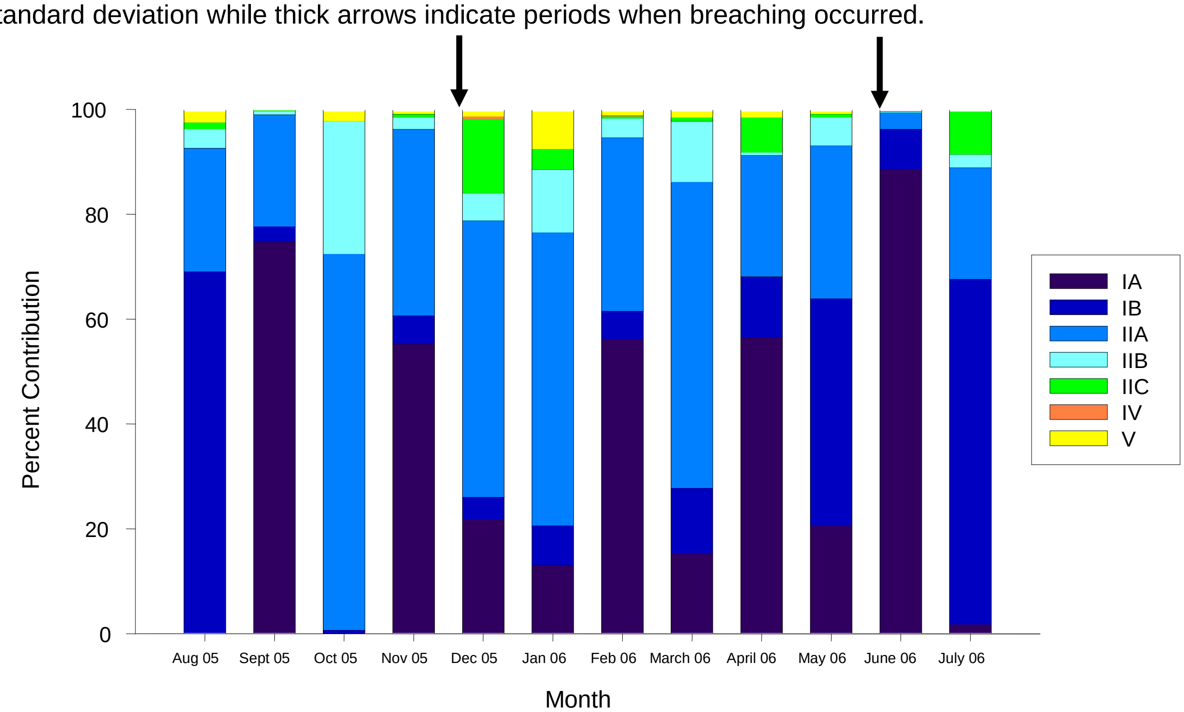

Figure 3.20: Percent contribution of fish abundance caught with the 30 m seine net in the different estuarine association categories for each month of the sampling period. Thick arrows indicate periods when breaching occurred.

Table 3.3: Total abundance of all species and total biomass of selected fish species caught in the 30 m seine net and the subsequent percentage contribution of each species to the total catch for the period August 2005 to July 2006. Species contributing < 3% to total abundance and <5% to total biomass (32.33% to total biomass cumulatively) have been omitted from the table. It should be noted that these species were included in all statistical and analyses.

				Abundance		Biomass	
Family	**Species**	**Common Name**	**Estuarine Association Category**	**Total Numbers**	**Percentage Contribution**	**Total Biomass (g wwt)**	**Percentage Contribution**
Atherinidae	*Atherina breviceps*	Cape Silverside	Ib	754	6.20	670.71	1.07
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV	148	1.22		<5
Clupeidae	*Gilchristella aestuaria*	Estuarine roundherring	Ia	6052	49.78	3498.94	5.60
Gobiidae	*Glossogobius callidus*	River goby	Ib	671	5.52	2552.52	4.08
	Psammogobius knysnaensis	Speckled sandgoby	Ia	4	0.03		<1
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa	1	0.01		<1
Monodactylidae	*Monodactylus falciformis*	Oval moony	IIa	85	0.70		<5
Muglidae	*Liza dumerelii*	Groovy mullet	IIb	169	1.39		<5
	Liza richardsonii	Southern mullet	IIc	293	2.41		<5
	Mugil cephalus	Flathead mullet	IIa	54	0.44		<5
	Myxus capensis	Freshwater mullet	Vb	526	4.33	7964.77	12.74
Soleidae	*Heteromycteris capensis*	Cape sole	IIb	5	0.04		<1
	Solea bleekeri	Blackhand sole	IIb	64	0.53		<5
Sparidae	*Lithognathus lithognathus*	White steenbras	IIa	178	1.46		<5
	Rhabdosargus holubi	Cape stumpnose	IIa	3151	25.92	27615.07	44.19
	Sarpa salpa	Strepie	IIc	1	<0.01		<1
Teraponidae	*Terapon jarbua*	Thornfish	IIa	1	<0.01		<1
			Total	12157	100	62496.33	100

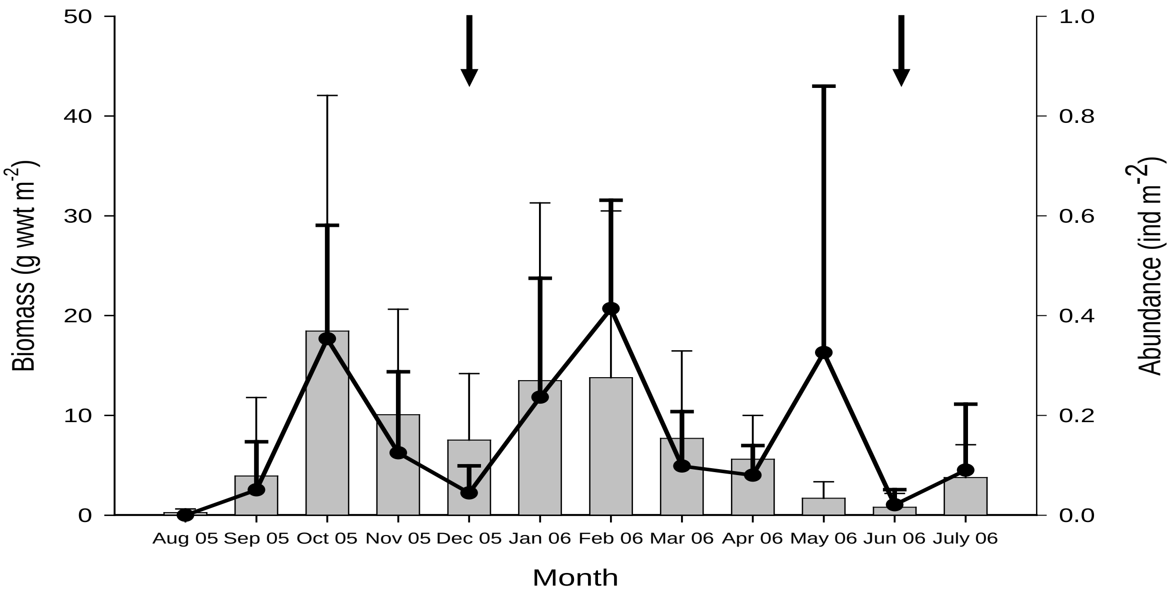

Figure 3.21: Mean monthly biomass (bars) and abundance (line) of *Rhabdosargus holubi* in the Riet River Estuary sampled with the use of the 30 m seine net over the period August 2005 to July 2006. Error bars show standard deviation while thick arrows indicate periods when breaching occurred.

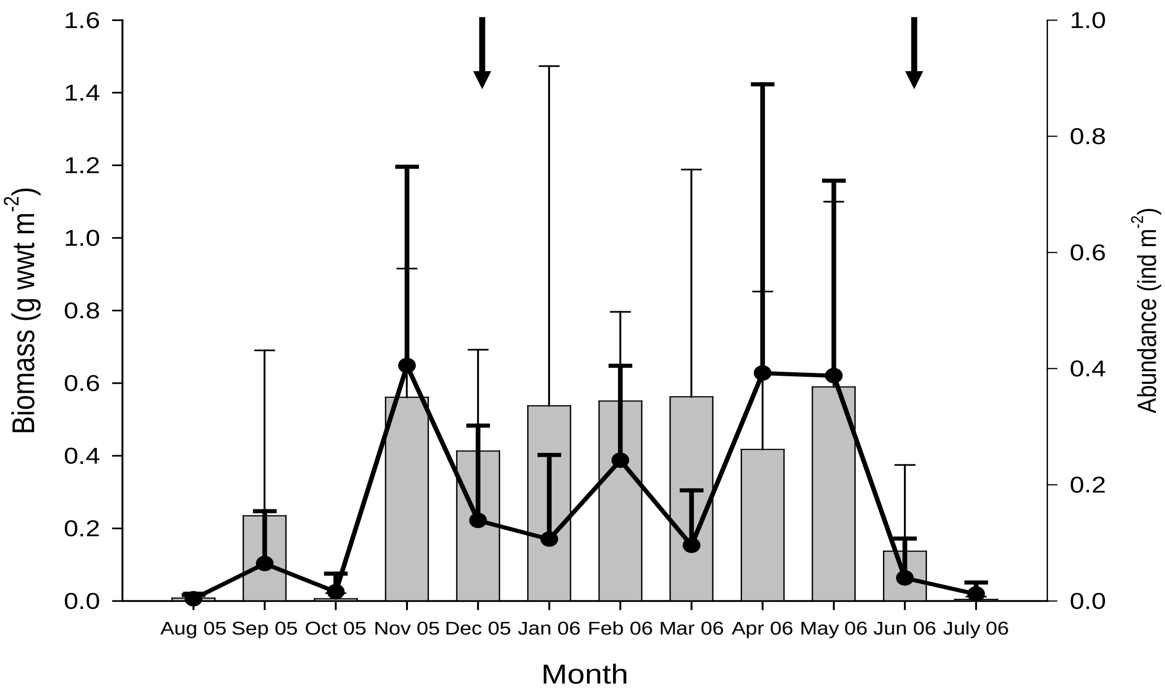

Figure 3.22: Mean monthly biomass (bars) and abundance (line) of *Glossogobius callidus* in the Riet River Estuary sampled with the use of the 30 m seine net over the period August 2005 to July 2006. Error bars show standard deviation while thick arrows indicate periods when breaching occurred.

