ICHTHYOFAUNAL COMMUNITY STRUCTURES IN DIFFERENT TYPES OF EASTERN CAPE ESTUARIES

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ABSTRACT

This investigation had three major objectives; firstly to document the estuarine fishes from several poorly studied Eastern Cape estuaries, secondly, to identify similarities and differences in the fish communities from permanently open and intermittently open estuaries, and thirdly, to establish which physico-chemical or environmental variables are responsible for the structuring of these communities. The study area incorporated 10 estuaries along a 70 km long stretch of the Eastern Cape coastline between the towns of Seafield (33° 32′ 42″ S, 27° 03′ 05″ E) in the south-east and Hamburg (33° 16′ 45″ S, 27° 29′ 50″ E) in the north-west. The systems investigated included two permanently open estuaries and eight intermittently open systems of varying sizes.

Overall fish abundance and species richness in the study area revealed no significant seasonal variation. A contrast between open and closed estuaries was evident in the dominance of species from different estuarine dependence categories. Open estuaries comprised mainly category Ib, IIa and IIb species, with a high proportion of category IV species. Closed estuaries were dominated by category IIa species, with few category IV species represented. Clear longitudinal trends in relative abundance were demonstrated for individual species. Margalefs species richness index for seine net catches, and a combination of the seine and gill net data, were significantly correlated with catchment size, mean annual runoff, estuarine area and linear length.

Fish assemblages in the permanently open and intermittently open estuaries were significantly different ($p<0.001$) when analysed on a community and density basis. Similarly, the communities in large and small intermittently open estuaries differed significantly on a community ($p=0.01$) and density basis ($p<0.001$). These differences where caused by changes in abundance of the dominant estuarine resident and marine migrant species. The environmental variable that was dominant in accounting for these differences was the estuary mouth status.

Estuarine resident species had smaller overall body lengths when compared with the marine migrant species. In addition, the estuarine resident species had smaller modal size classes in the closed estuaries when compared with the open estuaries. These differences may be linked to the foraging strategies of the species, as well as food availability and different levels of predation in the different estuary types. The marine migrant species did not show any trends in this respect although the closed systems had the largest individuals for all four dominant marine species. This finding may be linked to the inability of these species to breed in closed estuaries, thus channelling reproductive energy resources into somatic growth. In addition, prolonged periods of mouth closure prevent the emigration of large individuals back to the sea.

Otter trawling was conducted in five estuaries and captured mostly demersal species. The otter trawl data confirmed the seine net community analysis, with significantly different communities identified in the permanently open and intermittently open estuaries ($p=0.02$), as well as in the small and large intermittently open estuaries ($p=0.03$). The environmental variables responsible for these community differences were mouth status and variables associated with estuarine size.

The identification of estuary mouth status by this study as the most influential environmental factor is compounded by this variable affecting or being indicative of numerous other physico-chemical features. The large differences in the fish communities in different estuary types indicate the importance of each estuary type to various species. This should be taken into account before allowing any form of commercial fishing in these important nursery areas.

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CHAPTER 1

GENERAL INTRODUCTION

Many South African river-sea interfaces are not considered estuaries by the accepted definition of Pritchard (1967) which states that: "An estuary is a semi-enclosed body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage". Day (1980) commented on the two phrases, namely "a free connection with the open sea" and "*diluted* with fresh water", which are restrictive on South African systems as many are closed for varying amounts of time and may have hyper-saline conditions due to high rates of evaporation and low freshwater inputs. To circumvent this problem Day (1980) proposed a revised definition that would incorporate the smaller South African estuaries: "An estuary is a partially enclosed body of water which is either permanently or periodically open to the sea, and within which there is a measurable variation of salinity due to the mixture of sea water with fresh water derived from land drainage". For the purpose of this study the definition of Day (1980) will be accepted.

The above definition incorporates 258 estuaries along the South African coastline (Whitfield, 2000), which have a broad range of physico-chemical and geomorphological characteristics. Despite this large variability Whitfield (1992) proposed a method of classification for these systems. This classification uses five estuarine classes based on a number of physiographical, hydrographical and salinity characteristics. These classes include estuarine bays, river mouths, estuarine lakes, permanently open estuaries and temporarily open/closed systems. For the purpose of this study the intermittently open/closed estuaries will be referred to as closed, as the study systems that fall into this category were closed for the majority of the study period. Although closed systems constitute the bulk of South African estuaries (approximately 70%) the majority of estuarine research to date has been directed towards larger permanently open systems. This is due to these systems often being located close to coastal cities, where there is a greater threat of impact, requiring monitoring. These cities usually contain universities and research institutes seeking large estuaries for study purposes. Additionally, the larger systems are considered of more importance to the estuarine fish communities due to their permanently open mouths.

In the Eastern Cape Province ichthyological research has mostly been directed towards large permanently open systems such as the Swartkops (Melville-Smith and Baird, 1980; Beckley, 1983; De Wet and Marais, 1990; Marais, 1990; Baird *et al.*, 1996), Sundays (Beckley, 1984; Whitfield and Paterson, 1995; Baird *et al.*, 1996; Whitfield and Harrison, 1996), Kariega (Ter Morshuizen and Whitfield, 1994; Paterson and Whitfield, 1996; Paterson, 1998) and Great Fish (Ter Morshuizen *et al.*, 1996a; Ter Morshuizen *et al.*, 1996b; Whitfield *et al.*, 1994) estuaries. However, Dundas (1994) provided some insight into the ichthyofauna of three closed systems, namely the Kabeljous, Seekoei and Van Stadens estuaries, and Cowley (1998) conducted a quantitative study on the fish community of the East Kleinemonde Estuary. In KwaZulu-Natal Begg (1984a) undertook a comprehensive survey of faunal characteristics of the smaller estuaries in the province, while Harrison and Whitfield (1995) investigated the fish assemblages of three temporarily open/closed systems in more detail. In the Western Cape, Bennett *et al.* (1985) reported on the fish fauna in the Bot River Estuary in relation to mouth conditions and Bennett (1989) extended this work with a comparative study of the fish fauna in open and closed systems. Other estuarine ichthyological studies in the Western Cape include fish recruitment (Hall *et al.*, 1987; Whitfield, 1989b, 1989c), community structure (Whitfield, 1989a; Russell, 1996), food availability and resource utilization (Coetzee, 1982; Whitfield, 1988).

South African estuaries contain different floral and faunal assemblages interacting in a variety of ways, thus giving rise to different ichthyofaunal communities. The formation of the different assemblages and the types of interactions between them, may be influenced by a variety of physical, biological and chemical variables. Studies have been conducted on the influence of physical and chemical variables on fish communities, although more often than not only single variables are examined, e.g. Hanekom and Baird (1984) and Ter Morshuizen and Whitfield (1994) studied the influence of submerged macrophytes on fish communities; Kok and Whitfield (1986) the influence of mouth status; Harrison and Whitfield (1990) and Whitfield (1980b) the impact of estuarine size on fish communities. Two studies, one by Marais (1988) and another by Russell (1996) examined the effect of a variety of variables on fish communities in the Wilderness and Swartvlei systems, with the influence of each variable being analysed separately. Discussions of combinations of variables have been limited (e.g. Blaber, 1981; Whitfield, 1983; 1996), thus resulting in a lack of data relating combinations of physico-chemical variables to ichthyofaunal communities in estuaries.

This study aims to improve our understanding of ichthyofaunal communities in closed systems along the Eastern Cape coast by a) comparing them to large permanently open systems in this region, and b) relating any differences to selected physico-chemical and geomorphological variables within these systems.

The objectives of this study were to:

1) Collect fish community information from estuaries in the previous Ciskei region.
2) Determine whether there are longitudinal changes in fish composition within these systems.
3) Ascertain whether there are any differences in fish communities between the different types of systems.
4) Identify the physico-chemical variables responsible for any longitudinal or overall community variation within the different types of systems.

CHAPTER 2

STUDY AREA

2.1 Introduction

This study incorporates ten estuaries along a 70 km long stretch of the Eastern Cape coast between the towns of Seafield (33° 32′ 42″ S, 27° 03′ 05″ E) in the south-east and Hamburg (33° 16′ 45″ S, 27° 29′ 50″ E) in the north-west (Figure 2.1). This area was selected due to the diversity of estuary types and sizes occurring in close proximity. The estuaries investigated include the East Kleinemonde, Klein Palmiet, Great Fish, Mpekweni, Mtati, Mgwalana, Bira, Gqutywa, Ngculura and the Keiskamma (Figure 2.1).

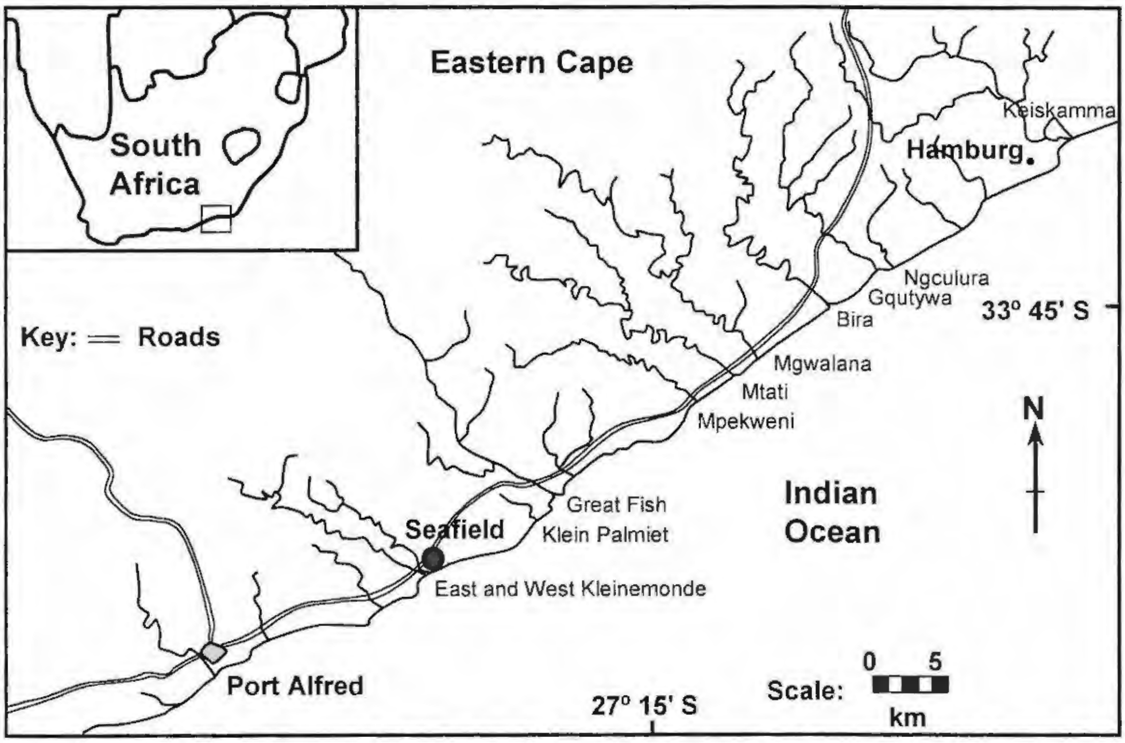


Figure 2.1: The study area showing the location of each estuary along the Eastern Cape coast (adapted from Walton, 1984).

Whitfield (2000) classified the condition of all of these systems as either good or excellent, indicating few anthropogenic impacts. The main negative impact is the narrowing of the lower estuary channels due to the bridges associated with the coastal road between Port Elizabeth and East London, with some systems also having housing developments on the banks in the lower reaches (Lubke, 1988; Whitfield, 2000). Land uses in the catchments of these estuaries include a variety of agricultural practices, mostly beef and pineapple farming, with several areas being set aside for private game farms.

In this chapter, the estuaries are described using data collected during this study. Detail of the methods used to collect these physico-chemical data can be found in Chapter 4.

2.1.1 Climatic conditions

Kopke (1988), Stone (1988) and Stone *et al.* (1998) agree that the coastal region between Port Alfred and East London has a predominantly subtropical climate, with temperatures normally between 10°C and 25.5°C (Figure 2.2). Air temperature fluctuations are reduced due to the cooling and warming effects of the sea, in summer and winter respectively (Stone, 1998). The maximum and minimum temperatures recorded at the Fish River Lighthouse (near the Fish River Mouth) from 1960 to 2000 were 26.4°C (January 1968) and 8.8°C (August 1996) respectively (as measured at 08h00, South African Weather Bureau records, *in litt.*).

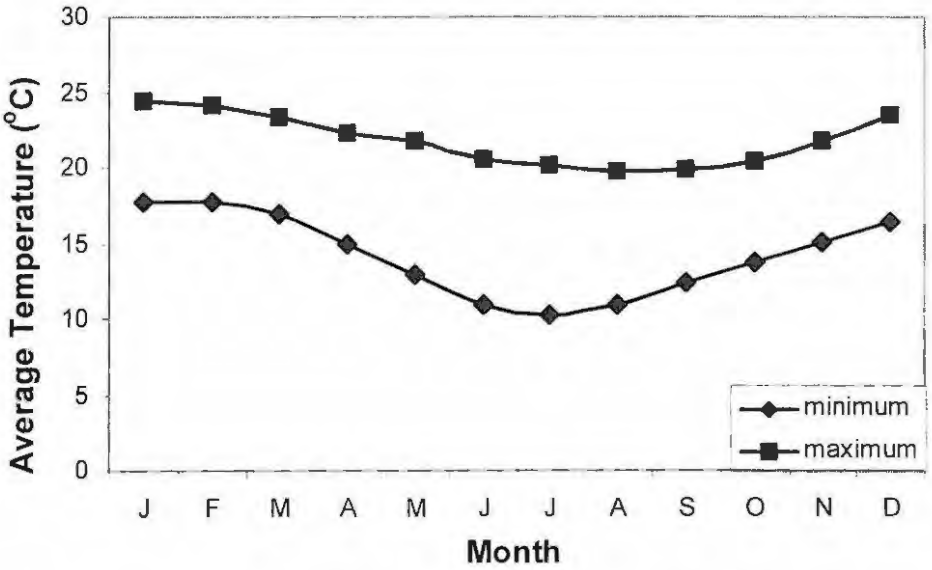


Figure 2.2: The average monthly air temperatures (°C) measured at the Fish River Lighthouse for the years 1960 to 2000 (South African Weather Bureau records, *in litt.*).

The observed rainfall in the coastal region demonstrates an autumn-spring bimodal pattern (Figure 2.3), with a spring peak (Kopke, 1988). The mean annual rainfall at the Fish River Lighthouse between 1960 and 1998 was 642 mm, although during 1996 to 1998 the mean annual rainfall did not exceed 540 mm (South African Weather Bureau records, *in litt.*).

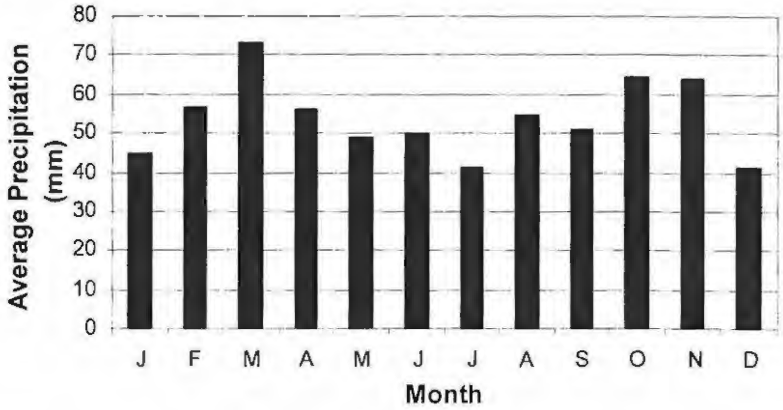


Figure 2.3: The mean monthly rainfall at the Fish River Lighthouse between 1960 and 2000 (South African Weather Bureau, *in litt.*).

2.1.2 Coastal hydrography

The coastal shelf narrows north of the Agulhas Bank to approximately 30km wide along the Eastern Cape and southern Natal coasts (Lutjeharms, 1998). The warm Agulhas Current flows along the edge of the shelf in a south-westerly direction (Ross, 1988) with occasional meanders having a profound effect on the inshore waters in this region. These meanders, also known as Natal Pulses, separate off the main stream of the current in a clock-wise direction and eventually flow towards the north-east. These meanders can cause upwelling of deeper, colder water, which may influence the inshore water masses for several days (Lutjeharms, 1998).

Close inshore the water movement tends to be wind driven. Prolonged easterly winds move the surface waters away from the coast, thereby causing upwelling of colder water. Persistent westerly winds tend to move the warm Agulhas Current closer inshore thus causing an increase in coastal water temperatures (Lutjeharms, 1998). However, overall the water masses on the coastal shelf have a fairly uniform temperature and salinity due to wind-driven mixing. The mean sea surface temperature at East London, north of the study area, ranged from 19°C in summer to 17°C in winter, showing a very small seasonal variation (Lutjeharms, 1998).

2.1.3 Aeolian and marine sand transport

Although there is a seasonal component, nett aeolian sand transport occurs in an easterly direction along the Eastern Cape coast (Stone *et al.*, 1998), while marine sediment transfer occurs in a nett westerly direction. The latter sediments are carried by nearshore currents running parallel to the Agulhas Current and have a significant influence on the status of estuary mouths along this coastline (Lutjeharms, 1998). These opposing directions of sediment transfer combine to deposit sediment loads in the mouths of intermittently open estuaries, resulting in rapid mouth closure.

2.2 East Kleinemonde Estuary

The East Kleinemonde (Figure 2.4) is a medium-sized temporarily open/closed estuary. It is situated approximately 20 km northeast of Port Alfred and the mouth meets the sea at 33° 32′ 42″ S and 27° 03′ 05″ E. A small township, Seafield, surrounds most of the lower reaches of this estuary, as well as the neighbouring West Kleinemonde Estuary. The coastal road (R72) between Port Elizabeth and East London crosses the estuary approximately 500 m from the mouth.

The estuary is 2.5 km long with a surface area of 17.5 ha. The catchment area is 46.3 km^2 and provides a mean annual run-off (MAR) of 2 x 10^6 m^3/yr (Badenhorst, 1988).

The width of the estuary is approximately 100 m in the lower and middle reaches and narrows down to 25 m in the upper reaches. The main channel has a maximum depth of 2.5 m, with most of the estuary having a littoral zone of less than one metre deep. The cross-sectional area of the system steadily decreases from the mouth (154 m^2) to the head (24.5 m^2) with an average of 82.1 m^2.

The mouth dynamics of this system are well documented (Bell *et al.*, in press). These data demonstrate that open mouth conditions were only evident 2.5% of the time, while overwash conditions appeared to be important in promoting marine influences on the system, occurring 16.4% of the time. During the period 1993-1998 open mouth conditions occurred during every month except March and July, demonstrating the unpredictable nature of the mouth condition (Cowley, 1998).

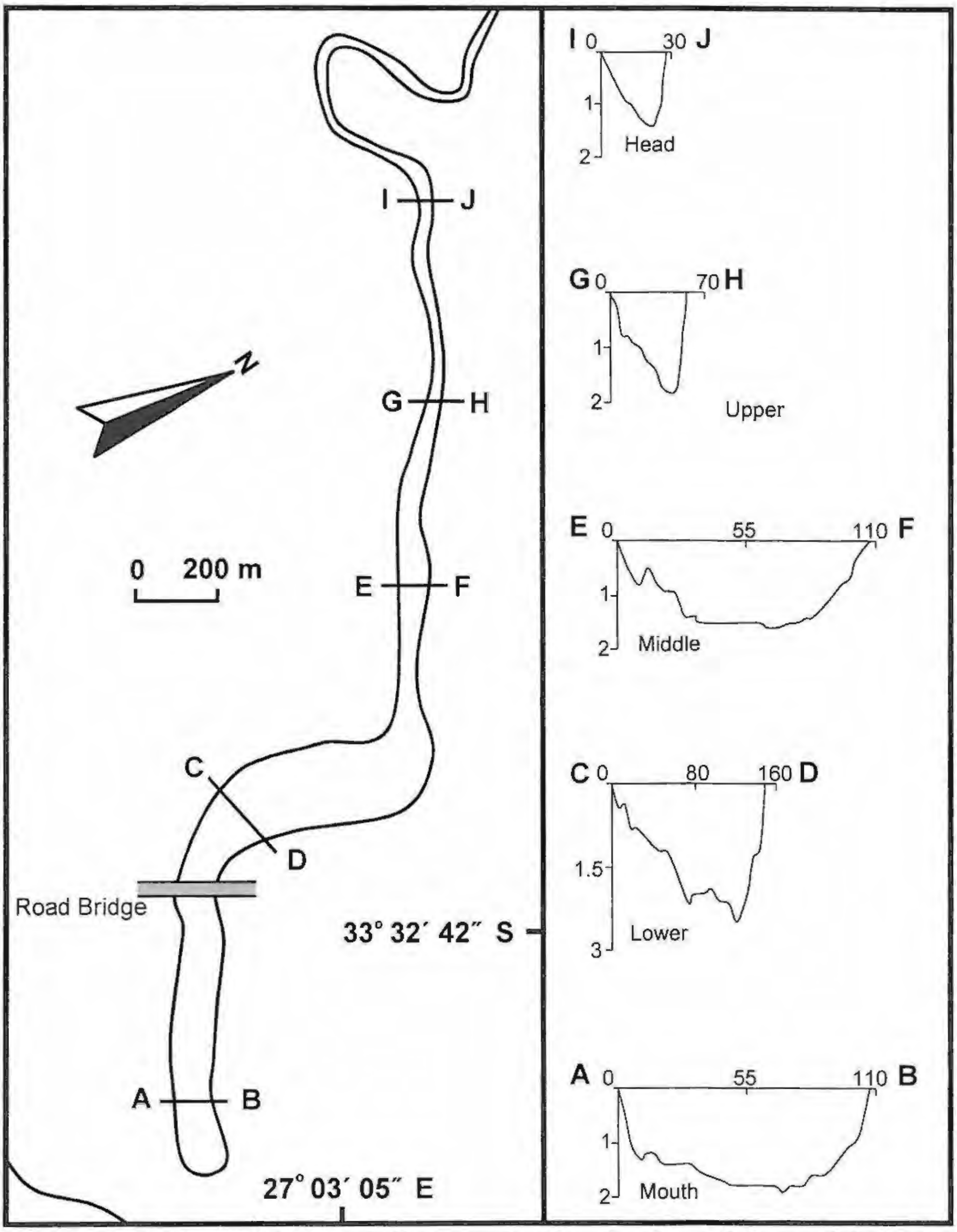


Figure 2.4: The East Kleinemonde Estuary, showing the size and shape of the system. The cross-sections indicate depths in the various sections of the estuary (drawn from data collected on the 3rd of June 1999).

The winter and summer temperatures recorded during the study period averaged 16.9°C and 26.4°C respectively. The winter temperatures ranged between 14.5°C and

19°C while the summer temperatures varied from 25.4°C to 27°C (Figure 2.5). During summer the bottom temperatures were consistently higher than surface water temperatures, while winter sampling reflected no trends in this regard. These temperatures are below the maximum (27°C) and minimum (14.9°C) values recorded by Cowley (1998).

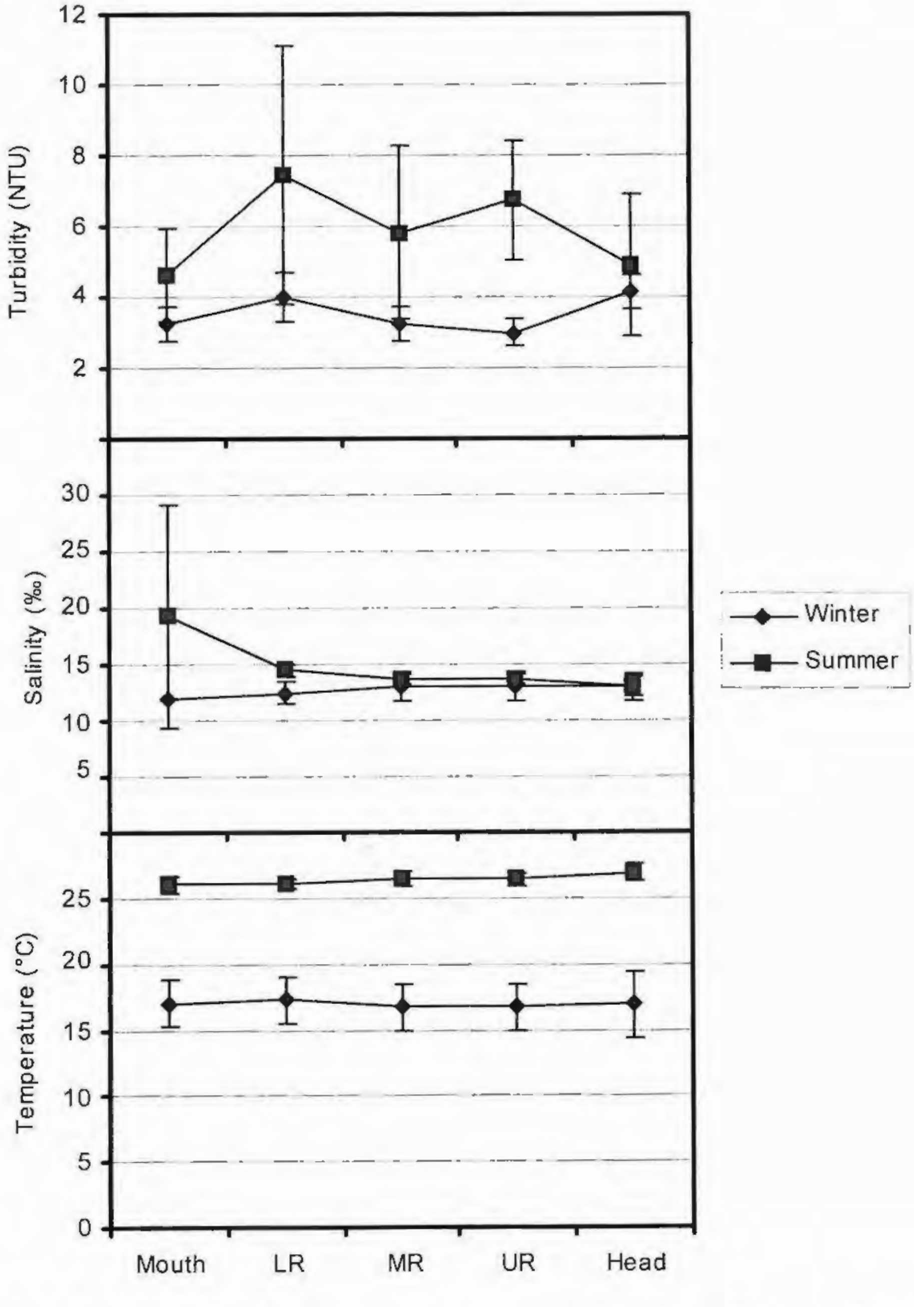


Figure 2.5: Mean (±S.D.) summer/winter temperature, salinity and turbidity measurements for different localities in the East Kleinemonde Estuary. The mean was determined from morning and midday samples collected in surface and bottom waters on the 3rd of June 1999 and the 6th of February 2000.

The seasonal salinities remained relatively constant during the study period with the average winter and summer salinities being 12.7‰ and 14.8‰ respectively. The only large variation was a mouth region sample during summer that had a relatively high salinity of 34‰. The summer salinities ranged from 13‰ to the high of 34‰, while winter salinities ranged between 12‰ and 14‰ (Figure 2.5). These salinities were higher than the 0-27‰ recorded by Cowley (1998).

Turbidity variations were extremely low, with winter turbidities of 3 to 4.5 NTU, and summer values ranging from 3.4 to 11 NTU (Figure 2.5). The winter and summer averages were 3.5 and 5.9 NTU respectively, with bottom turbidities being generally higher than surface turbidities during both seasons.

All the sites sampled in the East Kleinemonde contained mostly fine sands, with a general trend of decreasing larger particles (gravel, coarse and medium sands) as well as silts, from head to mouth (Figure 2.6). The sediment organic content showed a decreasing trend from head to mouth, although all sites had a relatively low organic content of between 0.8% and 6.5% (Figure 2.6).

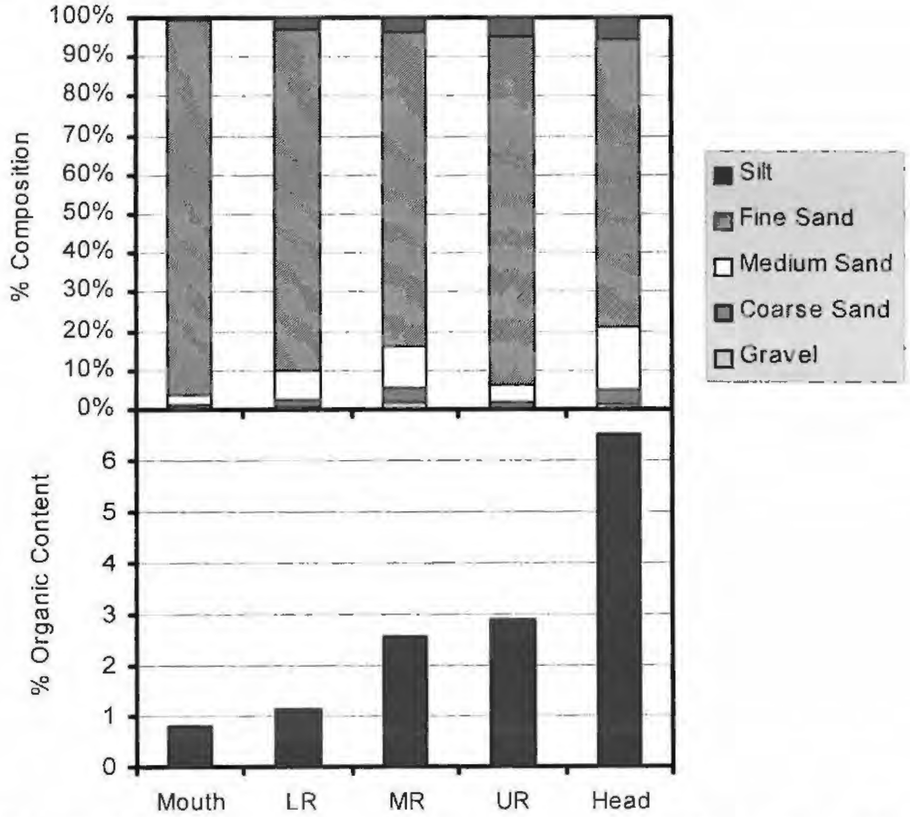


Figure 2.6: Particle size composition and organic content of the sediments in the East Kleinemonde Estuary (6th February 2000).

A brief botanical survey was conducted by Adams (1997) and revealed two species of submerged macrophytes, the dominant species being *Ruppia cirrhosa* that occurs in a continuous band along both banks of the estuary above the road bridge, and the less common species being the seagrass *Halophila ovalis*. Adams (1997) also noted a small salt marsh on the west bank just above the road bridge with bands of *Sarcocornia perennis*, *Sporobolus virginicus* and *Sarcocornia decumbens*, and patches of *Juncus kraussii*. Additional vegetation noted were small stands of *Phragmites australis* along the length of the estuary, particularly in the lower and middle reaches.

2.3 Klein Palmiet Estuary

The Klein Palmiet (Figure 2.7) is a small temporarily open/closed estuary that enters the sea approximately one kilometre west of the Great Fish Estuary on the coordinates 33° 30′ 00″ S and 27° 07′ 47″ E. A game farm surrounds the entire estuary and the anthropogenic impacts are minimal, with a farm road accessing the beach on the east bank at the mouth. The future development of eco-tourism (i.e. construction of chalets) on the farm may compete with the freshwater demands of this small estuary.

The estuarine surface area is 1.44 ha when full, but declines to approximately 0.4 ha when the estuary is empty. The catchment is 12.6 km^2 in size and provides a MAR of 0.67×10^6 m^3/yr (Smakthin, V., *pers. comm.*). The water level at the time of sampling was very low, with an average depth of 0.4 m and a maximum of 1.2 m in the deep pool at the mouth.

During the study, a single winter and summer physico-chemical sample was collected on the 15th of June 1999 and the 1st of February 2000. These samples showed very little variation in the salinity and turbidity of the estuary. The recorded winter salinity was 23‰ while during summer it was only slightly higher at 28‰. Similarly the winter turbidity was 5 NTU increasing during summer to 8.1 NTU. The temperatures showed a greater variation, rising from a winter value of 16°C to a summer recording of 25.2°C.

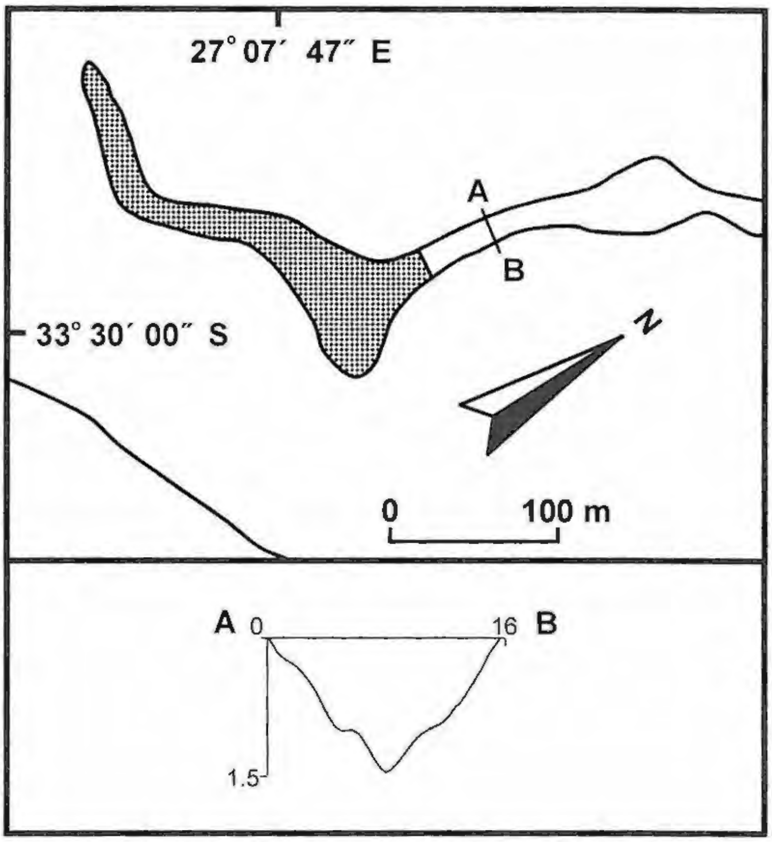


Figure 2.7: The Klein Palmiet Estuary, showing the size and shape of the system. The cross-section at A-B shows the depth profile at this point (drawn from data collected on the 15th of June 1999)

The sediment of the Klein Palmiet Estuary was dominated by fine sands, which constituted 99.8% of the sample, with all the other sediment sizes contributing less than 0.1%. The organic content of the sediment was the lowest of all the systems in the study, comprising 0.5% of the sample.

Ruppia cirrhosa was recorded in the deeper pools near the mouth, although not in very high densities. Stands of *Phragmites australis* were observed along the banks of the estuary although due to the low water levels these plants were approximately three metres away from the estuary edge.

2.4 Great Fish Estuary

The Great Fish system (Figure 2.8) enters the sea at 33° 29′ 28″ S and 27° 08′ 06″ E. It has a road bridge crossing the estuary approximately 400 m from the mouth. The river receives freshwater from the Orange River inter-basin transfer scheme with the result that there is a flood level run-off all year round.

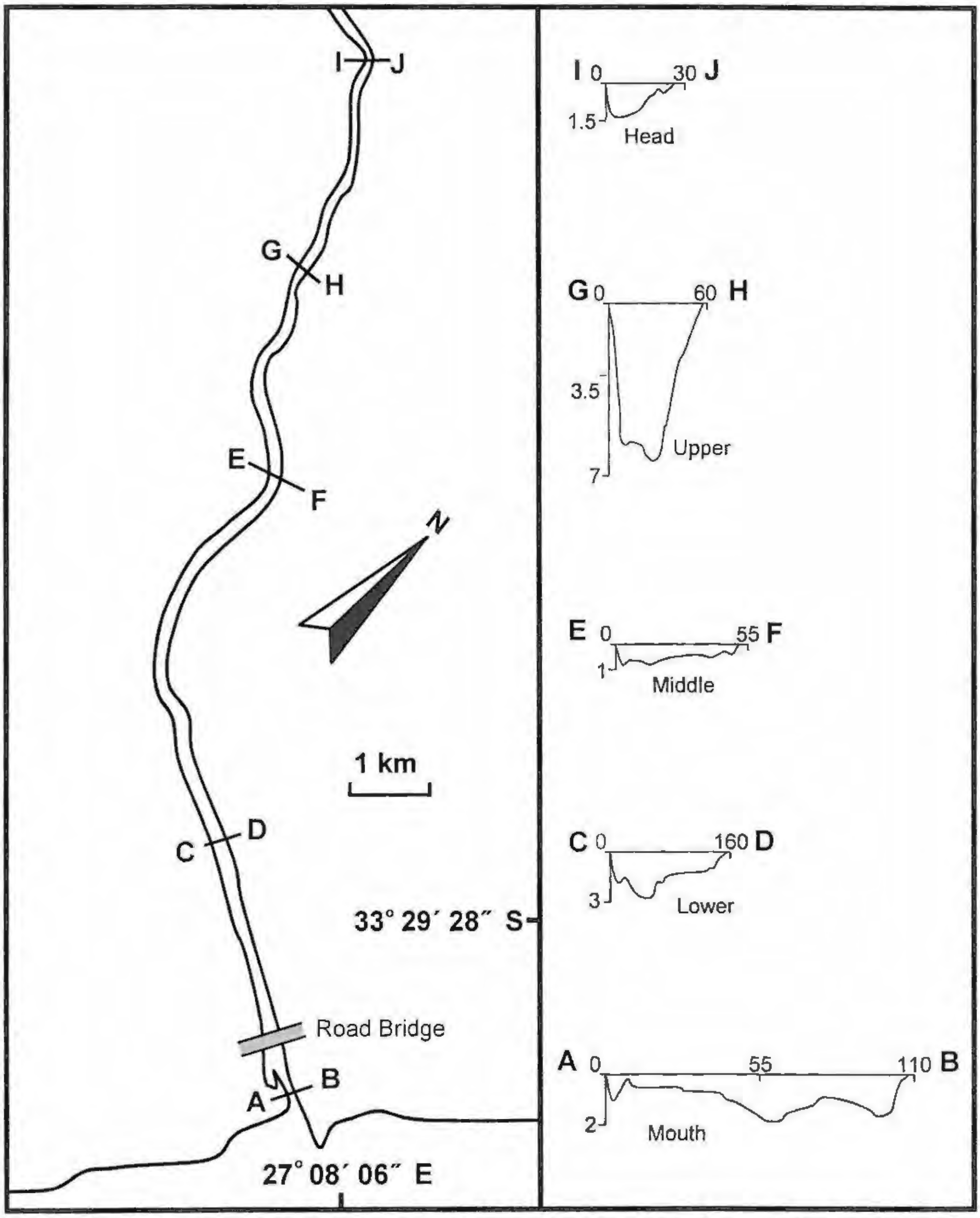


Figure 2.8: The Great Fish Estuary, showing the size and shape of the system. The cross-sections indicate depths in the various sections of the estuary (drawn from data collected on the 2nd of June 1999).

This system is a large permanently open estuary, with a catchment area of 29284 km^2 and a MAR of 526 x 10^6 m^3/yr (Smakthin, V., *pers. comm.*). The longitudinal length of the system is 15 km, encompassing a total estuarine area of 192.7 ha.

The estuary depth and width data were recorded on a neap low tide. There was a large shallow bay near the mouth with two channels flowing through it that were 1.8 m deep. The main estuary channel was a maximum of 6.4 m deep, with shallow intertidal mudbanks on either side, resulting in an average depth of 1.37 m. The estuary was relatively broad, with the narrowest area located in the head-waters (50 m) and the widest area (180 m) being located near the mouth (Figure 2.8). The average cross-sectional area was 106.9 m^2.

The seasonal variability in water temperatures during this study was most noticeable in the upper reaches, with the sea having a moderating influence on the mouth region (Figure 2.9). The average winter temperature was 16.1°C (range = 12-19°C), while the summer average was 24.2°C (range = 18.6-25.6°C). The temperatures presented by Ter Morshuizen *et al.* (1996a, 1996b) were within this range, except for their summer maximum of 28.5°C.

Salinities recorded during this study reflected the elevated fresh water inputs on this system, with the upper estuary having oligohaline salinities, 0-3‰ (Figure 2.9). Salinities in the mouth region were generally higher, 5-34‰, indicating a strong marine influence at times due to the open mouth (Figure 2.9). Salinity intruded further along the bottom than in the surface layers, with the surface waters generally having slightly lower salinities (1‰ or 2‰ lower in the upper reaches and 5‰ or 10‰ in the lower reaches). The average monthly salinity recorded in the middle and upper reaches from November 1992 up to January 1995 varied between 0‰ and 15‰ (Ter Morshuizen *et al.*, 1996a; 1996b).

Turbidity also reflected the dual nature of the Great Fish, with the upper reaches having higher turbidities from the elevated fresh water input and the lower reaches having clearer water as a result of the marine influence (Figure 2.9). There were no large differences between surface and bottom turbidities, except in the mouth region where surface and bottom readings sometimes differed by approximately 100 NTU.

The turbidity in this estuary is generally higher than in the surrounding systems with a winter and summer average of 124.9 NTU and 176.7 NTU respectively. Ter Morshuizen *et al.* (1996a; 1996b) recorded a mean of approximately 200 NTU in the middle and upper reaches of the estuary.

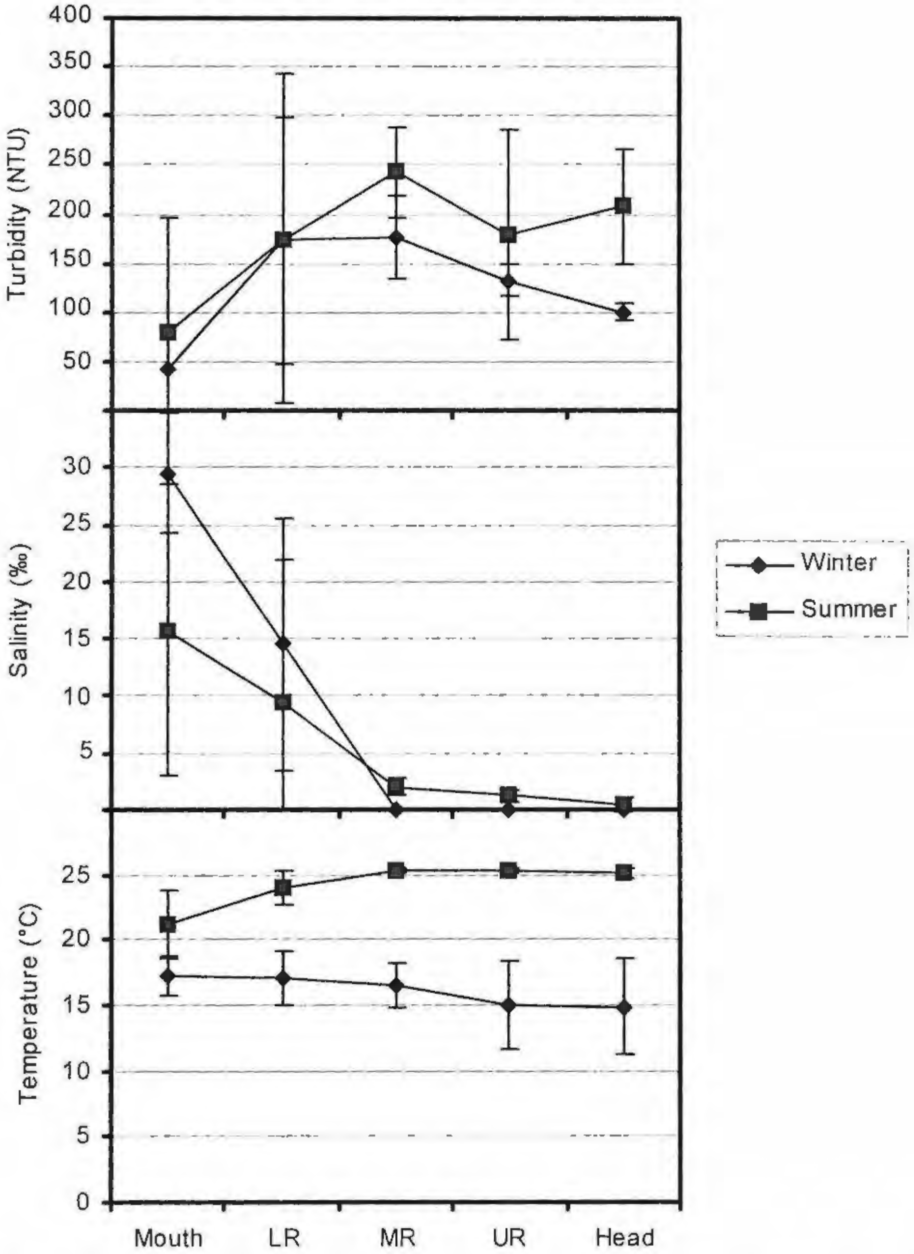


Figure 2.9: Mean (±S.D.) summer/winter temperature, salinity and turbidity measurements for different localities in the Great Fish Estuary. The mean was determined from morning and midday samples collected in surface and bottom waters on the 2nd of June 1999 and the 31st of January 2000.

The particle size distribution of sediments in the Great Fish increased from the head to the lower reaches and decreased again to almost completely fine sand at the mouth (Figure 2.10). The small sediment size in the mouth region may be due to this sample coinciding with the entry of a tributary that releases its load of medium sands into the estuary. The organic content in the sediment ranged between 1% and 2% at all sites, excluding the middle reach site (Figure 2.10), which contained approximately twice the organic content when compared with the other sites.

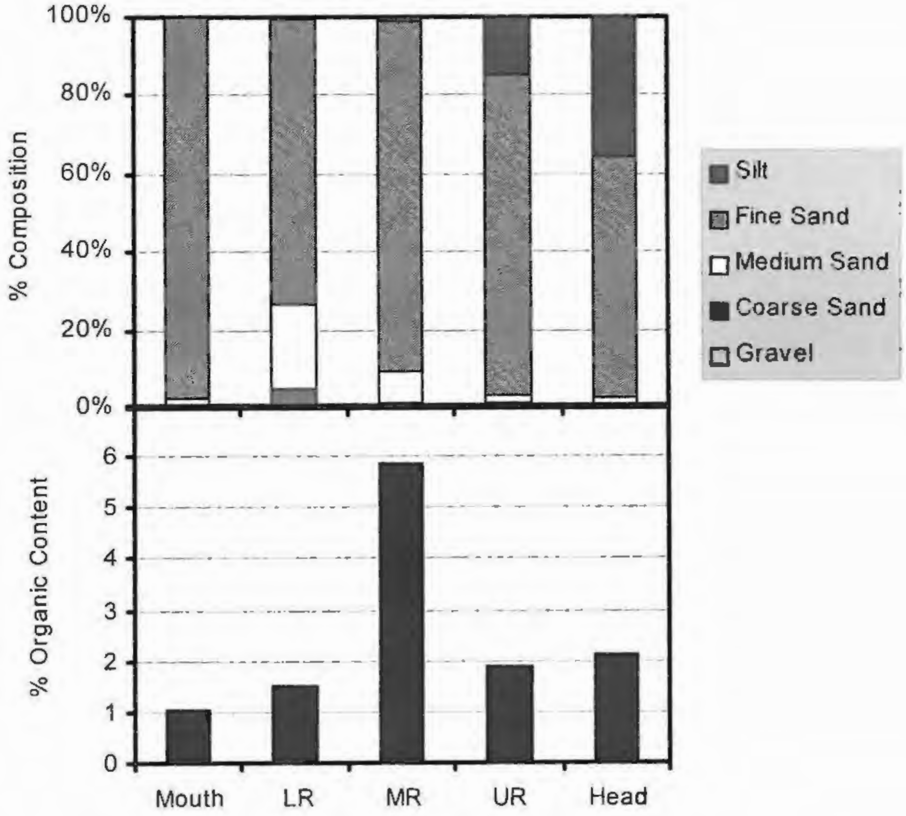


Figure 2.10: Particle size composition and organic content of the sediments in the Great Fish River Estuary (31st of January 2000).

This system has no submerged macrophytes, probably due to the high turbidity entering the system (Colloty, 2000). There is a relatively large (199 ha) salt marsh area on the west bank in the mouth region. Reeds and sedges do occur intermittently along the banks, covering a total of 16.6 ha (Colloty, 2000). The permanently open mouth facilitates the input of a variety of marine algae that may add to the productivity of the estuary.

2.5 Mpekweni Estuary

The Mpekweni (Figure 2.11) is a medium sized temporarily open/closed estuary that reaches the sea approximately 15 km north-east of the Great Fish at 33° 26′ 13″ S and 27° 13′ 57″ E. The coastal road between East London and Port Elizabeth crosses the estuary 300 m upstream from the mouth. Access to the mouth is limited to a private road through the Mpekweni Sun resort on the east bank of the estuary. A broken weir marks the headwaters of the estuary.

This system has a medium sized catchment (65 km^2) with a MAR of 3.45×10^6 m^3/yr (Smakthin, V., *pers. comm.*). The longitudinal length of the estuary is 3 km, encompassing a total estuarine surface area of 57.6 ha.

The Mpekweni Estuary is navigable in a small boat, with an average depth of 1.08 m and a maximum depth of 2.6 m. The mouth area is extremely shallow with only one section reaching one metre in depth. The cross-sectional area decreases from the lower reaches to the head of the system (Figure 2.11), with an average of 92.3 m^2. The mouth (110 m), lower (140 m) and middle (140 m) reaches are relatively wide when compared with the upper reaches (40 m) and head (40 m).

Water temperatures in the Mpekweni during this study ranged from 15.3°C to 18.3°C during winter and 27.6°C to 32.2°C during summer (Figure 2.12). The mean temperatures for winter and summer were 16.3°C and 29.4°C respectively. Surface and bottom temperatures showed very little variability, possibly due to the shallow nature of this system.

Salinities recorded during this study did not reveal any stratification, with surface and bottom salinities varying by approximately 0.2‰. Winter salinities ranged from 20‰ to 26‰, while during summer the variation was between 32‰ and 35‰ (Figure 2.12). The summer increase in salinity may be indicative of the shallow nature of the system and high evaporative potential.

Turbidities in the system showed no depth, longitudinal or seasonal trend (Figure 2.12), with the winter and summer averages being 7.1 NTU and 6.8 NTU respectively. The winter and summer ranges overlapped considerably, being 4-11 NTU and 3-13 NTU respectively.

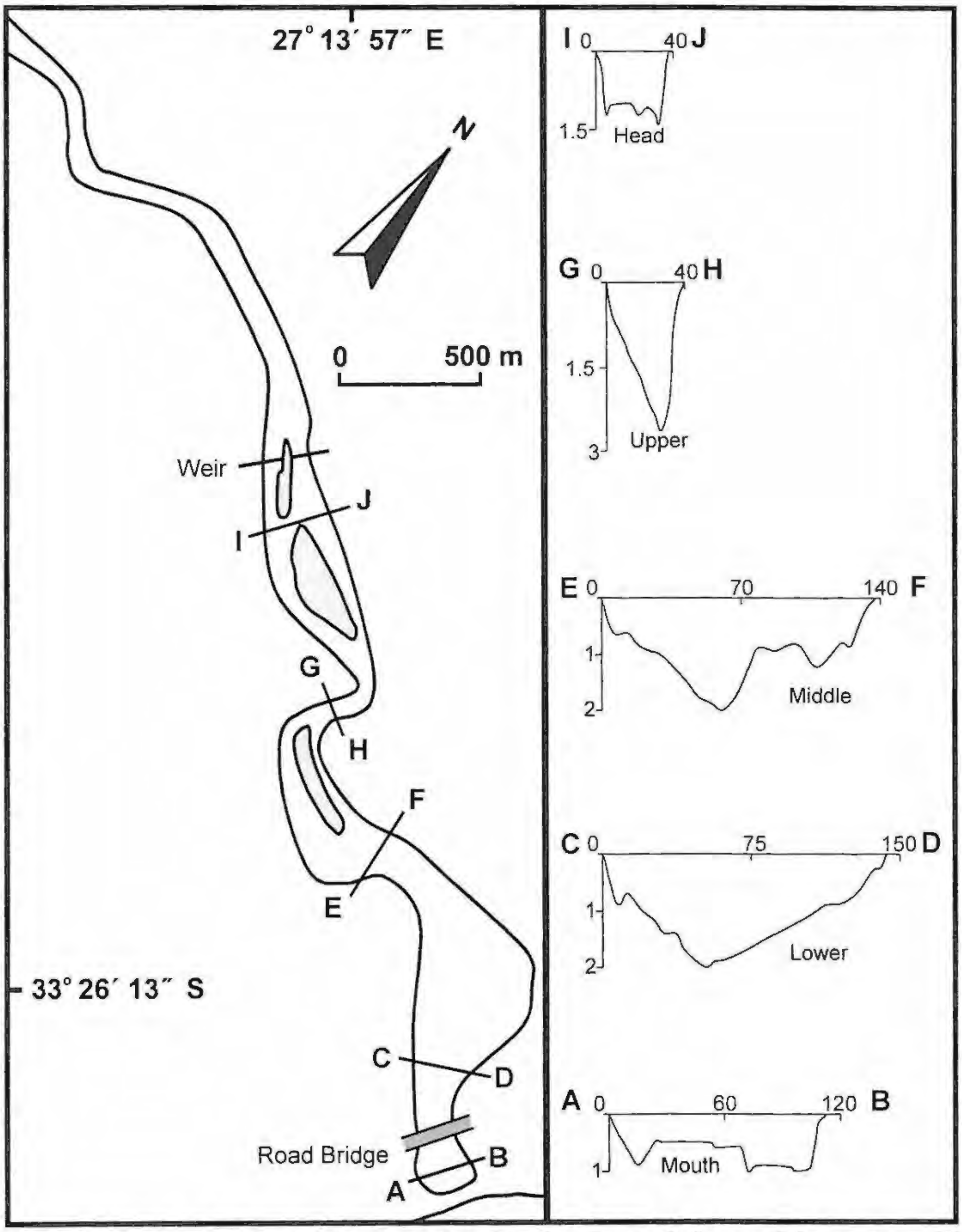


Figure 2.11: The Mpekweni Estuary, showing the size and shape of the system. The cross-sections indicate depths in the various sections of the estuary (drawn from data collected on the 6th of June 1999).

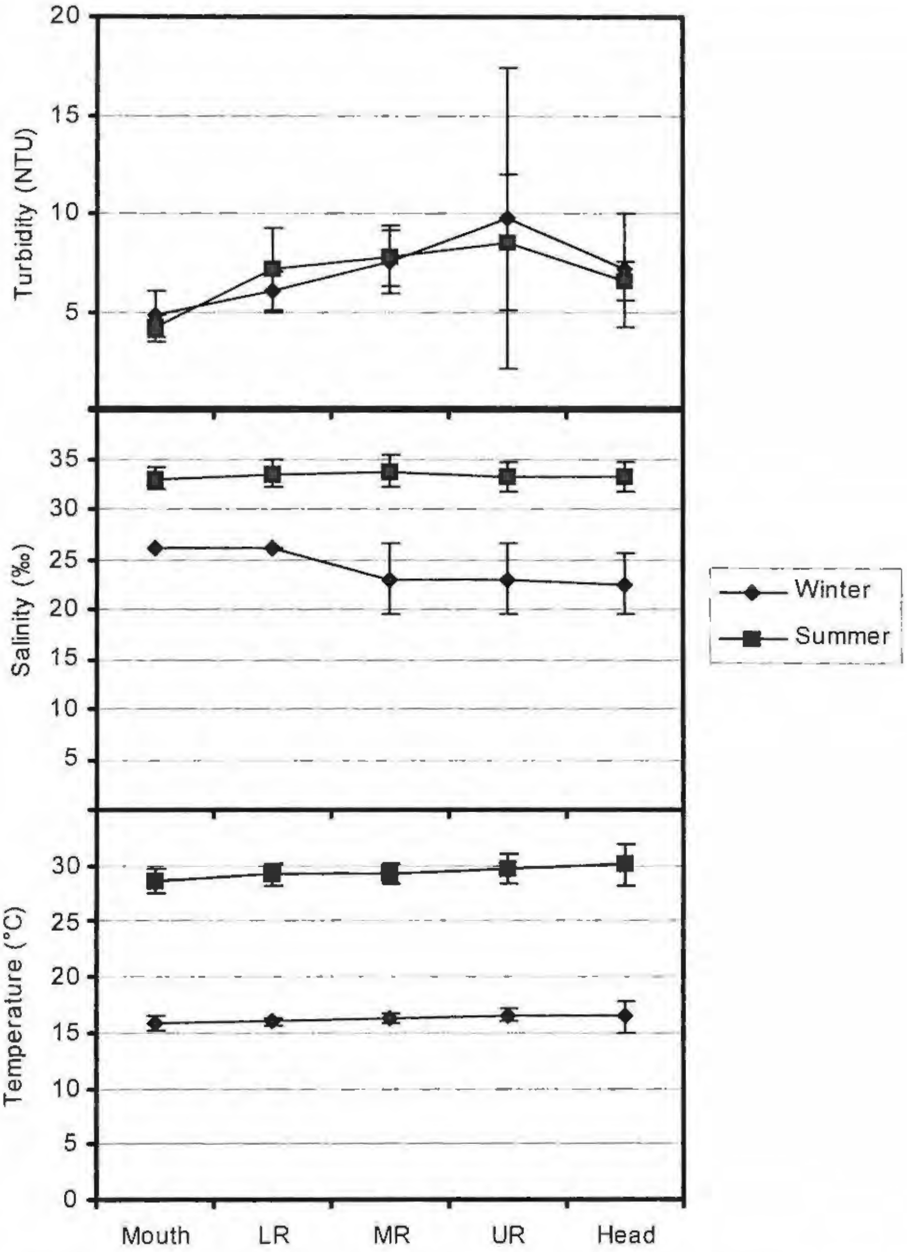


Figure 2.12: Mean (±S.D.) summer/winter temperature, salinity and turbidity measurements for different localities in the Mpekweni Estuary. The mean was determined from morning and midday samples collected in surface and bottom waters on the 6th of June 1999 and the 8th of February 2000.

Sediment particle sizes in the Mpekweni Estuary had a generally decreasing trend from head to mouth. The upper reach was the only site that didn't conform to this, consisting almost exclusively of silts and fine sands. The organic content of the system increased from the head to the middle reaches and then decreased towards the mouth (Figure 2.13).

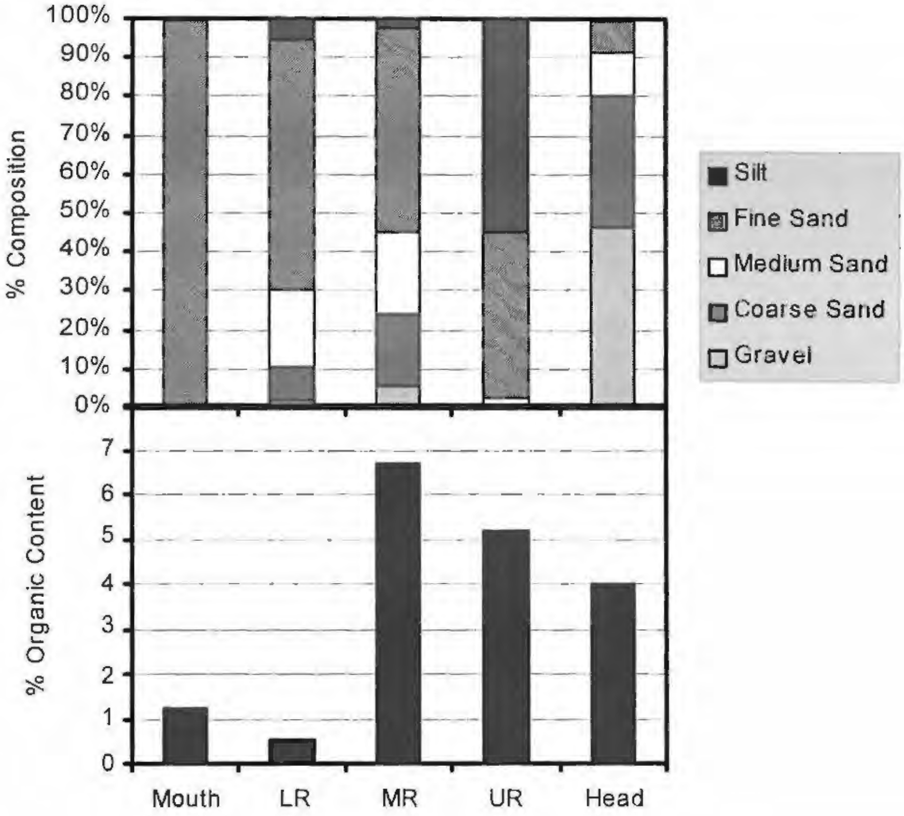


Figure 2.13: Particle size composition and organic content of the sediments in the Mpekweni Estuary (8th of February 2000).

The Mpekweni has a limited variety of estuarine plants. Colloty (2000) identified 1.59 ha of submerged macrophytes in the estuary and 27.2 ha of supratidal salt marsh on the east bank above the road bridge.

2.6 Mtati Estuary

The Mtati (Figure 2.14) is a medium sized temporarily open/closed estuary that reaches the sea at 33° 25′ 24″ S and 27° 15′ 34″ E. Anthropogenic impacts are restricted to the road bridge, which crosses the estuary approximately 300 m from the mouth and a low impact housing development on the east bank.

The catchment size of the Mtati is 130 km^2 with a MAR of 6.89×10^6 m^3/yr (Smakthin, V., *pers. comm.*). Freshwater inflow is not impeded in any way other than possibly by some small farm dams on the tributaries. The estuary has a surface area of 37.9 ha and a longitudinal length of approximately 4 km.

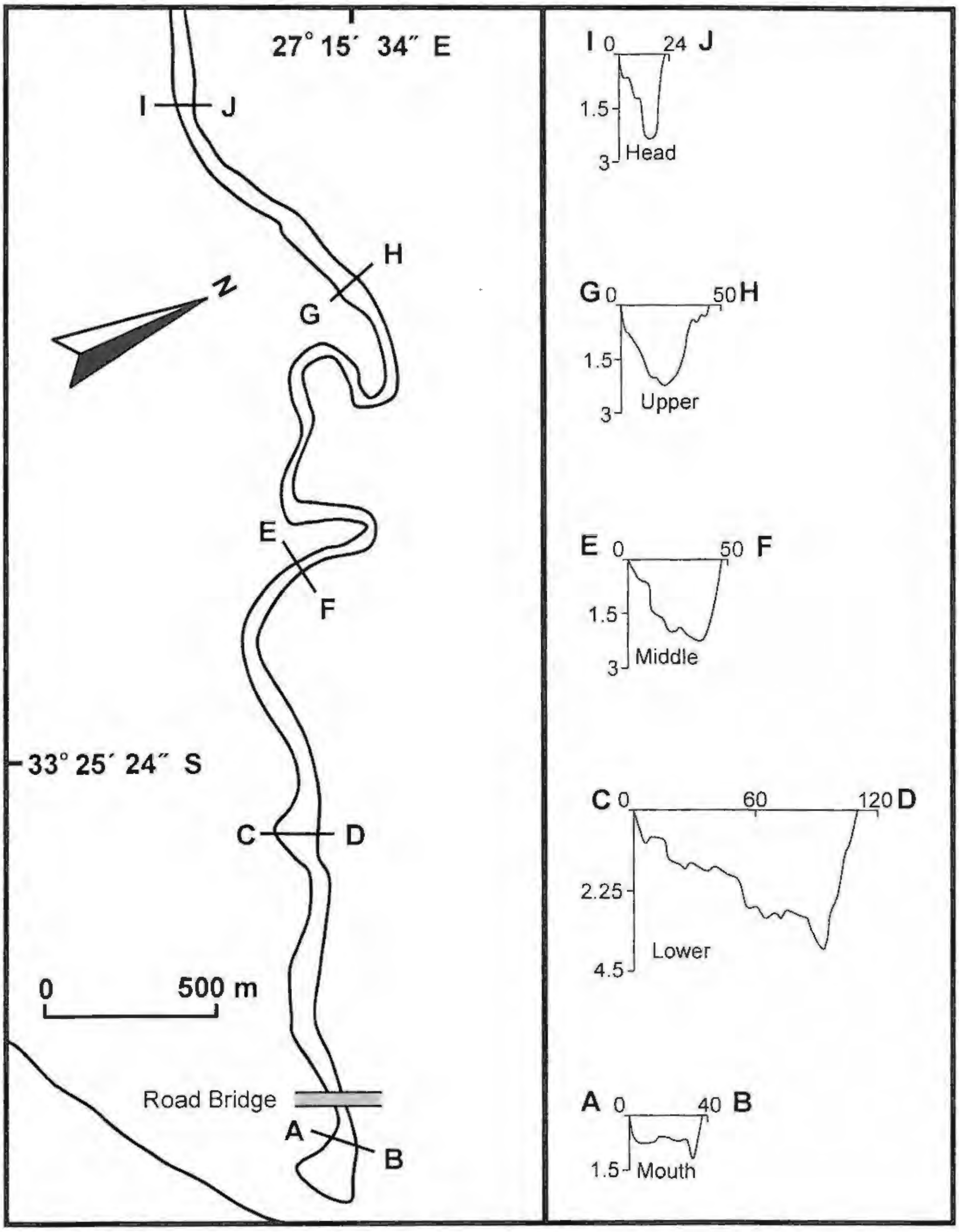


Figure 2.14: The Mtati Estuary, showing the size and shape of the system. The cross-sections indicate depths in the various sections of the estuary (drawn from data collected on the 31st of May 1999).

The Mtati is generally a narrow system, with an average width of 57.5 m, except for a bay area above the road bridge where it widens to approximately 110 m. The average recorded depth of the system was 1.6 m, although the main channel was generally deeper than 2 m reaching a maximum of 3.9 m in the lower reaches. The average cross-sectional area is 57 m^2 although this is mostly due to a relatively high value of 121 m^2 in the lower reaches.

Based on measurements taken on the 31st of May 1999 and the 9th of February 2000, temperatures in the Mtati Estuary showed a large seasonal variation with a winter average of 13°C and a summer average of 28.8°C. There was a small range during both seasons, 11-15°C during winter and 27-31°C during summer (Figure 2.15). There was no evidence of temperature stratification, possibly due to the shallowness of the estuary and the effects of wind mixing.

The salinity throughout the system was fairly uniform with only a small reduction towards the head during winter (Figure 2.15). The mean summer salinity, 20.1‰, is higher than the mean winter salinity, 16.5‰, possibly due to the shallow nature of the system promoting evaporation during the hot summer.

The overall turbidity in the system was relatively low with an average of 9.2 NTU. Winter turbidities were slightly lower with a mean of 5.1 NTU while the summer mean was 13.3 NTU (Figure 2.15).

Sediment particle sizes in the Mtati Estuary decreased from head to mouth, with the mouth sample comprising almost completely fine sands (Figure 2.16). The percentage organic content of the sediments also generally decreased from the head to the mouth (Figure 2.16). The only site not following this trend was the lower reach site, which had a higher organic content than the middle reaches.

The botanical importance of submerged macrophytes to this system is relatively low, with only 3.2 ha being identified (Colloty, 2000). The main contributors to productivity were the supratidal salt marsh area (54.3 ha) and reed stands along the banks (26.2 ha).

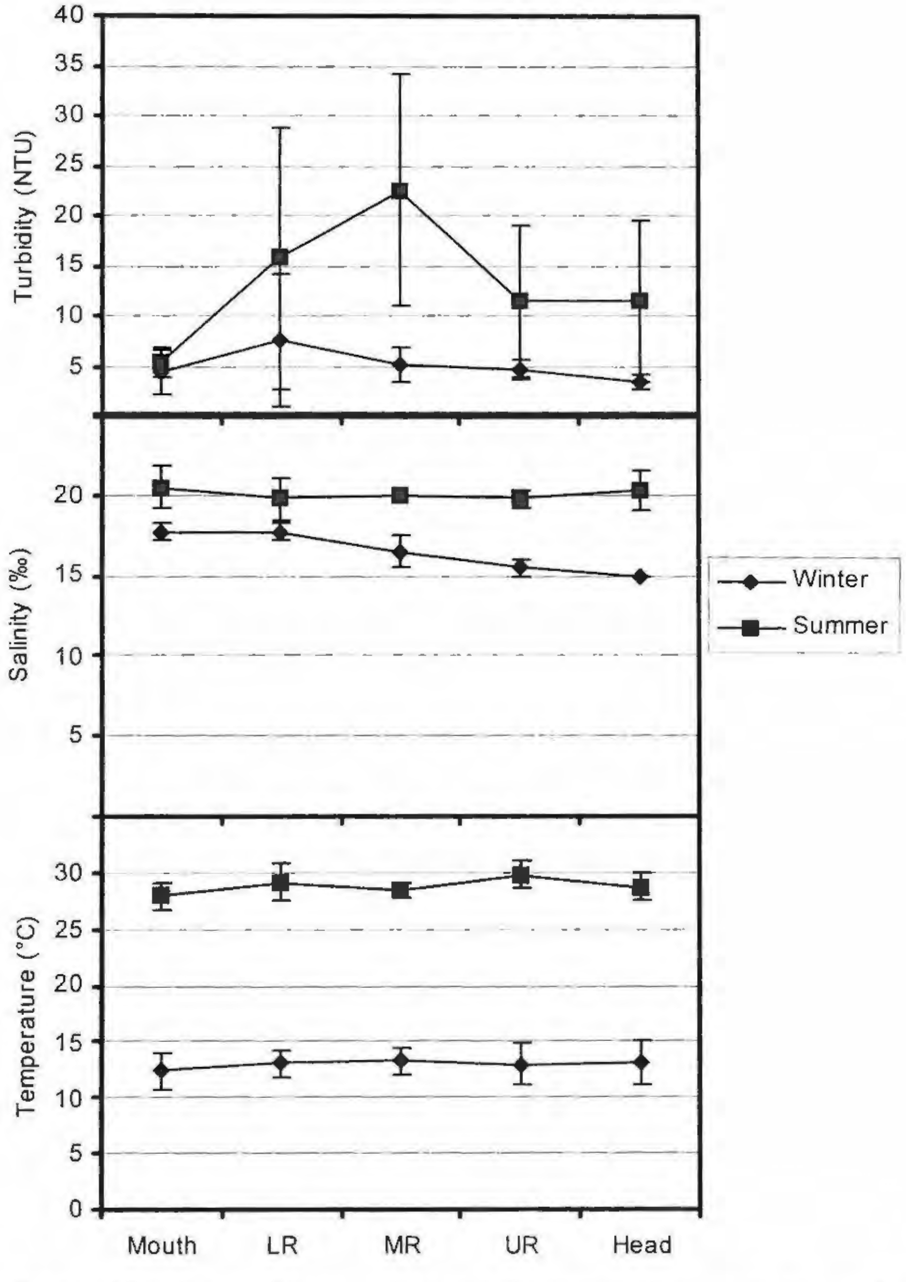


Figure 2.15: Mean (±S.D.) summer/winter temperature, salinity and turbidity measurements for different localities in the Mtati Estuary. The mean was determined from morning and midday samples collected in surface and bottom waters on the 31st of May 1999 and the 9th of February 2000.

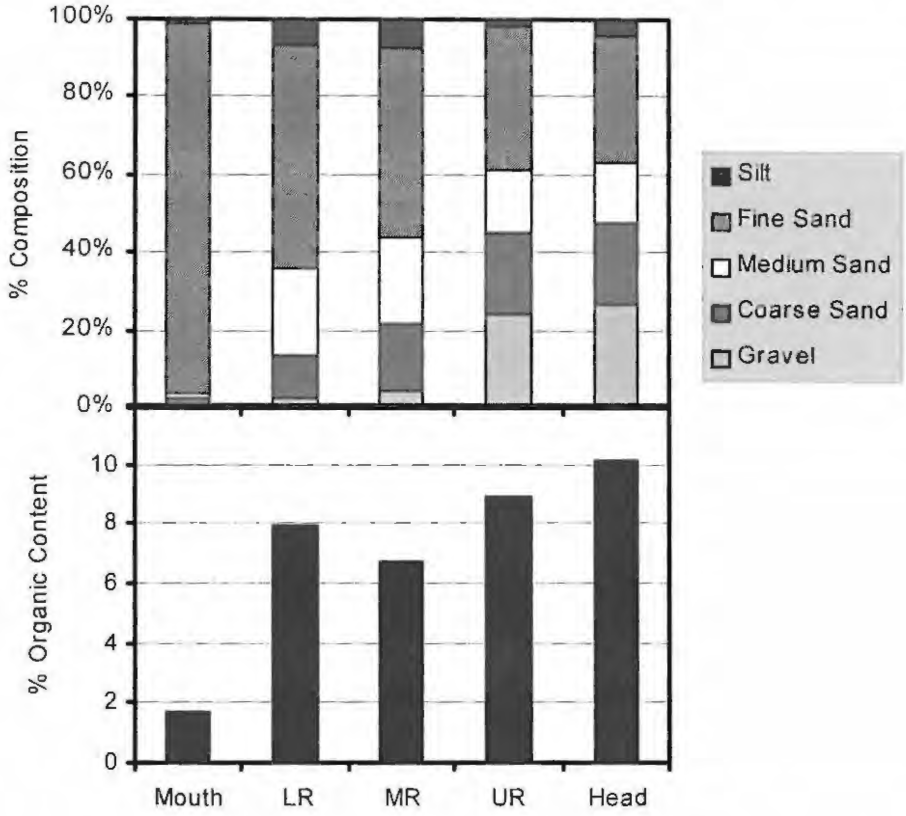


Figure 2.16: Particle size composition and organic content of the sediments in the Mtati Estuary (9th of February 2000).

2.7 Mgwalana Estuary

The Mgwalana (Figure 2.17) is a large temporarily open/closed estuary reaching the sea at 33° 24′ 52″ S and 27° 16′ 32″ E. Access to the mouth area is limited to a private road through a small holiday community on the east bank. The main anthropogenic influence on this system is the coastal road, which crosses the main channel approximately 400 m upstream of the mouth. Some small walls have been built on the eastern side of the mouth region to attempt to stop erosion of the beach access road.

This system has a relatively large catchment area of 200 km^2 and a MAR of 10.6 x 10^6 m^3/yr. The length of the estuary is 6.5 km and encompasses a total estuarine surface area of 62.9 ha.

The mouth area of the Mgwalana is very shallow (less than 0.25 m in depth), with the rest of the system being slightly deeper (average depth = 0.6 m), and having a maximum depth of 1.3 m. The estuary is also not very wide relative to the other systems, having a maximum width of 85 m and an average of 54.4 m. The system has a small average cross-sectional area of 29.7 m^2 with only the lower reaches being higher at 60 m^2.