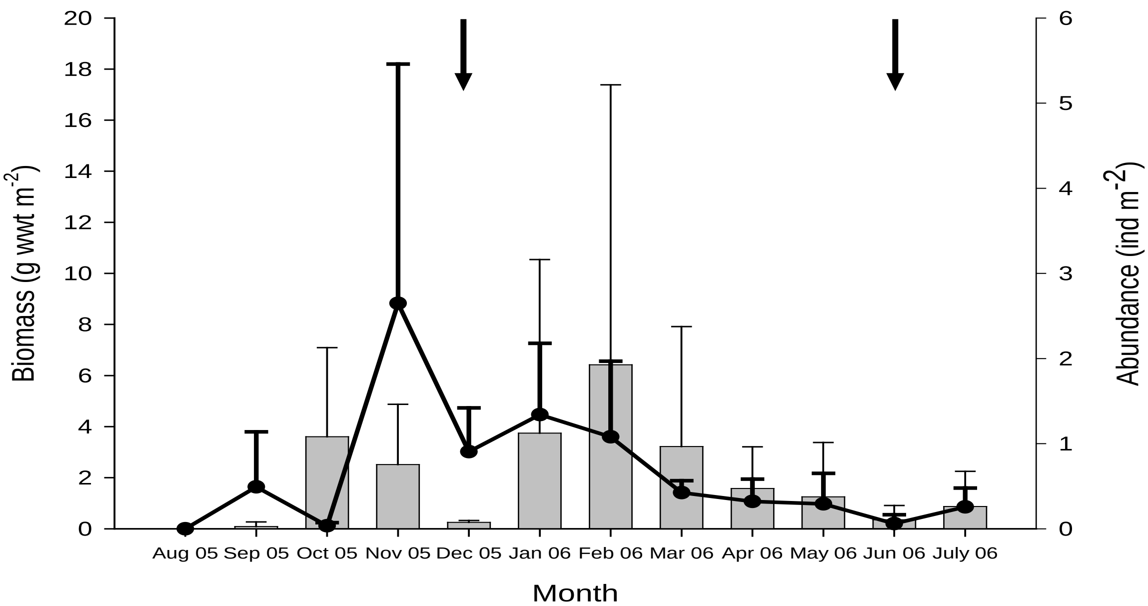

Figure 3.23: Mean monthly biomass (bars) and abundance (line) of *Myxus capensis* in the Riet River Estuary sampled with the use of the 30 m seine net over the period August 2005 to July 2006. Error bars show standard deviation while thick arrows indicate periods when breaching occurred.

3.6.3. Ichthyofaunal diversity

Both the total number of species and Shannon-Weiner Diversity Index showed similar trends over the study period. Total number of species ranged from a low of 6 in August 2005 to a high of 14 in November 2005. Shannon-Weiner Heterogeneity Index was lowest in June 2006 (H = 0.51) and highest in March 2006 (H = 1.94) (Figure 3.24). Margalef (R_{MG}) and Simpson (D) index values ranged from 1.96 to 3.64 and from 0.34 to 3.04, respectively (Figure 3.24). Margelef's Index was highest in August 2005 (R_{MG} = 3.64) while Simpson's Index revealed the highest diversity value in March 2006 (D = 3.04) The three indices showed increased ichthyofaunal diversity associated with the December 2005 breaching event, while a decrease in all diversity indices as well as total number of species was observed associated with the second breaching event in June 2006 (Figure 3.24).

3.6.4. Community analysis

Results of the Bray-Curtis similarity analysis showed that there were no significant spatial patterns in the ichthyofaunal abundance (P< 0.05). As a result, data for each month were pooled. Hierarchical cluster analysis (Figure 3.25) and Multi-dimensional scaling (Figure 3.26) revealed two distinct Groupings and two outliers (designated Groups 1 to 4). ANOSIM indicated that the two groupings were significantly different from one another (P< 0.05). The first of the Groupings, designated Group 3, was characterised by those months exhibiting elevated ichthyofaunal abundances (range 0.12 to 0.44 ind m^{-2}). Group 4 was characterised by those months where ichthyofaunal abundances were reduced (range <0.1 to 0.17 ind m^{-2}). The outliers (Groups 1 and 2) comprised those months where the lowest abundances were observed. SIMPER analysis showed that differences between Groupings could largely be attributed to changes in the relative abundances of *Myxus capensis,* and to a lesser degree *Glossogobius callidus, Rhabdosargus holubi, Heteromycteris capensis, Monodactylus falciformis* and *Liza richardsonii* (Table 3.4).

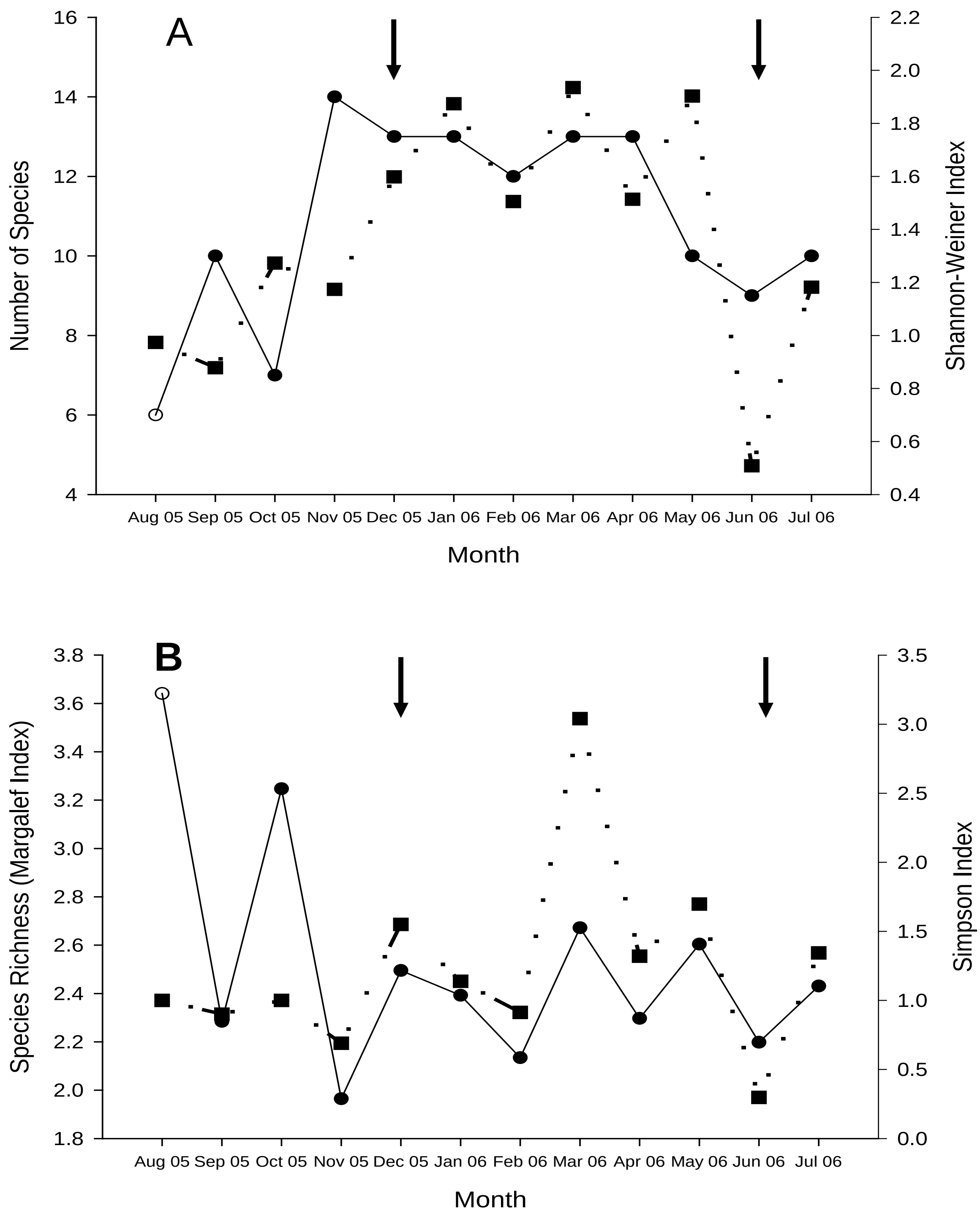

Figure 3.24: Monthly diversity of fishes in the Riet River Estuary caught with the 30m seine net based on**: A:** number of fish species present (●), and diversity using the Shannon -Weiner Index (■)**;** and **B:** fish species richness, using the Margalefs Index (●), and the Simpson Index (■).

Thick arrows indicate periods when breaching occurred.

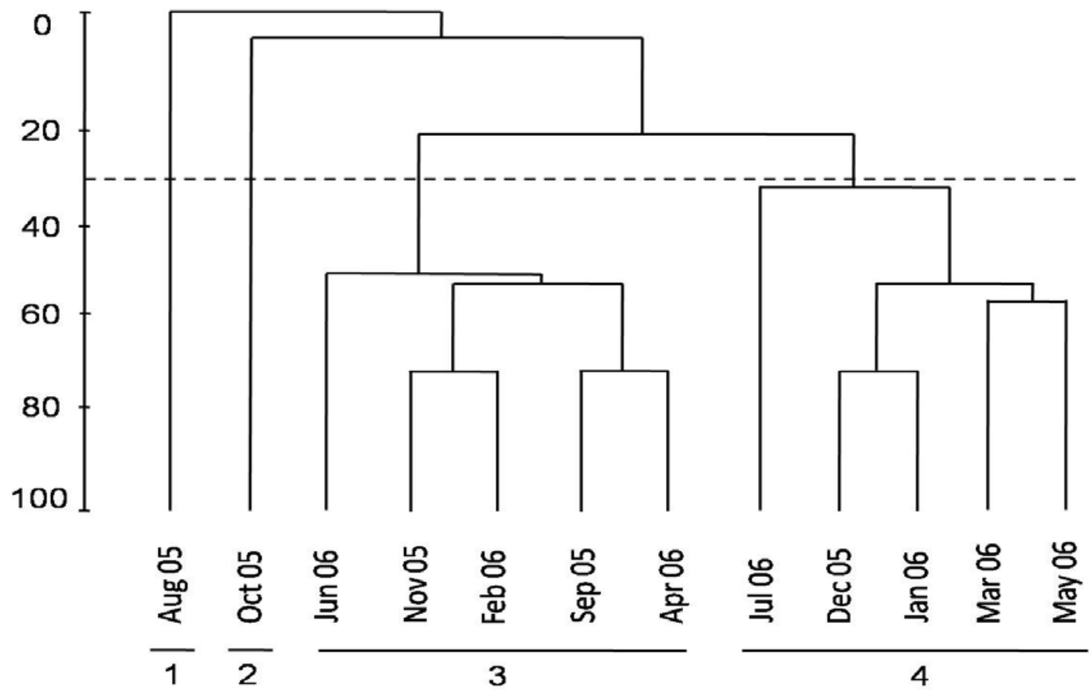

Figure 3.25: Similarity dendogram of the ichthyofaunal community data for the Riet River Estuary using Bray-Curtis hierarchical cluster analysis. Data were collected with the 30 m seine net.