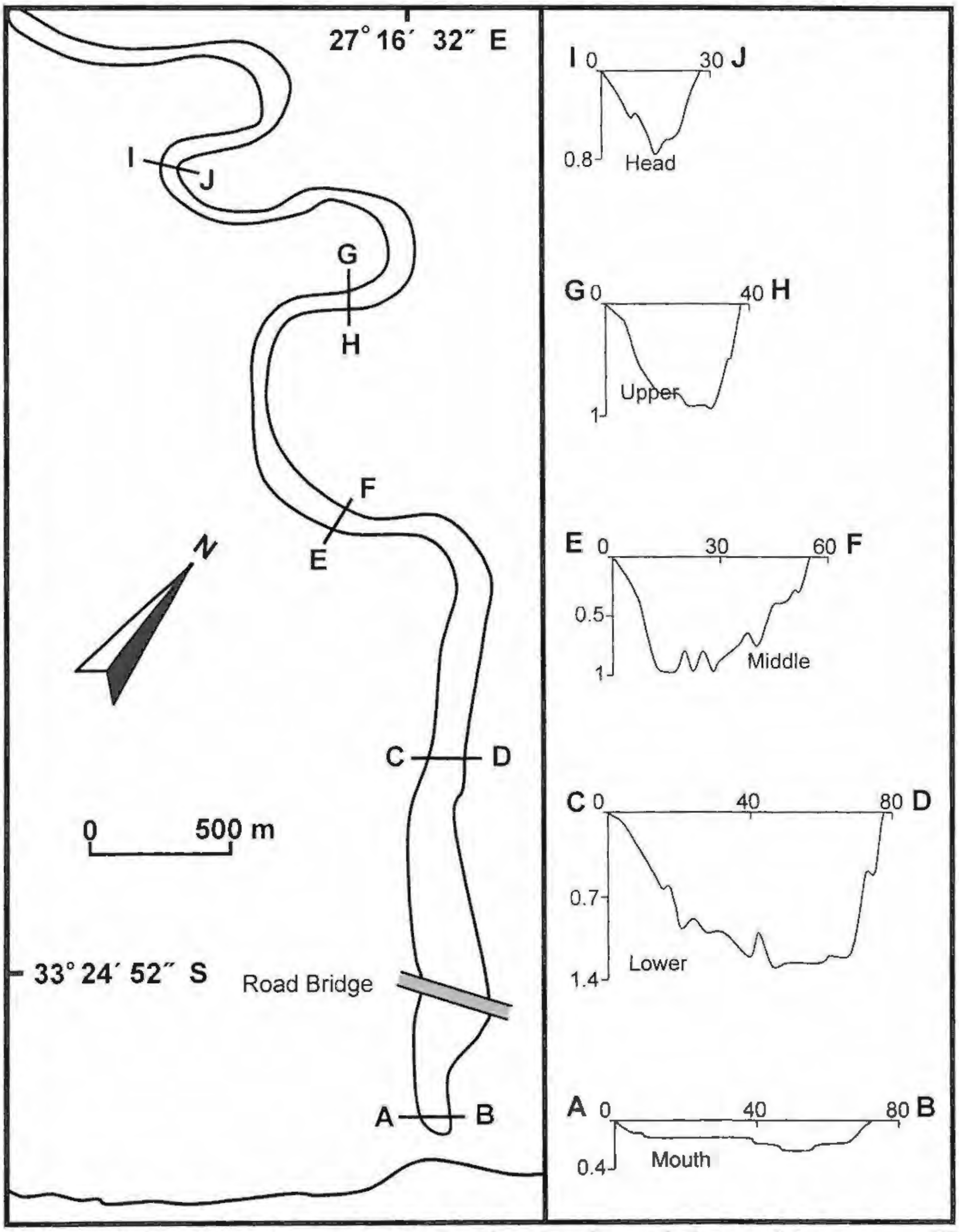


Figure 2.17: The Mgwalana Estuary, showing the size and shape of the system. The cross-sections indicate depths in the various sections of the estuary (drawn from data collected on the 6th of June 1999).

The two seasonal water samples collected in the Mgwalana revealed little temperature variation along the length of the system. This lack of variation is probably a result of the extremely shallow nature of the system, resulting in effective wind mixing of the water layers. The winter temperatures ranged from 14.3°C to 18°C (average = 16.1°C), while the summer temperatures ranged between 25°C and 32°C (average = 28.7°C) (Figure 2.18).

Similarly, the biannual samples yielded very little variability in salinity, particularly during winter when all salinities were 25‰, while during summer they ranged from 28‰ to 31‰. During summer there was a slightly negative salinity gradient, with the mouth having a mean of 28‰ and the head having a higher mean of 31‰ (Figure 2.18).

There was a slight turbidity gradient evident within the system, with turbidities at the head being approximately double those at the mouth during both winter and summer (Figure 2.18). This may be due to wind driven mixing stirring up some of the finer sediments that occur in the upper reaches littoral.

The sediment composition of the Mgwalana Estuary was similar from head to mouth, consisting primarily of fine sands (Figure 2.19). The only site that did not closely follow this trend was the lower reaches site where there was a higher percentage of medium (18.9%) and coarse (6.9%) sands. The percentage organic content in the system followed a decreasing trend from head to mouth, with the head reaches containing 25.6% and the mouth comprising only 1.5% organic content (Figure 2.19). The overall organic content of this system and the Keiskamma was relatively high when compared with the other study estuaries.

The Mgwalana has very low densities of submerged macrophytes with a total area cover of only 1.1 ha (Colloty, 2000). There is a small supratidal salt marsh area (7.6 ha) on the east bank above the coastal road bridge, but the majority of the primary productivity arises from patches of reeds and sedges along the banks of the estuary (total area cover = 48.8 ha).

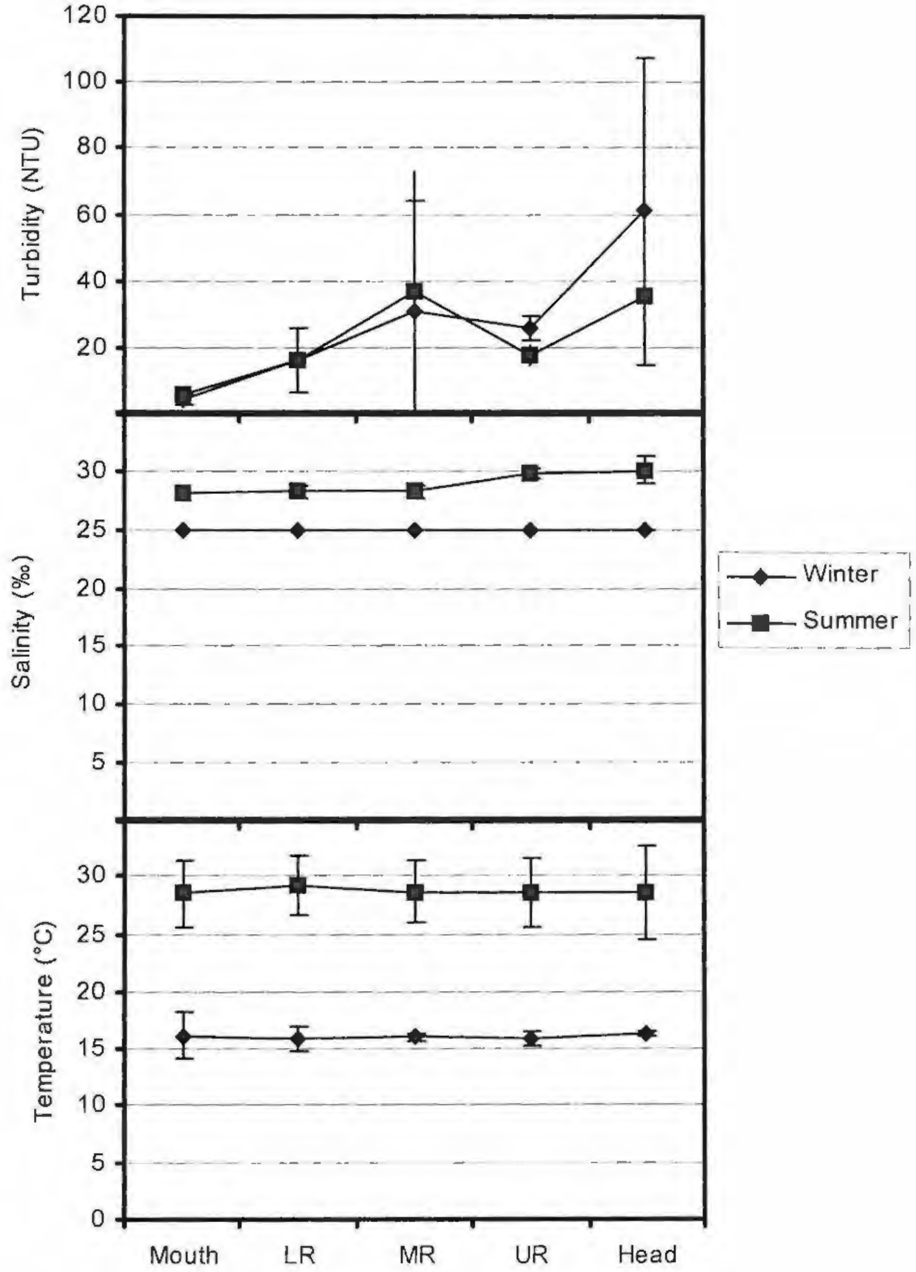


Figure 2.18: Mean (±S.D.) summer/winter temperature, salinity and turbidity measurements for different localities in the Mgwalana Estuary. The mean was determined from morning and midday samples collected in surface and bottom waters on the 6th of June 1999 and the 9th of February 2000.

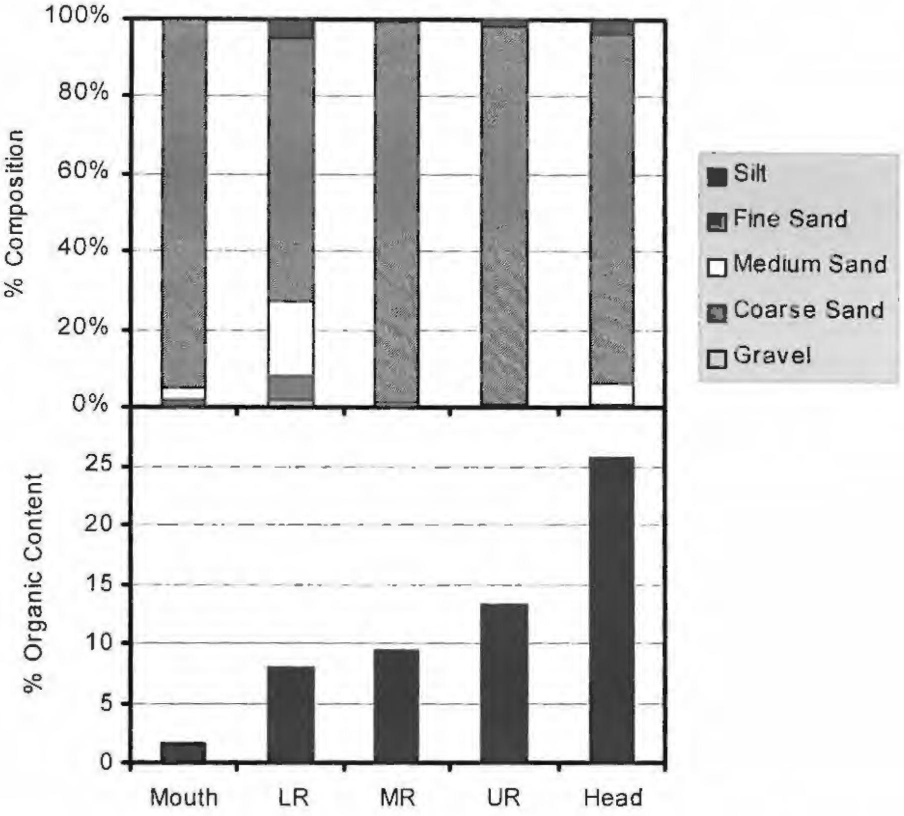


Figure 2.19: Particle size composition and organic content of the sediments in the Mgwalana Estuary (9th of February 2000).

2.8 Bira Estuary

The Bira (Figure 2.20) was the largest of the temporarily open/closed estuaries in this study, with a tidal influence extending 9 km up the estuary and encompassing an estuarine surface area of 122.3 ha. The system has a 255 km^2 catchment area and a MAR of 13.26 x 10^6 m^3/yr.

The estuary enters the sea approximately 40 km south-west of the eastern border of the study area at 33° 22′ 58″ S and 27° 19′ 47″ E. A coastal road bridge crosses the system approximately 600 m from the mouth, with access to the mouth area via a road on the eastern bank. This road comes through a small township that has encroached slightly on the estuary, in the form of retaining walls, along the first 300 m of the eastern bank.

The Bira is a relatively shallow system for its size, with an average depth of 1.2 m, and a maximum of only 2 m. The mouth area has a fairly shallow bay with a short, deep channel (1.8 m) along the east bank, adjacent to the retaining wall. This bay widens (152 m) above the road bridge, before the system narrows again towards the head (40 m). The average cross-sectional area is also relatively low at 80.6 m^2, with only the lower reaches exceeding this average at 188 m^2.

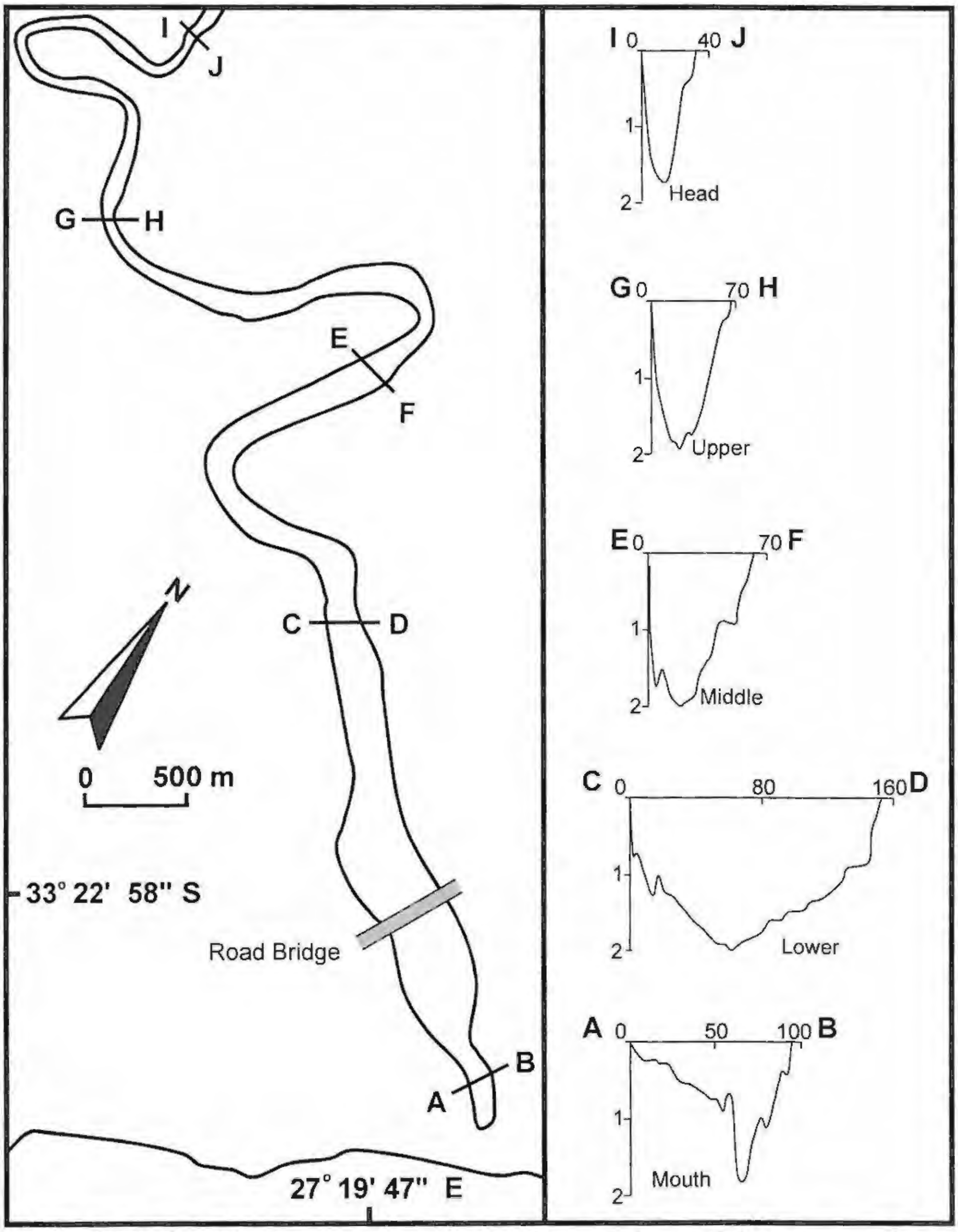


Figure 2.20: The Bira Estuary, showing the size and shape of the system. The cross-sections indicate depths in the various sections of the estuary (drawn from data collected on the 1st of June 1999).

The Bira demonstrated very little longitudinal variability in winter and summer temperatures (Figure 2.21). There was also very little temperature variability with depth, but a large seasonal difference was evident with a winter mean of 13.8°C and a summer mean of 28.3°C.

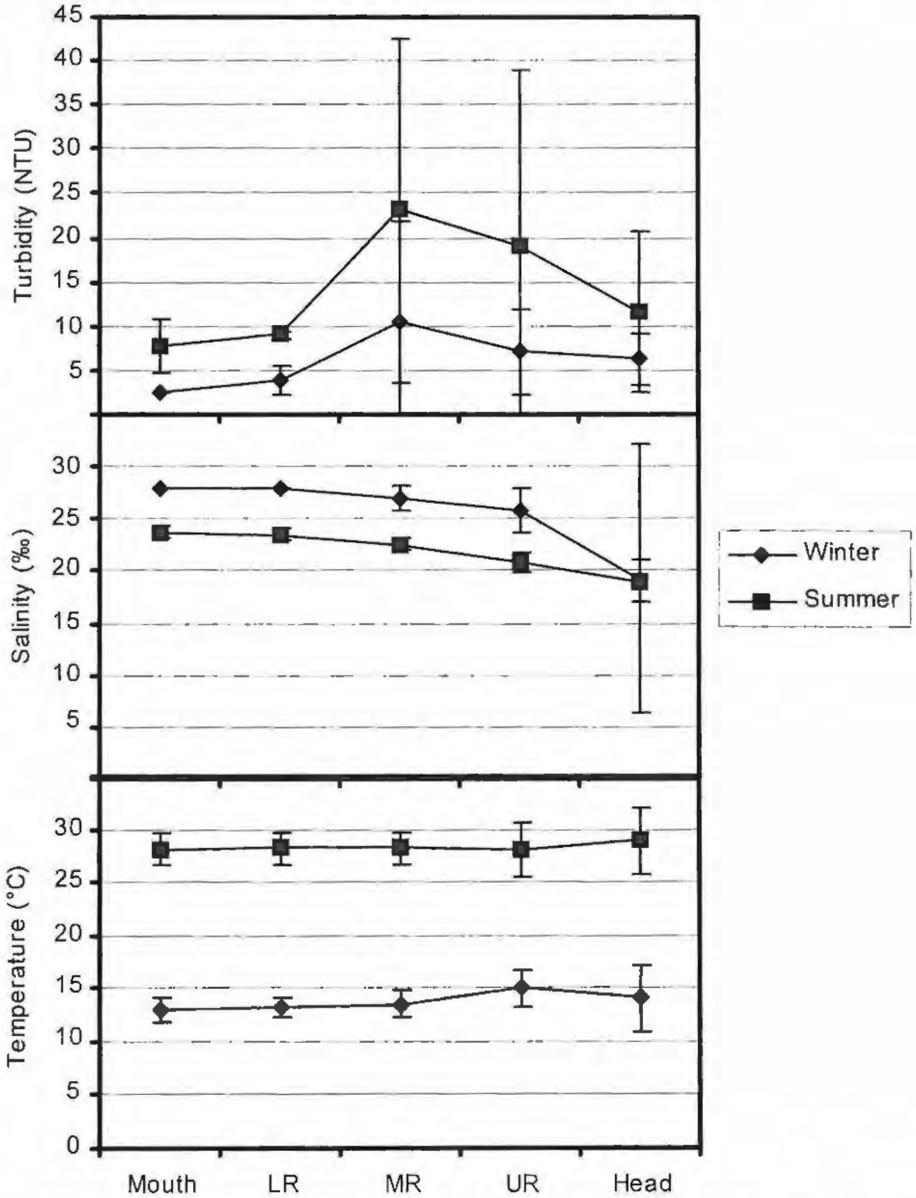


Figure 2.21: Mean (±S.D.) summer/winter temperature, salinity and turbidity measurements for different localities in the Bira Estuary. The mean was determined from morning and midday samples collected in surface and bottom waters on the 1st of June 1999 and the 9th of February 2000.

The variation in salinity in the system was very low, with a winter mean of 25.6‰ and a summer mean of 21.9‰. A small longitudinal distribution was recorded with the salinities between the mouth and head of the estuary (Figure 2.21).

There was a larger variability in turbidity, with a peak in the middle reaches (Figure 2.21) that may be due to outflow from a small tributary entering the estuary in this region. The summer turbidity was higher than winter throughout the system, although during both seasons the longitudinal trends were similar.

The sediments of the Bira Estuary indicate a reduction in large particles and an increase in fine sands from the head to the mouth (Figure 2.22). This sediment distribution pattern arises from the larger particles settling from the water column first as the river water velocity slows down. The percentage organic content of the sediments was relatively low throughout the estuary, with the middle, upper and head reaches having a higher organic content than the lower reaches and mouth region (Figure 2.22).

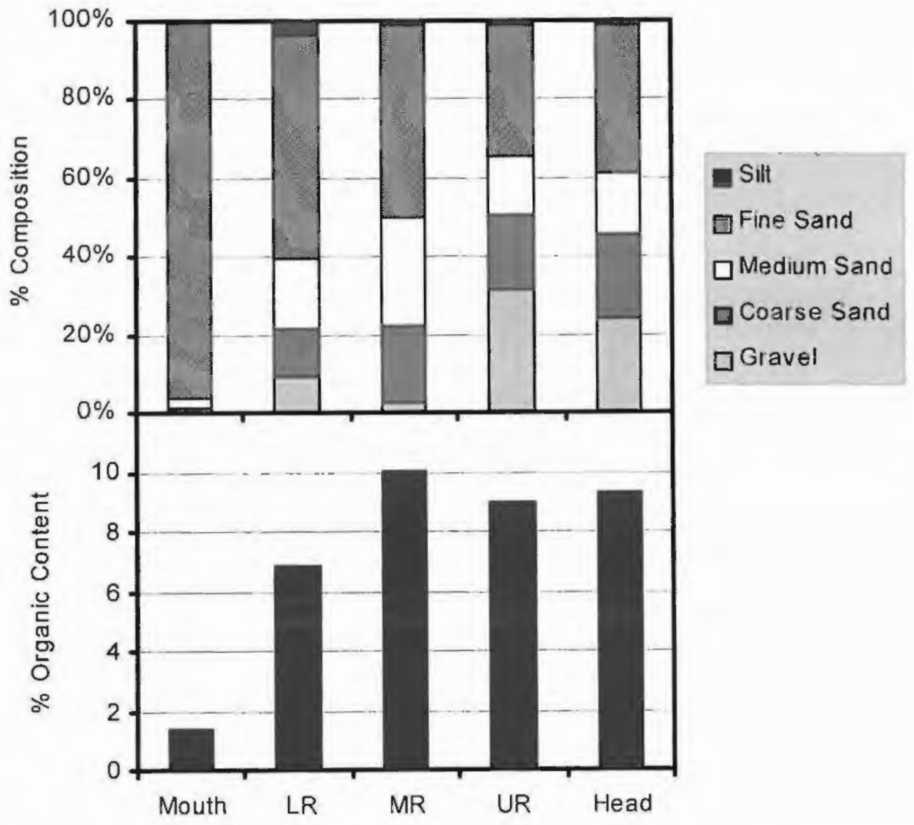


Figure 2.22: Particle size composition and organic content of the sediments in the Bira Estuary (9th of February 2000).

The Bira has limited macrophyte primary producers, with a very small area (2.6 ha) of supratidal salt marsh on the east bank above the road bridge and a total of only 5.3 ha of submerged macrophytes (Colloty, 2000). There are several patches of reeds and sedges up the system (total area = 15.2 ha), although most of these plants occur on the banks in the lower reaches.

2.9 Gqutywa Estuary

The Gqutywa (Figure 2.23) was one of the most pristine systems in this study, with no anthropogenic impacts directly on the estuary. The coastal road does not cross this system as it has moved further inland when it passes the Gqutywa and the only way to access the mouth area is via the beach.

The estuary is a medium sized temporarily open/closed system that enters the sea at 33° 21′ 59″ S and 27° 21′ 34″ E. The MAR of 4.42 x 10^6 m^3/yr arises from a catchment area of 85 km^2 (Smakthin, V., *pers. comm.*). The linear length of the estuary is 3 km encompassing a total estuarine surface area of 39.9 ha.

The Gqutywa has a shallow embayment (average depth = 0.9 m) in the mouth region extending up into the middle reaches with one deep channel (1.9 m) along the east bank. The head and upper regions are slightly deeper on average (average depth = 1.0 m), although the channel is slightly shallower at 1.4 m. The system is fairly narrow in the head and upper reaches (27.5 m and 45 m respectively) but widens in the middle and lower reaches (98 m and 137.5 m) before narrowing near the mouth. The average cross-sectional area is relatively low (62.2 m^2), although the lower reaches has a substantially higher cross-sectional area of 165 m^2.

The bi-annual sampling in the Gqutywa demonstrated very little variability in temperature with depth and distance up the estuary. There was a slight decrease in temperature up the system during winter and a slight increase during summer (Figure 2.24). The mean winter temperature was 17.5°C (range = 15-19.3°C) while the summer mean was 28.6°C (range = 27.4-30.2°C).

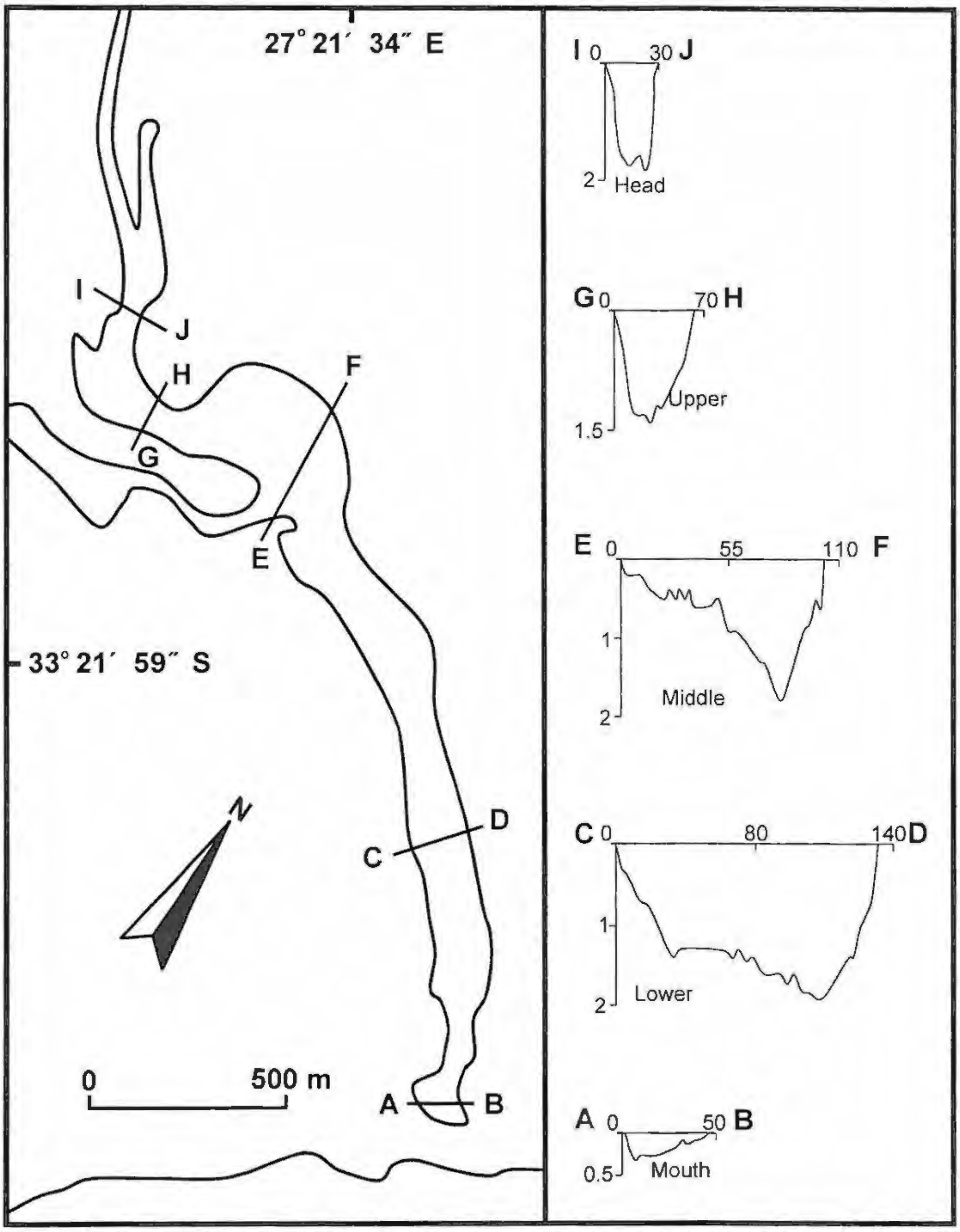


Figure 2.23: The Gqutywa Estuary, showing the size and shape of the system. The cross-sections indicate depths in the various sections of the estuary (drawn from data collected on the 5th of June 1999).

Salinity also revealed very little variability, with only a small seasonal variation (Figure 2.24). The winter salinities ranged from 24-25‰ (mean = 25.0‰), while the summer salinities ranged between 27‰ and 29‰ (mean = 28.1‰).

The summer and winter turbidities showed similar trends, peaking in the upper reaches and decreasing towards the head region (Figure 2.24). Summer turbidities were generally higher than winter, with means of 13.3 NTU and 8.6 NTU respectively.

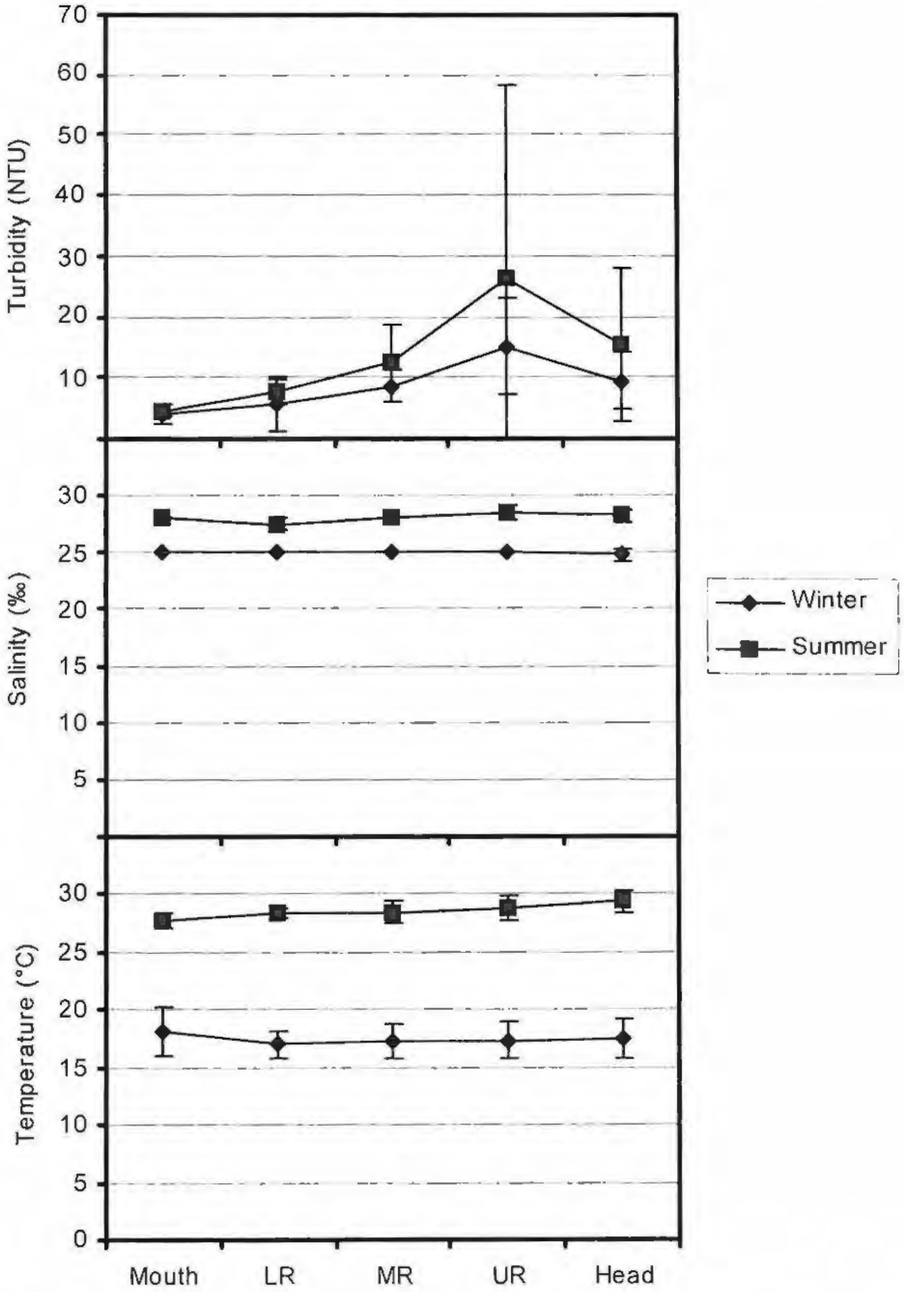


Figure 2.24: Mean (±S.D.) summer/winter temperature, salinity and turbidity measurements for different localities in the Gqutywa Estuary. The mean was determined from morning and midday samples collected in surface and bottom waters on the 5th of June 1999 and the 8th of February 2000.

Sediment particle sizes in the Gqutywa decreased from the head to the lower reaches, with the mouth having slightly larger particles than the lower and middle reaches (Figure 2.25). The organic content of the Gqutywa increased from the head of the system towards the middle reaches and then decreased towards the mouth (Figure 2.25).

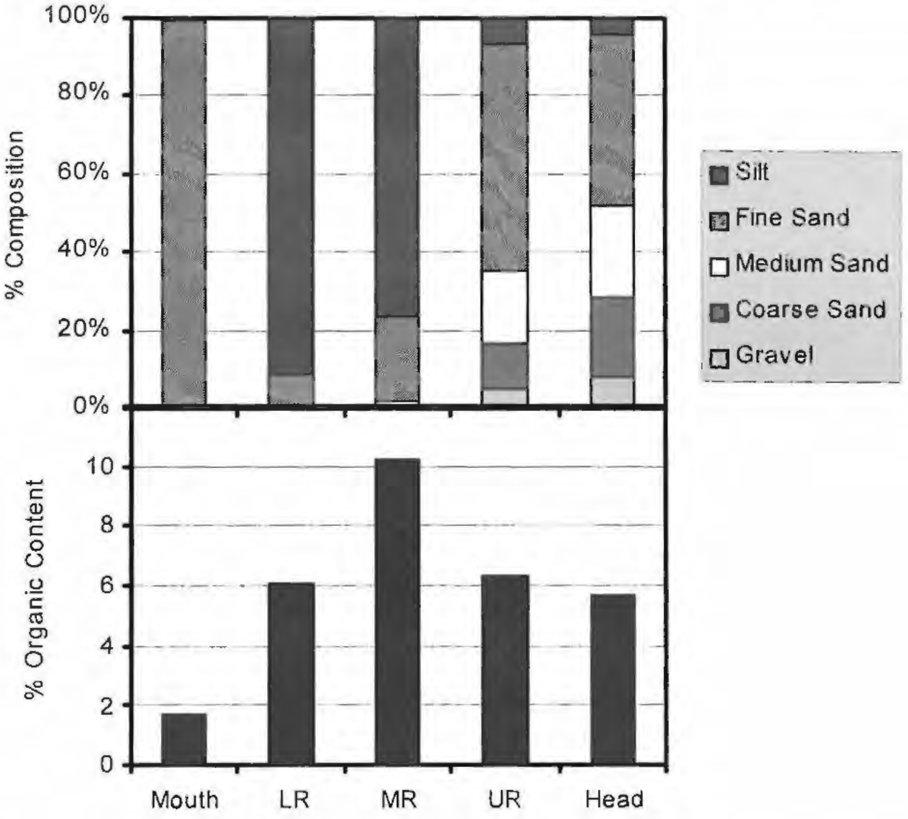


Figure 2.25: Particle size composition and organic content of the sediments in the Gqutywa Estuary (8th of February 2000).

There are very low submerged macrophyte densities in the Gqutywa, with the total area cover of macrophytes being 2.5 ha. In addition there was only a small salt marsh area on the east bank in the middle reaches covering an area of 1.2 ha. There were reed and sedge patches on both banks of the system (total area = 3.8 ha).

2.10 Ngculura Estuary

The Ngculura (Figure 2.26) is a small temporarily open/closed estuary that is in an excellent condition. There are no visible impacts on the estuary with two holiday homes situated 500 m away from the system on the east bank. It is not used for any form of boating due to its small size and no roads have encroached on the channel. The system enters the sea at 33° 21′ 21″ S and 27° 22′ 23″ E approximately 700 m east of the Gqutywa.

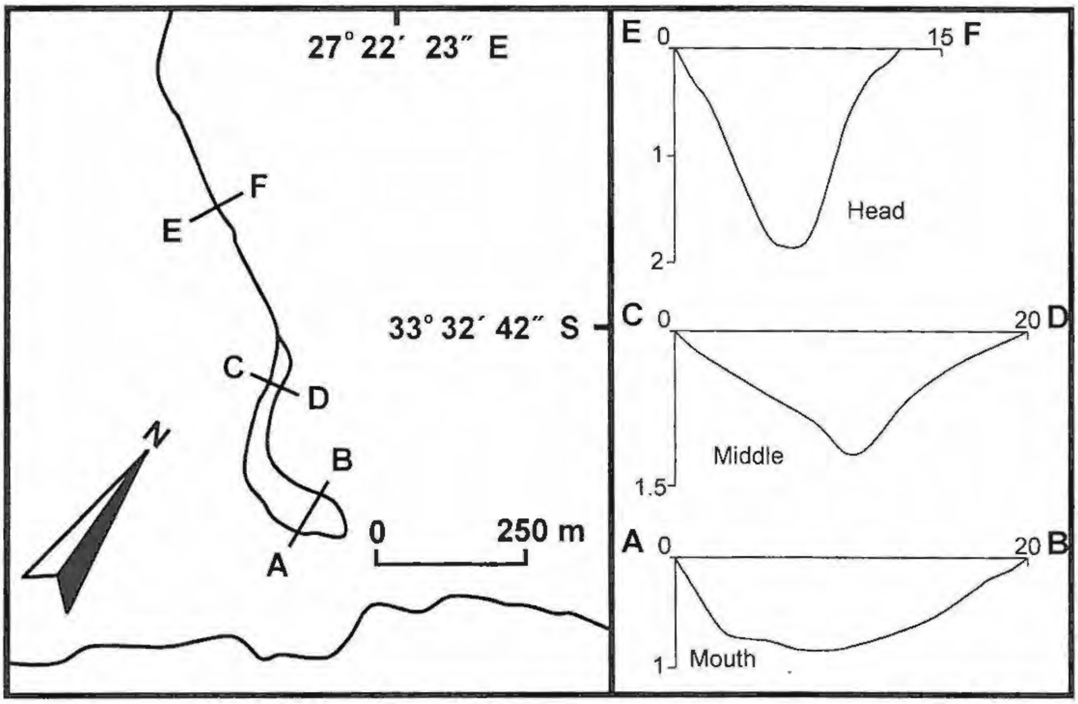


Figure 2.26: The Ngculura Estuary, showing the size and shape of the system. The cross-sections indicate depths in the various sections of the estuary (drawn from data collected on the 5th of June 1999).

The estuary has a small catchment of 15 km^2 that provides a MAR of 0.78 x 10^6 m^3/yr (Smakthin, V., *pers. comm.*). A tidal influence is only evident approximately 600 m up the system resulting in a total estuarine surface area of only 1.6 ha.

The estuary is very narrow (average width = 14 m), the widest point being the mouth area at 20 m, and the narrowest being the head region at 10 m. The estuary is generally shallow (average depth = 0.8 m) with only the upper reaches and head region being deeper at 1.5m and 1.8 m respectively. The average cross-sectional area was 10.9 m^2.

Water temperatures in the Ngculura showed small summer/winter variability, and no longitudinal or depth trends (Figure 2.27). The mean winter temperatures were 16.7°C while the mean summer temperatures were 27.9°C. The low variability may be due to the shallow nature of the system and limited water volume.

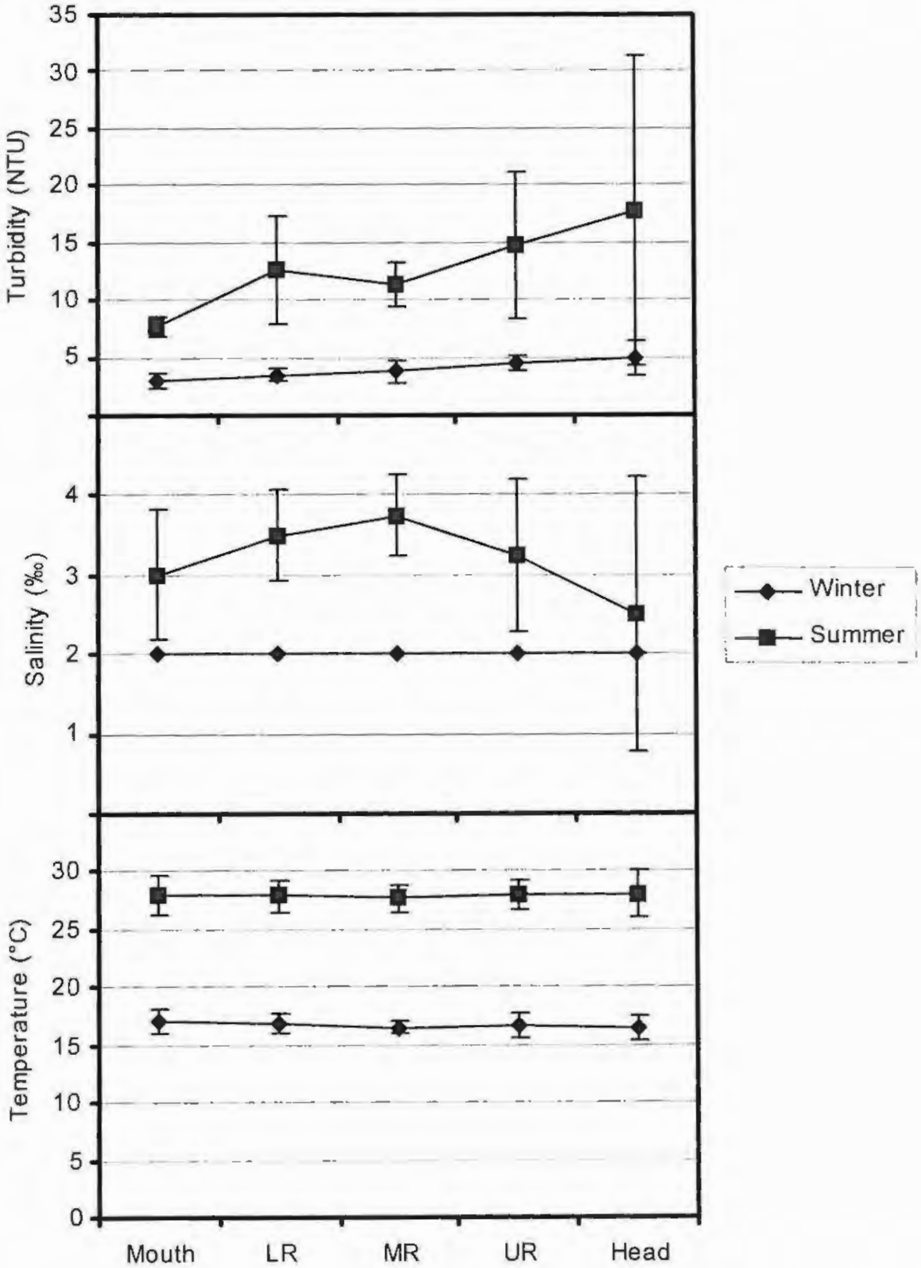


Figure 2.27: Mean (±S.D.) summer/winter temperature, salinity and turbidity measurements for different localities in the Ngculura Estuary. The mean was determined from morning and midday samples collected in surface and bottom waters on the 5th of June 1999 and the 8th of February 2000.

The salinity was very low throughout the system during both seasons, with winter having an average 2‰ and summer 3.2‰ (Figure 2.27). There was almost no longitudinal or depth variability within the system.

The estuary also had very low turbidities during both seasons, with the winter turbidity being lower than summer (means of 3.9 NTU and 12.8 NTU respectively) (Figure 2.27). A slight increase in turbidity gradient from mouth to head was evident during both seasons, although barely detectable during winter.

In the Ngculura, fine sands dominated the sediments in all reaches (Figure 2.28). This arises through most of the estuary being situated in a wind blown dune area of the beach, with only the head and upper reaches extending beyond that into a vegetated dune ridge. The percentage organic content was also extremely low in this system, peaking with a value of 6.9% in the upper reaches (Figure 2.28). This peak coincides with the entrance of the estuary into the vegetated dune area.

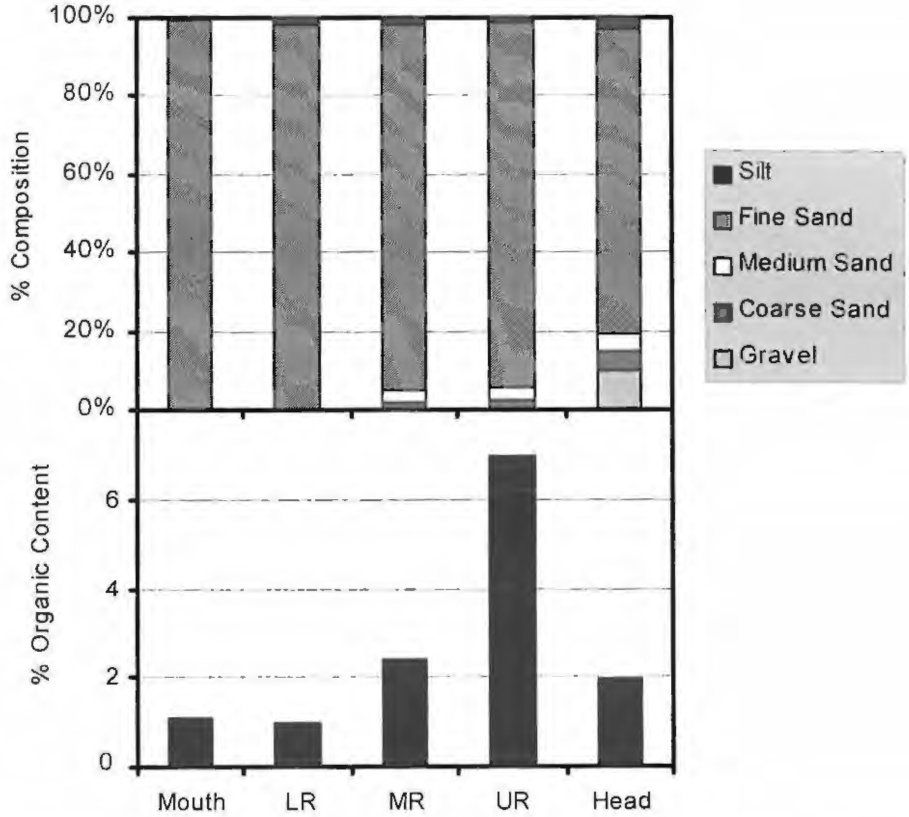


Figure 2.28: Particle size composition and organic content of the sediments in the Ngculura Estuary (8th of February 2000).

The system has very low macrophyte densities, with no submerged macrophyte beds or salt marsh areas (Colloty, 2000). The only plants present in the system are reeds and sedges, with a relatively large patch near the mouth and a few very small areas further upstream (total area cover = 0.7 ha) (Colloty, 2000).

2.11 Keiskamma Estuary

The Keiskamma (Figure 2.29) is a large, permanently open estuary, with the mouth situated at 33° 16′ 45″ S and 27° 29′ 50″ E. This system represented the eastern boundary of the study area with the small town of Hamburg lying on its western bank.

The Keiskamma has a large catchment (2745 km^2) with a MAR of 142.7 x 10^6 m^3/yr (Smakthin, V., *pers. comm.*). The linear length of the estuary is approximately 12 km, encompassing a total estuarine area of 197 ha.

The estuary has a wide, embayment near the mouth with depths ranging from 0.5 m to 2 m. The main estuary channel has a minimum 1.6 m depth, attaining a maximum of 2.7 m in the upper reaches. The average depth is 1.35 m with the middle and lower reaches having relatively shallow banks on either side of the main channel, while the upper reaches and head of the system have sharp slopes from the bank into the main channel. The average cross-sectional area is 116 m^2 and the average width is 86.5 m with a minimum of 30 m in the upper reaches and a maximum of 172.5 m near the mouth.

There was little longitudinal variability in winter water temperatures (Figure 2.30), with a mean of 17.6°C and a recorded range of 15.5°C to 19°C. Summer temperatures increased with distance up the estuary from a mean of 21.3°C at the mouth to 27°C at the head of the system (Figure 2.30). Summer temperatures ranged from 16°C to 28°C. Read (1983) recorded an identical maximum temperature, although the minimum recorded was lower (12°C) than during this study.

Longitudinal salinity trends during both winter and summer decreased rapidly from the mouth (31‰ and 31.8‰ respectively) to the head (6.3‰ and 0‰ respectively) thus indicating a perennial fresh water input together with open mouth conditions

(Figure 2.30). The lowest salinity recorded by Read (1983) was also 0‰. The average salinities during winter and summer were 19.5‰ and 11.8‰ respectively.

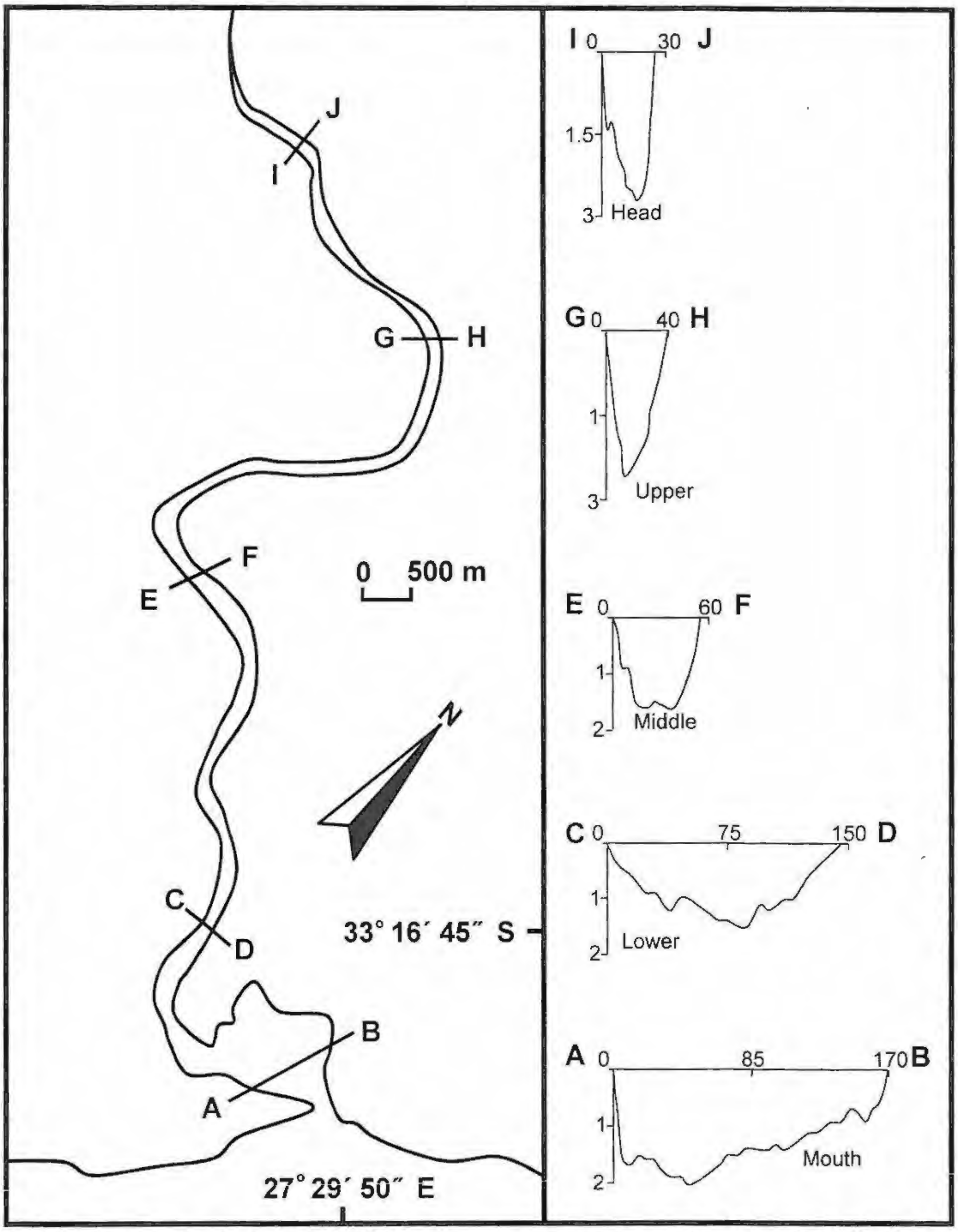


Figure 2.29: The Keiskamma Estuary, showing the size and shape of the system. The cross-sections indicate depths in the various sections of the estuary (drawn from data collected on the 4th of June 1999).

No longitudinal turbidity trends were evident during winter, although during summer the turbidity increased with distance up the estuary, peaking in the upper reaches

(Figure 2.30). The summer turbidities were generally higher than the winter turbidities with a mean of 74.8 NTU during summer and 15.5 NTU during winter.

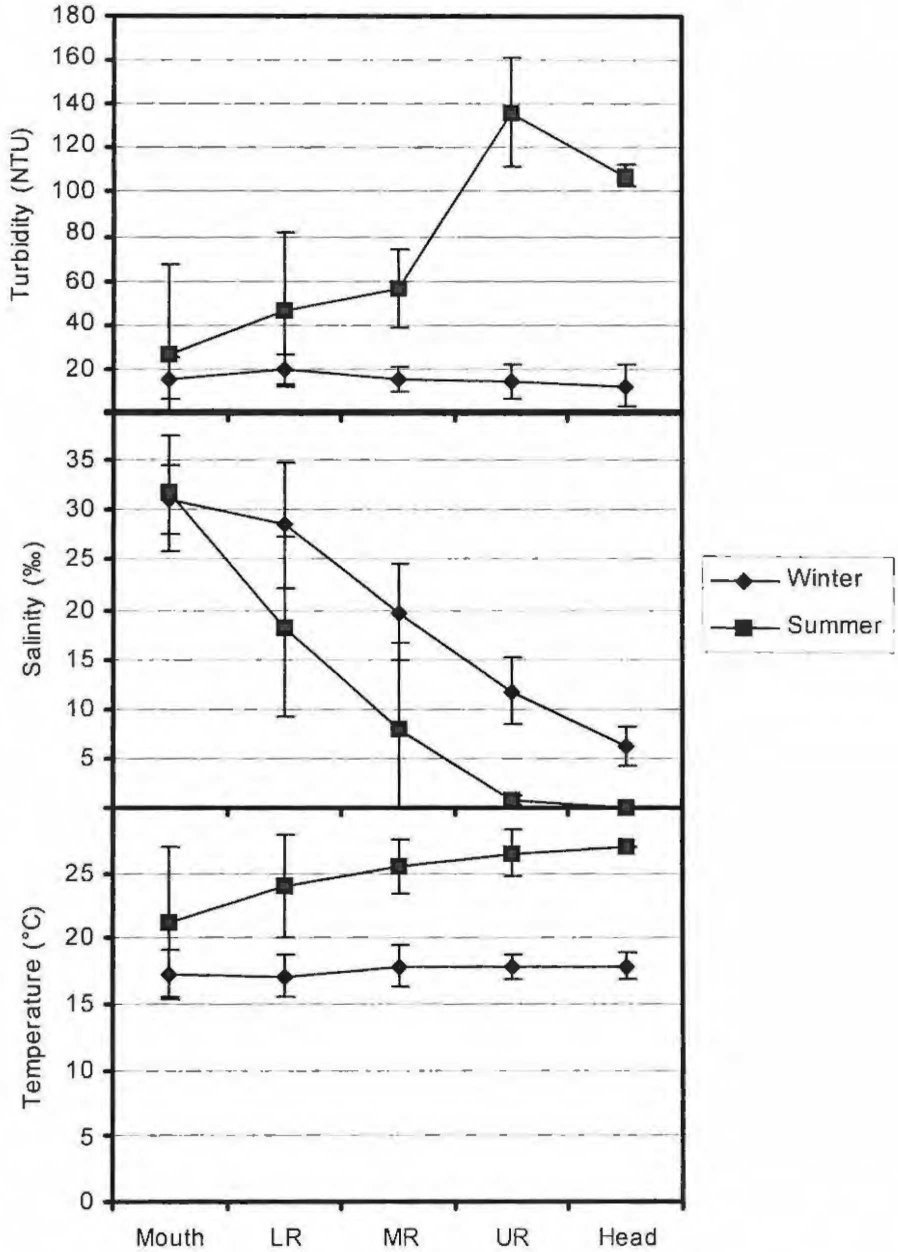


Figure 2.30: Mean (±S.D.) summer/winter temperature, salinity and turbidity measurements for different localities in the Keiskamma Estuary. The mean was determined from morning and midday samples collected in surface and bottom waters on the 4th of June 1999 and the 11th of February 2000.

Sediment composition in the Keiskamma Estuary did not reveal any distinct trends (Figure 2.31). The middle reach samples were dominated by silt, and the mouth region by fine-grained sands. Similarly the percentage organic content of the sediments did not show any general trends, with a peak of 27.4% in the upper reaches, a minimum of 1.7% at the mouth, and the other samples containing between 10% and 15% organics (Figure 2.31).

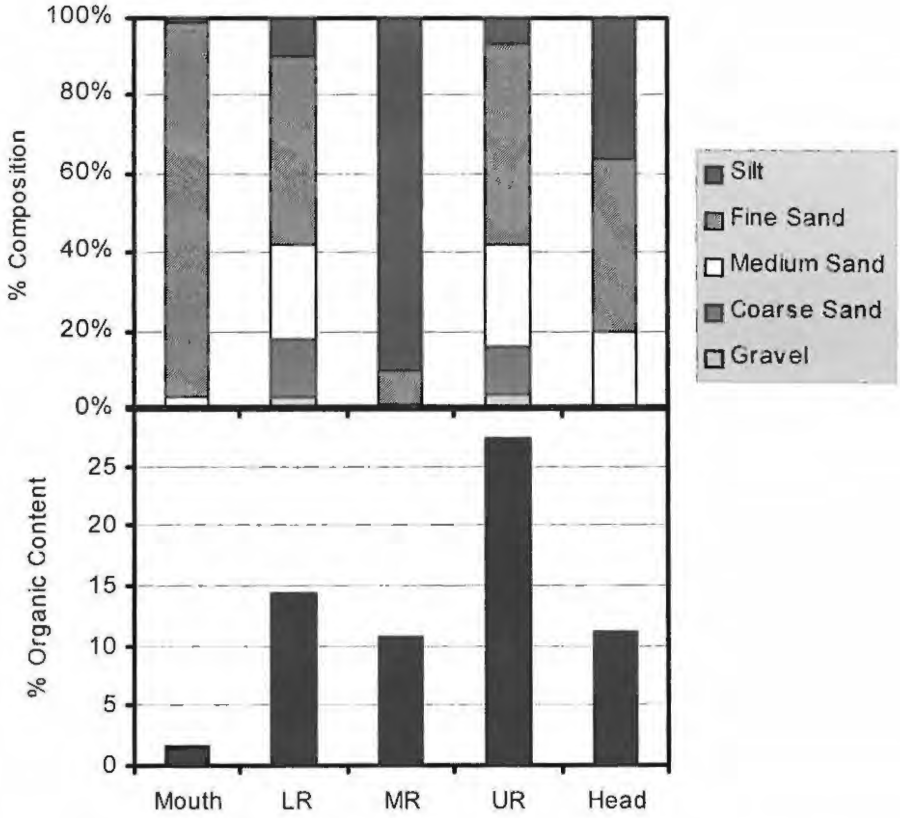


Figure 2.31: Particle size composition and organic content of the sediments in the Keiskamma Estuary (9th of February 2000).

The macrophyte vegetation of the estuary comprises mainly salt marsh, reed and sedge species, which together cover approximately 112 hectares (Colloty, 2000). In addition there are relatively small stands of submerged macrophytes (total area = 11 ha).

CHAPTER 3

SPECIES COMPOSITION, RICHNESS, DIVERSITY AND LONGITUDINAL DISTRIBUTION

3.1 Introduction

Little to no published information is available on the ichthyofauna associated with most Eastern Cape estuaries. However, the fishes of two estuaries under investigation in this study, namely the East Kleinemonde (Cowley, 1998) and Great Fish (Ter Morshuizen, 1996; Ter Morshuizen *et al.*, 1996a; Ter Morshuizen *et al.*, 1996b; Whitfield *et al.*, 1994), have been previously studied. Additional research on selected fish species (Griffiths, 1997; Jubb, 1978) or the influence of inter-basin transfers (Laurenson and Hocutt, 1984; Laurenson and Hocutt, 1986; Laurenson *et al.*, 1989) has been conducted in the Great Fish Estuary. The general lack of baseline information emphasizes the need to document and interpret the community structure and diversity of fishes in each of these estuaries.

The numbers of individuals and species in samples may be reflected by indices of richness and diversity. These indices facilitate comparisons between samples as they eliminate variables such as sample size (Clarke and Warwick, 1994). The indices are less informative than an examination of the samples on a per species basis (Clarke and Warwick, 1994), but are still commonly used to compare different fish communities (Costa *et al.*, 1994; Harrison and Whitfield, 1995). The data presented in this chapter aim to compare the species composition, diversity and richness, as determined from seine and gill net catches within the 10 study estuaries. Any correlations between these data and any variables will also be presented.

The longitudinal distribution of species within an estuary is indicative of the niche occupied by each species as well as the differing physico-chemical conditions along an estuary. These conditions may determine the localities in which species will be caught and the extent to which they contribute to the catch in a certain reach of the estuary. In this chapter, a comparison of the fish communities in different reaches of the estuaries will be presented.

3.2 Materials and Methods

3.2.1 Ichthyofaunal sampling

The ichthyofauna of the different estuaries was sampled bi-annually, during June or July (winter) and January or February (summer), on a single day or two consecutive days (Table 3.1). A range of gear types, including a small and large seine net and a fleet of gill nets were used. Different gear types targeted specific groups and/or size ranges of fishes (Table 3.2). Fish were identified using Smith and Heemstra (1986) and van der Elst and Wallace (1976). The fish were then assigned to an estuarine dependence category according to the definitions in Table 3.3.

Table 3.1: Dates on which ichthyofaunal sampling was conducted in each of the study estuaries, except the East Kleinemonde which was sampled every year during both seasons.

Estuary	Winter Dates	Summer Dates
Klein Palmiet	15 June 1999	1 February 2000
Great Fish	16/17 June 1999	31 January/1 February 2000
Mpekweni	10/12 June 1996	28/29 January 1997
Mtati	1/2 June 1998	26/27 January 1999
Mgwalana	10/12 June 1997	17/18 February 1998
Bira	14/15 June 1999	26/27 January 2000
Gqutywa	11/30 June 1997	17/18 February 1998
Ngculura	3 June 1998	25/26 January 1999
Keiskamma	26/27 June 1996	4/6 February 1997

The large mesh seine net (50 m x 2 m with a 3 cm stretch mesh in the wings and 1 cm stretch mesh in the bag) targeted the marine spawning and freshwater species, excluding the smaller size classes (< 40 mm SL). Netting was carried out during daylight hours at a variable number of sites in each estuary depending on the size of the system and the catch rate of new species (Table 3.4). In each estuary all possible littoral habitats were sampled, with the sites being restricted to areas without submerged obstructions. The net was laid in a semi-circle from the bank by motorised boat and hauled in by three or four people, ensuring the lead line was dragged along the bottom. The area sampled on each haul varied between 500 m^2 and 550 m^2 depending on the width of the system. All fish captured were identified and measured to the nearest millimetre standard length (SL) and returned to the water.

Table 3.2: The target groups and size classes (mm standard length) of the different gear types.

Gear Type	Stretch Mesh Size	Target Group	Target Size Classes
Small mesh seine (30 m x 2 m)	1 cm	Estuarine-spawning species	All size classes excluding small individuals (<10 mm SL)
Large mesh seine (50 m x 2 m)	3 cm	Marine-spawning and freshwater species	All size classes excluding small individuals (< 40 mm SL)
Gill nets (10 m x 2 m)	45, 75 and 100 mm	Marine-spawning and freshwater species	Larger individuals (> 100 mm SL)

Table 3.3: The major categories of fishes that utilise southern African estuaries, after Whitfield (1998).

Categories	Description of Category
I	Estuarine species which breed in southern African estuaries. Further subdivided into: Ia. Resident species which have not been recorded spawning in marine or freshwater environments. Ib. Resident species which also have marine or freshwater breeding populations.
II	Euryhaline marine species which usually breed at sea with juveniles showing varying degrees of dependence on southern African estuaries. Further subdivided into: IIa. Juveniles dependent on estuaries as nursery areas. IIb. Juveniles occur mainly in estuaries, but are 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. This category includes some species which may breed in both freshwater and estuarine systems.
V	Catadromous species which use estuaries as transit routes between the marine and freshwater environments but may also occupy estuaries in certain regions. Further subdivided into: Va. Obligate catadromous species requiring a freshwater phase in their development. Vb. Facultative catadromous species not requiring a freshwater phase in their development.

The small mesh seine net (30 m x 2 m, with a 1 cm stretch mesh in the wings and bag) targeted estuarine spawning species. It was used to capture marine spawning species in the small Ngculura Estuary where the large seine could not be deployed. The sampling protocol was identical to that used with the large seine except that due to the large numbers of individuals, the fish captured in this net were preserved in formalin and returned to the laboratory where identification and measurements (mm standard length) were conducted. The swept area of each sample was approximately 100 m^2.

Monofilament gill nets were used to sample larger individuals of both marine spawning and freshwater species, as they are known to actively avoid seine nets (Cowley, 1998). The nets were 10 m in length and 2 m in depth consisting of three equal length sections of 45 mm, 75 mm and 100 mm stretch meshes. Generally two nets were used in each reach (upper, middle and lower) of an estuary, although this was changed depending on the size of the system (see Table 3.4). No gill nets were set in the smaller systems. The nets were deployed in the evening (at approximately 18h00) and lifted the following morning (at approximately 06h00). All fish captured were identified and measured to the nearest millimetre standard length.

The otter trawl data and sampling techniques are not presented here as they were only conducted in five estuaries thus precluding a comparison between all systems (see Chapter 6 for this section).

Table 3.4: The number of times each net type was deployed per season in each estuary.

Estuary	Large Seine Net		Small Seine Net		Gill Net	
	Winter	Summer	Winter	Summer	Winter	Summer
East Kleinemonde	8,6,4,7	7,6,4,9	6,4,3,6	7,4,5,6	6	6
Klein Palmiet	0	0	1	1	0	0
Great Fish	8	8	12	8	6	6
Mpekweni	9	8	9	5	12	6
Mtati	10	8	9	9	6	6
Mgwalana	13	7	10	5	6	6
Bira	12	10	9	6	6	6
Gqutywa	4	4	4	3	6	6

3.2.2 Indices and analysis

The richness and diversity of the fish communities in each system were expressed using Margalefs richness index and the Shannon-Wiener diversity index respectively. Margalefs richness index (Equation 1) calculates the number of species relative to the number of individuals in the sample, which reduces sample size bias (Clarke and Warwick, 1994).

$$d = (S-1)/ \log N \qquad \text{(Eq. 1)}$$

Where: d is Margalefs index, S is the number of species and N is the number of individuals (Clarke and Warwick, 1994).

The Shannon-Wiener diversity index (Equation 2) incorporates equitability in its calculation (Zar, 1996). This gives a better assessment of composition diversity, as it indicates whether a community is dominated by a few species.

$$H' = - \Sigma_i p_i (\log p_i) \qquad \text{(Eq. 2)}$$

Where: H' is the resultant diversity, i is the sample number and p_i is the proportion of the total count represented by the ith species (Clarke and Warwick, 1994).

The rank correlation between these indices and the catchment size, mean annual run-off (MAR), estuarine area and linear length were tested using a Spearman Rank Correlation (run using Microsoft Excel, p-values determined from Zar, 1996).

Longitudinal distributions were investigated using non-parametric multivariate analysis (Clarke and Ainsworth, 1993; Clarke and Warwick, 1994) from the Primer Package (Version 4.0, Plymouth Marine Laboratory). The raw data consisted of catch per unit effort (CPUE) for each species at each sampling site, which was then grouped by estuarine reach and averaged either per season or by combining the seasons. These data were standardised and root-root transformed, producing a Bray-Curtis similarity matrix. The clusters were produced using a group average hierarchical sorting strategy. The relationships between the estuarine reaches, based on their fish communities, were examined using dendograms and non-metric multidimensional scaling (MDS). Analysis of similarity (ANOSIM) was carried out to determine if the reaches were significantly different. Where significant differences were found the SIMPER routine (from the PRIMER Package) determined the relative contribution of individual fish species to differences between reaches. A non-parametric Kruskal-Wallis one-way ANOVA (Analysis of Variance) was used to test for differences in densities from both the small and large seines between the different reaches of the estuaries.

3.3 Results

3.3.1 Relative abundance of species

A total of 75533 fish representing 57 species were captured using three gear types in all the estuaries during the study. Seasonal catches combining all the gear types for all the estuaries were similar, with summer and winter totals of 38211 individuals comprising 48 species and 37322 individuals of 47 species respectively (Table 3.5).

Table 3.5: Numbers of individuals and species caught seasonally and overall by each gear type.

Gear type	Number of individuals			Number of species		
	Summer	Winter	Combined seasons	Summer	Winter	Combined seasons
Small seine	30292	31181	61473	8	13	14
Large seine	7311	5535	12846	35	30	42
Gill net	608	606	1214	20	20	23
Total	38211	37322	75533	48	47	57

The number of species in each system ranged from a minimum of eight in the Ngculura to a maximum of 30 in the Keiskamma and Great Fish estuaries (Table 3.6). Thirty-nine species occurred during both summer and winter, with only 15 species being restricted to either season, and these were generally the species that were poorly represented. The numerical contribution of each species to the total catch was similar within both the permanently open and closed estuaries (Table 3.6, Appendix I – III for gill net and small and large seine nets).

Table 3.6: The percentage contribution by number of each species caught by seine and gill nets in the 10 study estuaries (percentage contributions of each species in various estuaries for individual gear types are given in Appendices I, II and III).

Family	Species	Common Name	Bira*	East Kleinemonde*	Gqutywa*	Great Fish**	Keiskamma**	Klein Palmiet*	Mgwalana*	Mpekweni*	Mtati*	Ngculura*
Ambassidae	*Ambassis natalensis*	Slender glassy				0.4						
Anguillidae	*Anguilla mossambica*	Longfin eel				0.1						
Ariidae	*Galeichthys feliceps*	White seacatfish				0.1	1.3		<0.1			
Atherinidae	*Atherina breviceps*	Cape silverside	42.0	38.8	79.3	0.2	1.3	56.5	18.5	14.6	43.3	16.1
Carangidae	*Caranx sexfasciatus*	Bigeye kingfish				0.5	0.1		<0.1	<0.1		
	Lichia amia	Leervis		<0.1	0.1		0.3		<0.1	<0.1	<0.1	
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	0.4	1.5	<0.1	0.3			2.3	0.8	0.1	0.6
Clariidae	*Clarius gariepinus*	Sharptooth catfish				0.2						
Clinidae	*Clinus superciliosus*	Super klipfish					<0.1					
	Fucomimus mus	Mousey klipfish					<0.1					
Clupeidae	*Gilchristella aestuaria*	Estuarine roundherring	21.6	31.3	7.2	47.0	65.7	29.7	54.0	71.8	41.5	7.8
Cyprinidae	*Barbus aeneus*	Smallmouth yellowfish				0.2						
	Cyprinus carpio	Carp				0.1						
Elopidae	*Elops machnata*	Ladyfish	0.2				0.1		<0.1	<0.1	0.5	
Gerreidae	*Gerres acinaces*	Smallscale pursemouth			<0.1							
Gobiidae	*Caffrogobius gilchristi*	Prison goby				0.7	3.0					
	Caffrogobius natalensis	Baldy	<0.1									
	Caffrogobius nudiceps	Barehead goby	0.3				2.6		0.2			
	Glossogobius callidus	River goby	10.2	10.6	2.6	0.3	<0.1	8.7	4.3	2.2	1.7	10.7
	Oligolepis acutipennis	Sharptail goby				<0.1						
	Oligolepis keiensis	Speartail goby					0.1					
	Psammogobius knysnaensis	Speckled sandgoby	0.2	<0.1	0.2	2.6	0.8		<0.1	<0.1	<0.1	<0.1
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	0.4	0.2	0.3	4.0	3.6		1.6	0.1	0.2	

Table 3.6: continued…

Family	Species	Common Name	Bira*	East Kleinemonde*	Gqutywa*	Great Fish**	Keiskamma**	Klein Palmiet*	Mgwalana*	Mpekweni*	Mtati*	Ngculura*
Haemulidae	*Pomadasys olivaceum*	Piggy	0.1		0.3				<0.1			
Hemiramphidae	*Hemiramphus far*	Spotted halfbeak							<0.1			
	Hyporhamphus capensis	Cape halfbeak	<0.1							<0.1	<0.1	
Monodactylidae	*Monodactylus falciformis*	Oval moony	0.8	2.1	<0.1			0.2	0.2	0.7	0.5	0.9
Mugilidae	Juvenile Mugilidae	Juvenile mullet		0.7		0.2						
	Liza dumerilii	Groovy mullet	2.3	1.0	0.4	2.2	2.5		1.3	0.8	2.6	0.2
	Liza macrolepis	Largescale mullet	<0.1									
	Liza richardsonii	Southern mullet	1.9	1.3	1.0	19.1	5.5	0.9	1.2	0.2	2.2	21.4
	Liza tricuspidens	Striped mullet	<0.1	0.1	0.2	0.4	1.0		<0.1	0.2	<0.1	0.3
	Mugil cephalus	Flathead mullet	1.2	0.9	0.2	5.7	2.0	0.3	0.4	0.3	<0.1	2.3
	Myxus capensis	Freshwater mullet	0.5	3.6	<0.1	0.4	1.8		0.5	0.5	1.5	15.0
	Valamugil buchanani	Bluetail mullet					<0.1				<0.1	
	Valamugil cunnesius	Longarm mullet	0.2		<0.1	0.4					<0.1	
Notocheiridae	*Iso natalensis*	Surf sprite					0.3					
Pomatomidae	*Pomatomus saltatrix*	Elf	<0.1		0.9				<0.1	<0.1		
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	0.2		0.1	1.3	3.4		0.4	0.1	0.2	
	Johnius dorsalis	Small kob					<0.1					
Serranidae	*Epinephelus andersoni*	Catface rockcod					<0.1					
Soleidae	*Heteromycteris capensis*	Cape sole		<0.1	0.4	1.0	<0.1		<0.1	<0.1	<0.1	<0.1
	Solea bleekeri	Blackhand sole	<0.1	<0.1	0.5	6.8	0.7		0.3	0.2	<0.1	
Sparidae	*Acanthopagrus berda*	Estuarine bream	<0.1			0.2	0.1			0.1		
	Diplodus cervinus	Zebra	<0.1									
	Diplodus sargus	Blacktail	<0.1									
	Lithognathus lithognathus	White steenbras		1.8	0.4	2.0	<0.1	2.2	0.2	0.3	0.1	0.1
	Rhabdosargus globiceps	White stumpnose	<0.1		<0.1							

Table 3.6: continued…

Family	Species	Common Name	Bira*	East Kleinemonde*	Gqutywa*	Great Fish**	Keiskamma**	Klein Palmiet*	Mgwalana*	Mpekweni*	Mtati*	Ngculura*
Sparidae	*Rhabdosargus holubi*	Cape stumpnose	17.2	6.0	5.7	3.3	3.4	1.6	14.3	7.0	5.4	24.4
	Rhabdosargus sarba	Tropical stumpnose							<0.1	<0.1		
	Rhabdosargus thorpei	Bigeye stumpnose							<0.1			
	Sarpa salpa	Strepie	<0.1									
Syngnathidae	*Syngnathus acus*	Longsnout pipefish		<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	
	Syngnathus watermeyeri	Estuarine pipefish		0.1								
Teraponidae	*Terapon jarbua*	Thornfish			<0.1				<0.1		<0.1	
Tetraodontidae	*Amblyrhynchotes honckenii*	Evileye puffer				0.3						
Torpedinidae	*Torpedo fuscomaculata*	Blackspotted electric ray	<0.1									
		Total Individuals	10448	5615	7962	1257	2952	1534	10891	19768	12729	2377
		Total Species	29	20	25	30	30	8	29	25	24	14

* = intermittently open estuary; ** = permanently open estuary

3.3.2 Life cycle categories

The permanently open estuaries had more marine and freshwater species than the closed systems (Figure 3.1, individual systems in Appendix IV and V), however the latter demonstrate a higher number of marine species dependent on estuaries (category IIa). Neither the permanently open or intermittently closed estuaries conformed to the general trends in numbers of species from southern African systems. The estuaries demonstrate a decrease in number of species from class IIa to III compared with an increase across these classes in the southern African data (Figure 3.1).