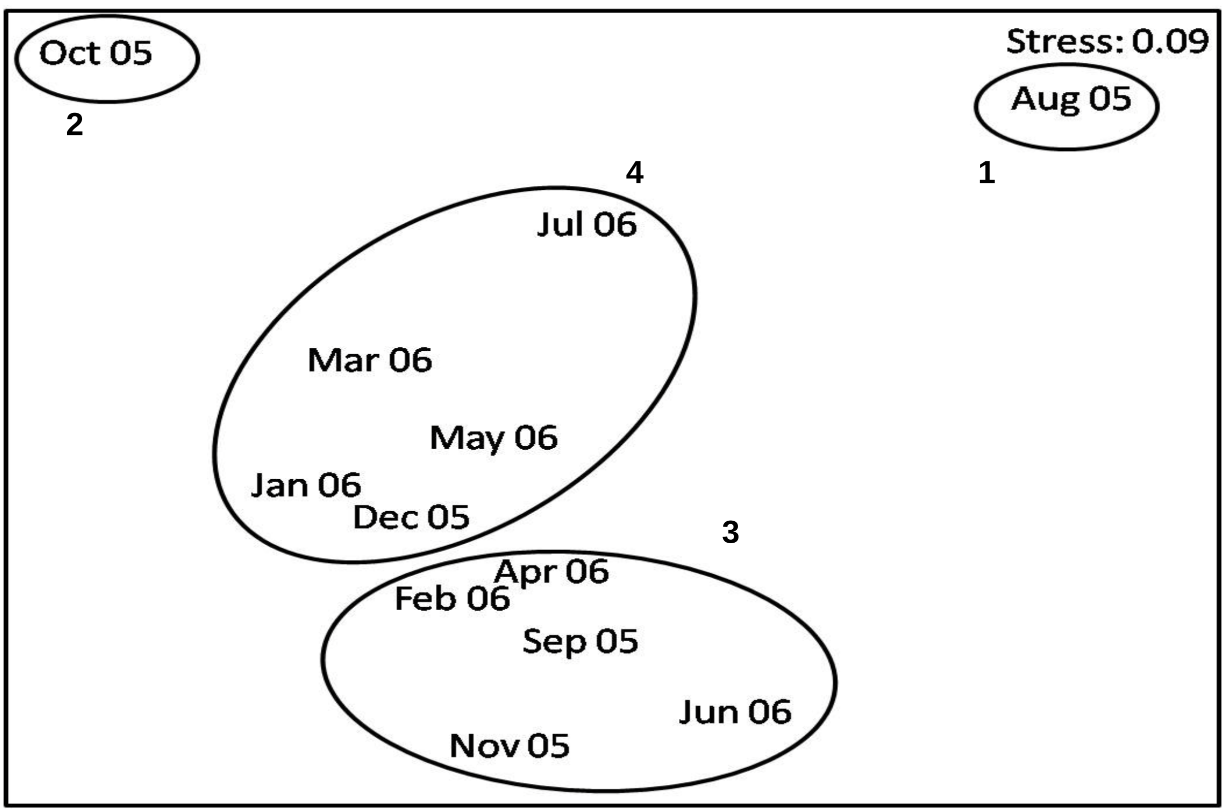

Figure 3.26: Multidimensional scaling plot of the ichthyofaunal community data for the Riet River Estuary using Bray-Curtis hierarchical cluster analysis. Data were collected with the 30 m seine net.

Table 3.4: Species contributing up to *ca.* 92% of the similarity within the four groupings (1, 2, 3 and 4) identified with the SIMPER analysis. Data collected with the use of the 30 m seine net. Group 1 and 2 were represented by outliers representing single months and as such are not presented in the table.

Group 3 (92.94)			**Group 4** (92.17)		
Species	Average Abundance (ind m^{-2})	Percent Contribution %	Species	Average Abundance (ind m^{-2})	Percent Contribution %
Gilchristella aestuaria	2.25	66.96	*M. capensis*	0.74	36.65
Myxus capensis	0.92	18	*G. aestuaria*	0.35	22.91
Glossogobius callidus	0.23	7.53	*G. callidus*	0.18	10.58
			Rhabdosargus holubi	0.18	8.79
			Heteromycteris capensis	0.09	5.44
			Monodactylus falciformis	0.09	5.44
			Liza richardsonii	0.07	2.36

3.7. Discussion

3.7.1. Environmental parameters

Reduced freshwater inflow as a result of small catchment size (generally <500 km^2), shallow depth and strong coastal winds which facilitate the horizontal and vertical mixing of the water column, contribute to TOCE's in Eastern Cape generally exhibiting the absence of any horizontal and vertical patterns in temperature and salinity (Froneman, 2002a, James *et al.*, 2007a, James *et al.*, 2007b). It is now well documented that horizontal gradients in salinity and to a lesser extent turbidity, contribute to the spatial heterogeneity of estuarine organisms (Froneman, 2002b; Tweddle, 2004; Lukey, 2005, James *et al.*, 2007a, James *et al.*, 2007b). The absence of any distinct spatial patterns in the selected biological variables within the Riet River Estuary during this study can therefore, likely be attributed to the virtual absence of a salinity gradient within the system.

The weak seasonal pattern in salinity observed during the study can likely be related to the seasonal pattern in rainfall recorded within the Eastern Cape region. The establishment of a link to the marine environment following the breaching in December 2005 was associated with increased salinity values reflecting the inflow of marine waters into the estuary. The gradual increase in salinity (3.50‰ to 30.50‰) observed when the estuary was closed over the summer period (November 2005 – February 2006) can most likely be attributed to high evaporation rates due to elevated air temperatures over the same period. Water temperatures exhibited a distinct seasonal pattern over the study period with maximum values recorded in summer and minimum in winter. This observed pattern is consistent with studies conducted in the same region (Tweddle, 2004; Lukey, 2005). Dissolved oxygen (surface and bottom) over the study period did not show a seasonal pattern, elevated dissolved oxygen concentrations were recorded over periods of breaching due to increased water movement.

3.7.2. Chlorophyll-*a* and zooplankton

The measurements of total chlorophyll-a (chl-*a*) concentration (range 0.71 to 1.90 mg Dwt m^{-3}) and zooplankton biomass (range 19.41 to 86.18 mg Dwt m^{-3}) recorded in the Riet River Estuary during this study are in the range reported for other TOCE's within the same geographic region (Froneman, 2002; Tweddle, 2003; Lukey *et al.,* 2005). The increase in chl-*a* concentration following freshwater inflow into the estuary can be ascribed to increased phytoplankton growth as a result of elevated nutrient concentrations (Adams *et al.,* 1999). Similarly, the elevated zooplankton biomass recorded following freshwater inflow into the estuary can likely be attributed to increased food availability. In agreement with studies conducted in the same region (Tweddle, 2004; Lukey, 2005), the breaching events within the Riet River Estuary were generally associated with a decline in total chl-*a* concentrations. The observed pattern can be attributed to the outflow of biologically rich estuarine water into the marine environment (Froneman, 2002b). Zooplankton biomass showed a marked increase associated with the December 2005 breaching event, Conversely, a decrease in the total zooplankton biomass was observed after the June 2006 breaching event. The absence of any apparent correlation between zooplankton biomass and mouth dynamics may reflect the complex relationship between the zooplankton community in the near shore marine environment (availability of potential recruiters) and the estuary.

3.7.3. Littoral zone ichthyofauna

The measurements of the ichthyofaunal abundance (range 1.60 ind m^{-2} to 8.67 ind m^{-2}) and biomass (range 0.45 g wwt m^{-2} to 21.76 g wwt m^{-2}) within the littoral zone of the Riet River Estuary during this investigation are in the range reported for other TOCE's within the Eastern Cape region (see for example Cowley 1998; Vorwerk *et al.* 2001; Tweddle 2004; Lukey, 2005). Numerous studies conducted in TOCE's within the same region using the same sampling gear (Tweddle, 2004; Lukey, 2005, James *et al*., 2007a, James *et al.,* 2007b) have reported a decline in the ichthyofaunal biomass within the littoral zone following breaching events. During the current study, no consistent trend in the ichtyofaunal biomass was observed following the breaching of the estuary. The lack of a consistent trend can likely be attributed to both the infrequency as well as the short duration of the mouth opening events during the study (Whitfield *et al*. 2008)..

Temporarily open / closed estuaries differ from permanently open estuaries in terms of relative abundances and biomass of estuarine resident fish species and marine breeding species (Vorwerk *et al.*, 2003; Lukey, 2005; Lukey *et al.*, 2006). Permanently open estuaries are generally characterised by high ichthyofaunal diversity and are dominated in terms of both abundance and biomass by marine breeding species (Whitfield, 1980; 1983; 1993; Vorwerk *et al.*, 2001). The ichthyofaunal community within South African TOCE's are characterised by estuarine spawning species dominating in terms of abundance but due to the relatively smaller size of these species, the contribution to the total ichthyofaunal biomass is generally low (Cowley and Whitfield, 2002; Lukey *et al.*, 2005). For example, in the Grants Valley Estuary (Eastern Cape), estuarine resident species contributed 89% of the total abundance and only 24% of the total biomass (Lukey, 2005). Similarly, in the Moore River Estuary, Australia, estuarine resident species contributed 95% of the total abundance, but only 44% of the total biomass (Young *et al.*, 1997). During the present study, estuarine resident species contributed *ca* 72% (SD ±27) of the total biomass of fish caught in the littoral zone. The low contribution of marine breeding species to the total ichthyofaunal biomass within the Riet River Estuary can likely be attributed to both the infrequency of overtopping and short length of breaching events recorded over the study period which would have limited the potential for marine breeding species to recruit into the estuary. This result highlights the importance of the establishment of a link to the marine environment in determining the ichthyofaunal species composition within Eastern Cape TOCE's.

The establishment of a link with the marine environment has been shown to be important for marine breeding fish species to recruit into TOCE's (Kok and Whitfield, 1986; Cowley and Whitfield, 2001b; Vivier and Cyrus, 2002). The breaching event in June 2006 coincided with an increased contribution of marine breeding fish species to the total ichthyofaunal abundance and biomass. Estuarine resident species did, however, contribute the majority of the ichthyofaunal community for the entire study period. It is important to note that breaching events were not always associated with a change in the ichthyofaunal community structure, as observed in December 2005. The observed trend can likely be attributed to the short interval over which time (*ca*. 1 day) this event occurred and highlights the importance of the extent / magnitude of the breaching events in structuring the fish communities within these systems. The results of the numerical analysis conducted during this study confirm these findings.

Despite the dominance of estuarine resident species, distinct ichthyofaunal assemblages were associated with the breaching events. Groups 1 and 2 were recorded at the onset of the study and in June / July 2006. The distinction of these two groups was largely the result of the increased contribution of marine breeding species (e.g. *Rhabdosargus holubi,* and *Atherina breviceps*) to total fish counts. The remaining months were characterised by a littoral fish community that was numerically dominated by estuarine resident species, mainly *Gilchristella aestuaria* and *Glossogobius callidus*. The small size of the estuary, the small catchment and the lower frequency of overtopping and breaching events associated with the Riet River Estuary may account for the lower species richness in this system when compared to other systems characterised by larger catchment and estuary sizes and more frequent overtopping and breaching events (Cowley, 1998; Vorwerk, 2001).