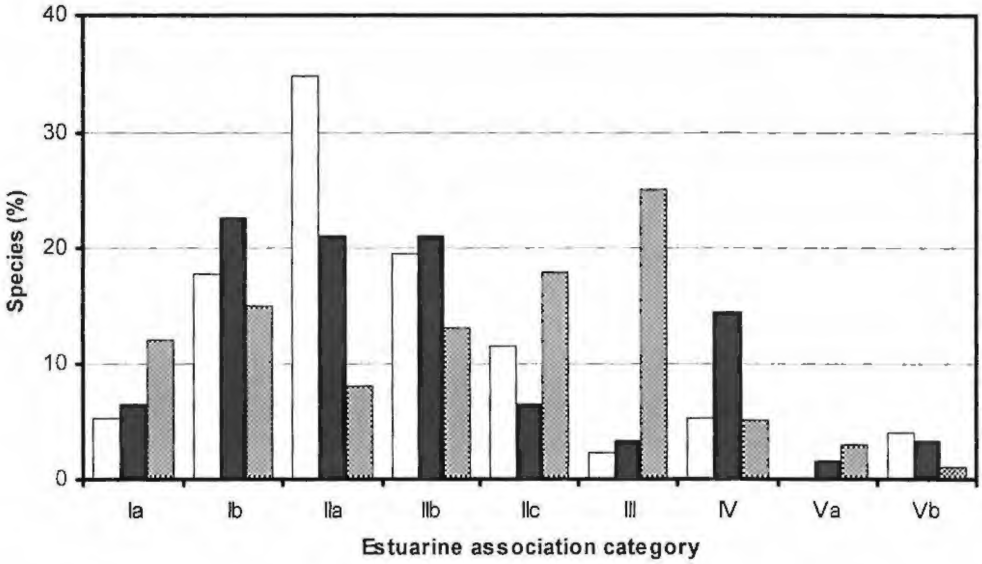


Figure 3.1: The percentage of species in each estuarine association category for closed estuaries in this study (open bars), open systems in this study (dark bars) and southern African estuaries in general (stippled bars). The southern African data were obtained from Whitfield (1998).

The abundance of the different estuarine dependence categories illustrate different results from the number of species in each category. The estuarine resident species were dominant in all the systems except the small-closed Ngculura Estuary (Figure 3.2). The increased abundance of marine migrants in this system was due to the proportional increase in *Rhabdosargus holubi* and *Liza richardsonii*, with *Myxus capensis*, a catadromous migrant, contributing a similarly large proportion of the catch. The permanently open estuaries had a greater abundance of marine migrant species compared with the closed systems, although the large intermittent Bira Estuary had equivalent proportions of marine migrants (Figure 3.2).

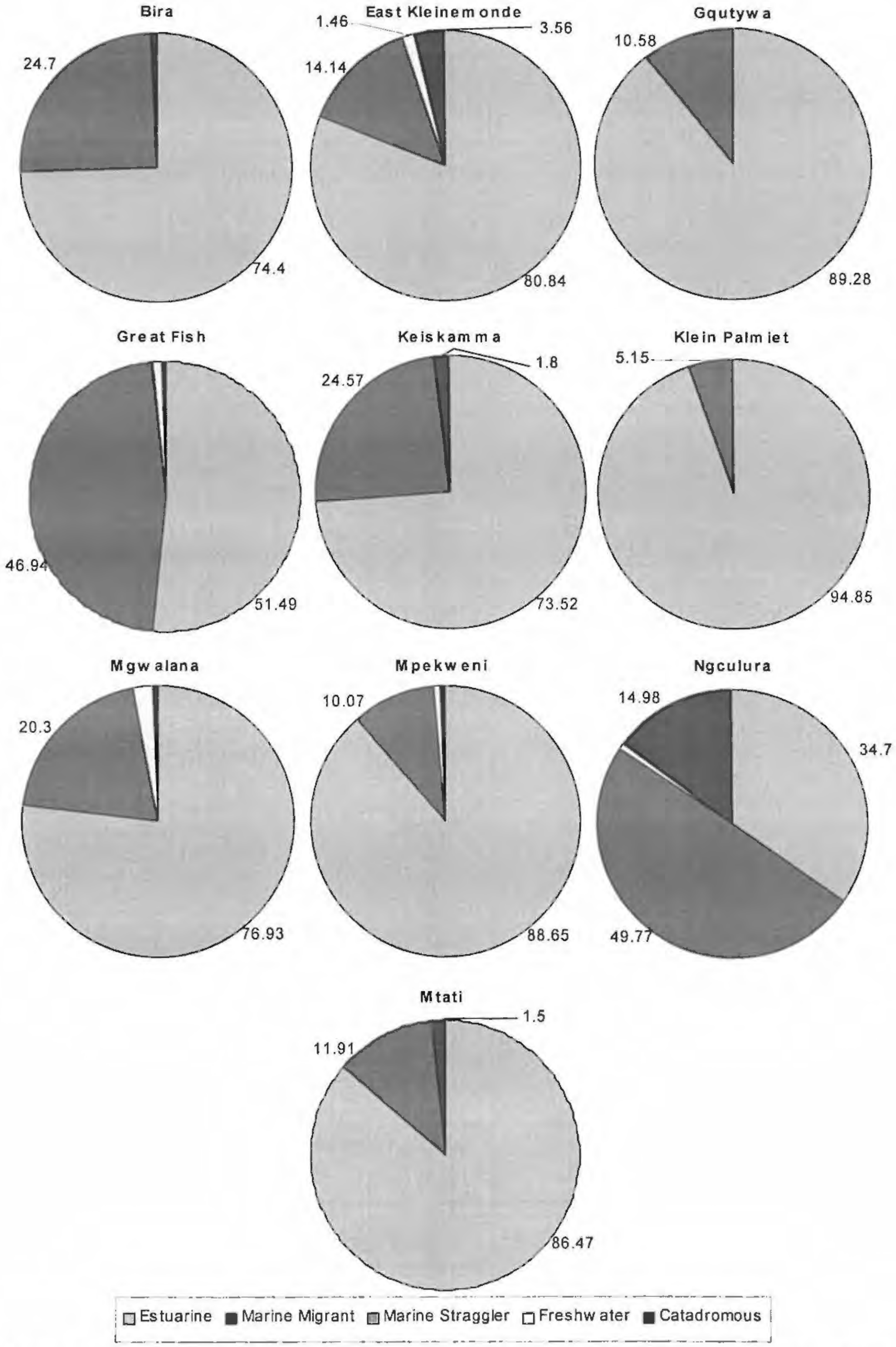


Figure 3.2: The percentage abundance of estuarine resident, marine migrant, marine straggler, freshwater migrant and catadromous migrant fish populations in each estuary.

3.3.3 Richness and diversity indices

The open systems, the Keiskamma and Great Fish, had the greatest richness in terms of seine netting (11.9 and 15.8 respectively) and a combination of seine and gill netting (14.3 and 16.4) (Table 3.7). In terms of gill netting, the Great Fish had the lowest richness (5.45), while the Keiskamma maintained a high richness (14.3). The Margalefs Richness calculated for the communities correlated significantly with the linear length of the study estuaries when the gears were combined (r_s=0.95; p<0.001) and when analysing seine net results independently (r_s=0.91; p<0.001) (Figure 3.3). Other estuarine size factors that increased proportionally with richness, were the catchment size (r_s=0.71; p<0.02), mean annual run-off (r_s=0.79; p<0.02) and estuarine area (r_s=0.94; p<0.001) of the estuaries when combining both the seine and gill net data. The trends in richness from the seine net data similarly correlate with these factors, except for a slightly higher correlation between the mean annual run-off and richness than in the combined data (r_s=0.84; p<0.005).

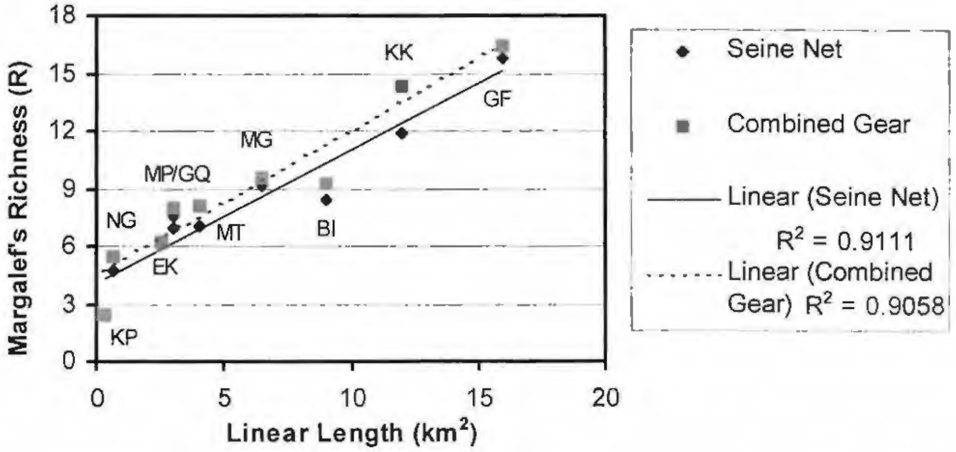


Figure 3.3: A plot of the linear length of the study estuaries versus the calculated Margalefs Richness for each system. Each estuaries plot is labelled by a two letter code (BI=Bira, EK=East Kleinemonde, GF=Great Fish, GQ=Gqutywa, KK=Keiskamma, KP=Klein Palmiet, MG=Mgwalana, MP=Mpekweni, MT=Mtati, NG=Ngculura).

The Shannon-Wiener Diversity did not show any trends relative to estuary size or mouth status. The two open estuaries had very different diversities, with the Keiskamma having a much lower diversity (0.51) with nine species making up 90% of the catch, of which *Gilchristella aestuaria* contributed 65% (Table 3.8). The Great Fish had the greatest diversity for the seine net data (0.80), with the smallest closed estuary, the Ngculura, having a similarly high diversity of 0.79. The remaining closed estuaries all had relatively low diversities in the seine and combined gear results (Table 3.8). The gill net diversity was relatively high in all systems with only the Great Fish having a diversity lower than 0.75.

Table 3.7: Calculated Margalefs richness for the data from seine netting, gill netting and a combination of these gears in each system. The N/A in the Klein Palmiet row is due to gill nets not being used in this system.

System	Seine	Gill	Combined
Keiskamma	11.90	14.30	14.30
Ngculura	4.71	11.30	5.49
Gqutywa	6.99	11.20	8.04
Bira	8.41	12.40	9.22
Mgwalana	9.19	9.48	9.63
Mtati	7.02	12.10	8.15
Mpekweni	7.62	15.10	7.98
Great Fish	15.80	5.45	16.40
Klein Palmiet	2.43	N/A	N/A
East Kleinemonde	6.16	7.06	6.22

Table 3.8: The calculated Shannon-Wiener diversity for the data from seine netting, gill netting and a combination of these gears in each system. The N/A in the Klein Palmiet row is due to gill nets not being used in the system.

System	Seine	Gill	Combined
Keiskamma	0.56	0.91	0.51
Ngculura	0.79	0.77	0.83
Gqutywa	0.38	0.95	0.33
Bira	0.62	0.91	0.57
Mgwalana	0.55	0.95	0.50
Mtati	0.55	0.82	0.49
Mpekweni	0.38	0.97	0.33
Great Fish	0.80	0.36	0.75
Klein Palmiet	0.48	N/A	N/A
East Kleinemonde	0.76	0.79	0.72

3.3.4 Longitudinal distributions

Analysis of the seine and gill net data provided very little evidence of longitudinal trends in fish distribution within the estuaries (Figure 3.4 and 3.6). When using multidimensional scaling, however, a general gradient was apparent in the seine net data (Figure 3.4), but no trends were found in the gill net data set (Figure 3.6). The results from a Kruskal-Wallis ANOVA run on the densities in the different reaches confirm this with no significant difference evident with either the large (p=0.19) or small seine data (p=0.92). When the different reaches seine net data sets were tested using ANOSIM, the upper and lower reaches were found to differ significantly (p=0.01), while neither the upper nor lower were significantly different from the middle reaches.

The SIMPER routine showed that 50% of the dissimilarity between the upper and lower reaches in the seine results was accounted for by seven species. These included *Atherina breviceps* (10.3%), *G. aestuaria* (8.8%), *R. holubi* (6.8%), *Glossogobius callidus* (6.6%), *L. richardsonii* (6.4%), *Liza dumerilii* (5.6%) and *M. capensis* (5.4%). Three of the four species dominating the dissimilarity (*A. breviceps*, *G. aestuaria* and *G. callidus*) are estuarine residents, with only one (*R. holubi*) being a marine migrant. The remaining three species are all marine migrants.

Although on a community basis the three reaches did not separate out, some species when analysed individually revealed specific range preferences. *A. breviceps* and *G. aestuaria* demonstrated opposite habitat preferences (Figure 3.8), with *A. breviceps* dominating in the lower reaches and *G. aestuaria* becoming more abundant further upstream. The freshwater *Oreochromis mossambicus* exhibited a preference for the upper reaches with the majority (43%) of the individuals being captured in this region (Figure 3.9). The catch of *M. capensis*, a catadromous species, was similarly highest in the upper reaches (Figure 3.9). In contrast, the marine migrant *R. holubi* showed a relatively uniform distribution throughout the three estuarine reaches (Figure 3.9).

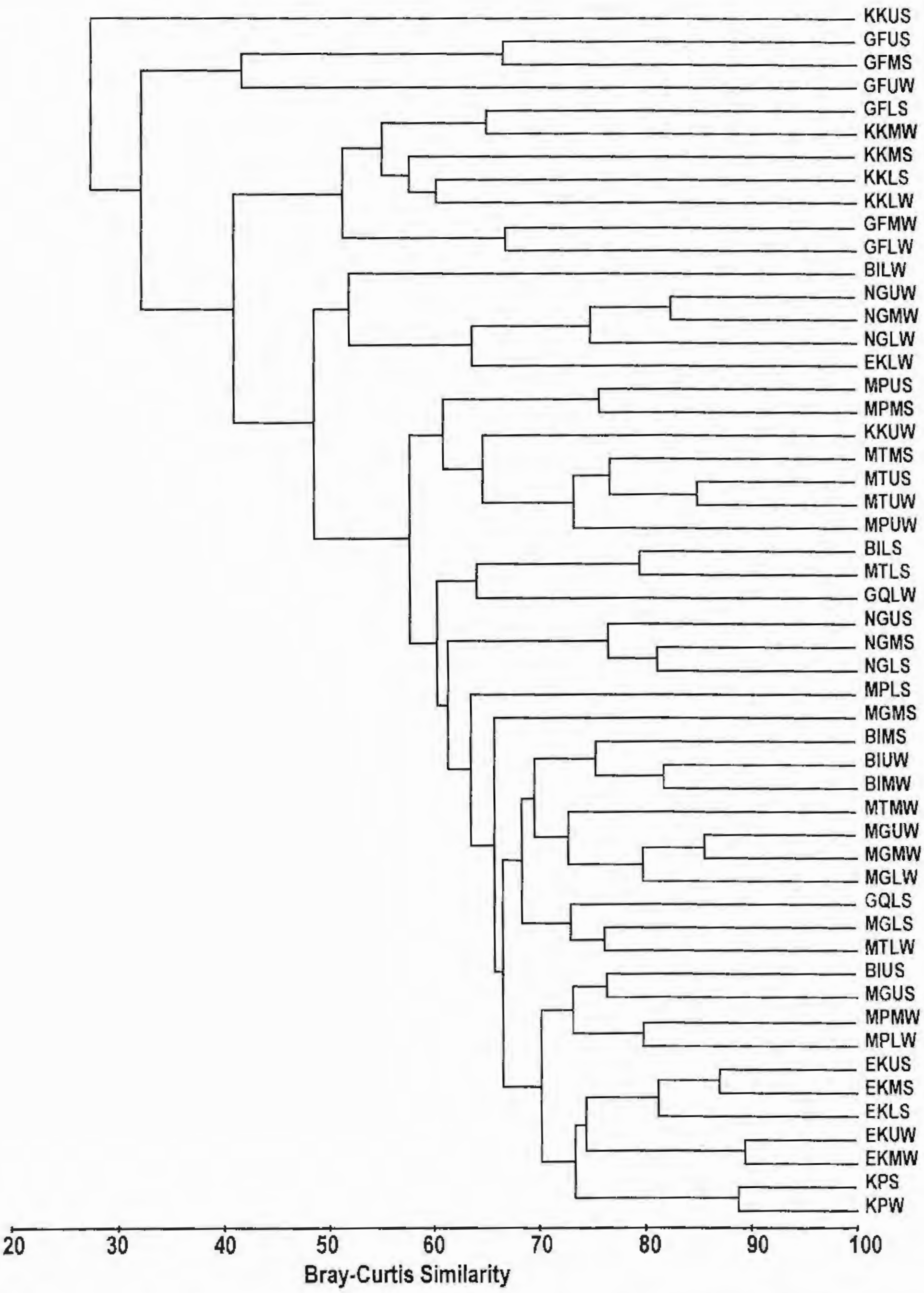


Figure 3.4: Similarity dendogram of the combined small and large seine CPUE (catch per unit effort) data per reach per season. Each sample is represented by a four letter code, the first two letters are an estuary code (BI=Bira, EK=East Kleinemonde, GF=Great Fish, GQ=Gqutywa, KK=Keiskamma, KP=Klein Palmiet, MG=Mgwalana, MP=Mpekweni, MT=Mtati, NG=Ngculura), the third a reach code (L=Lower Reach, M=Middle Reach, U=Upper Reach) and the fourth a season code (S=Summer, W=Winter).

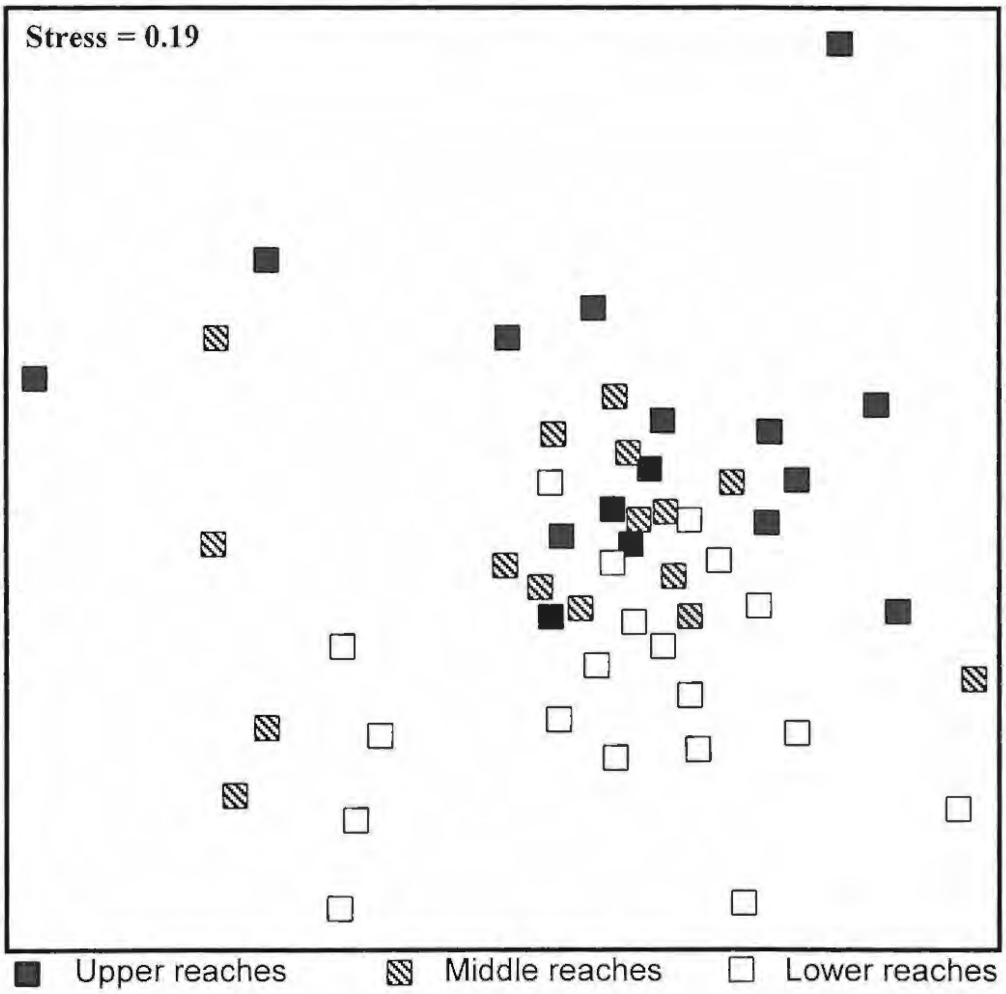


Figure 3.5: A two dimensional MDS (multidimensional scaling) plot of the combined small and large seine catch per unit effort (CPUE) per reach per season. The axes are arbitrary. For the origin of each sample (estuary name and season) see Appendix VI.

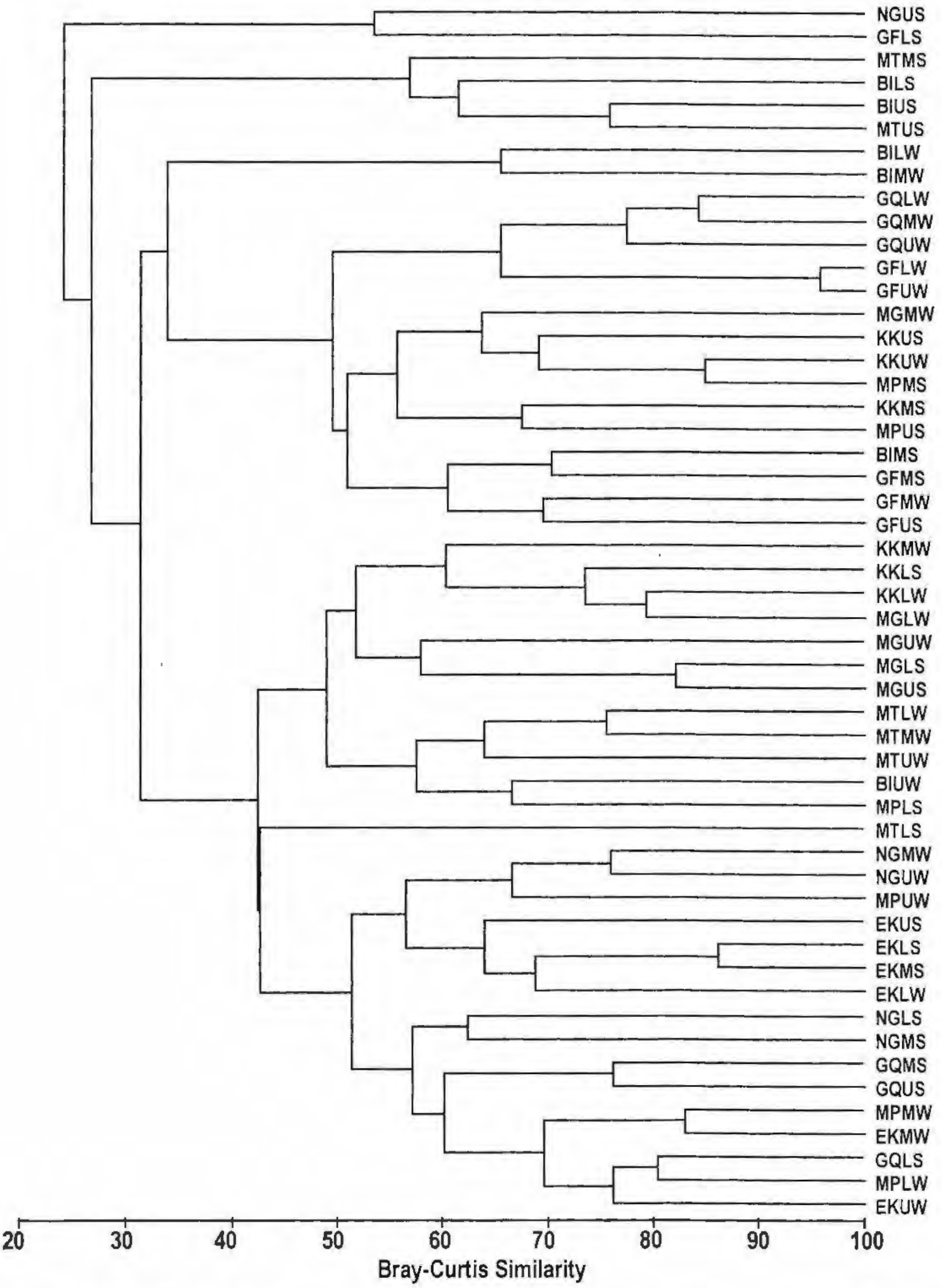


Figure 3.6: Similarity dendogram of the gill net catch per unit effort (CPUE) data per reach per season. Each sample is represented by a four letter code, the first two letters are an estuary code (BI=Bira, EK=East Kleinemonde, GF=Great Fish, GQ=Gqutywa, KK=Keiskamma, KP=Klein Palmiet, MG=Mgwalana, MP=Mpekweni, MT=Mtati, NG=Ngculura), the third a reach code (L=Lower Reach, M=Middle Reach, U=Upper Reach) and the fourth a season code (S=Summer, W=Winter).

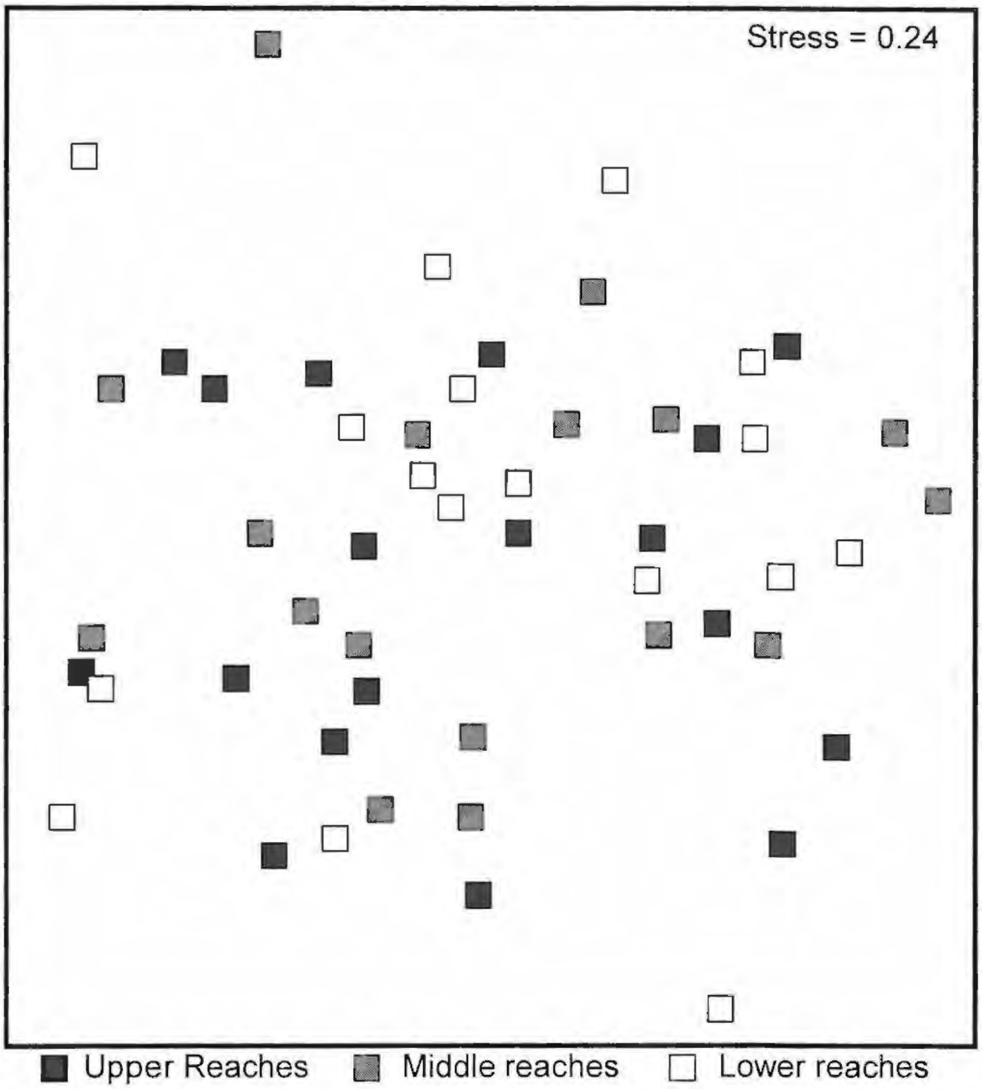


Figure 3.7: A two dimensional MDS plot of the gill net catch per unit effort (CPUE) per reach per season. The axes are arbitrary. For the origin of each sample (estuary name and season) see appendix VII.

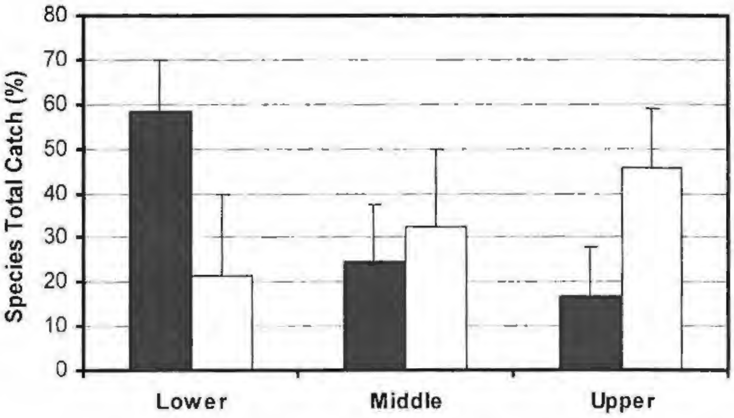


Figure 3.8: The average longitudinal distribution (+SD) of *Atherina breviceps* (solid bars) and *Gilchristella aestuaria* (clear bars) from all the estuaries sampled presented as a percentage of the total catch of each species.

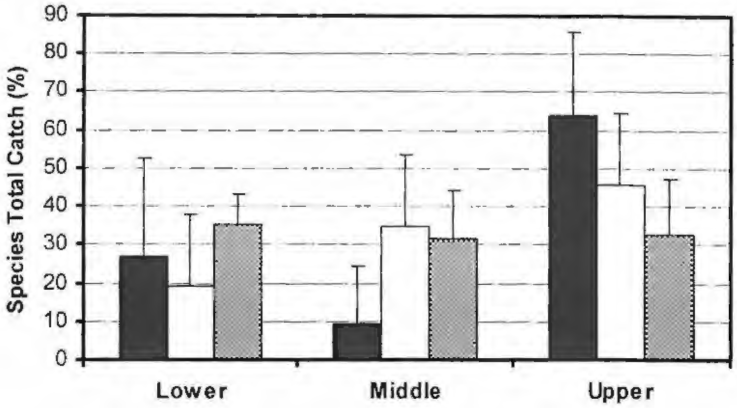


Figure 3.9: The average longitudinal distribution (+SD) of *Myxus capensis* (solid bars), *Oreochromis mossambicus* (clear bars) and *Rhabdosargus holubi* (stippled bars) from all the estuaries sampled presented as a percentage of the total catch of each species.

3.4 Discussion

The lack of seasonal differentiation in the number of individuals caught during this study is surprising, as several authors (e.g. Bennett, 1989; Harrison and Whitfield, 1995) have described large seasonal variations in ichthyofaunal densities. Similarly, the number of species in estuaries reportedly varies seasonally (Harrison and Whitfield, 1995), but this was not evident during this study. The lack of seasonal variation may be due to the mouth status of these systems. The majority of the estuaries in this study are classified as intermittently open and remained closed for most of the study period, thus preventing large immigrations or emigrations of species. Conversely, the permanently open systems retained a connection to the sea for the duration of the study, allowing species to move freely.

The relatively large proportion of category IIa and IIb species occurring in the intermittent systems may be explained by their strong attraction to estuaries. Cowley (1998) recorded that some of these species, *R. holubi* in particular, can recruit during overwash conditions. However, once they have entered these estuaries, there is no means of leaving until the following mouth opening event. The low number of marine straggler species (category III) in the closed systems may be related to the weak attraction these species have for these estuaries when compared with category II taxa.

The low proportion of category III species recorded in the permanently open systems during this study was surprising due to the accessibility of these systems to all marine species. An earlier study on the Great Fish reported four additional category III species (Whitfield *et al.*, 1994), but this coincided with a greater marine influence in the middle reaches relative to this study (5-18‰ vs 0-3 ‰). The high proportion of category IIa and IIb species in the two open estuaries is due to the accessibility of these estuaries to marine taxa. The large representation of freshwater species can be attributed to these estuaries having perennial river flows, thus allowing these species to enter and retreat from estuarine waters as conditions changed. Additionally, there were two exotic species, *Clarias gariepinus* and *Cyprinus carpio* (found in the Great Fish Estuary), which may have added to the representation of this category (Laurenson and Hocutt, 1984; Laurenson *et al.*, 1989).

In a study conducted in Wilson Inlet, a seasonally closed Australian estuary, the marine straggler component of the community contributed a higher proportion of species (10%) than closed systems in this study (2.2%), with the estuarine resident component also contributing a greater proportion of species (55.5%) compared with this study (23%) (Potter *et al.*, 1993). This is due to Wilson Inlet opening to the sea several times during the study, compared with the closed systems in this study not opening at all. In the Nornalup-Walpole Estuary, a permanently open Australian system, Potter and Hyndes (1994) identified a similar percentage (57%) of marine migrant species to the open systems in this study (49%), while the estuarine resident component contributed a greater percentage of species (43%) relative to this study (23%). The higher contribution of estuarine resident species in the Nornalup-Walpole compared with this study, may be as a result of slower current velocities due to a large embayment at the mouth.

Two species, *G. aestuaria* and *A. breviceps*, numerically dominated the catches (more than 60% of the catch) in every estuary except the Ngculura and the Great Fish (Table 3.6). These planktivorous fishes are both estuarine residents, completing their entire lifecycles within estuaries (Whitfield, 1996). To avoid competition these species undergo spatial segregation (Harrison and Whitfield, 1995; Cowley, 1998), with *A. breviceps* densities dropping fourfold from the lower to the upper reaches and *G.*

aestuaria densities increasing twofold in the same direction (Figure 3.7). Cowley (1998) found an identical trend in the East Kleinemonde during his study, with other authors identifying similar distribution patterns for *G. aestuaria* (Harrison and Whitfield, 1995). Whitfield (1980a) identified the converse distribution of *G. aestuaria* in the Mhlanga Estuary, with the highest densities occurring in the lower reaches and the numbers decreasing further upstream. This may be due to the lack of *A. breviceps* in the Mhlanga samples, thus opening up the lower reaches to colonisation by *G. aestuaria*.

The third most dominant species was *R. holubi*, representing between 5% and 25% of the overall catch in all the estuaries except the permanently open systems and the Klein Palmiet (Table 3.6). The large *R. holubi* populations may be attributed to this species being able to recruit during overwash conditions (Bell *et al.*, in press) and hence having growing populations in closed estuaries. This species was unique in its universal distribution through the different reaches of the estuaries, with approximately 33% in each reach (Figure 3.9). These distributions are similar to those recorded by several authors for this species (Hanekom and Baird, 1984; Whitfield *et al.*, 1989; Cowley 1998).

R. holubi has also been reported to associate with submerged macrophyte beds (Hanekom and Baird, 1984; Whitfield *et al.*, 1989), yet in the three systems in this study where it predominated, the Mgwalana (14.3%), the Bira (17.2%) and the Ngculura (24.4%), very low macrophyte densities were reported (Colloty, 2000). Similar results have been recorded in the mouth area of the East Kleinemonde, where there were very low macrophyte densities but high *R. holubi* abundance (Cowley, 1998). Where these large catches of *R. holubi* were made away from macrophyte beds in the East Kleinemonde, Cowley (1998) noted the presence of thick filamentous algal mats.

Blaber (1985) commented that the mugilids are probably the most abundant family of marine fishes in south-east African estuaries. The mugilids were found to represent a minimum of 5% of the catch in all the systems except the Gqutywa, Klein Palmiet, Mgwalana and Mpekweni (Table 3.6). Of the eight mugilid species captured during this study *L. richardsonii* and *M. capensis* were the most common (Table 3.5). *M.*

capensis is a catadromous species whose overall distribution was highest in the upper reaches with a drop in density in the middle reaches and an increase again near the mouth (Figure 3.9). Most authors have reported a linear trend increasing from lower to upper reaches (Whitfield *et al.*, 1994; Cowley, 1998). The relatively high numbers in the lower reaches during this study may be due to some individuals attempting to migrate out to sea to breed.