The estuarine resident species *Gilchristella aestuaria* was the major contributor to the total ichthyofaunal abundance and biomass over the study period, particularly during the closed phase. This result is in agreement with previous studies within TOCE's in the same geographic region (Tweddle, 2004; Lukey, 2005). This species impacted the heterogeneity in the system over the summer period where abundances were shown to be high. Previous studies have shown that mouth closure for extended periods results in estuarine resident species, such as *G. aestuaria*, dominating the total ichthyofaunal abundance with the decline in abundance of marine breeding species within these systems (Potter *et al.,* 1993; Griffiths, 2001; Lukey 2005).

The absence of Category III species (marine species which occur in estuaries in small numbers, but are not dependent on these systems) within the Riet River Estuary during this study can probably be attributed to the small size of the system and infrequent periods of breaching or overtopping, thus limiting recruitment. Indeed, similar results were observed in small TOCE's in the same biogeographic area (Vorwerk, 2001; James *et al.*, 2007a). Furthermore, the Riet River Estuary is characterised by a small catchment thus limiting available cues for marine species (Category III) that are likely to enter estuaries (Bell *et al.*, 2001).

In summary, the results of the 5 m seine net analysis revealed that the link to the marine environment through breaching events did not account for any consistent changes in the ichthyofaunal community structure within the littoral zone of the Riet River Estuary. In the absence of links, total ichthyofaunal abundance and biomass was dominated by estuarine resident species, mainly *G. aestuaria*.

3.7.4. Channel zone ichthyofauna

The measures of ichthyofaunal abundance (range <0.10 to 0.44 ind m^{-2}) and biomass (range 0.58 to 36.52 g wwt m^{-2}) obtained with the 30 m seine net during this study are in the range reported in similar studies using similar gear in a number of TOCE's within the same biogeographic region (Cowley, 1998; Vorwerk, 2001; Tweddle, 2004; Lukey 2005; James *et al.*, 2007a; 2007b). The values recorded in the present study are, however, substantially lower than those recorded in the larger, permanently open systems in close proximity (Vorwerk, 2001; Vorwerk *et al.*, 2001; James *et al.*, 2007a; 2007b). The reduced abundance and biomass values in the estuary can likely be attributed to continual recruitment found in the larger systems (Cowley, 1998; Whitfield, 1998; Vorwerk, 2001; James *et al.*, 2007a; 2007b). There was no distinct seasonal pattern in ichthyofaunal abundance and biomass within the channel of the estuary which agrees with previous studies conducted in both permanently open and temporarily open / closed estuaries within the same region (Vorwerk, 2001; Vorwerk *et al.,* 2003; Tweddle, 2004). The lack of a distinct seasonal pattern is likely due to growth of fish within the system and the prolonged mouth closure that would have prevented the emigration of marine breeding species in the estuary to the marine environment.

The estuarine association Category I species dominated the total ichthyofaunal catch over the study period, while Category II species dominated the total biomass, as in Cowley (1998), Vorwerk (2001) and Tweddle (2004). The total ichthyofaunal biomass recorded over the study period was dominated by Category II species, namely *R. holubi*, which contributed 25.92% of the total catch and 44.19% of the total biomass. The contribution to the total catch by *Gilchristella aestuaria* was 49.78% with a contribution to the total biomass of only 5.06%. The numerical dominance of *R. holubi* within the fish assemblages of TOCE's is now well documented and can be related to several factors including a prolonged breeding season (Whitfield 1998) and an ability to recruit into estuaries during overtopping events (Kemp and Froneman, 2004). The absence of Category III species, as previously mentioned, can be attributed to small estuary size, small catchment size and infrequency of overtopping/breaching events.

The December 2005 breaching event coincided with increased contributions of marine breeding fish species to the total ichthyofaunal abundance and biomass while the June 2006 breaching event revealed a decrease in the contribution of marine breeding species to the total catch. *R. holubi*, the most common marine breeding species, was found in high numbers pre-breaching but when the estuary breached in December 2005 and June 2006, the abundances and biomasses recorded were lower than those of the previous months. Following the breaching events, juvenile *R. holubi* recruited into the estuary causing a subsequent increase in numbers.

The overall ichthyofaunal diversity of the fish sampled with the use of the 30 m seine net calculated with three commonly used methods, the Shannon-Weiner Diversity Index, Margalef's Richness Index and Simpson's Index, all showed increased diversity corresponding to the December 2005 breaching event. On the other hand, the June 2006 breaching event was characterised by a decrease in ichthyofaunal diversity within the estuary. This trend can likely be attributed to the reduced availability of possible recruits in the adjacent surf zone in winter (Kemp and Froneman, 2004; Whitfield *et al.*, 2008). Finally, the elevated Margalef diversity index value recorded at the onset of the study can be related to the low number of fish caught with the 30m seine net (Figures 3.20 and 3.24).

Shannon-Weiner Diversity Index showed a distinct seasonal pattern with higher diversities corresponding with the summer months. Both Margalef's and Simpson's Indices express the overall numbers of fish caught resulting in low species richness for the Riet River Estuary due to the large contribution of *R. holubi* to the catches. An exception to the generally low richness values recorded over the study year is the extremely high richness recorded in March 2006. The Shannon-Weiner Index reduces the bias attributed to single species such as *R. holubi* and as such, gives a better indication of overall community diversity. Kemp and Froneman (2004) demonstrated that *R. holubi* is well adapted to utilising overtopping events to recruit into TOCE's and is well suited to enter estuaries during brief breaching events. Also, *R. holubi* demonstrates an extended breeding season, which allows juveniles to recruit into estuaries following breaching events over a longer time period (Kemp and Froneman, 2004). The numerical dominance of *R.holubi* in the 30m sein net catches in the Riet River Estuary is therefore, not surprising.

Numerical analysis indicated the presence of two distinct groupings and two outliers consisting of single months. No relationship between breaching events and groupings was identified. Grouping 3 was generally related to lower species richness and diversity while grouping 4 was related to slightly higher species richness and diversity.

In summary, the results of the 30 m seine net analysis revealed that the link to the marine environment through breaching events did not account for changes in the ichthyofaunal community structure within the Riet River Estuary. The larger marine breeding species, namely *R. holubi*, did however, account for the majority of the total ichthyofaunal biomass while *G. aestuaria*, a smaller Category Ia species dominated in terms of abundance.

3.7.5. Conclusion

Results of the present study indicate that the breaching events in the Riet River Estuary are generally associated with the decline in the total abundance and biomass of littoral zone ichthyofauna within the estuary as well as an increase in diversity. The channel zone ichthyofaunal community was dominated by estuarine resident species and breaching did not lead to a common trend in changes to the ichthyofaunal community. This may be due to the inability of larger marine species to utilise the breaching events due to the infrequency and small scale of these events. The observed trends in abundance and biomass are consistent with what is reported in the literature and can be attributed to the export of estuarine rich waters into the marine environment immediately after the breaching of the estuary and the subsequent recruitment of juvenile marine breeding species into the system in the summer months. Also, TOCE's move from an estuarine-species dominated system to a marine-breeding dominated system following the breaching of the estuary.

Chapter 4:

Aspects of the population dynamics of piscivorous birds in the temporarily open / closed Riet River Estuary

4.1. Introduction

Birds comprise a dominant faunal component of estuaries along the South African coastline (Hockey and Turpie, 1999). There are 41 bird species associated with South African estuaries whose diet consists primarily of fish and a further 32 species who prey on fish as a minor dietary item (Siegfried, 1984; MacLean, 1993). Estuarine systems are important habitat for numerous bird species including a number of threatened species. Thirteen species of estuarine-associated avifauna have Red Data Book status (Barnes, 2000), seven of these are classified as near threatened, three as vulnerable, two as endangered (Damara Tern and Saddle-billed Stork), and one is classified as critically endangered (Eurasian Bittern) (Barnes, 2000).

Most studies conducted on estuarine avifauna have concentrated on permanently open systems including Lake St. Lucia (Whitfield, 1978; Whitfield and Blaber, 1978; 1979a; 1979b; Berruti, 1980; 1983), the Kosi Estuary system (Jackson, 1984), the Swartkops (Martin and Baird, 1987) and the Knysna Estuary (Martin *et al.*, 2000). Apart from a few studies (Blaber, 1973; Cowley, 1998), information on the avifauna of TOCE's is generally lacking. A large proportion of the avifauna found in TOCE's tends to be piscivorous due to increased productivity of these systems and the associated increased food availability in comparison to surrounding terrestrial areas (Blaber, 1973). Indeed, the densities of piscivorous birds have been shown to correlate with fish densities (Blaber, 1973; Whitfield, 1978; Junor and Marshall, 1987). Temporarily open / closed estuaries have been shown to be important nursery grounds for marine-spawning fishes (Cowley and Whitfield, 2001b), which in turn are important prey items for piscivorous birds (Cowley, 1998). A study conducted by Blaber (1973) in the temporarily open / closed East Kleinemonde Estuary reported that piscivorous birds were responsible for up to 80% mortality in the population of the sparid, *Rhabdosargus holubi*. These results suggest that piscivorous birds may play an important role in the structuring of the ichthyofaunal communities within TOCE's.

The aim of this section of the study is to assess the spatial and temporal patterns in the piscivorous bird community structure within the Riet River Estuary as well as to provide an estimate of fish biomass consumption by piscivorous avifauna.

4.2. Materials and methods

4.2.1. Bird counts

Estuarine avifauna counts were conducted monthly along a repeat transect along the length of the estuary traversed by motorized boat prior to the fish survey described in the previous chapter. The estuary was divided into lower, middle and upper reaches (Figure 4.1) and bird species and numbers observed in each of the reaches were recorded. The observations were conducted during the day between 09:00 and 16:00 hours. To avoid re-counts of birds, the highest recorded number for each species on the upstream and downstream leg was recorded as the number present on each sampling trip. The mean number of bird species and total bird counts in each reach were then determined. The frequency of occurrence for each species was calculated by dividing the number of times a species was recorded by the total number of counts (i.e. 12). The species were then classified according to an encounter rate ranking. Species present 0-24% of the time were classified as rare, 25-49% as occasional, 50-74% as frequent and 75-100% as regular (Cowley, 1998).