The dominant freshwater species in the study area, *O. mossambicus*, demonstrated an increasing linear trend from the lower reaches to the upper reaches (Figure 3.8). Whitfield and Blaber (1979) related the distribution of this species within estuaries to several factors including salinity stability, slow water currents, suitable breeding areas, marginal vegetation and the absence of marine competitors and piscivores. These authors remarked that this species would occur where four of these factors where favourable, and be more abundant if more factors were favourable. The increasing abundance of this species further upstream during this study, is due to the increasing number of favourable factors, e.g. fewer piscivorous predators and marine competitors, slower water currents, more stable salinities and an increase in the marginal vegetation.

The dominance by a few species (e.g. *A. breviceps* and *G. aestuaria*) in the overall catch, resulted in relatively low diversity indices for the majority of estuaries (Table 3.8). Two of the closed systems, the Ngculura and East Kleinemonde, had higher diversities (0.83 and 0.72 respectively) as greater proportions of species contributed >5% of the catch. Although *G. aestuaria* accounted for nearly 50% of the catch in the Great Fish, eight other species contributed between 2% and 19%, thus allowing for a relatively high richness (0.75).

Similar trends were evident in the seine net fish diversity, with the Ngculura (0.79), East Kleinemonde (0.76) and Great Fish (0.80) having the highest overall diversities (Table 3.8). The fish diversity in the gill nets was high in most systems due to the relatively low densities and high species numbers normally caught in the gill nets. The low diversity in the Great Fish was possibly due to this estuary producing very poor gill net catches in terms of both fish densities and species numbers. These low species numbers in the Great Fish gill nets are reflected by the low species richness

(5.45) for gill netting in this system (Table 3.7). The gill net catches in the remaining estuaries, except for the Mgwalana and East Kleinemonde, all produced richness values greater than 10. Once again, the seine net results controlled the resultant richness when both gear types were combined (Table 3.7).

The strong correlation between estuary size and fish species richness values (Table 3.7), is similar to trends highlighted by other authors. Whitfield (1980b) considered estuary size to be one of the major controlling factors of species richness in Maputaland estuaries. Similarly, Marais (1988) found that fish abundance and biomass in Eastern Cape estuaries could be correlated to catchment size ($r=0.46$, $p<0.001$; $r=0.59$, $p<0.001$). Suggestions have been made that it is not estuarine or catchment proportions that influence these trends, but more likely the hydrological consequences of the dimensions (Marais, 1988; Whitfield, 1996). Hydrological factors include increased nutrient input into systems with perennial freshwater inputs (Whitfield, 1996), positive salinity gradients and increased turbidity associated with larger systems (Marais, 1988). An important consideration is the effect of river flow and tidal prism on mouth status, with the smaller estuaries tending to close for longer periods. The closed phase reduces recruitment of juvenile marine fish and prevents adult immigration back to the sea. Additionally, during the closed phase estuarine salinities may increase sharply due to evaporation or decrease due to dilution with freshwater, resulting in only strongly euryhaline species surviving these conditions (Whitfield, 1983).

The lack of distinguishable fish assemblages in the different estuarine reaches is surprising due to reported (Cowley, 1998; Whitfield, 1980a) and observed (Figure 3.8; Figure 3.9) longitudinal density differences by the dominant species. The observed assemblage differences in the seine net results between the upper and lower reaches were due to certain species being at extremes of their distribution ranges. The species that accounted for the community differences were dominated by estuarine residents (category I), followed by marine species dependent on estuaries for their juvenile stages (II).

CHAPTER 4

SIMILARITY ANALYSIS AND FACTORS INFLUENCING SPECIES COMPOSITION

4.1 Introduction

Only two studies comparing fish communities in open and closed estuaries have been conducted along the southern African coastline. Whitfield and Kok (1992) investigated ichthyofaunal differences between the Knysna and Swartvlei estuaries, and Bennett (1989) examined the permanently open Palmiet, the intermittently open Kleinmond and the normally closed Bot estuaries. Both of these studies identified differences in the fish communities between the open and closed systems, with higher species numbers associated with the open estuaries. These authors attributed these differences to the mouth status.

Several authors have studied the influence of environmental variables on estuarine fish communities in an attempt to gain a better understanding of these relationships. Kok and Whitfield (1986) studied the influence of the mouth status on the fish community in the Swartvlei Estuary, concluding that there were limited differences between the open and closed phases. This limited influence was mostly due to the open mouth condition coinciding with the recruitment period of the marine migrant species, therefore allowing all potential recruits to enter the system. Similarly, Bennett *et al.* (1985) found that the timing, duration and frequency of mouth opening events influenced the fish communities in the Bot River Estuary. Russell (1996) also indicated that in the Wilderness and Swartvlei systems fish abundance was affected mostly by the mouth status, but additionally by the biomass of submerged macrophytes. Both Hanekom and Baird (1984), and Whitfield (1986) found linkages between the presence of macrophyte beds and the associated fish communities in the Kromme and Swartvlei estuaries. Although the absence of macrophytes did not lead to the loss of fish species from the community, the density of at least two species, *Rhabdosargus holubi* and *Monodactylus falciformis*, declined under these conditions.

Ter Morshuizen and Whitfield (1994) found that the fish communities in eelgrass beds in different regions of the Kariega Estuary varied, possibly in relation to factors such as the distance from the sea, and the degree of predation. Another variable that Whitfield *et al.* (1994) identified as important in the Kowie and Great Fish was riverine flow, which directly influences the allochthonous organic input and turbidity of the estuary. Cyrus and Blaber (1987a) similarly found that fish communities, particularly those made up of juvenile marine migrant species, were influenced by turbidity gradients in KwaZulu-Natal estuaries. Other factors, such as calm water and food availability, may also affect these juveniles (Cyrus, 1992).

Salinity was not an over-riding factor in the Kariega Estuary where no significant longitudinal changes were noted in the ichthyofaunal communities, despite a reversed salinity gradient in the system (Ter Morshuizen and Whitfield, 1994). Conversely, Blaber and Whitfield (1976), and Forbes and Cyrus (1993) identified extreme hypersaline conditions as a factor in reducing the fish densities in the St Lucia estuarine lake. Further afield, Cyrus and Blaber (1992) found that densities of certain fish species were influenced by the salinity gradients in the northern Australian Embley Estuary, while Young *et al.* (1997) reported that the low salinities in the Moore River Estuary in south-western Australia were restrictive to immigration of marine straggler species.

An additional variable noted by several authors is that of temperature. Although its effects have been considered minimal within limited seasonal ranges (Cyrus and Blaber, 1992), extremes of temperature (in association with salinity extremes) have caused fish kills in St Lucia Estuary (Cyrus and McLean, 1996).

This study examined the above-mentioned variables and expanded them to incorporate other variables relating to the physical size of the estuaries and their catchments. The additional environmental factors incorporated in this investigation included sediment organics and particle sizes, catchment size, mean annual run-off, estuarine area and linear length, average width, depth and cross-sectional area of the estuary. The aim of the study was to highlight any similarities or differences in the fish assemblages from the various estuary types and to identify the environmental and physico-chemical variables that may influence fish community structure.

4.2 Materials and Methods

4.2.1 Ichthyofaunal sampling

Please refer to the methods in Chapter 3 for this section.

4.2.2 Physico-chemical sampling

Water temperature was measured at the time of fish sampling using an alcohol thermometer. Water samples were simultaneously collected at the same sites for laboratory analyses of salinity (using a Reichert optical salinometer) and turbidity (using a Hach 2100A turbidimeter). Additionally, a winter and summer set of physico-chemical samples were collected in all the study estuaries during July 1999 and February 2000 respectively. This involved sampling temperature, salinity and turbidity in the water column at 1 m intervals (with a minimum of a surface and bottom sample) at five stations along each estuary. Sampling was conducted during early mornings (approximately 06h00 in summer and 07h00 in winter) and mid-afternoons (approximately 14h00-15h00) to obtain measurements during the coolest and warmest periods of the day. Data on the area cover of submerged macrophytes in each system were obtained from Colloty (2000).

During the February 2000 physico-chemical expedition, a sediment sample was collected from each region (mouth, lower, middle, upper and head) of each estuary. These samples were then subjected to organic content and particle size distribution determinations as described in Black (1965). The method for determining sediment organic content involved drying approximately 20 g wet weight of each sample at 56°C for a minimum of 8 hrs or until a constant mass. The samples were then weighed and ashed at 460°C for a further 8 hrs and re-weighed. The weight difference represented the organic content of the sample and a percentage could then be determined. Particle size distribution of sediment was assessed using dried samples (56°C to a constant mass). All large clods were broken up and samples were dry sieved for 15 minutes. The weight retained by each sieve was determined and a particle size distribution calculated. The samples were classified into a gravel (>2 mm), coarse sand (2-0.5 mm), fine sand (0.5-0.063 mm), silt (<0.063 mm) or combination of these categories (Walsh *et al.*, 1999).

The width and depth of the estuary was determined at five sites within each system. In the smaller systems a rope marked at 2.5 m intervals was strung across the channel. A measuring pole was then used at every marker to determine the depth at that point. In the larger systems a Lowrance depth sounder was used to take a reading every 3 sec while crossing the estuary at a steady speed. The full width of the estuary at the point of the cross-section was measured using a graduated rope.

4.2.3 Statistical analyses

Fish communities in the different estuaries were compared using CPUE (catch per unit effort) data averaged by season for each species in each estuary. These data were analysed using non-parametric multivariate analyses from the PRIMER package (Version 4.0, Plymouth Marine Laboratory). The CPUE data were standardised, root-root transformed and a Bray-Curtis Similarity matrix calculated for each estuary during each season. Clusters in a dendogram format were produced using a group average hierarchical sorting strategy and converted using non-metric MDS (multidimensional scaling) for ease of reading. Analysis of similarity (ANOSIM) was carried out on groups of estuaries (viz. permanently open, small and large closed systems) to determine if they differed significantly from one another. Where differences were found, the SIMPER routine determined the relative contribution of individual species to the similarities and differences between groups. The BIOENV function (a multiple regression function) using a Harmonic Spearman correlation was then used to relate environmental variables to the fish communities. Zar (1996) was used to determine a p-value for the R-statistic produced from these correlations. The differences in densities between the open and closed estuaries were analysed using a non-parametric Kolmogorov-Smirnov two sample test.

4.3 Results

The environmental data recorded from each region in each estuary are presented in Chapter 2. The catchment size, mean annual run-off and estuarine area, length, depth and width for each estuary can be found in Table 4.1. A visual depiction of the above parameters (relative to the Great Fish Estuary) is shown in Figure 4.1. Table 4.2 and 4.3 contain the summer and winter means (±SD) for the physico-chemical variables in the individual estuaries.

Table 4.1: The estuarine and catchment measurements for each estuary. Macrophyte cover data were obtained from Colloty (2000).

Variable	Keiskamma	Ngculura	Gqutywa	Bira	Mgwalana	Mtati	Mpekweni	Great Fish	Klein Palmiet	East Kleinemonde
Catchment size (km^2)	2745	15	85	255	200	130	65	29284	13	46
Mean annual run-off (x10^6 m^3/yr)	142.7	0.8	4.4	13.3	10.6	6.9	3.4	526.0	0.7	2.0
Estuarine surface area (ha)	197.4	1.7	39.9	122.3	62.9	37.9	57.6	192.7	0.4	17.5
Estuarine length (km)	12.0	0.6	3.0	9.0	6.5	4.0	3.0	15.0	0.1	2.5
Mean depth (m)	1.4	0.8	1.4	1.2	0.6	1.6	1.1	1.4	0.7	1.3
Mean width (m)	86.5	14.0	70.1	115.0	54.4	57.5	94.0	122.0	16.0	65.0
Mean cross-sectional area (m^2)	116.0	10.9	62.2	80.6	29.7	57.4	92.3	106.9	7.0	82.1
Sediment organics (%)	13.0	2.7	6.0	7.3	11.6	7.1	3.5	2.5	0.5	2.8
Macrophyte cover (ha)	11.3	0	2.5	5.3	1.2	3.2	1.6	0	0.1	4.7
Mouth status	Open	Closed	Closed	Closed	Closed	Closed	Closed	Open	Closed	Closed

Table 4.2: The mean (±SD) summer (February 2000) environmental variables (S=surface and B=bottom) for each estuary.

Variable	Keiskamma	Ngculura	Gqutywa	Bira	Mgwalana	Mtati	Mpekweni	Great Fish	Klein Palmiet	East Kleinemonde
Temperature (S) (°C)	25.9 (±2.9)	28.1 (±1.7)	28.0 (±1.3)	28.9 (±2.2)	27.1 (±3.1)	28.8 (±1.4)	28.7 (±2.3)	25.3 (±1.7)	25.2	27.4 (±2.0)
Temperature (B) (°C)	25.6 (±3.0)	27.6 (±0.8)	28.2 (±1.3)	28.4 (±1.4)	26.8 (±3.0)	28.8 (±1.4)	28.2 (±2.3)	24.1 (±2.0)	25.2	28.1 (±1.8)
Salinity (S) (‰)	6.8 (±11.1)	3.5 (±0.7)	32.3 (±0.8)	21.4 (±7.6)	27.5 (±2.1)	19.3 (±2.0)	32.6 (±1.8)	3.4 (±7.8)	28.0	14.5 (±5.2)
Salinity (B) (‰)	7.9 (±10.6)	3.3 (±1.3)	32.0 (±7.6)	22.4 (±1.0)	26.8 (±2.0)	19.2 (±1.7)	32.9 (±1.8)	8.6 (±10.3)	28.0	13.9 (±5.0)
Turbidity (S) (NTU)	75 (±36.8)	9.6 (±2.2)	8.7 (±3.4)	6.4 (±2.2)	27.0 (±18.4)	7.5 (±4.5)	8.0 (±4.3)	131.8 (±105.3)	8.1	16.4 (±37.4)
Turbidity (B) (NTU)	85.3 (±45.4)	16.1 (±9.7)	18.8 (±21.4)	19.9 (±6.4)	42.5 (±25.4)	17.8 (±11.2)	15.5 (±22.5)	146.0 (±96.2)	8.1	22.1 (±47.7)

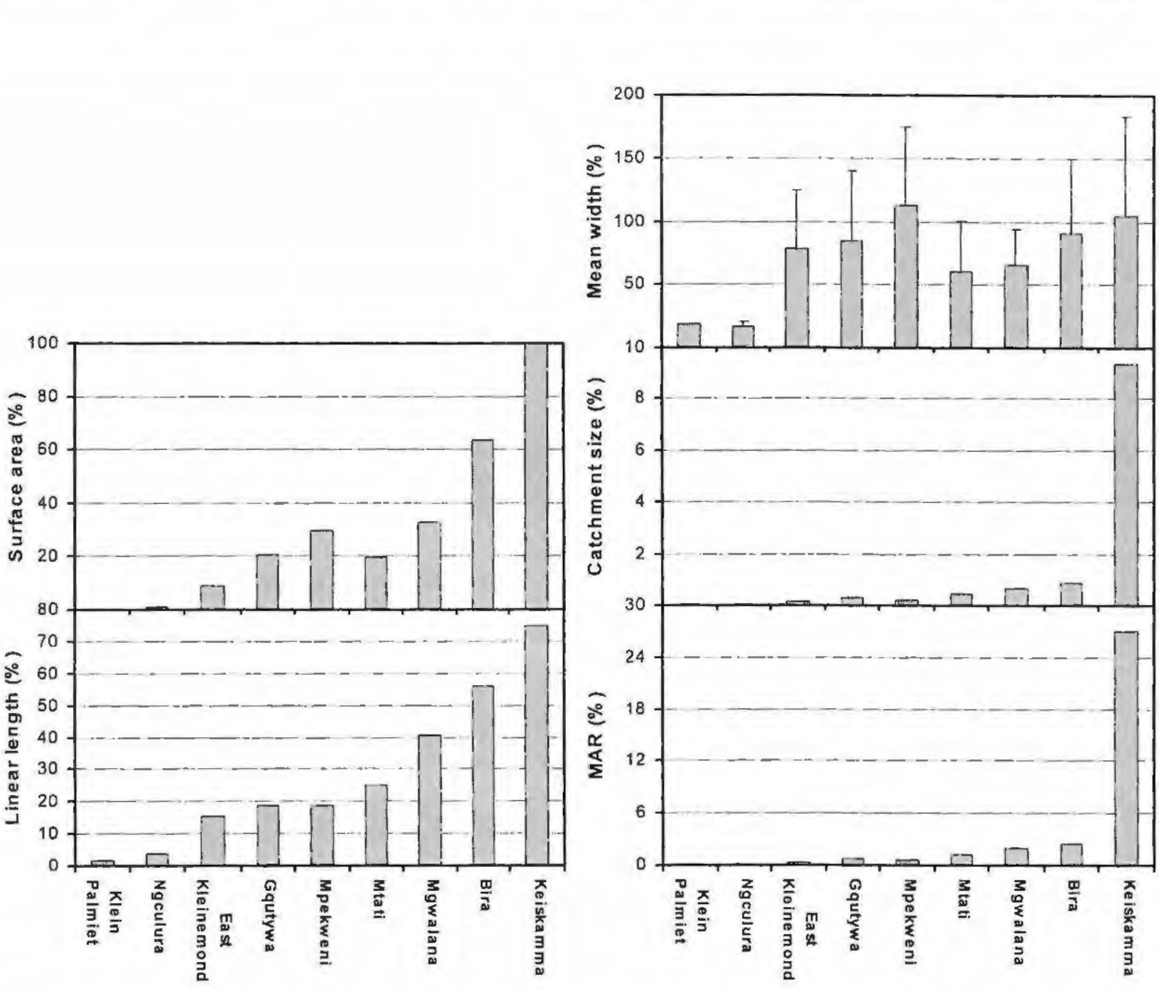


Figure 4.1: Summary of the size characteristics (viz. mean width, catchment size, MAR, surface area and linear length) expressed as a percentage of the Great Fish Estuary (hence the absence of the Great Fish).

Whereas considerable variation was evident in the fish communities from the different sized estuaries when the seine net data was analysed, no major trends were evident in the gill net data. A cluster analysis of the seine net catches demonstrated that the greatest difference in the fish communities occurred between the permanently open and temporarily closed estuaries, with a separation at the 50% similarity level (Figure 4.2). There was an additional separation of the smaller and larger closed systems at a 65% similarity level (Figure 4.2).

Table 4.3: The mean (±SD) winter (June 1999) environmental variables (S=surface and B=bottom) for each estuary.

Variable	**Keiskamma**	**Ngculura**	**Gqutywa**	**Bira**	**Mgwalana**	**Mtati**	**Mpekweni**	**Great Fish**	**Klein Palmiet**	**East Kleinemonde**
Temperature (S) (°C)	16.9 (±1.5)	16.5 (±1.1)	16.5 (±2.1)	14.2 (±1.8)	16.2 (±1.0)	13.8 (±2.2)	15.4 (±1.5)	16.0 (±2.4)	16.0	16.7 (±1.9)
Temperature (B) (°C)	16.6 (±1.2)	15.7 (±2.2)	16.5 (±2.0)	14.2 (±1.2)	16.1 (±0.9)	13.8 (±2.0)	15.1 (±1.5)	16.0 (±2.2)	16.0	16.6 (±1.7)
Salinity (S) (‰)	15.3 (±11.8)	5.8 (±7.2)	26.8 (±3.4)	24.6 (±2.0)	24.6 (±1.1)	16.6 (±1.6)	21.8 (±3.9)	9.1 (±13.5)	23.0	14.8 (±3.4)
Salinity (B) (‰)	21.2 (±9.0)	5.8 (±7.3)	26.9 (±3.7)	27.4 (±1.5)	24.6 (±1.1)	16.9 (±1.4)	21.7 (±3.8)	10.8 (±14.0)	23.0	15.1 (±3.8)
Turbidity (S) (NTU)	42.5 (±48.2)	4.2 (±2.1)	14.5 (±17.7)	4.3 (±1.9)	14.5 (±11.9)	4.7 (±2.3)	19.2 (±19.4)	112.7 (±67.0)	5.0	4.9 (±2.9)
Turbidity (B) (NTU)	48.4 (±43.3)	5.6 (±2.4)	18.2 (±13.8)	8.0 (±14.9)	34.3 (±34.5)	7.3 (±4.2)	22.1 (±19.8)	124.3 (±84.1)	5.0	5.9 (±4.6)

The fish groupings within permanently open, smaller and larger closed estuaries are more evident when plotted graphically as an MDS ordination (Figure 4.3). The ordination shows sites that are similar occupying positions closer to one another, and on this occasion the communities were distributed according to an estuarine size and/or mouth status axis (X-axis).

Variations in the seine net fish assemblages were found to be significant (ANOSIM), with the open systems differing from the closed estuaries at a significance level of $p<0.001$ ($R=0.882$), while a significance level of $p=0.01$ ($R=0.656$) was calculated between the ichthyofaunal communities of the small and large intermittent estuaries. These differences were also evident when the density of fish in the different estuaries was examined using a Kolmogorov-Smirnov test. The ichthyofaunal densities occurring in the open systems were significantly different ($p<0.001$) from the closed systems using both the large ($n=136$) and small seine ($n=127$) data.

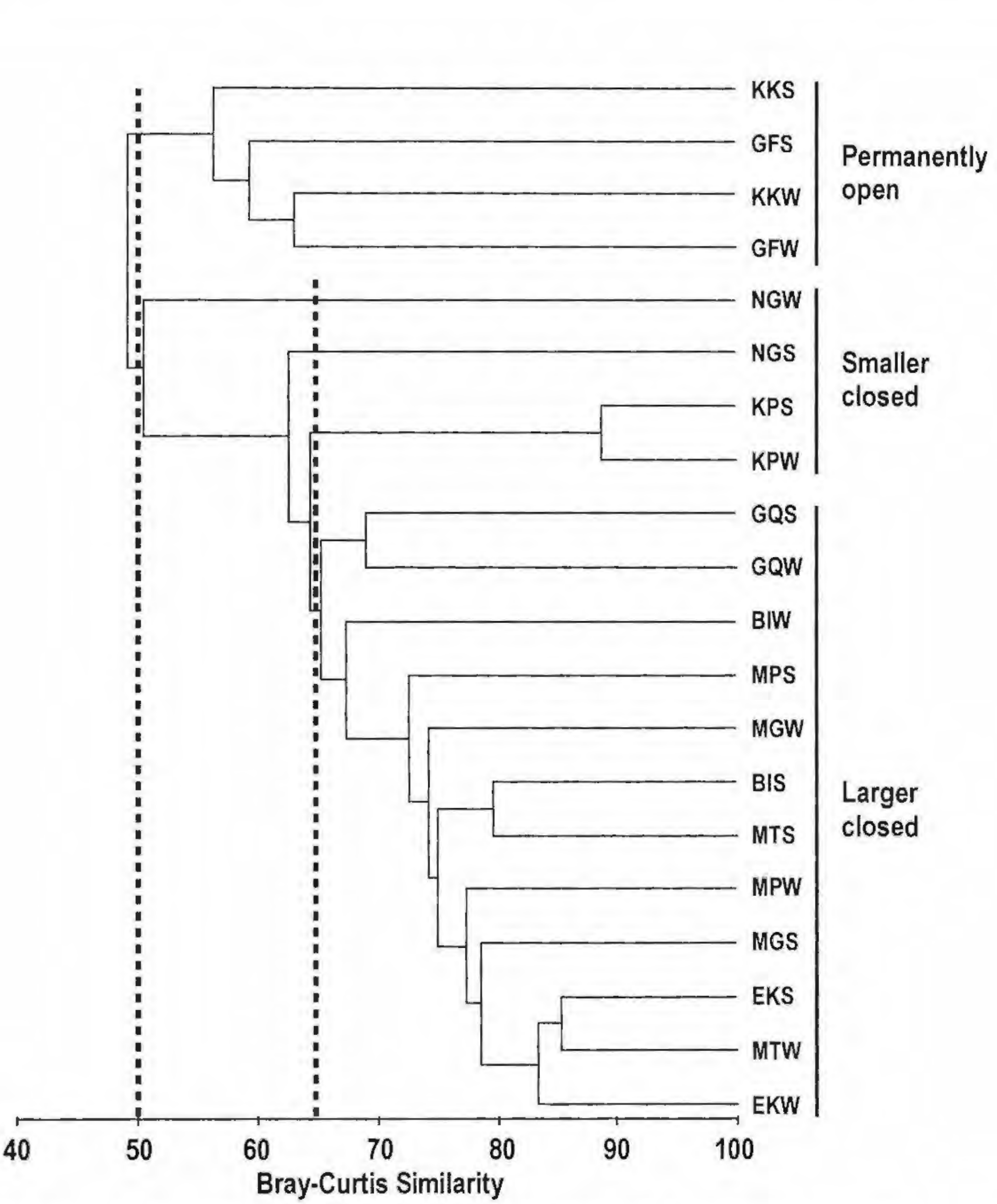


Figure 4.2: Similarity dendogram of the seasonal fish community data for each estuary. The open and closed estuaries separate off at a 50% similarity while the smaller and larger closed estuaries separate at a 65% similarity. Each sample is represented by a three letter code; the first two letters are an estuary code (BI=Bira, EK=East Kleinemonde, GF=Great Fish, GQ=Gqutywa, KK=Keiskamma, KP=Klein Palmiet, MG=Mgwalana, MP=Mpekweni, MT=Mtati, NG=Ngculura) and the third is a season code (S=Summer, W=Winter).

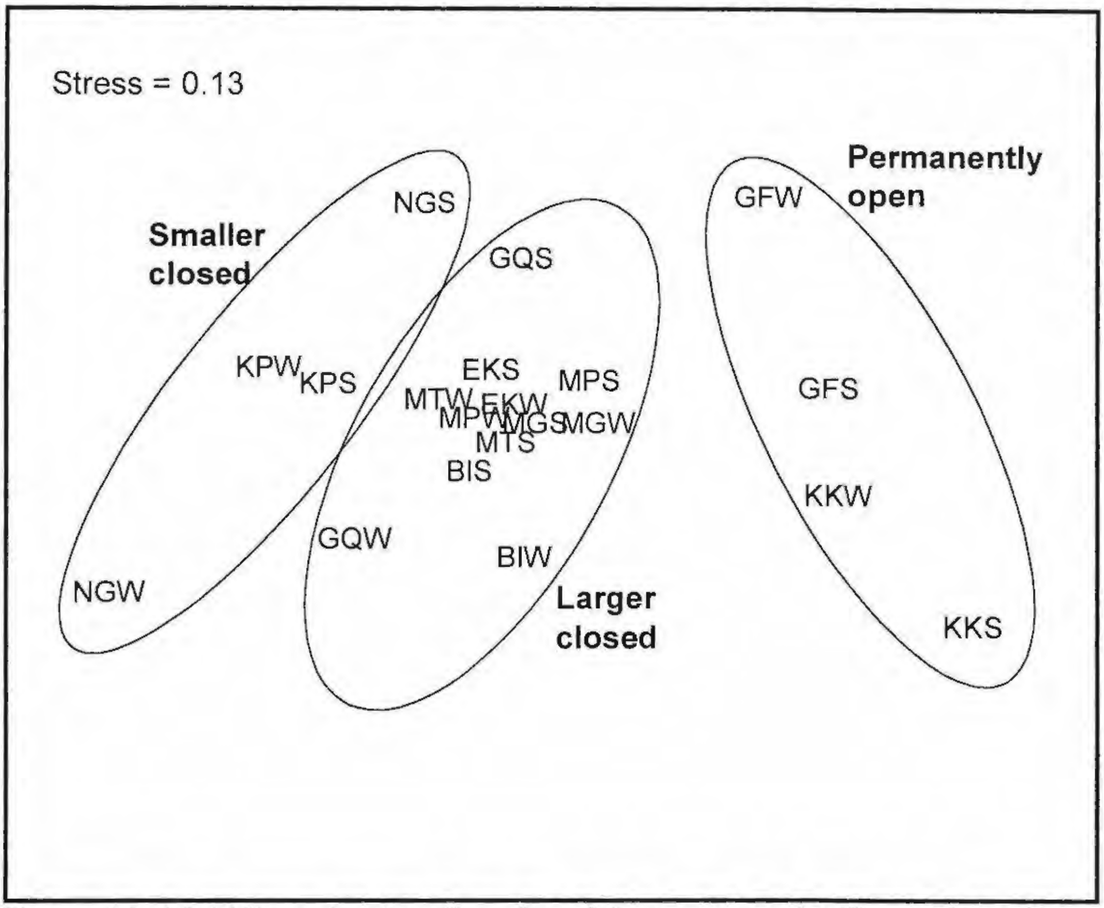


Figure 4.3: Multidimensional scaling plot of the two most significant dimensions of the estuarine fish community data. The circled groups indicate estuaries with significantly different communities representing three groups namely permanently open and small and large temporarily closed estuaries. Each sample is represented by a three letter code; the first two letters are an estuary code (BI=Bira, EK=East Kleinemonde, GF=Great Fish, GQ=Gqutywa, KK=Keiskamma, KP=Klein Palmiet, MG=Mgwalana, MP=Mpekweni, MT=Mtati, NG=Ngculura) and the third is a season code (S=Summer, W=Winter).

Data analyses using the SIMPER routine revealed that 18 fish species contribute more than two percent to the dissimilarity between the communities in open and closed estuaries. These included six estuarine resident species, namely *Atherina breviceps* (11.3%), *Glossogobius callidus* (7.4%), *Gilchristella aestuaria* (5.9%), *Caffrogobius gilchristi* (3.9%), *Caffrogobius nudiceps* (2.8%) and *Psammogobius knysnaensis* (2.2%), that contributed a cumulative 33.5% towards the dissimilarity. Similarly, 11 marine migrant species, namely *R. holubi* (6.5%), *M. falciformis* (3.9%), *Myxus* *capensis* (3.6%), *Solea bleekeri* (3.3%), *Liza richardsonii* (3.2%), *Liza dumerilii* (2.9%), *Lithognathus lithognathus* (2.8%), *Pomadasys commersonnii* (2.8%), *Argyrosomus japonicus* (2.7%), *Liza tricuspidens* (2.1%) and *Heteromycteris capensis* (2.1%) contributed 35.9% to the dissimilarity. Only one freshwater species *Oreochromis mossambicus* (2.1%) contributed more than 2% towards the dissimilarity.

The dissimilarity between the fish communities in the smaller and larger closed systems was represented by 16 species that independently contributed more than two percent towards this dissimilarity. Estuarine resident species, namely *G. aestuaria* (8.4%), *A. breviceps* (6.3%), *G. callidus* (5.8%) and *P. knysnaensis* (3.5%) contributed 24% towards the dissimilarity. While 11 marine migrant species, namely *M. capensis* (7.5%), *L. dumerilii* (6.6%), *L. richardsonii* (5.8%), *P. commersonnii* (5.3%), *R. holubi* (5.2%), *L. lithognathus* (5%), *S. bleekeri* (3.8%), *M. falciformis* (3.6%), *Mugil cephalus* (3.5%), *L. tricuspidens* (3.1%) and *H. capensis* (2.8%), collectively contributed 52.2% towards the dissimilarity, only one freshwater species, *O. mossambicus* (5.1%), represented more than two percent of the dissimilarity between these two groups of estuaries.

The BIOENV procedure identified different variables influencing the fish communities during different seasons (Table 4.4). The single most important factor appeared to be mouth status (i.e. open versus closed) as it produced the highest correlation during summer ($R=0.734$; $p<0.03$), winter ($R=0.617$; $p=0.05$) and both data sets combined ($R=0.635$; $p=0.01$). Other variables that appeared to have a significant influence on fish communities when both seasons were combined included estuarine area ($R=0.452$; $p=0.05$), catchment size ($R=0.451$; $p=0.05$), linear length ($R=0.446$; $p=0.05$) and mean annual runoff ($R=0.442$; $p=0.05$). The highest correlation of $R=0.787$ ($p=0.01$) occurred during winter with a combination of mouth status, estuarine area, linear length, average width and bottom salinity (Table 4.4). The most significant correlation ($R=0.649$; $p<0.003$) resulted from an analysis of both seasons using the variables of mouth status, linear length, cross-sectional area and bottom salinity (Table 4.4).

Table 4.4: Summary statistics for the Harmonic Spearman correlation between environmental variables and community composition. The combined seasons column represents an analysis incorporating the data from both seasons. An asterisk (*) on the p-value indicates the variable contributed to the highest correlation of combined variables.

S=surface B=bottom	**Summer (n=10)**		**Winter (n=10)**		**Combined Seasons (n=20)**	
Variable	**R**	**p**	**R**	**p**	**R**	**p**
Mouth Condition	0.734	0.025*	0.617	0.05*	0.635	0.01*
Catchment Size	0.490	>0.05	0.482	>0.05	0.451	0.05
Mean Annual Runoff	0.487	>0.05	0.467	>0.05	0.442	0.05
Estuarine Surface Area	0.470	>0.05	0.508	>0.05*	0.452	0.05
Linear Length	0.451	>0.05	0.545	>0.05*	0.446	0.05*
Average Depth	-0.280	>0.05	-0.280	>0.05	-0.170	>0.05
Average Width	0.090	>0.05	0.226	>0.05*	0.202	>0.05
Cross-sectional Area	0.242	>0.05*	0.178	>0.05	0.240	>0.05*
Temperature (S)	0.257	>0.05	-0.310	>0.05	-0.180	>0.05
Temperature (B)	0.351	>0.05*	-0.330	>0.05	-0.170	>0.05
Salinity (S)	0.165	>0.05*	0.254	>0.05	0.207	>0.05
Salinity (B)	0.125	>0.05*	0.182	>0.05*	0.140	>0.05*
Turbidity (S)	0.417	>0.05	0.379	>0.05	0.381	0.05
Turbidity (B)	0.528	>0.05	0.315	>0.05	0.379	>0.05
Sediment Organics	0.143	>0.05*	0	>0.05	0.121	>0.05
% Submerged Macrophytes	0.166	>0.05*	0.152	>0.05	0.226	>0.05
Highest Correlation	0.749	0.01	0.787	0.01	0.649	<0.003

4.4 Discussion

The results from two independent South African studies confirmed that fish communities in nearby permanently open and temporarily closed systems do reveal marked differences. Bennett (1989) found that the intermittently open Bot Estuary had a lower species richness and abundance compared with the permanently open Palmiet Estuary. Similarly, Whitfield and Kok (1992), reported a higher species count in the permanently open Knysna Estuary when compared with the intermittently open Swartvlei system, but abundance of individuals in the two systems were not dissimilar. This study has identified considerable differences in the fish communities of open and closed estuaries. The differences are attributed primarily to a higher species richness in the open systems, and an increased abundance of fish in the closed estuaries.

The species that accounted for these differences in the distinct estuary types include both marine migrants and estuarine residents. The taxa accounting for the majority of the dissimilarity between the open and closed systems were the estuarine *A. breviceps* and *G. aestuaria*. *A. breviceps* represented a large proportion of the catch in the closed estuaries (mean = 39%) and a very low proportion in the open systems (mean = 0.8%). Conversely, *G. aestuaria* dominated the catches (47% in the Great Fish and 66% in the Keiskamma) in the open systems, but contributed less to the catch in the closed estuaries (mean = 33%). The low representation of *A. breviceps* and the high percentage of *G. aestuaria* in the open systems may be due to the lower salinities predominating in these estuaries. *A. breviceps* tends to be associated with more saline waters, whereas *G. aestuaria* is more abundant in low salinity estuaries (Whitfield, 1998).

G. callidus also represented a significant degree of the dissimilarity (7.4%) between the open and closed estuaries. This was a result of this species representing a greater proportion of the catch in the closed estuaries (mean = 7%) compared with the open systems (mean = 0.2%). The reasons for these differences in abundance in the two types of estuaries are unknown.

Eleven marine migrant species collectively contributed 38.6% to the dissimilarity between the open and closed estuaries. These taxa generally represented a higher proportion of the catch in the open systems than the closed estuaries. This may be attributed to the year-round access to open systems, while recruitment opportunities into the intermittently open estuaries is more limited due to the predominantly closed mouths of these systems. The marine migrant species that are found in a higher proportion in the closed estuaries included *R. holubi* and *M. falciformis*. Their lower abundance in the open estuaries is possibly linked to a paucity of dense aquatic macrophyte beds, that these species have been shown to associate with (Whitfield *et al.*, 1989; Hanekom and Baird, 1984).

This study also demonstrated significant differences between the fish communities in the smaller and larger closed estuaries (R=0.656; p=0.01), and between the smaller closed and permanently open systems (R=0.906; p=0.03). These differences were attributed to the small closed estuaries having a much lower fish species richness and density than the larger closed and permanently open estuaries. Similar findings were published for the Bellambi and Werri lagoons and Fairy creek in Australia (Griffiths and West, 1999). The significantly smaller Bellambi lagoon supported only five species while the similar sized Werri lagoon and Fairy creek supported 21 and 20 species respectively.

The individual marine migrant species that accounted for the separation of large from small closed estuaries are similar to those responsible for the dissimilarity between the permanently open and closed systems. The reasons for these differences can be attributed to the absence or very low contributions of these species in the smaller estuaries, possibly a result of the less frequent and shorter duration mouth opening events in the smaller estuaries.

Estuary mouth characteristics are widely regarded as the single most important environmental or physical variable responsible for structuring fish communities within different types of estuaries (Bennett *et al.*, 1985; Kok and Whitfield, 1986; Bennett, 1989). This factor correlated well with the observed differences in the Eastern Cape fish communities (Table 4.4). The frequency, timing and duration of the open mouth phase of intermittently open systems have been shown to be of importance in the structuring of the fish communities, as if mouth opening events correspond with the breeding period then reproductive adults may leave the estuaries to breed at sea (Wallace, 1975a; Wallace *et al.*, 1984), similarly the duration of this open period is influential in allowing the juveniles of marine migrant species to enter the estuaries after they have completed their planktonic larval stage (Bennett, 1989; Whitfield and Kok, 1992). In addition, Cowley (1998) recorded significantly higher population sizes of marine migrant species in the East Kleinemonde after an extended mouth opening event. A prolonged closed mouth phase will prevent fish recruitment other than during overwash events, thus resulting in a lower species richness and lower abundance of marine migrant species. Conversely, permanently open systems are always accessible to new recruits, and allow for unrestricted emigration when these fish mature.