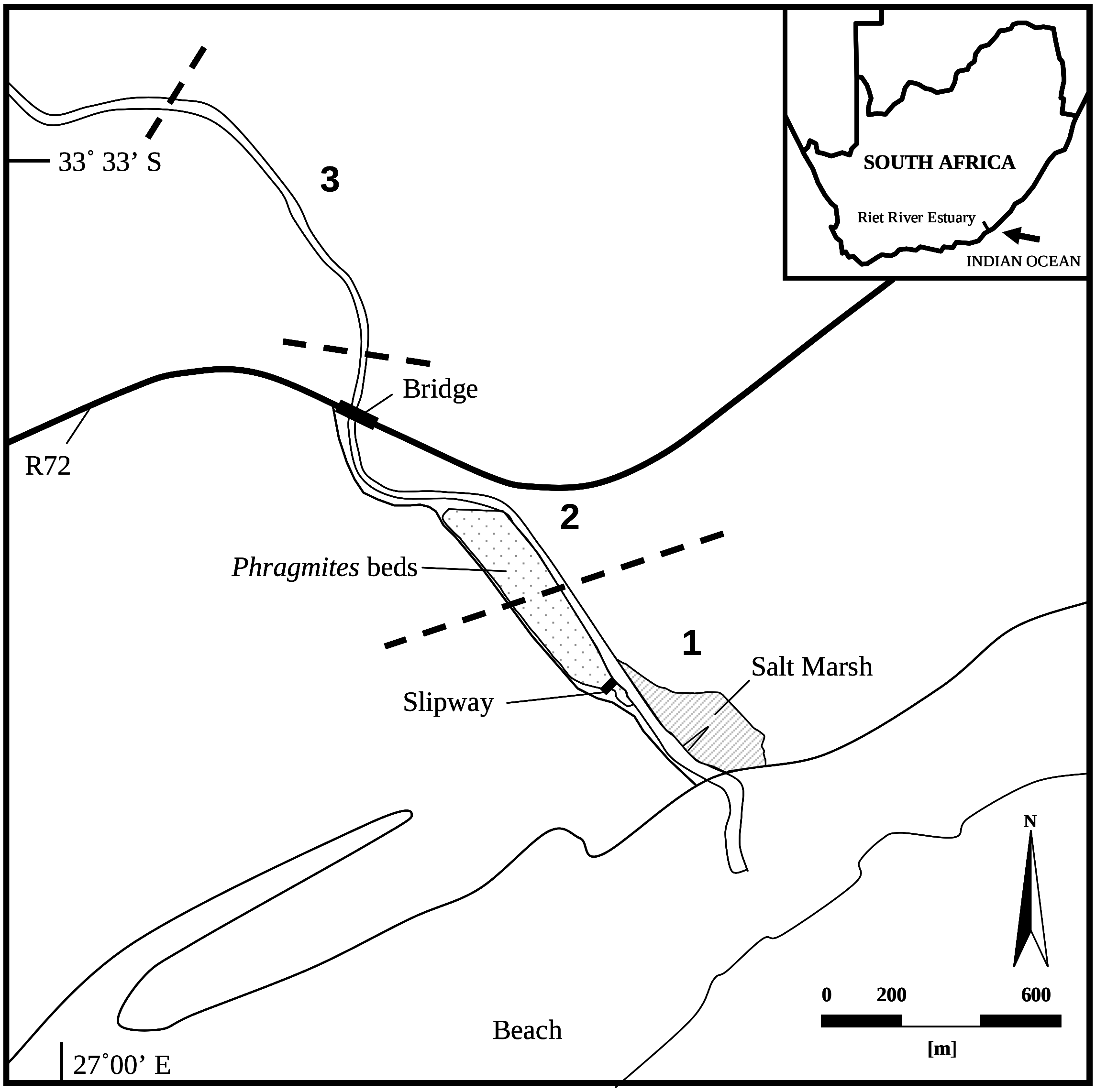

Figure 4.1. Map of the Riet River Estuary, Eastern Cape, South Africa showing the basic form, dominant vegetation and associated anthropogenic structures. Monthly avifaunal sampling regions (1-3) are shown. 1 = lower reaches, 2 = middle reaches and 3 = upper reaches.

4.2.2. Community analysis

4.2.2.1. Feeding dynamics

The bird species recorded during the study period were placed into feeding groups according to their foraging method (Whitfield and Blaber, 1978; 1979a; 1979b; Whitfield and Cyrus, 1978; Berruti, 1983). Three feeding groups were identified, i.e. waders, pursuit swimmers and aerial divers.

4.2.2.2. Feeding rates

Daily feeding rate of the piscivorous birds was calculated using the expression of Nagy (2001).

$$\mathbf{DMI = 0.638\ BM^{0.685}}$$

Where **DMI** = dry matter intake (grams)

and **BM** = Body mass (grams)

The maximum error of this equation to predict the feeding rates of the species is *ca.* 40% (Nagy, 2001). Body mass values were obtained from the literature (Berruti, 1983; Maclean, 1993; Nagy, 2001). For those bird species that have a mixed diet, it was assumed that fish comprised 50% of their diet.

The above equation was altered to estimate DMI for the marine birds observed in the estuary, i.e. Cape Cormorant and the Caspian Tern. The alteration to the above equation reduces the maximum error of prediction to *ca* 28% (Nagy, 2001). The equation is thus:

$$\mathbf{DMI = 0.880\ BM^{0.658}}$$

Where **DMI** = dry matter intake (grams)

and **BM** = Body mass (grams)

The dry mass values from the above equation were converted to fresh matter intake (**FMI**) by multiplying **DMI** by 3.448, based on the estimate that water comprises 71% of fish wet mass (Marais, 1990).

To estimate total monthly intake, daily FMI values for individual bird species were multiplied by the number of days in each month. Values were pooled to estimate the monthly intake of the entire piscivorous community within the estuary.

4.3. Results

4.3.1. Species composition

A total of 13 piscivorous bird species were recorded over the period August 2005 to July 2006 in the Riet River Estuary (Table 4.1). Of the recorded species, 6 (46.15%) species were wading piscivores, 4 species were (30.77%) aerial divers with the remaining 3 species being (23.08%) pursuit swimmers (Table 4.1). The Reed Cormorant (*Phalacrocorax africanus*) was the dominant species throughout the study, with a mean of 8.25 (SD ± 7.90) individuals per count (Table 4.2). Mean values of the Pied Kingfisher (*Ceryle rudis*) and Giant Kingfisher (*Megaceryle maximus*) were 3.42 (SD ± 1.20) and 1.17 (SD ± 0.60) individuals per count, respectively. The remaining species revealed mean values < 0.50 individuals per count (Table 4.2).

In terms of frequency of occurrence, three species were regarded as residents (recorded in >75% of counts); these were the Pied Kingfisher (100%), the Giant Kingfisher (91.67%) and the Reed Cormorant (91.67%) (Figure 4.2). The Little Egret (*Egretta garzetta*) was encountered frequently (50%), while the Cape Cormorant (*Phalacrocorax capensis*) (33.33%), Night Heron (*Nycticorax nycticorax*) (33.33%), Goliath Heron (*Ardea goliath*) (25.00%), Grey Heron (*Ardea cinerea*) (25.00%) and the Purple Heron (*Ardea purpurea*) (25.00%) were encountered occasionally (25 – 50% of counts). The African Fish-eagle (*Haliaeetus vocifer*) (16.67%), Great White Egret (*Egretta alba*) (16.67%), Caspian Tern (*Sterna caspia*) (16.67%) and the African Darter (*Anhinga rufa*) (8.33%) were classified as rare (<25% of counts) (Figure 4.2).

Table 4.3: Common name, scientific name, individual mass and feeding method of the piscivorous bird species recorded at the Riet River Estuary over the August 2005 – July 2006 study period (After Berruti, 1983; Maclean, 1993; Nagy, 2001).

Species (Common Name)	Scientific Name	Individual Mass (g)	Feeding Method
Goliath Heron	*Ardea goliath*	4505	Wading
African Fish-eagle	*Haliaeetus vocifer*	1616	Aerial Diving
African Darter	*Anhinga rufa*	1508	Pursuit Swimming
Grey Heron	*Ardea cinerea*	1450	Wading
Cape Cormorant	*Phalacrocorax capensis*	1231	Pursuit Swimming
Great White Egret	*Egretta alba*	1100	Wading
Purple Heron	*Ardea purpurea*	920	Wading
Night heron	*Nycticorax nycticorax*	780	Wading
Caspian Tern	*Sterna caspia*	587	Aerial Diving
Reed Cormorant	*Phalacrocorax africanus*	559	Pursuit Swimming
Little Egret	*Egretta garzetta*	480	Wading
Giant Kingfisher	*Megaceryle maximus*	361	Aerial Diving
Pied Kingfisher	*Ceryle rudis*	76	Aerial Diving

Table 4.4: The mean number of individuals per count of the piscivorous avifauna recorded at the Riet River Estuary between August 2005 and July 2006.

Species	Mean Number per Count
African Darter	0.08
Caspian Tern	0.08
Great White Egret	0.17
African Fish-eagle	0.17
Goliath Heron	0.25
Grey Heron	0.25
Purple Heron	0.25
Night Heron	0.42
Cape Cormorant	0.42
Little Egret	0.75
Giant Kingfisher	1.17
Reed Cormorant	8.25
Pied Kingfisher	3.42

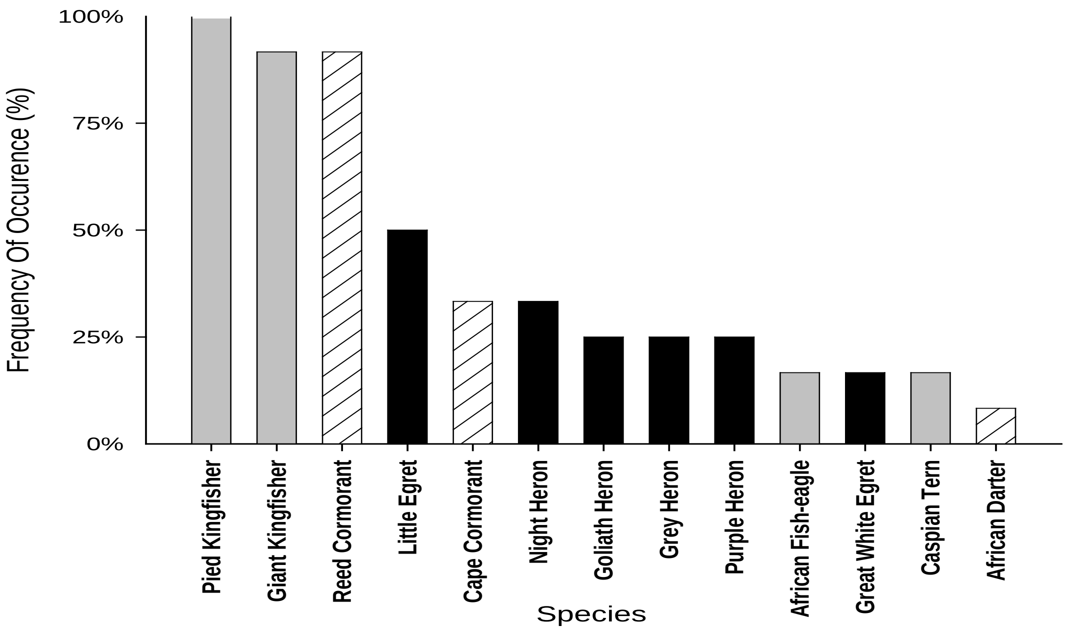

Figure 4.2: Frequency of occurrence of all recorded piscivorous birds at the Riet River Estuary between August 2005 and July 2005. Grey bars stand for aerial divers, solid bars for wading piscivores and striped bars for pursuit swimmers.