System features, such as catchment size and mean annual runoff tend to influence the mouth status, length and area of an estuary, since they determine the amount of water entering a system (Whitfield, 1996). The average width and cross-sectional area may also have an influence as the wider systems generally have a larger littoral, thus allowing more light penetration for aquatic macrophyte growth. Macrophyte density influences fish communities directly as certain species, such as *M. falciformis*, are most abundant in estuaries with extensive macrophyte beds (Hanekom and Baird, 1984).

Temperature has a marked influence on fish communities, especially in combination with salinity extremes (Cyrus and McLean, 1996). Water temperatures may have had an influence on the fish communities in this study during summer (Table 4.4), but temperature was a co-variant of mouth phase, with open estuaries tending to maintain lower summer temperatures due to the sink influence of the sea on these systems. Salinity has been described as being important in determining the longitudinal distributions of species within estuaries (Marais, 1988; Russell, 1996), thereby influencing the structure of fish communities. The influence of this factor during the current study is difficult to determine, as it may be the estuary mouth phase that is influencing the salinity, and not salinity per se that is affecting the fish assemblages.

Turbidity is a significant factor in South African estuaries and has been considered important in increasing fish catch rates in Eastern Cape estuaries (Marais, 1988). Turbidity can also influence fish negatively due to clogging of gills, but this only occurs under extreme sediment loads (Cyrus and Blaber, 1987a; Whitfield and Paterson, 1995). The greatest effect of this factor on fish communities is via its influence as a cue to juveniles for entering estuaries, its reduction of predation pressure and its influence on submerged macrophyte densities (Blaber and Blaber, 1980). The lack of any significant influence of this factor during the current study is interesting, particularly as greater turbidities occurred in the open compared with the closed estuaries.

In conclusion, permanently open and closed estuaries have significantly different fish communities. Similarly, the fish communities in small and large intermittently open systems differ significantly. These dissimilar assemblages may be attributed to differing densities of six estuarine resident, eleven marine migrant and one freshwater species. The dominant environmental variable responsible for the changes in relative abundance of these species is estuarine mouth characteristics. Other variables contribute to varying degrees, but the principal factor is the predominant mouth phase of these estuaries.

CHAPTER 5

LENGTH FREQUENCY ANALYSIS OF THE ABUNDANT SPECIES

5.1 Introduction

Studying length frequencies of fish species found in estuaries allows the determination of several factors. These include the spawning season of certain species (Harrison and Whitfield, 1995), the recruitment period of marine migrant species (Whitfield, 1989a) and whether a marine species has recruited during overwash conditions or not (Cowley *et al.*, in press). Researchers have also used length frequency analysis to determine which life-history stages utilise estuaries (e.g. Wallace, 1975b; Marais and Baird, 1980; Marais, 1981; Marais, 1983) as well as specific habitats within estuaries such as saltmarshes (Paterson and Whitfield, 1996). Length frequency data are equally valuable to environmental and fisheries managers. Harrison and Whitfield (1995) used length frequency data in conjunction with species numbers to support their conclusion that temporarily closed estuaries on the KwaZulu-Natal coast are important nursery areas for marine migrant species. In addition, fisheries managers in South Africa use length frequency data to determine the status of populations of targeted species and to set minimum size limits.

The aim of this chapter is to describe and compare the length frequency distributions of the eight most abundant species in this study in both the permanently open and temporarily closed estuaries.

5.2 Materials and Methods

5.2.1 Ichthyofaunal sampling

Refer to Chapter 3 for the seine-netting methods used to capture the fish on which these data were based.

5.2.2 Analysis

Length data were analysed for the eight most abundant species only. These included four estuarine resident species (*Atherina breviceps, Gilchristella aestuaria, Glossogobius callidus* and *Psammogobius knysnaensis*) and four marine migrant species (*Rhabdosargus holubi, Liza dumerilii, Liza richardsonii* and *Pomadasys commersonnii*). Data for each species were combined for the large closed and permanently open estuaries. No analysis was conducted on the small closed estuaries due to the limited data sets from these systems. These data were analysed using a Kolmogorov-Smirnov test to detect differences in lengths between the large closed and permanently open estuaries. The test was run from the STATISTICA® for Windows software package. Length at age estimates were based on the following research: *A. breviceps* (Ratte, 1989), *G. aestuaria* (Talbot, 1982), *G. callidus* (Boullé, 1989), *P. knysnaensis* (Bennett, 1989), *L. dumerilii* (van der Horst and Erasmus, 1981), *L. richardsonii* (de Villiers, 1987), *R. holubi* (Blaber, 1974) and *P. commersonnii* (Wallace, 1975b).

5.3 Results

5.3.1 Estuarine resident species

G. aestuaria demonstrated a normal distribution of individuals across size classes in both the permanently open and large closed estuaries (Figure 5.1). The modal size class in the large closed systems was 25-30 mm compared with 40-45 mm in the permanently open estuaries. The mean size range of 40 mm SL (±8.7 SD) in the open systems was significantly larger ($p<0.001$) than the mean size of 31 mm SL (±8.2 SD) in the closed estuaries. Conversely, the mean size class in each individual system within each estuary type (Figure 5.2) was similar, with the majority of individuals being approximately one year old in both estuary types (Figure 5.1).

The other pelagic estuarine resident, *A. breviceps*, produced a slightly left skewed-normal size class distribution in the large closed estuaries and a bimodal distribution in the permanently open estuaries (Figure 5.3). The modal size class in the large closed systems was 25-30 mm and in the permanently open estuaries the two peaks included the 30-35 mm and 55-60 mm size classes. There was very little mean size class variation between individual systems within each estuary type (Figure 5.4). When comparing estuary types, however, there were significant differences ($p<0.001$) with the permanently open estuaries having a mean size of 45 mm SL (±12.2 SD) and the large closed systems having a mean of 34 mm SL (±8.6 SD). There is consequently a large difference in the average age of this species within the different estuary types with the majority of captured individuals in the closed estuaries being under one year old and the majority of individuals sampled in the open systems being approximately one year or older (Figure 5.3).

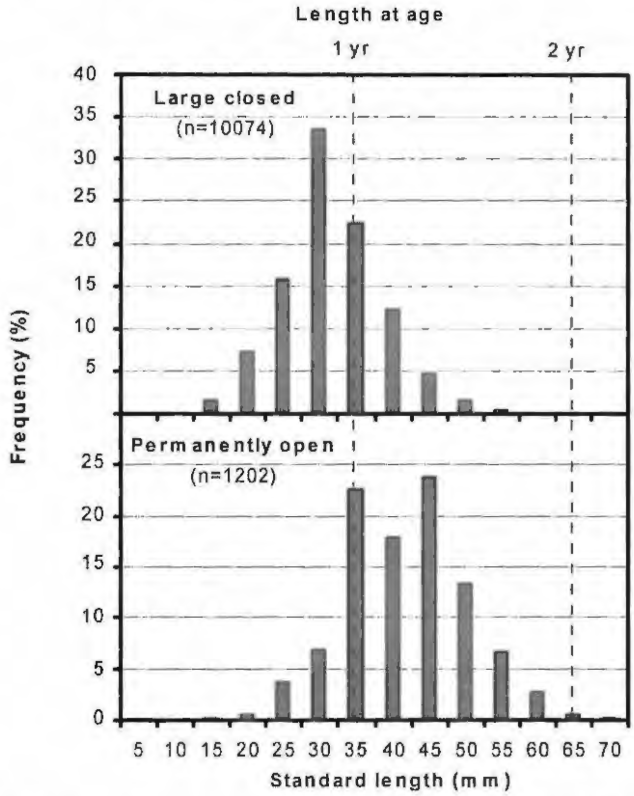


Figure 5.1: The length-frequency histograms for *Gilchristella aestuaria* in the large temporarily closed and permanently open systems. Length at age estimates after Talbot (1982).

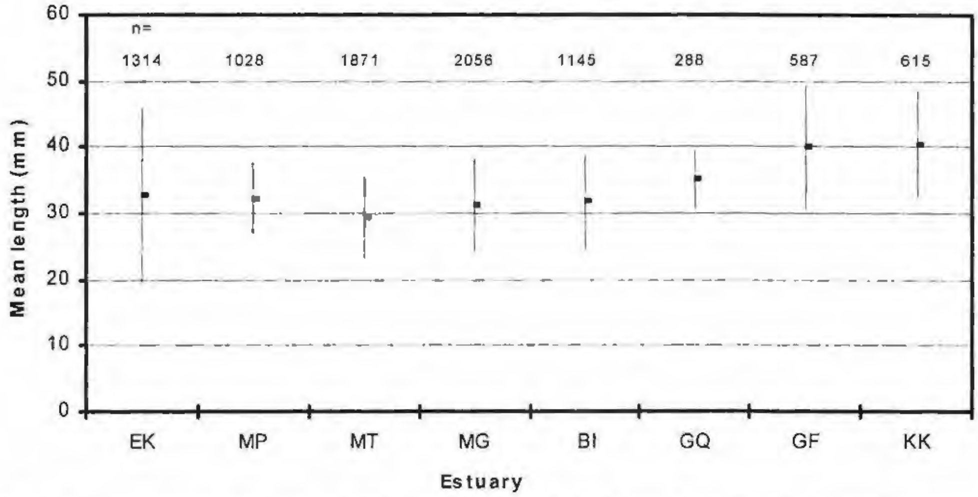


Figure 5.2: The mean and standard deviation of the lengths of *Gilchristella aestuaria* in each estuary. The number of fish measured (n) for each system is also shown. Each estuary is represented by a two letter code: EK=East Kleinemonde, MP=Mpekweni, MT=Mtati, MG=Mgwalana, BI=Bira, GQ=Gqutywa, GF=Great Fish and KK=Keiskamma.

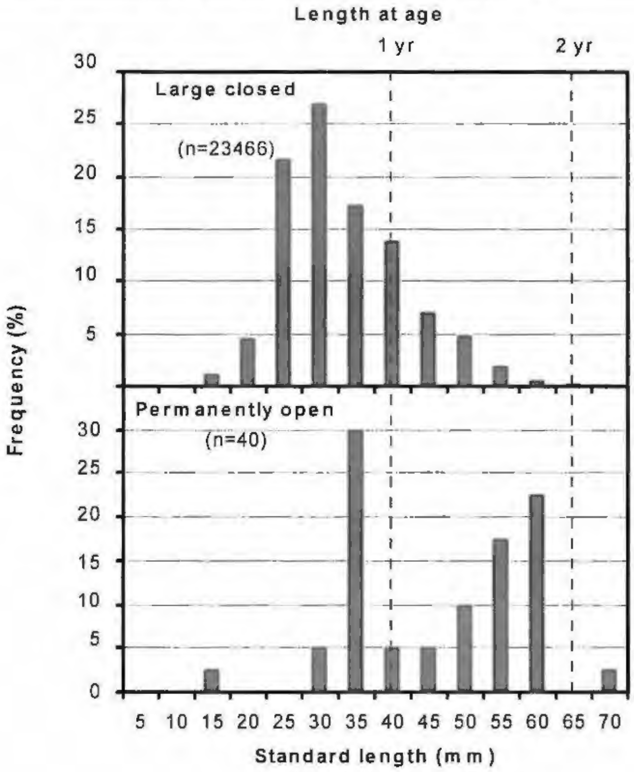


Figure 5.3: The length-frequency histograms for *Atherina breviceps* in the large temporarily closed and permanently open systems. Length at age estimates after Ratte (1989).

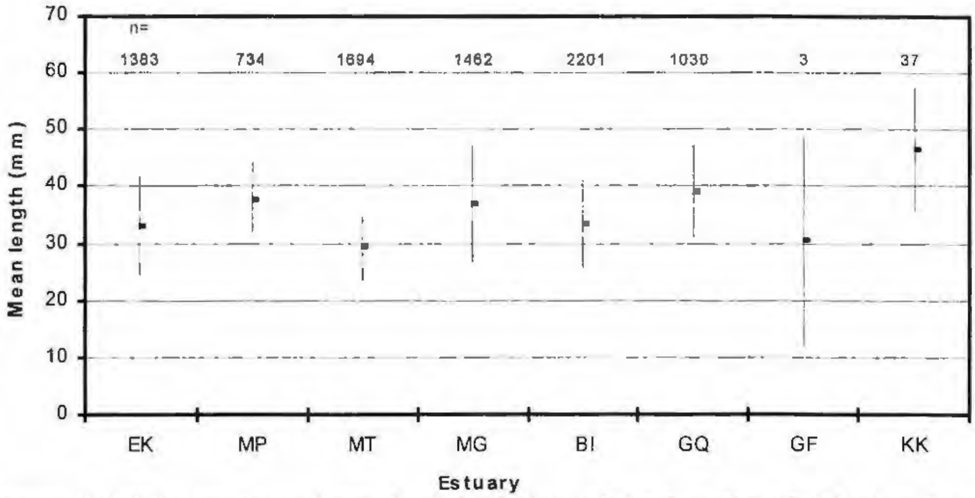


Figure 5.4: The mean and standard deviation of the lengths of *Atherina breviceps* in each estuary. The number of fish measured (n) for each system is also shown. Each estuary is represented by a two letter code: EK=East Kleinemonde, MP=Mpekweni, MT=Mtati, MG=Mgwalana, BI=Bira, GQ=Gqutywa, GF=Great Fish and KK=Keiskamma.

G. callidus length frequency distribution revealed a slightly skewed normal distribution in the closed systems, with only six individuals from four size classes recorded in the open systems (Figure 5.5). The modal size class of 35-40 mm in the large closed estuaries coincided with an age of one year. The majority of the fish were under two years of age with very few specimens recorded above that age (Figure 5.5). There was little variation in the mean length of fish within or between estuary types (Figure 5.6), with the mean length in the open estuaries being 44 mm SL (±7.8 SD) and the mean for the closed systems being 41 mm SL (±13.8 SD).

A second gobiid species, *P. knysnaensis*, had similar distributions of individuals in both estuary types, with the modal distribution in the open systems being one size class larger than in the closed estuaries (Figure 5.7). The majority of fish in both estuary types were approximately one year old. Figure 5.8 shows the limited differences in mean fish length between the individual systems, which is mirrored by the estuary types with an identical mean of 34 mm SL.

5.3.2 Marine migrant species

The distribution of individuals across the size classes for *P. commersonnii* is similar between the open and closed estuaries, being left-skewed in both cases (Figure 5.9). The modal size classes were between 70 mm and 120 mm in both estuary types with the majority of individuals being in the 0+ age class. There was a lack of variation in the individual estuaries (Figure 5.10) and between estuary types, with the permanently open systems having a mean fish length of 139 mm SL (±67.3 SD) and the large closed estuaries producing a mean of 145 mm SL (±85.1 SD). However the largest individuals were captured in the closed systems, with a maximum size of 562 mm, compared with 421 mm in the open estuaries.

R. holubi produced a left-skewed distribution in the large closed estuaries with the majority of individuals being under one year old (Figure 5.11). Similarly in the open systems most fish were under one year old, with a slightly more condensed length frequency distribution of individuals recorded. Very little variation was evident in the mean fish lengths between individual estuaries of the same type (Figure 5.12), yet a significant difference ($p<0.005$) between estuary types was calculated using the Kolmogorov-Smirnov test. The mean length in the open systems was 75 mm SL (±17.3 SD) and in the closed estuaries was 78 mm SL (±19.4 SD). The maximum sized individuals in the closed systems (222 mm SL) were considerably larger than those in the open estuaries (165 mm SL).

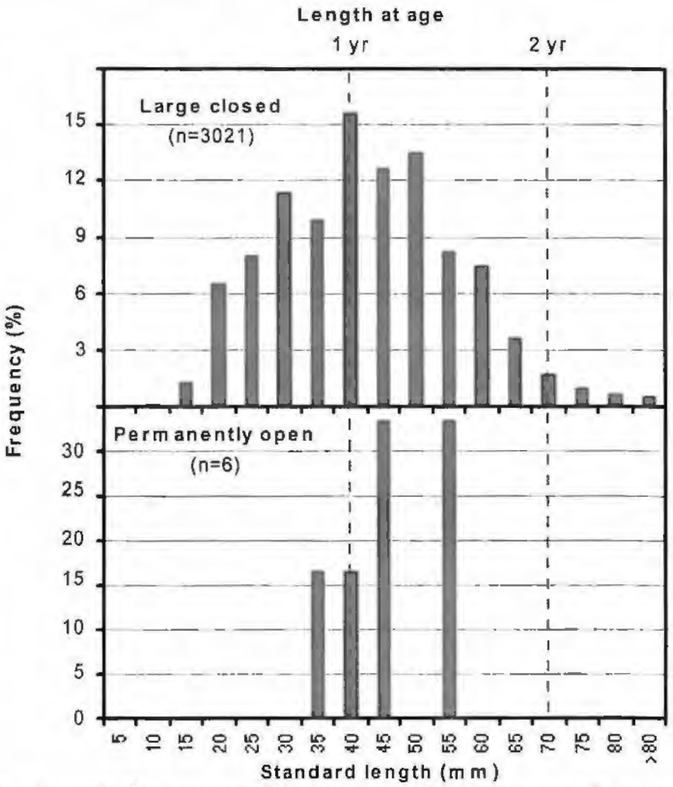


Figure 5.5: The length-frequency histograms for *Glossogobius callidus* in the large temporarily closed and permanently open systems. Length at age estimates after Boullé (1989).

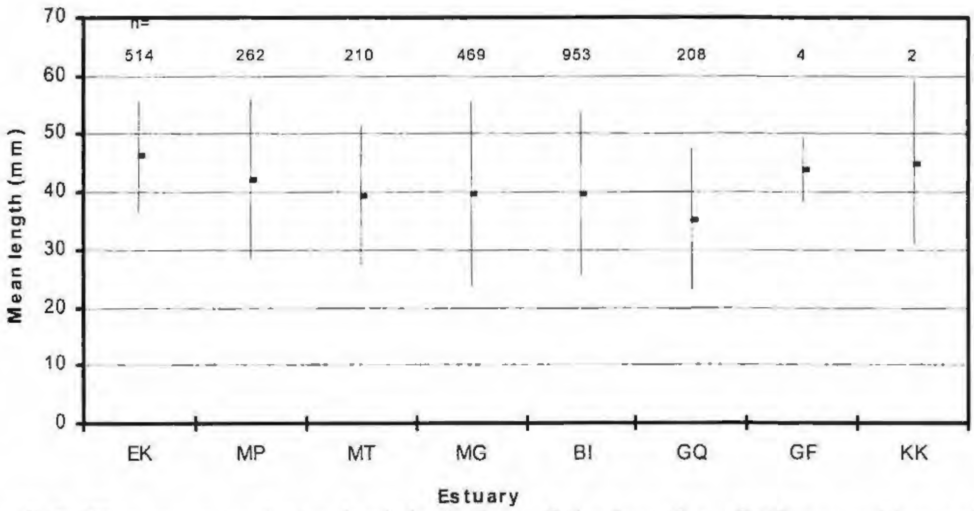


Figure 5.6: The mean and standard deviation of the lengths of *Glossogobius callidus* in each estuary. The number of fish measured (n) for each system is also shown. Each estuary is represented by a two letter code: EK=East Kleinemonde, MP=Mpekweni, MT=Mtati, MG=Mgwalana, BI=Bira, GQ=Gqutywa, GF=Great Fish and KK=Keiskamma.

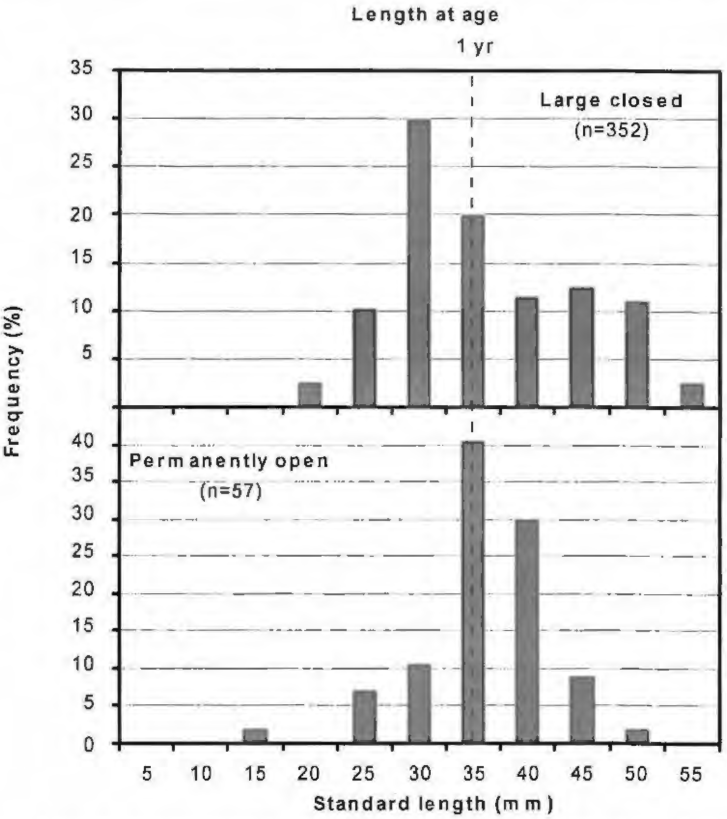


Figure 5.7: The length-frequency histograms for *Psammogobius knysnaensis* in the large temporarily closed and permanently open systems. Length at age estimates after Bennett (1989).

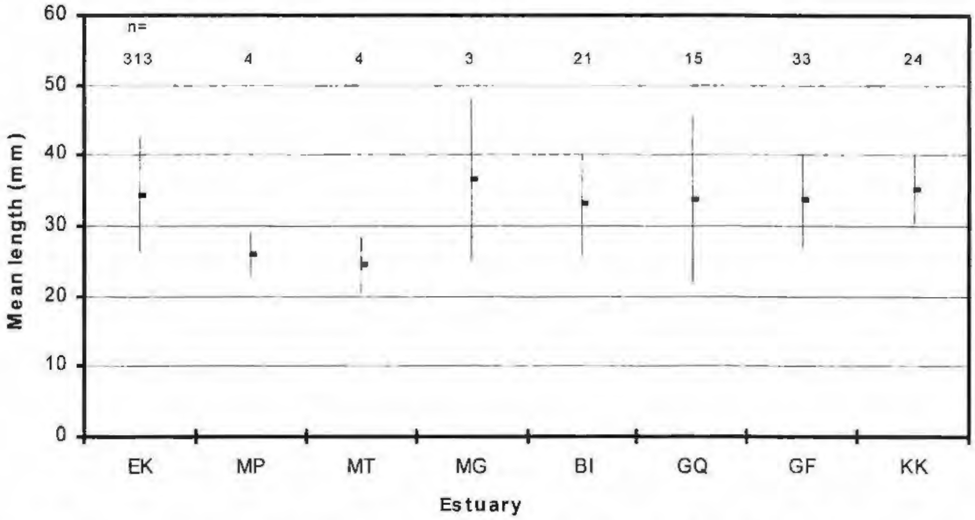


Figure 5.8: The mean and standard deviation of the lengths of *Psammogobius knysnaensis* in each estuary. The number of fish measured (n) for each system is also shown. Each estuary is represented by a two letter code: EK=East Kleinemonde, MP=Mpekweni, MT=Mtati, MG=Mgwalana, BI=Bira, GQ=Gqutywa, GF=Great Fish and KK=Keiskamma.

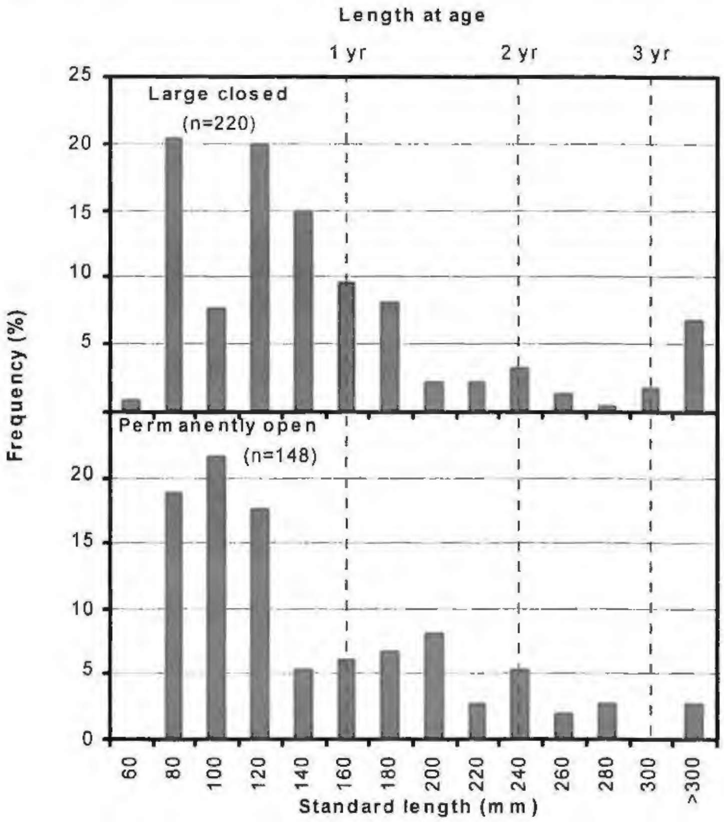


Figure 5.9: The length-frequency histograms for *Pomadasys commersonnii* in the large temporarily closed and permanently open systems. Length at age estimates after Wallace (1975b).

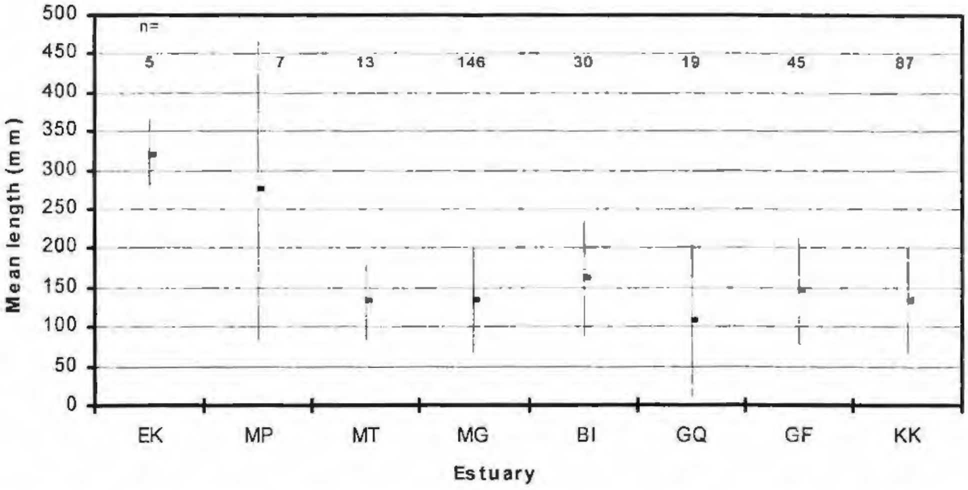


Figure 5.10: The mean and standard deviation of the lengths of *Pomadasys commersonnii* in each estuary. The number of fish measured (n) for each system is also shown. Each estuary is represented by a two letter code: EK=East Kleinemonde, MP=Mpekweni, MT=Mtati, MG=Mgwalana, BI=Bira, GQ=Gqutywa, GF=Great Fish and KK=Keiskamma.

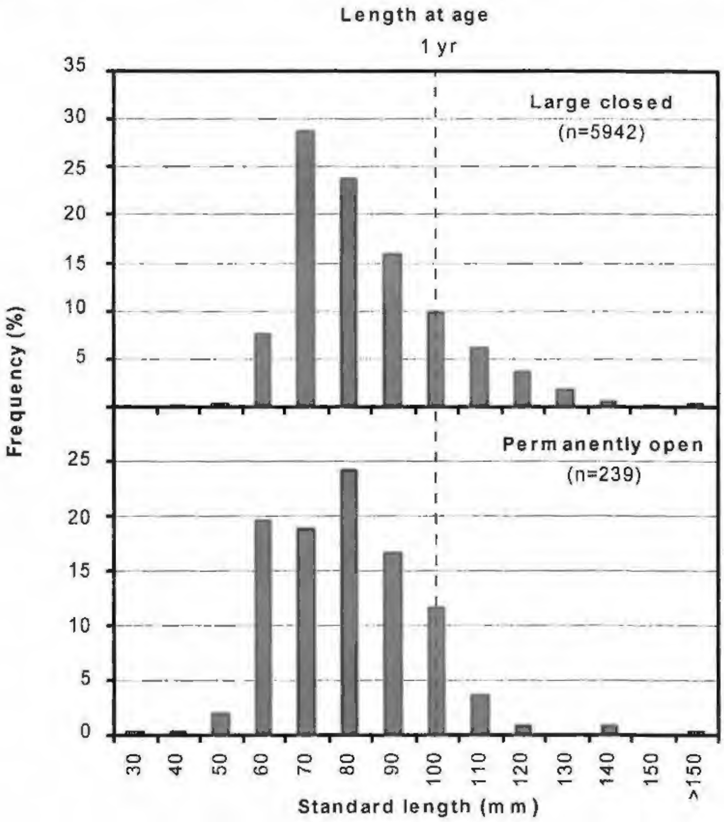


Figure 5.11: The length-frequency histograms for *Rhabdosargus holubi* in the large temporarily closed and permanently open systems. Length at age estimates after Blaber (1974).

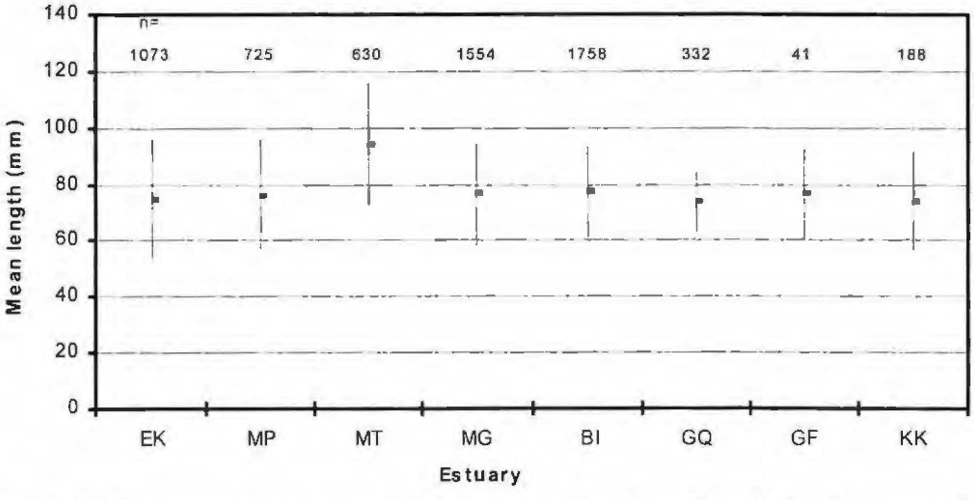


Figure 5.12: The mean and standard deviation of the lengths of *Rhabdosargus holubi* in each estuary. The number of fish measured (n) for each system is also shown. Each estuary is represented by a two letter code: EK=East Kleinemonde, MP=Mpekweni, MT=Mtati, MG=Mgwalana, BI=Bira, GQ=Gqutywa, GF=Great Fish and KK=Keiskamma.

A slightly left-skewed distribution was evident in the large closed estuaries compared with a much stronger left-skewed plot in the permanently open systems for *L. dumerilii* (Figure 5.13). Thirty-three percent of the individuals in the closed estuaries were below one year of age compared with 70% of individuals in the permanently open systems. Minimal differences were evident when comparing individual systems within each estuary type (Figure 5.14). However, the length frequency of *L. dumerilii* in the permanently open estuaries was calculated to be significantly smaller ($p<0.001$) than those in the large closed estuaries. This was evident in the mean fish length of 105 mm SL (±44.9 SD) for open estuaries and 137 mm SL (±36.3 SD) in closed estuaries.

Similar length frequency distributions were produced for the other mugilid species, *L. richardsonii* (Figure 5.15). In the large closed systems, the majority of individuals were in size classes corresponding to an age between one and two years, whereas in the permanently open systems most individuals belonged to the 0+ cohort. The open systems contained significantly smaller individuals ($p<0.001$) with a mean size of 118 mm SL (±54.6 SD) compared with *L. richardsonii* in the closed estuaries with a mean of 142 mm SL (±42.0 SD). The variation between different systems within the large closed estuary type was relatively small, with the two open systems showing increased differences in both mean size and ranges (Figure 5.16).

5.4 Discussion

The small sizes of estuarine resident species relative to marine migrant taxa is partly due to the estuarine residents having stenotopic traits and the marine migrants having eurytopic traits (sensu Ribbink, 1994). Whitfield (1990) also suggests that a small body size is well suited to a completely estuarine life-history style, with no requirement to undergo extensive migrations between the estuarine and marine environments. Whitfield (1990) further argues that many South African estuaries are shallow or have extensive littoral areas and smaller bodied species can utilise these more effectively than large taxa.

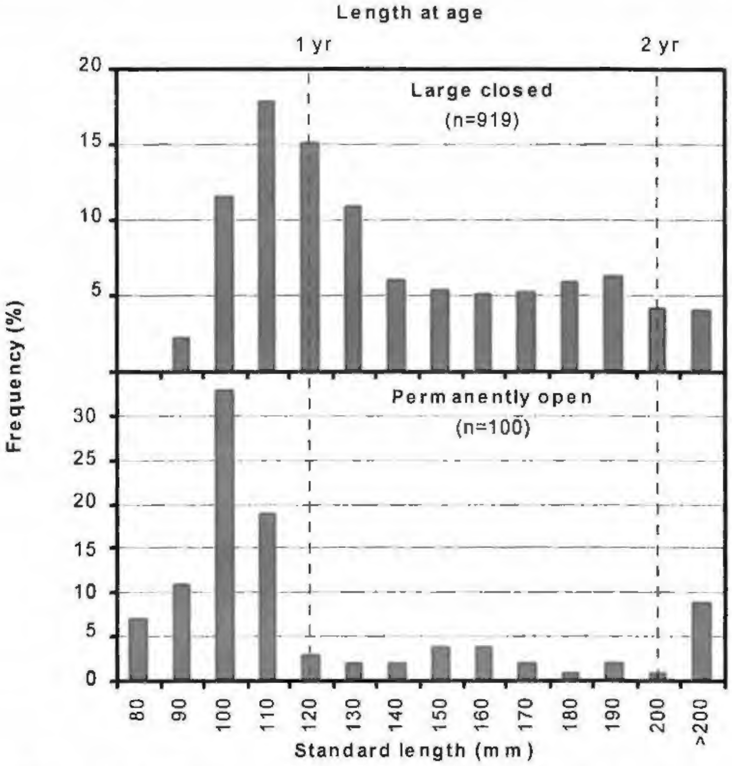


Figure 5.13: The length-frequency histograms for *Liza dumerilii* in the large temporarily closed and permanently open systems. Length at age estimates after van der Horst and Erasmus (1981).

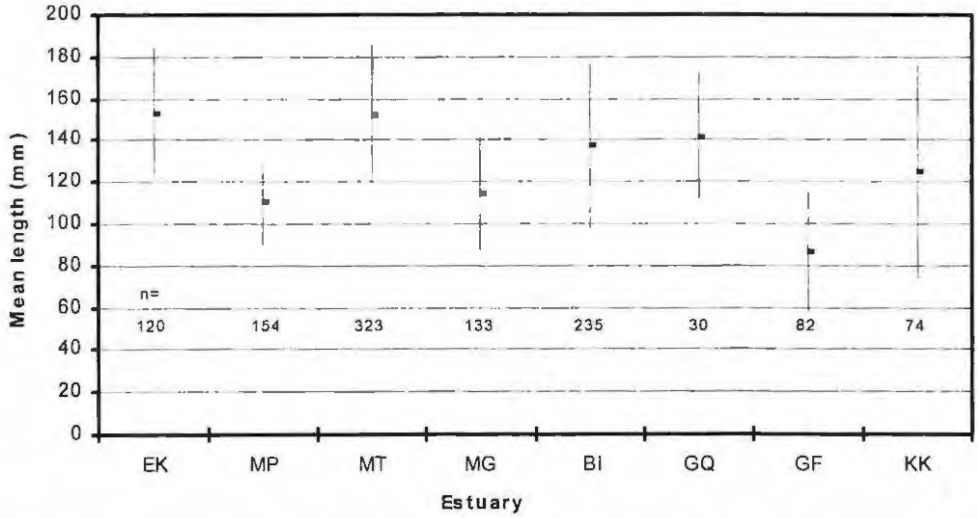


Figure 5.14: The mean and standard deviation of the lengths of *Liza dumerilii* in each estuary. The number of fish measured (n) for each system is also shown. Each estuary is represented by a two letter code: EK=East Kleinemonde, MP=Mpekweni, MT=Mtati, MG=Mgwalana, BI=Bira, GQ=Gqutywa, GF=Great Fish and KK=Keiskamma.