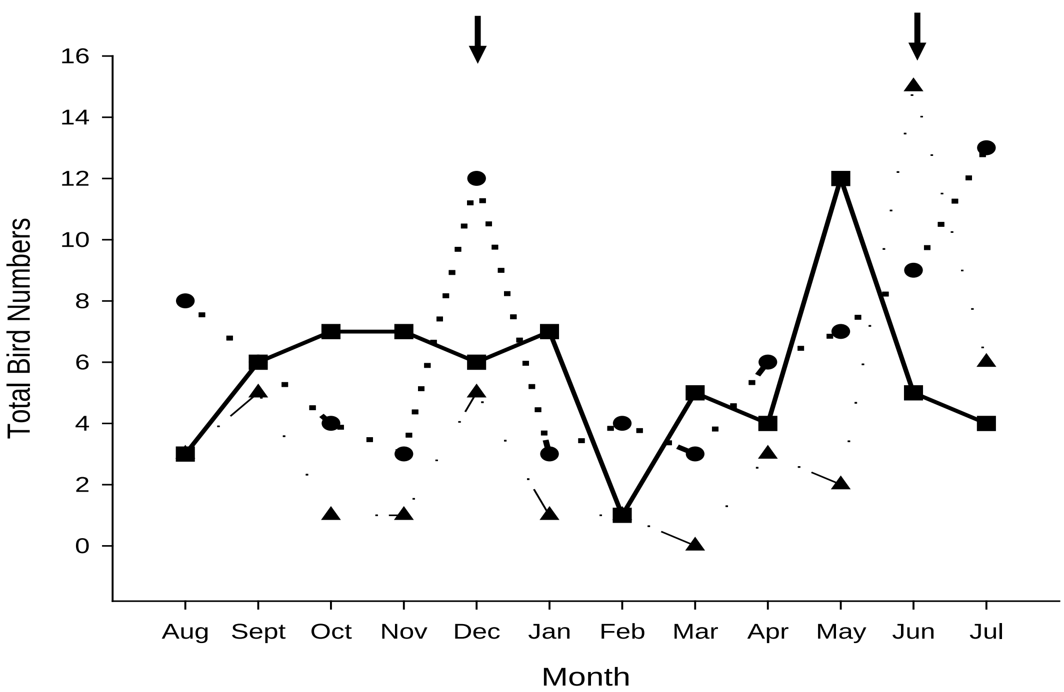

Figure 4.3: Total number of birds recorded in the upper (Triangle and dashed line), middle (Square and solid line) and lower (Circle and dotted line) reaches of the Riet River Estuary over the study period August 2005 – July 2006.

4.3.2. Spatial distribution

Total bird numbers for the upper, middle and lower reaches revealed that the majority (41.49%, 78 individuals) of birds counted were recorded in the lower reaches while 35.64% (67 individuals) were recorded in the middle reaches. Only 22.87% (43 individuals) of the piscivorous birds were recorded in the upper reaches of the estuary (Figure 4.3).

In terms of feeding guilds, pursuit swimmers were the dominant component contributing 79.06%, 49.25% and 48.72% of the total counts in the upper, middle and lower reaches, respectively (Figure 4.4). Aerial divers constituted 20.93%, 22.39% and 45.59% in the upper, middle and lower reach of the estuary, respectively. Waders were absent from the upper reaches, but constituted 28.36% and 7.69% of the middle and lower reaches populations, respectively (Figure 4.4).

4.3.3. Temporal distribution

Total avian piscivore numbers showed no distinct seasonal pattern but high total counts (range 23.00 to 29.00) were observed when breaching occurred (Figure 4.5). Pursuit swimmers were present in high numbers during winter and when breaching occurred. Waders were recorded in high numbers over the late spring period but their numbers declined dramatically after the December 2005 breaching period. The numbers of aerial divers were relatively constant throughout the year, with a peak of 7 individuals in September and October 2005 (Figure 4.5). The mean number of all piscivorous birds ranged from 0.15 (± 0.49) to 0.74 individuals (± 2.71) over the study period (Figure 4.6). The mean monthly number of individuals showed a similar trend to that of total numbers, with peaks observed in winter and early summer, intermediate values were recorded in spring with the lowest mean values recorded in autumn (Figure 4.6). There were no significant correlations between the total piscivore numbers and the estimates of fish abundance and biomass obtained with the 5 and 30 m seine nets ($P > 0.05$ in all cases).

The Reed Cormorant generally showed the highest individual numbers of all species throughout the study period (Figure 4.7). Highest values were recorded in the late autumn (May 2006) and early winter months (June and July 2006) as well as the months associated with breaching events (December 2005 and June 2006). The Reed Cormorant was absent from the Riet River Estuary in February 2006. Aerial divers (Pied and Giant Kingfisher) contributed the second largest contribution with waders (Little Egret) contributing the least to the total bird population observed at the Riet River Estuary over the study period August 2005 to July 2006 (Figure 4.7).

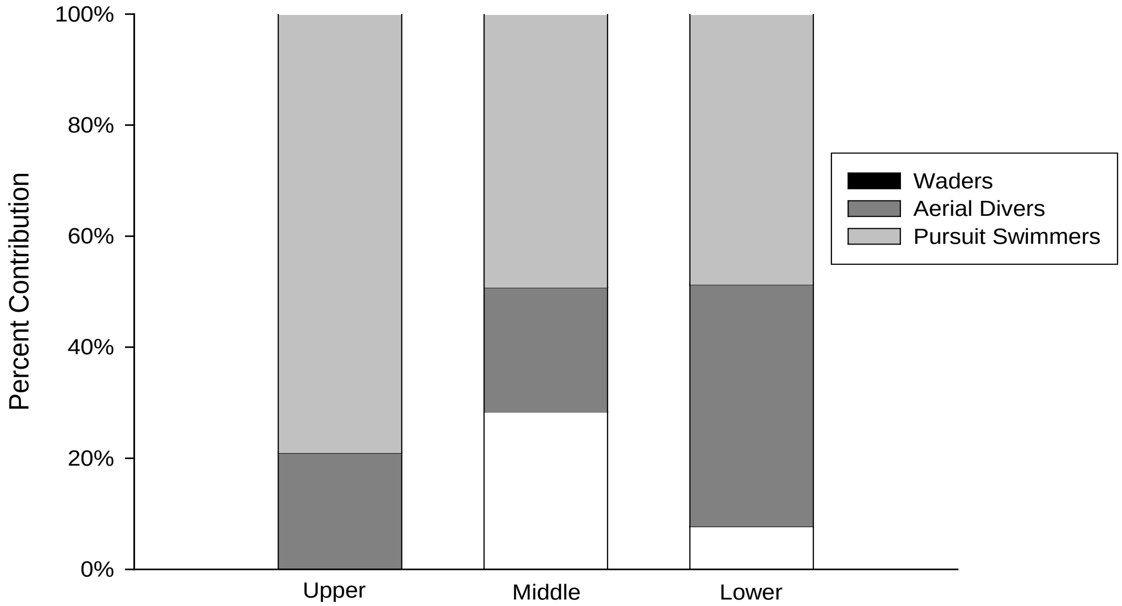

Figure 4.4: Spatial distribution of the feeding groups of all avifauna recorded in the Riet River Estuary over the period August 2005 to July 2006. Black bars represent waders, light grey bars represent pursuit swimmers and dark grey bars represent aerial divers
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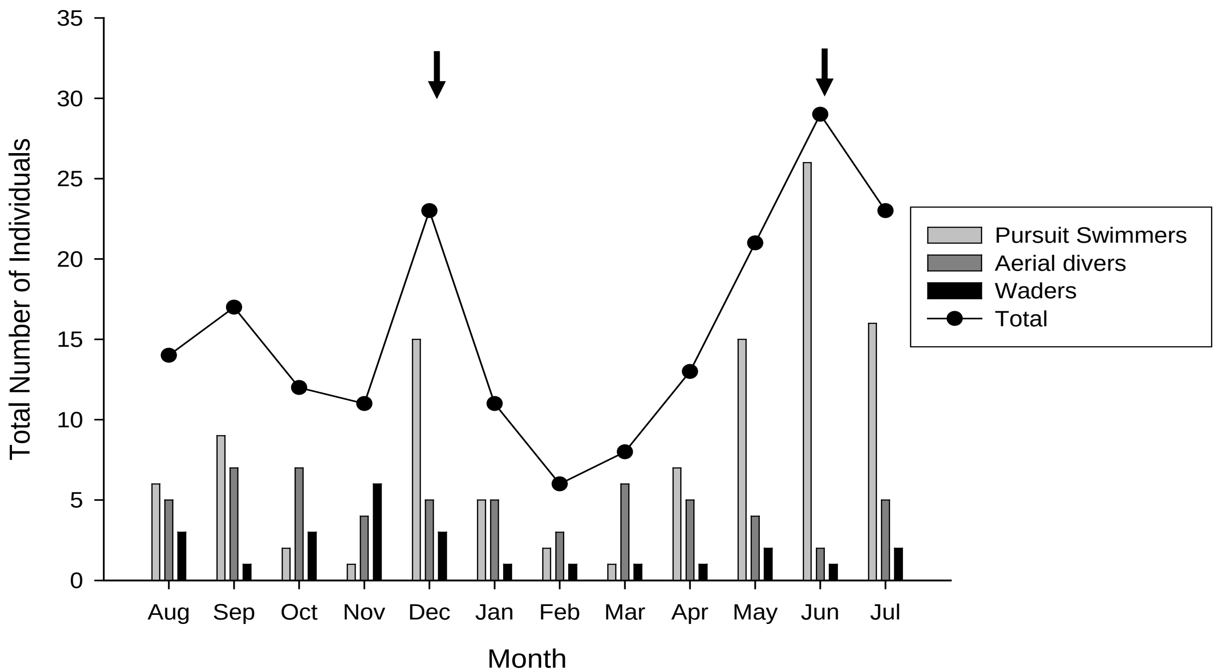

Figure 4.5: Temporal distribution of feeding groups of the piscivorous avifauna in the Riet River Estuary between August 2005 and July 2006. Black bars represent waders, light grey bars represent pursuit swimmers and dark grey bars represent aerial divers, the solid line represents total bird numbers. Thick arrows indicate periods when breaching occurred.

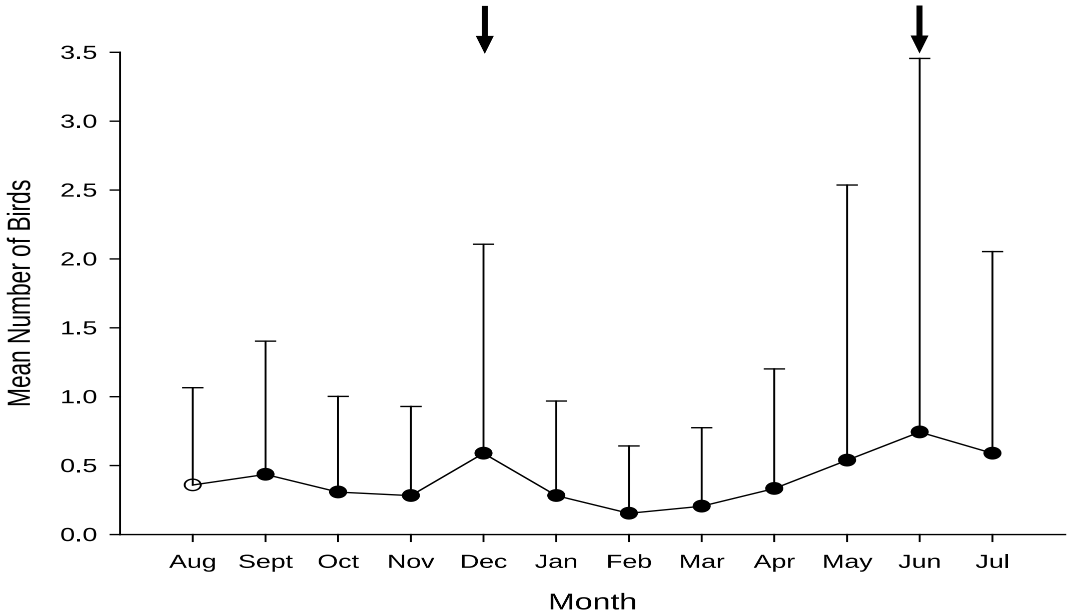

Figure 4.6: Mean piscivorous bird numbers recorded at the Riet River Estuary over the study period August 2005 to July 2006. Error bars show standard deviation (only positive deviation shown for clarity).

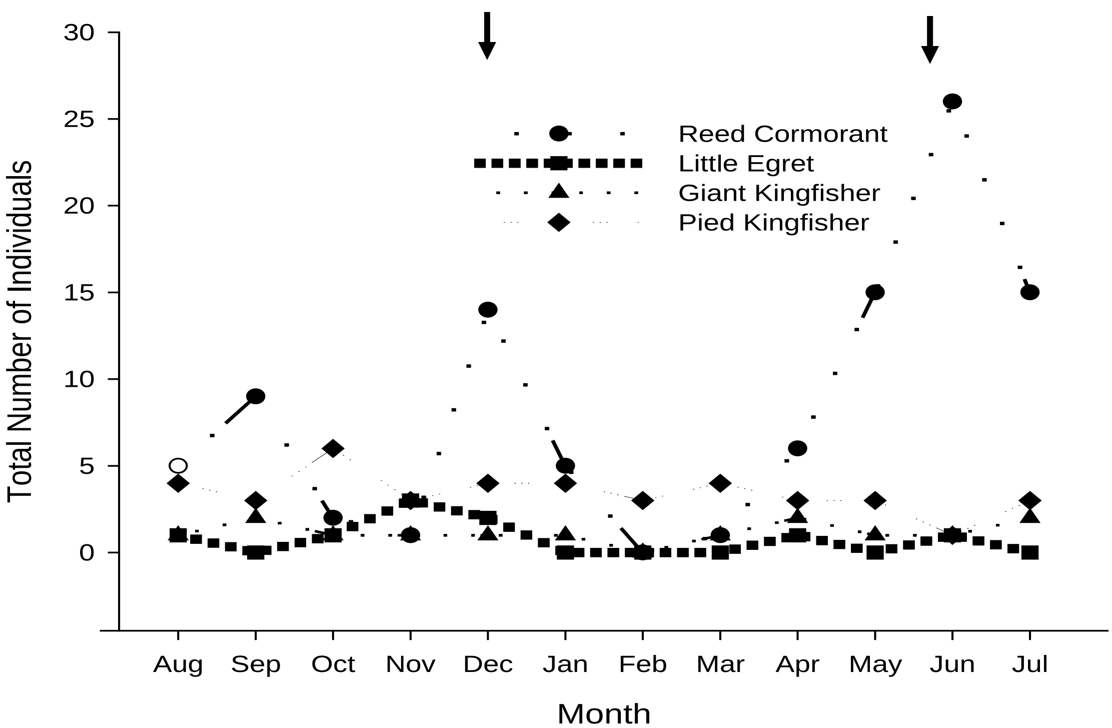

Figure 4.7: Total monthly number of individuals of the four most abundant piscivorous bird species recorded at the Riet River Estuary over the study period August 2005 to July 2006.

4.3.4. Food consumption

Fresh matter intake (FMI) values for all piscivorous birds calculated from Nagy (2001) ranged from 43.02 g per day for the Pied Kingfisher to 700.11 g per day for the Goliath Heron (Table 4.3). No distinct seasonal pattern was observed in the total monthly FMI estimates (Figure 4.8). Maximum values were recorded in the months associated with breaching, i.e. December 2005 (110.36 kg) and June 2006 (140.58 kg) as well as in July 2006 (114.33 kg) (Figure 4.8). The lowest values were generally observed in late spring and summer (range 26.35 to 54.72 kg per month) although values decreased following the breaching events (Figure 4.8). The observed patterns in FMI were related to the observed total numbers of piscivorous avifauna.

The majority of the estimated total consumed fish biomass for the study period (909.71 kg) was consumed by the Reed Cormorant (55.80%) (Figure 4.9). The Goliath Heron, Giant Kingfisher and Pied Kingfisher were the only other species that contributed more than 5.00% to the estimated total ichthyofaunal consumed biomass (7.05%, 5.82% and 5.92% respectively) (Figure 4.9).

Pearson correlation indicated there were no significant correlations between the estimates of the total ichthyofaunal abundance and biomass in the littoral and channel zone and the total bird abundances during the study ($P > 0.05$ in all cases).

Table 4.3: The estimated fresh matter intake (FMI) in grams per day of piscivorous bird species recorded at the Riet River Estuary over the study period August 2005 to July 2006, based on equations from Nagy (2001) for 'non-marine bird species' and 'marine bird species' multiplied by 3.448 to convert to wet mass.

Species (Common Name)	FMI (g/day) 'Non-marine species'	FMI (g/day) 'Marine species'
Goliath Heron	700.11	
African Fish-eagle	506.87	
African Darter	331.82	
Grey Heron	322.43	
Cape Cormorant		327.50
Great White Egret	267.23	
Purple Heron	236.33	
Night Heron	210.78	
Caspian Tern		201.50
Reed Cormorant	168.65	
Little Egret	151.22	
Giant Kingfisher	124.32	
Pied Kingfisher	43.02	

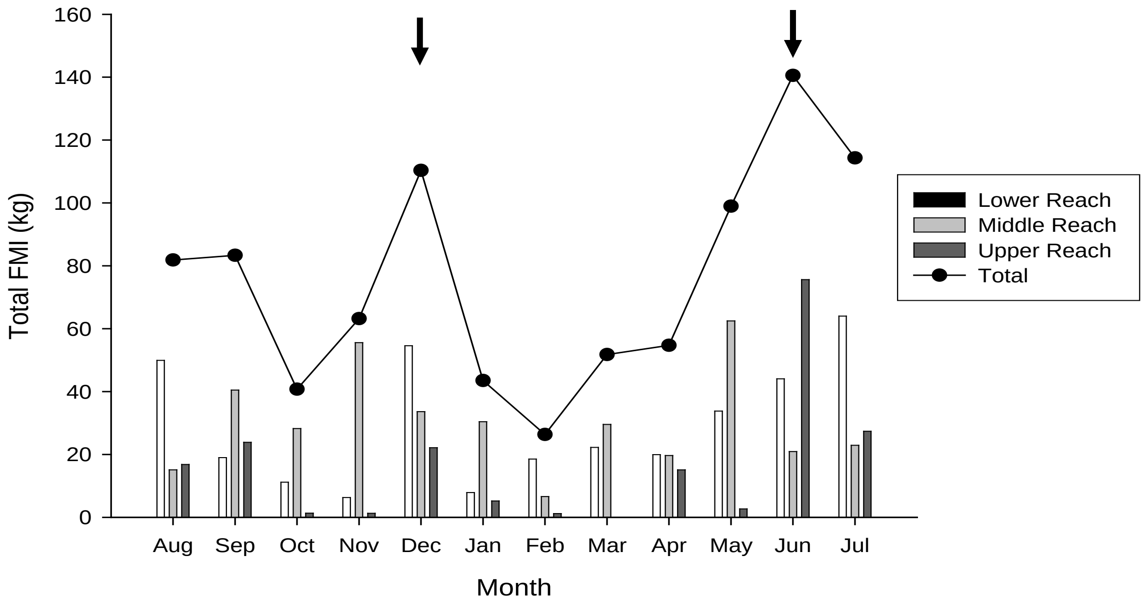

Figure 4.8: Temporal distribution of total monthly FMI (kg) for the piscivorous avian population in the Riet River Estuary between August 2005 and July 2006. Black bars represent the lower reach, light grey bars represent the middle reach, and grey bars represent the upper reach, the solid line represents total FMI.

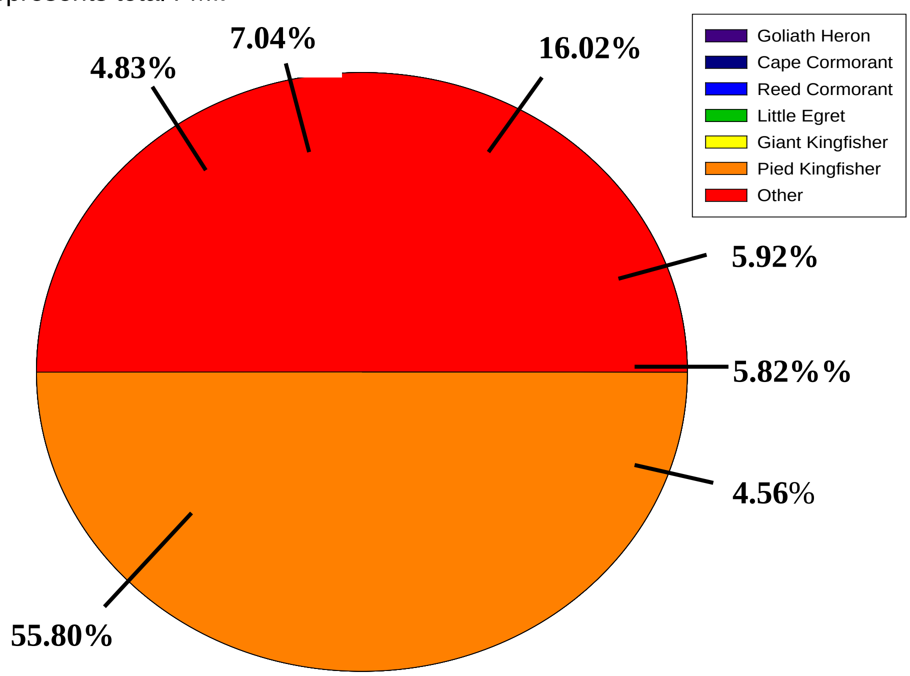

Figure 4.9: The percentage contribution of the total estimated biomass consumed by all piscivorous bird species at the Riet River Estuary over the study period August 2005 to July 2006. (Other species comprise the African Darter, Great White Egret, Purple Heron, Caspian Tern, African Fish-eagle, Grey Heron and the Night Heron).

4.4. Discussion

4.4.1. Total numbers

Temporarily open / closed estuaries differ from permanently open estuaries in terms of diversity, relative abundances and biomass of predominantly piscivorous avian species (Siegfried, 1984). During the course of the study, thirteen piscivorous bird species were recorded in the Riet River Estuary, while *ca.* 16 piscivorous bird species were recorded in permanently open the Swartkops Estuary (Martin and Baird, 1987) and at Lake St Lucia (Berruti, 1983). The lower number of species within the Riet River Estuary can likely be attributed to small size and reduced habitat availability as well as the poor representation of Palaearctic migrants within the system.

Although high bird numbers were observed over the months associated with the two breaching events, a decrease in piscivorous bird numbers within the estuary were observed in the months post breaching. The observed decrease could largely be attributed to reduced number of waders and pursuit swimmers. The reduction in the number of waders during mouth opening events could be attributed to the decrease in available habitat for the waders due to the drop in water level from normal levels thus reducing the area of inundated macrophytes. Similarly, the increase in water turbidity values during these events would likely create unfavourable conditions for the pursuit feeders.

4.4.2. Species composition

Although the Reed Cormorant (*Phalacrocorax africanus*) numerically dominated the bird counts, pursuit swimmers as a feeding group contributed the least to the total number of species observed. The low contribution of the pursuit feeders to the total species count may reflect the high turbidity of estuarine waters, particularly following freshwater inflow into the system (Hulley, *pers com*. Rhodes University). The waders were the group with the highest diversity but in terms of frequency of occurrence, only the Little Egret was observed on more than 30.00% of the sampling trips. The higher diversities of the wading piscivores could be attributed to the communal nesting behaviour exhibited by these species and to their large size and high visibility (Birkhead, 1978; Maclean, 1993). Of the aerial divers, the Pied and Giant Kingfishers occurred on more than 90.00% of sampling trips but the remaining 2 diving species were observed in low frequencies. The Pied and Giant Kingfishers were resident species and the Pied Kingfishers were observed breeding at the estuary. Due to the Giant Kingfisher habit of perching in dense trees, their numbers may have been underestimated despite their large size and known behaviour of breeding at the estuary (Maclean, 1993). Kingfishers live singly or in pairs and exhibit territorial behaviour and as such, the lower diversities but higher frequencies of occurrence of aerial divers are expected (Maclean, 1993).

4.4.3. Spatial distribution

Studies conducted in larger TOCE's (Jackson, 1984; Boshoff *et al.*, 1991a; 1991b; 1991c; Hockey and Turpie, 1999) as well as permanently open systems reveal that elevated bird abundances and diversities are generally recorded in the lower reaches. The elevated number of bird species and bird numbers recorded in the lower reaches of the estuary during this study are therefore, consistent with the published literature. In agreement with the published literature, (see for example Boshoff *et al.*, 1991a; 1991b; Hockey and Turpie, 1999)., the lower reaches of the Riet River estuary were numerically dominated by aerial divers and pursuit swimmers (Figure 4.4). The observed spatial pattern in bird communities within southern African estuaries has been linked to habitat availability and potential foraging habitat (Boshoff *et al.*, 1991a; 1991b; 1991c; Hockey and Turpie, 1999).

4.4.4. Temporal distribution

Birds are highly mobile animals, many of which migrate seasonally in response to food availability or to breed (Heÿl and Currie, 1985; Martin and Baird, 1987; Cowley, 1998; Taylor ,1999). It is now well documented that Reed Cormorants move from inland wetlands to coastal areas during winter (Martin and Baird, 1987; Cowley, 1998). Similarly, Cape Cormorant, which breed between Ilha dos Tigros, Angola and Algoa Bay, South Africa, are winter visitors to estuarine habitats (Martin and Baird, 1987; Boshoff *et al.*, 1991a; Cowley, 1998). The increased contribution of pursuit piscivorous birds in late autumn and winter to total bird counts observed in the Riet River Estuary during this study is, therefore, consistent with the published literature. It is suggested that cormorants migrate to the estuaries during winter due to the increased food availability (fish) within these systems. Also, the reduced water temperatures in estuaries during winter lead to lower metabolic rates and subsequent increased catchability of the ichthyofaunal prey.

In agreement with previous studies, the highest number of waders was recorded in the estuary during the late spring and summer months (Siegfried, 1984; Martin and Baird, 1987; Boshoff *et al.*, 1991c). The breaching events were associated with decreased numbers of waders and can be attributed to the loss of inundated reed beds utilised by waders due to the reduced water levels.

The absence of any significant relationship between the estimates of the total ichthyofaunal abundance and biomass in the littoral and channel zone and the bird abundances during the study can likely be attributed to the highly mobile nature of birds, which allows them to forage in different estuaries. Alternatively, the sampling strategy employed may not have adequately targeted those fish species that are preferentially consumed by piscivorous birds.

4.4.5. Food consumption

It should be noted that there are several sources of errors in the estimates of the daily feeding rate of the birds during this study. Firstly amphibians, invertebrates and small mammals also form part of the birds' diets and results presented here may therefore be overestimates as food consumption does not necessarily equal fish consumption (Whitfield and Cyrus 1978; Whitfield and Blaber, 1978; 1979a; 1979b; Berruti, 1983; Maclean, 1993; Hockey and Turpie, 1999). Secondly, body mass estimates are derived from several specimens from different regions and may not represent exact values of local birds (Maclean, 1993). Finally, the food consumption estimates do not give an indication of where the food was consumed as more than one estuary may have been utilized in a single days' foraging (Hockey and Turpie, 1999). Despite these potential sources of error, the estimates of predation impact of the piscivorous birds do provide an indication of the potential role of birds in the Riet River Estuary ecosystem.

Cowley (1998) demonstrated that Reed Cormorant had the greatest monthly and total biomass consumption of fish at the East Kleinemonde Estuary, within the same geographic region, over a one-year period. This is in accordance with the present study, which showed the Reed Cormorant as the single most important consumer of fish biomass in the Riet River Estuary. The largest piscivore (Goliath Heron) recorded at the Riet River Estuary was the second most important consumer while the resident Pied and Giant Kingfishers contributed a substantial amount to the total biomass consumed. The estimated mean monthly consumption of fish in the Riet River Estuary during the study (range 26.35 to 140.58 kg month^{-1}) is substantially lower than that of Cowley (1998) (range *ca.* 32 to *ca.* 466 kg month^{-1}). The difference between the two estimates can likely be attributed to the different size of the two estuaries and the lower abundances of birds observed at the Riet River Estuary. Although the estimates of the predation impact of the birds within the Riet River Estuary are lower than those reported for the East Kleinemonde Estuary, it is likely that the cumulative effects of bird predation on the fish community would be greatest in the latter system as result of extended mouth closure which would contribute to reduced recruitment of marine breeding species into the estuary. Unfortunately, there are no data to support this hypothesis.

Chapter 5:

General Discussion

The lack of distinct horizontal gradients in selected physico-chemical and biological variables observed in the Riet River Estuary during this study is in keeping with previous studies in temporarily open/closed estuaries within the Eastern Cape region (Cowley, 1998; Vorwerk, 2001; Vorwerk *et al.*, 2001; Tweddle, 2004; Lukey, 2005). The lack of gradients can be attributed to the small catchment size resulting in reduced freshwater inflow and the horizontal and vertical water column mixing due to strong coastal winds (Froneman, 2002a; 2002b).

Results of the present study indicate that estimates of ichthyofaunal abundances and biomass in the Riet River Estuary are lower than those recorded in the larger permanently open estuaries within the same region (e.g. Kariega and Great Fish) (Ter Morshuizen *et al.,* 1996; Vorwerk *et al.*, 2001). The reduced overall diversity observed during this investigation can likely be attributed to the presence of a sandbar at the mouth, which limited recruitment of marine breeding species into the estuary (Whitfield, 1999b). The ichthyofaunal community structure within the littoral zone of the Riet River Estuary was linked to seasonality (Chapter 3). The observed pattern in ichthyofaunal community structure within the small temporarily open / closed Riet River Estuary was in agreement with studies conducted in larger TOCE’s (e.g. East Kleinemonde and Kasouga) (Cowley and Whitfield, 2001a; Tweddle, 2004) as well as a recent study conducted in a small TOCE (Lukey, 2005).

The establishment of a link to the marine environment through breaching events generally coincided with increased contributions of marine breeding fish species to the total ichthyofauna. In keeping with previous studies in TOCE’s within the same biogeographic region, (e.g. East Kleinemonde, Kasouga and Kariega) (Cowley and Whitfield, 2001a; Tweddle, 2004; Lukey, 2005; Vorwerk, *et al.*, 2008), *R. holubi* was identified as the dominant recruiter species when breaching occurred, while *G. aestuaria* dominated the ichthyofaunal community when the estuary was separated from the marine environment.

The larger, channel zone, ichthyofaunal biomass was dominated by *R. holubi*, while increased abundances of marine breeding species were observed coinciding with the summer breaching event due to recruitment of these species into the estuary. Other studies conducted on larger TOCE's within the same biogeographic region revealed larger abundances in the littoral zone of the estuaries as well as larger differences within the ichthyofaunal community structure in relation to breaching events (Cowley, 1998; Vorwerk *et al.*, 2001; Kemp and Froneman, 2004; Vorwerk *et al.*, 2008). This may be attributed to the brief and infrequent occurrence of these events.

Results of the piscivorous avifauna study conducted in the Riet River Estuary revealed that the Reed Cormorant was the dominant species in terms of abundance, frequency of occurrence as well as in terms of the estimated daily consumption. This is in accordance with a study conducted by Cowley (1998) in the nearby East Kleinemonde Estuary. The wading Goliath Heron, had the greatest estimated daily consumption per individual bird, but occurred infrequently and in low numbers. The aerial divers (Pied and Giant Kingfishers) were important in terms of abundances and frequency of occurrences, but their small sizes resulted in a low daily fish consumption estimate. A seasonal pattern was observed over the study period with wading piscivores being recorded in higher numbers in the spring and summer months while the winter months were dominated by the presence of pursuit swimmers. Again, this is in keeping with previous studies on estuarine avifauna within the same biogeographic zone (Siegfried, 1984; Martin and Baird, 1987; Cowley, 1998). No significant relationships between the fish and the piscivorous avifauna in the Riet River Estuary were observed ($P < 0.05$). This could be attributed to the high mobility of the birds as well as a possible inadequacy in the sampling strategy (Cowley, 1998).

The present study has investigated spatial and temporal patterns in the ichthyofaunal community in the littoral zone of the small temporarily open / closed Riet River Estuary using data collected over a one year period. Spatial and temporal changes in the avian population structure as well as estimated ichthyofaunal consumption were investigated over the same period based on models and year-long data. The results of the study indicate the importance of seasonal changes and, to a lesser degree, mouth status on the ichthyofaunal and avian populations within the estuary. It should be noted that the present study was limited to a one year period over which time breaching occurred only twice and in different seasons. The short term and infrequency of these breaching events led to the lack of apparent trends and patterns in the data.

With the increased pressure on estuarine systems through increased coastal development and freshwater extraction in the catchments of these systems, there is an ever-increasing need for research and conservation effort to be directed towards these systems. The lack of information on many of these systems, particularly in the Eastern Cape region, highlights the need for more research effort in order to better understand temporarily open / closed estuaries and the associated food web structures and mouth dynamics within these highly dynamic systems.

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