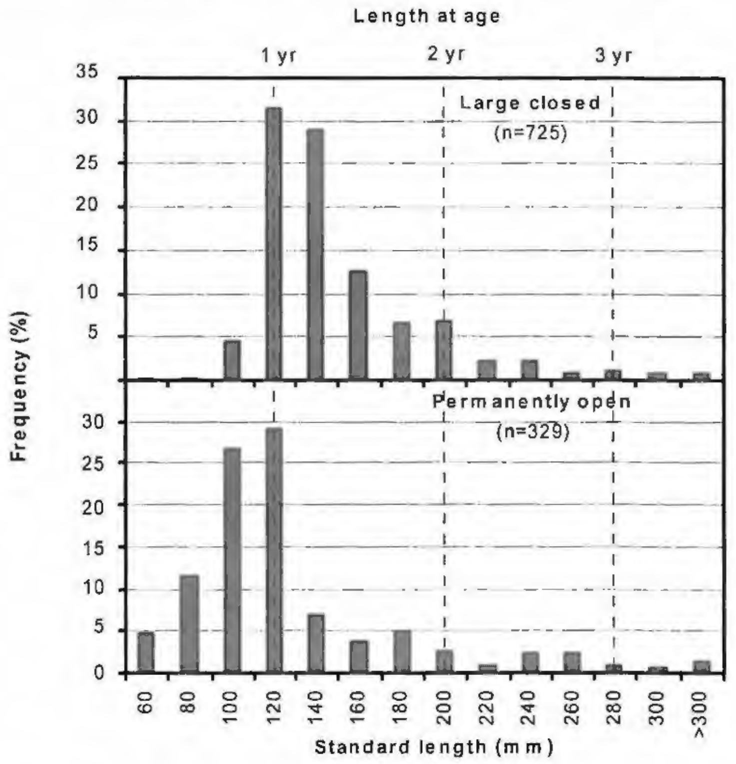


Figure 5.15: The length-frequency histograms for *Liza richardsonii* in the large temporarily closed and permanently open systems. Length at age estimates after de Villiers (1987).

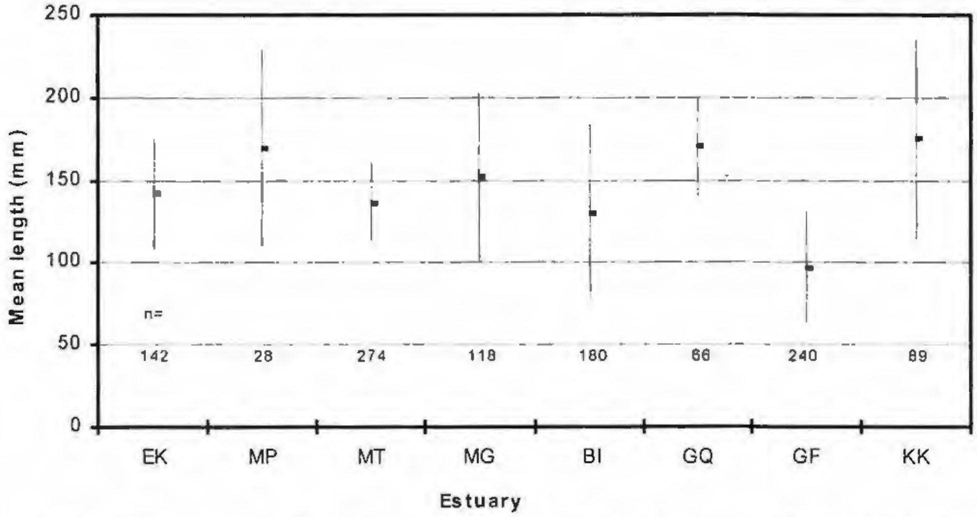


Figure 5.16: The mean and standard deviation of the lengths of *Liza richardsonii* in each estuary. The number of fish measured (n) for each system is also shown. Each estuary is represented by a two letter code: EK=East Kleinemonde, MP=Mpekweni, MT=Mtati, MG=Mgwalana, BI=Bira, GQ=Gqutywa, GF=Great Fish and KK=Keiskamma.

The larger modal size of estuarine resident species in permanently open compared with closed systems may be indicative of a higher survival rate of smaller individuals in closed estuaries. The higher predation rate of larger individuals in the closed systems may be linked to the clearer waters found in these estuaries. Cyrus and Blaber (1987a; 1987b) have suggested that small fish undergo lower predation rates in turbid water environments. In this study, the open estuaries had higher turbidity levels than the closed systems, thus providing better protection to the larger (more visible) size cohorts of the small pelagic estuarine species. The increased loss of larvae and juveniles from the open estuaries due to the flushing effect of the ebb tide is also a possibility. In contrast, all these size classes would be retained in closed estuaries thus elevating their relative contribution to the overall population.

In the permanently open estuaries the maximum size of the two goby species was smaller than in the closed systems, whereas the two planktivorous species (*A. breviceps* and *G. aestuaria*) revealed the opposite trend. These results may be due to differences in available resources. Feeding studies on *G. aestuaria* and *A. breviceps* have shown that these species feed mainly on a variety of small crustaceans and insect larvae (Coetzee, 1982; White and Bruton, 1983; Cyrus *et al.*, 1993). Blaber (1979) found that in turbid estuaries, *G. aestuaria* was a planktonic filter feeder, whereas in clear water systems this species was predatory (Blaber *et al.*, 1981). The two goby species, *G. callidus* and *P. knysnaensis*, also feed on small crustaceans and insect larvae but are not planktivorous (Whitfield, 1988; Bennett and Branch, 1990). The trends of larger gobiid individuals in the closed estuaries and larger clupeid and atherinid individuals in the open systems may be due to differences in food resources in the different systems. The open estuaries are plankton rich due to riverine and marine nutrient inputs (Froneman, *pers. comm.*, Froneman, in press), while the closed systems have numerous small crustaceans associated with the extensive submerged macrophyte beds (Reavell and Cyrus, 1989; Takeuchi and Hino, 1997).

The length-frequency distributions of *G. aestuaria* in an earlier study of the closed Mhlanga Estuary (Harrison and Whitfield, 1995) showed similar trends and an identical modal size class of 30 mm when compared with the closed systems in this study. Kok and Whitfield (1986) reported almost identical size distributions for *A. breviceps* in the Swartvlei Estuary during the open and closed mouth stages. The current study identified significantly different length-frequency distributions, with the closed systems having a modal size class half that recorded in the Swartvlei system during closed mouth phases.

The gobiid species, *G. callidus* and *P. knysnaensis*, had similar length frequencies in closed estuaries during this study when compared with an earlier investigation of the temporarily open East Kleinemonde (Cowley, 1998). The modal size class of *G. callidus* in this study was one size class higher than that recorded by Cowley (1998), while *P. knysnaensis* had an identical modal size class during both studies. The mean size of *G. callidus* during this study was the same as the earlier East Kleinemonde study, with means of 41.0±13.8 mm and 41.6±12.8 mm respectively. Also, the modal size class and length-frequency distributions of *G. callidus* in the closed estuaries during this study and in the closed Damba and Zotsha estuaries were similar (Harrison and Whitfield, 1995).

The length frequency of estuarine species peaks under one year of age in the closed estuaries compared with one year or older in the open systems. All these species commence breeding at approximately seven to nine months of age (Bennett, 1989; Boullé, 1989; Ratte, 1989; Talbot, 1982). As discussed earlier, the difference in dominant age classes is probably a feature of differential mortality or resource availability.

Three of the four marine migrant species, namely *P. commersonnii*, *L. dumerilii* and *L. richardsonii*, had different length-frequency distributions in the two estuary types. These species had a greater proportion of smaller individuals in the open systems and fewer middle to large size class individuals compared with the closed estuaries. The modal size class for all four species was however similar in both estuary types, e.g. *P. commersonnii* and *R. holubi* in the permanently open estuaries was one size class greater than in the closed systems, while *L. dumerilii* was one size class smaller in the open estuaries. *L. richardsonii* had an identical modal size class in both estuary types. The relatively similar length-frequency distributions between these two estuary types is difficult to explain, as a smaller size range of marine migrant species would be expected in closed systems due to restricted temporal linkages with the sea (Bennett, 1989). Conversely, access to the sea is always available to these species in the permanently open estuaries, and therefore a more even distribution of individuals across a range of size classes would be expected.

The larger maximum sized marine migrant individuals occurring in closed systems may be as a result of these species being trapped in closed estuaries for extended periods. In addition, the inability to reproduce in the estuarine environment means that all surplus energy obtained from feeding is used for growth and not channelled into gonad development. The fish entering open systems are often 0+ juveniles that reside in these systems for 1-3 years before departing in time for the breeding season (Bennett, 1989; Whitfield, 1990). Adults of certain marine species are known to enter these systems to feed, but this is generally for short periods, hence the lower catches of these large individuals.

Harrison and Whitfield (1995) found that the length-frequency distributions of mugilids in temporarily closed KwaZulu-Natal estuaries generally demonstrated a bimodal trend, dominated by juvenile and adult size classes. These size distributions differ from those identified during this study, with mostly juveniles and sub-adults (<140) predominating (Figure 5.13 and 5.15). These differences may be due to the more frequent mouth opening events in the KwaZulu-Natal estuaries (at least once annually) compared with mouth openings in this study. Conversely, *R. holubi* was only found in small size classes (<100 mm) in the closed Zotsha Estuary (Harrison and Whitfield, 1995), which is comparable to the findings in this study. In a previous investigation of the permanently open Great Fish Estuary (Whitfield *et al.*, 1994), *R. holubi* had a higher frequency of individuals greater than 100 mm compared with this study, but *L. dumerilii* had an identical modal size class during the two studies.

The length frequency distributions have demonstrated differences between the permanently open and closed systems, which can be related to the variation in access these species have to the marine environment in these different estuarine types and differences in foraging strategies.

CHAPTER 6

ESTUARINE OTTER TRAWLING

6.1 Introduction

There have been very few studies that have used otter trawl nets to sample fishes within South African estuaries. These include studies by Paterson (1998) in the permanently open Kariega Estuary, and by Harrison and Whitfield (1995) in the temporarily closed Zotsha, Damba and Mhlanga estuaries. However, in other parts of the world, particularly north America, otter trawling has been used to assess fish stocks in estuaries and salt marshes since the 1960's (Robson and Regier, 1964; Kjelson and Johnson, 1978; Hartman and Herke, 1987; DeAlteris *et al.*, 1989; Rulifson, 1991; Stokesbury *et al.*, 1999).

As with most gear types, the selectivity of trawl nets is dependent on the design and deployment of the gear (Barkley, 1972). Capture efficiency has been shown to increase with mouth width (Kjelson and Johnson, 1978) and towing speed (DeAlteris *et al.*, 1989). Capture rates of benthic species were also shown to increase when a tickler chain was included in the net design (Chittenden and Van Engel, 1972) and when tow durations were increased (Stokesbury *et al.*, 1999).

Otter trawling is also subject to species selectivity. Rulifson (1991) found that this technique was particularly efficient at capturing small bodied, schooling species, while DeAlteris *et al.* (1989) found that demersal species were over represented in the trawl samples. In a study comparing various gear types, Hartman and Herke (1987) concluded that otter trawling had the lowest capture efficiency for most species, except for some schooling and benthic individuals.

The data from this sampling technique has been presented separately, as the technique was included in the latter years of the study and consequently it was only used in a few of the estuaries. This chapter attempts to identify any otter trawl differences in fish community structure between open and closed estuaries, and also attempts to describe the benefits or disadvantages of this sampling technique.

6.2 Materials and Methods

6.2.1 Ichthyofaunal sampling

The estuaries included in this study were the East Kleinemonde, Great Fish, Mtati, Bira and Ngculura. The total number of trawls conducted in each estuary depended on the size of the system and differed between seasons (Table 6.1). Otter trawling took place bi-annually with all five estuaries being sampled between 1-5 June 1999 (winter sample) and 7 and 11 February 2000 (summer sample). All sampling was conducted at night to reduce net evasion and on a slack tide in the open systems to reduce tidal drag on the net.

Table 6.1: The number of trawls conducted in each estuary per season.

Estuary Name	Estuary Type	Number of Trawls in Winter	Number of Trawls in Summer
Ngculura	Small Closed	2	2
East Kleinemonde	Large Closed	10	6
Mtati	Large Closed	10	9
Bira	Large Closed	12	12
Great Fish	Permanently open	12	12

The conical shaped otter trawl net, with a 1.25 m long chain bottom line and a 2 m buoyed head rope, consisted of 6 mm stretch mesh. The wings of the net were attached to otter boards (42 cm x 22 cm) on a 20 m rope. The net was slowly lowered over the stern of the motorized boat while idling forward, once the entire length of the rope had been paid out the speed was increased to a standard throttle setting. The duration of each trawl was three minutes covering a distance of approximately one hundred metres as determined by the standard throttle position.

After trawling the samples were pulled onto the boat and emptied into a sorting tray, where all freshwater and marine migrant or straggler species were measured and released, and all estuarine resident species were retained and fixed in 10% formalin for measurement and identification in the laboratory.

6.2.2 Physico-chemical sampling

At each sampling site bottom temperature, salinity and turbidity were recorded. In addition, water depth, cross-sectional area, average estuary width, percentage macrophyte cover and sediment organics were documented (See Chapter 4 for details).

6.2.3 Data analysis

Species richness and diversity were calculated using the Margalefs and Shannon-Wiener indices as described in Chapter 3. The method of analysis used to describe the community structures in the different estuaries is given in Chapter 4.

A Kruskal-Wallis ANOVA (Analysis of Variance) by ranks was used to test for significant differences in the CPUE between small closed, large closed and permanently open estuaries, with each sample being entered independently. Similarly, a Kolmogorov-Smirnov test was used to determine the significance of any seasonal differences or overall differences between open and closed estuaries. Both these tests were conducted using the computer program STATISTICA® for Windows.

6.3 Results

6.3.1 Physico-chemical results

The mean physico-chemical results for each estuary on a seasonal basis are presented in Table 6.2. The estuarine size measurements that were used in the community analysis are presented in Table 4.1 (see Chapter 4). The mean depth of the samples was identical during both seasons in all systems except the Ngculura and East Kleinemonde (Table 6.2). In the Ngculura the mean winter water level was 0.5 m deeper than during summer and in the East Kleinemonde the mean summer water level was 0.2 m deeper than the winter sample. The salinity variation across the systems was more pronounced; within the large closed systems there was approximately a 5‰ salinity difference between the seasons, and only a 1-2‰ difference in the small closed and permanently open estuaries (Table 6.2). In all the closed systems there were relatively large temperature differences between summer and winter of between 8°C and 16°C, while the permanently open system had a relatively small temperature variation of 5°C. The measured turbidity followed an estuarine size rank, with only the Mtati Estuary being out of rank order in that it had a higher turbidity than the Bira. The permanently open Great Fish was significantly higher by an order of magnitude during winter, while during summer the Mtati had a relatively high turbidity reading of 76.9 NTU (Table 6.2).

Table 6.2: Physico-chemical results (bottom samples: mean (±SD)) during the otter trawls in each system.

Estuary	**Depth (m)**		**Salinity (‰)**		**Temperature (°C)**		**Turbidity (NTU)**	
	Win	**Sum**	**Win**	**Sum**	**Win**	**Sum**	**Win**	**Sum**
Ngculura	1.1 (0.71)	0.6 (0.18)	4.0 (0.00)	3.0 (1.41)	17.0 (0.18)	28.2 (0.28)	4.0 (1.41)	9.3 (1.06)
East Kleinemonde	2.0 (0.47)	2.2 (0.45)	11.5 (0.50)	17.2 (8.26)	17.9 (0.32)	26.3 (0.10)	4.4 (0.39)	11.8 (7.58)
Mtati	1.9 (0.23)	1.9 (0.23)	15.7 (0.48)	20.6 (0.53)	12.4 (0.47)	28.5 (0.80)	24.7 (36.34)	76.9 (51.81)
Bira	1.5 (0.51)	1.5 (0.51)	27.0 (1.04)	22.3 (1.60)	14.0 (0.45)	27.7 (0.78)	25.5 (30.33)	19.9 (24.30)
Great Fish	1.6 (0.30)	1.6 (0.30)	16.3 (14.41)	14.5 (15.92)	18.0 (0.85)	23.2 (3.07)	114.4 (62.83)	115.1 (47.46)

6.3.2 Species composition and comparative abundance

A total of 7265 individuals consisting of 14 species were caught during the otter trawl sampling (Table 6.3). Two of the three most abundant species, namely *Glossogobius callidus* (85% of the catch) and *Solea bleekeri* (4% of the catch) were demersal taxa, while the third, *Gilchristella aestuaria* (8% of the catch) was a pelagic species. A wide size range of the two dominant demersal species was recorded, while the pelagic *G. aestuaria* was represented mainly by adults. Eight species were caught in only one or two estuaries, while the remaining six species were caught in a minimum of three systems. Only two species, namely *G. aestuaria* and *G. callidus* were caught in all five estuaries (Table 6.3).

Table 6.3: The number, rank and size range of species caught in the otter trawl net.

Family	Species	Total caught	Rank (n)	Size range (mm)	Presence in N estuaries
Ambassidae	*Ambassis natalensis*	6	8	47-55	1
Ariidae	*Galeichthys feliceps*	6	8	45-135	1
Atherinidae	*Atherina breviceps*	40	6	22-46	2
Clupeidae	*Gilchristella aestuaria*	594	2	14-47	5
Gobiidae	*Caffrogobius nudiceps*	1	11	108	1
	Glossogobius callidus	6179	1	9-85	5
	Psammogobius knysnaensis	46	5	11-67	4
Haemulidae	*Pomadasys commersonnii*	37	7	95-780	4
Hemiramphidae	*Hyporhamphus capensis*	1	11	43	1
Monodactylidae	*Monodactylus falciformis*	1	11	90	1
Sciaenidae	*Argyrosomus japonicus*	5	10	71-154	2
Soleidae	*Heteromycteris capensis*	1	11	28	1
	Solea bleekeri	282	3	15-81	4
Sparidae	*Rhabdosargus holubi*	66	4	27-108	3

6.3.3 Seasonal variation

There was very little seasonal variation in the total number of individuals and species caught, with 3204 individuals (11 species) caught in summer and 4061 individuals (14 species) in winter. There was a lower percentage of estuarine residents caught in winter in all the systems except for the Mtati, which had the same contributions during both seasons, and the Ngculura, which had fewer estuarine residents in summer (Figure 6.1).

6.3.4 Relative contribution of estuarine dependence categories

The closed estuaries were dominated by estuarine resident species (90-99%), while the permanently open estuary was dominated by marine migrant species (80-86%) (Figure 6.1). There were no individuals of any other estuarine association category captured.

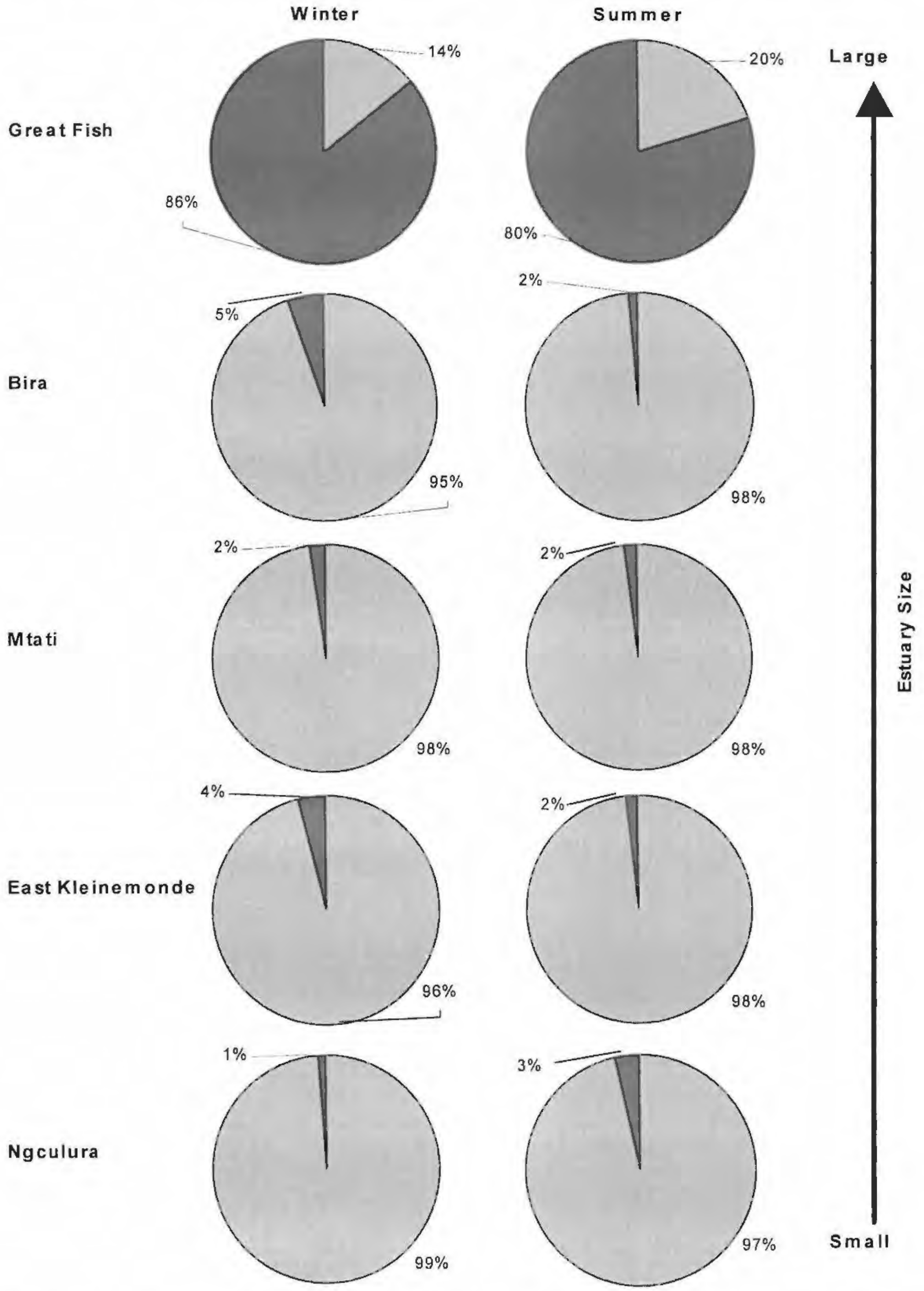


Figure 6.1: The contribution of each estuarine association category to abundance of fishes in the otter trawl samples in each system during summer and winter. Dark shading represents the marine migrant contribution and light shading represents the estuarine resident contributions.

6.3.5 Species abundance in different estuaries

G. callidus dominated the catches in the closed systems, contributing over 90% of the catch in each estuary except the Mtati (76.4%). The dominant marine migrant in the large closed estuaries was *S. bleekeri* (1.4-2% of the catch), while in the Ngculura, a small closed estuary, *Rhabdosargus holubi* was the dominant marine migrant (Table 6.4). The catch in the permanently open Great Fish Estuary was dominated by the marine migrant *S. bleekeri* (73.3%), with *G. callidus*, an estuarine resident contributing only 8.9% (Table 6.4).

Table 6.4: The percentage contribution of each species to the overall catch in each estuary and the total number of individuals and species caught during both seasons.

Family	**Species**	**Bira**	**East Kleinemonde**	**Great Fish**	**Mtati**	**Ngculura**
Ambassidae	*Ambassis natalensis*	0.2				
Ariidae	*Galeichthys feliceps*			2.5		
Atherinidae	*Atherina breviceps*	1.5			0.1	
Clupeidae	*Gilchristella aestuaria*	2.9	5.5	6	20.2	0.6
Gobiidae	*Caffrogobius nudiceps*		0.6			
	Glossogobius callidus	90.8	90.5	8.9	76.4	97.1
	Psammogobius knysnaensis	0.3	0.6	3	1	
Haemulidae	*Pomadasys commersonnii*	0.5	0.1	4.6	0.6	
Hemiramphidae	*Hyporhamphus capensis*				0.1	
Monodactylidae	*Monodactylus falciformis*				0.1	
Sciaenidae	*Argyrosomus japonicus*	0.4		1.7		
Soleidae	*Heteromycteris capensis*				0.1	
	Solea bleekeri	2	1.7	73.3	1.4	
Sparidae	*Rhabdosargus holubi*	1.4	1			2.3
	Total individuals	2559	1772	237	2008	689
	Total species	9	7	7	9	3

6.3.6 Species richness and diversity

The diversity and richness values calculated from the otter trawl data ranged from 0.05 – 0.44 and 0.89 – 6.03 respectively (Table 6.5). The ranking of the estuaries on the basis of the index values corresponded to an estuarine size ranking, but the small sample size does not permit an accurate correlation analysis to be run. The Mtati is the only system that is out of rank order, as it has a higher richness and diversity than the Bira, which is a larger estuary (Table 6.5). The permanently open Great Fish has a higher richness (6.03) and diversity (0.44) than any of the closed systems, while the small closed Ngculura has the lowest values for both indices (0.89 and 0.05 respectively).

Table 6.5: Margalefs Richness Index and the Shannon-Wiener Diversity calculated from the otter trawl samples for each estuary. The estuaries are ordered according to size, from smallest to largest.

Estuary	Margalefs Richness Index	Shannon-Wiener Diversity
Ngculura	0.89	0.05
East Kleinemonde	2.89	0.16
Mtati	3.96	0.29
Bira	3.95	0.19
Great Fish	6.03	0.44

6.3.7 Community analysis

The cluster analysis of the fish communities, using Bray-Curtis similarity, produced two distinct separations (Figure 6.2). These include a separation between the permanently open and closed estuaries at a similarity level of 50% ($p=0.02$, $R=0.76$), and a further separation between the small and large closed estuaries at a similarity level of 62% ($p=0.03$, $R=0.93$). There were no significant differences between the summer and winter samples ($p>0.05$), with both seasons from each estuary separating as a pair (Figure 6.2). The multi-dimensional scaling plot of this cluster analysis shows the fish communities separating out according to estuary size (Figure 6.3). Although not significant ($p>0.05$), a difference between the Mtati Estuary and the remaining large closed estuaries was also evident. Figure 6.3 also reveals the lack of seasonal differences.

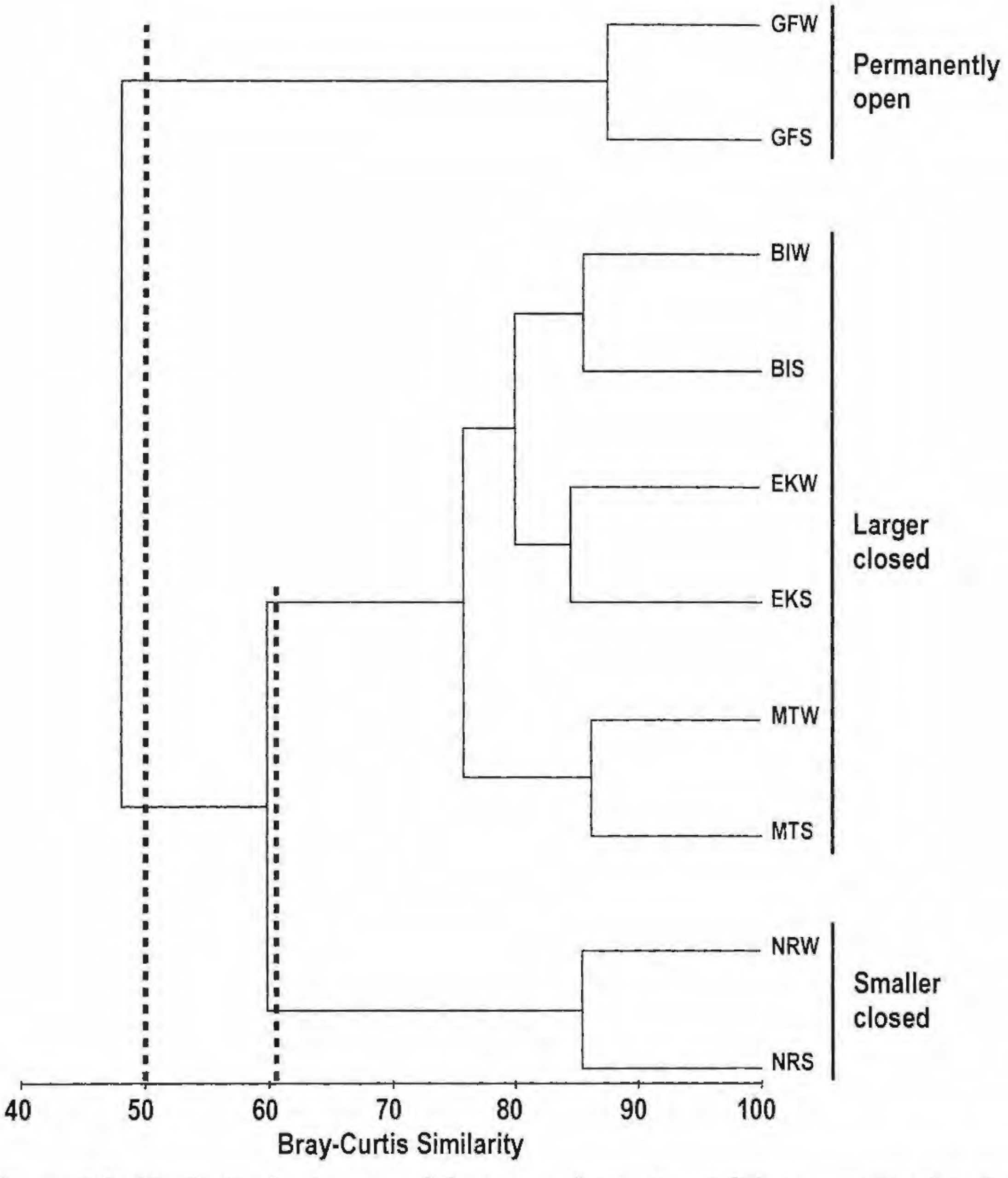


Figure 6.2: Similarity dendogram of the seasonal otter trawl fish community data for each estuary. The open and intermittent systems separate at a 50% similarity (p=0.02, R=0.76) while the small and large intermittent systems separate at a 62% similarity (p=0.03, R=0.93). There is a three letter code representing each sample, the first two letters are an estuary code (BI=Bira, EK=East Kleinemonde, GF=Great Fish, MT=Mtati, NG=Ngculura) and the last is a season code (S=summer, W=winter).

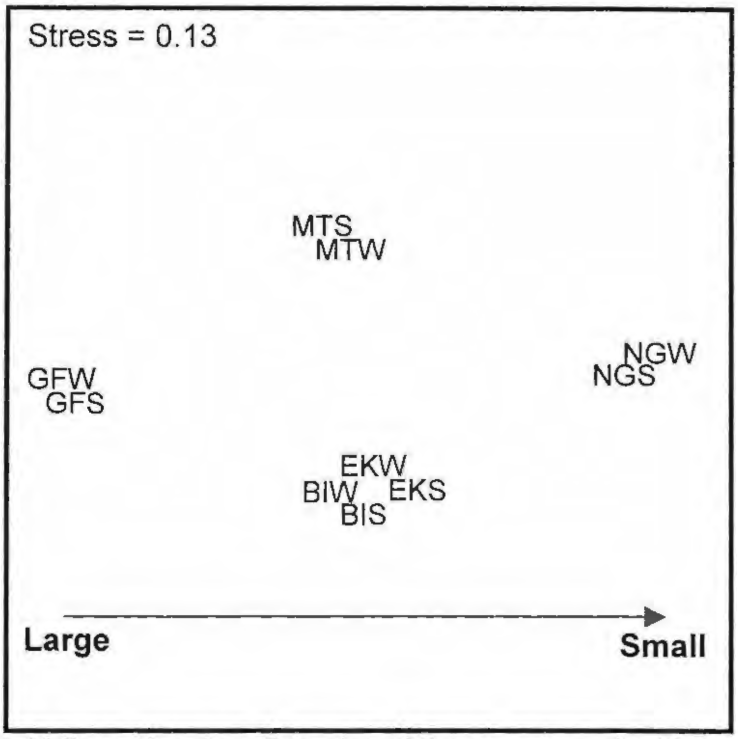


Figure 6.3: Multidimensional scaling plot of the two most significant dimensions of the otter trawl fish community data. The line shows the distribution of estuaries along a size axis from large to small. There is a three letter code representing each sample, the first two letters are a river code (BI=Bira, EK=East Kleinemonde, GF=Great Fish, MT=Mtati, NG=Ngculura) and the last is a season code (S=summer, W=winter).

Further analyses of the CPUE data provided confirmation of the above findings. The Kolmogorov-Smirnov two sample test on the differences in CPUE between the open and closed estuaries identified significant differences ($p<0.01$, $n=87$). Similarly, a Kruskall-Wallis ANOVA of the CPUE's from the small and large closed estuaries were significantly different ($p=0.0001$, $n=63$). A Kolmogorov-Smirnov two sample test on the CPUE results revealed that the seasonal variation was not significant ($p>0.1$, $n=87$).

SIMPER showed that three species accounted for more than 50% of the dissimilarity between the open and closed estuaries. *G. callidus* accounted for the highest percentage of dissimilarity (31.56%), *S. bleekeri* and *R. holubi* contributed 10% each towards the dissimilarity, while the remaining eleven species collectively contributed approximately 45% towards the dissimilarity of the samples.

The dissimilarity between the large closed and small closed estuaries was dominated by five species, which all contributed more than 10% towards the overall dissimilarity. These five species collectively accounted for over 70% of the dissimilarity between these systems. *S. bleekeri* (18.7%) accounted for the greatest dissimilarity, followed by *G. aestuaria* (17.8%), *R. holubi* (12.1%), *Pomadasys commersonnii* (12.0%) and *Psammogobius knysnaensis* (12.0%).

Three environmental variables provided significant correlations with the community analysis results (Table 6.6). These were catchment size (R=0.65, p=0.05), mean annual run-off (R=0.659, p=0.05) and the cross-sectional area (R=0.771, p=0.02). The remaining variables did not correlate significantly with the community analyses (Table 6.6). The highest correlation (R=0.868, p=0.005), and therefore the best explanation of the community differences, is a combination of three variables, namely mouth status, cross-sectional area and the percentage cover of submerged macrophytes.

Table 6.6: Summary statistics for the Harmonic Spearman correlation between environmental variables and the otter trawl community analysis. An asterisk (*) on the p-value indicates the variable contributed to the highest correlation of combined variables.

Variable	**Combined Seasons (n=10)**	
	R	**p**
Mouth Status	0.62	>0.05*
Catchment Size	0.65	0.05
Mean Annual Runoff	0.65	0.05
Estuarine Area	0.58	>0.05
Linear Length	0.63	>0.05
Depth	0.26	>0.05
Average Width	0.45	>0.05
Cross-sectional Area	0.77	0.02*
Temperature	-0.21	>0.05
Salinity	0.16	>0.05
Turbidity	0.59	>0.05
Sediment Organics	0.34	>0.05
%Submerged Macrophytes	0.42	>0.05*
Highest Correlation	0.86	0.005

6.4 Discussion

The domination by estuarine resident species in the closed systems and by marine migrant species in the permanently open systems (Figure 6.1) is mainly due to the nature of these species, but does indicate that this technique reflects the status of the marine connection of these estuaries. The relatively high percentage contribution of *R. holubi*, a comparatively fast-swimming pelagic species, to the catch in the Ngculura when compared with the other closed systems, can be explained by the shallow nature of this system when compared with the other estuaries. Effectively, the otter trawl was sampling a greater proportion of the water column in this system when compared with the others and hence reducing the opportunity for net avoidance, resulting in the higher contribution by a non-demersal marine migrant species.

Similar results have been recorded in the other studies conducted in South African estuaries. In the seasonally open Zotsha, Damba and Mhlanga estuaries, Harrison and Whitfield (1995) identified *G. aestuaria*, *G. callidus* and *Oreochromis mossambicus* as the dominant species. The much lower contribution of *S. bleekeri* is surprising as these KwaZulu-Natal systems opened more frequently than the intermittently open estuaries during this study. The higher proportion of *G. aestuaria* in the Zotsha, Damba and Mhlanga may be due to their shallow nature, allowing for sampling a greater proportion of the water column, thereby increasing the chances of catching this species. The otter trawl study conducted in the permanently open Kariega Estuary (Paterson, 1998) had similar results to that of the Great Fish in this study. The catch in both estuaries was dominated by *S. bleekeri*, although in the Kariega it represented a lower proportion of the total catch (53.2%) compared with the Great Fish (73.3%). *G. callidus* was the second most dominant species in both systems, followed with much lower contributions by *P. knysnaensis* and *G. aestuaria*.

In all five study estuaries the samples were numerically dominated by demersal species, with very small contributions from pelagic fishes. DeAlteris *et al.* (1989) found a similar result when conducting trials on two different sized otter trawl nets. Conversely, Rulifson (1991) found that the dominant species in otter trawl samples from South Creek Estuary, North Carolina, were schooling species. Rulifson (1991) suggested that when these individuals were captured the entire schools were trapped in the nets, thereby increasing the proportion of these species. This theory was supported by the Mtati Estuary results where the pelagic *G. aestuaria* contributed 20% of the catch, with the majority (64%) being captured in only four of the 19 trawls in this system.

In the Great Fish Estuary the higher diversity calculated was due to a higher abundance of each species caught. Although in this estuary the catch was dominated by *S. bleekeri*, the remainder of the species all contributed more than 1.5% to the catch (Table 6.4). The other estuaries were dominated by one or two species, while the remaining species made very small contributions to the overall catch (Table 6.4). The rank order correlation between the richness and diversity indices and the sizes of the estuaries is similar to the trend observed with other sampling techniques such as seine and gill nets (Table 3.6 and 3.7, Chapter 3).

The cluster analysis of the five estuaries shows a similar trend, with the different estuary types grouping separately from one another (Figure 6.2). The estuary types were shown to be significantly different using both the ANOSIM procedure on the community data and the use of non-parametric ANOVA on the CPUE data. These results may be due to the larger systems being more accessible to fish recruitment. The marine migrant species can recruit via the mouth into permanently open systems at any time, while they are also more likely to recruit via overtopping into the larger closed estuaries than the smaller more isolated systems. This is reflected in the otter trawl samples, where only one marine migrant species was recorded in the small Ngculura Estuary compared with three to four recorded in the other systems (Table 6.4). The permanently open Great Fish also had only four marine migrant species, but each one contributed a larger proportion to the total catch than in the closed systems (Table 6.4).

The lack of any significant seasonal variation was unexpected, especially in the Great Fish Estuary. Due to the permanently open nature of this system, different recruitment patterns were expected to alter the fish communities during the different seasons. The lack of variation may be due to the gear type targeting a few demersal species and therefore negating the effect of different recruitment periods. The lower number of marine migrant fish caught in summer is also surprising, as the majority of these species recruit into the estuaries during spring and early summer (Whitfield, 1998).

Catchment size and mean annual run-off are proportional as all the estuaries drain areas with similar rainfall patterns. These variables influence the fish community structure by controlling the salinity and turbidity gradient from the head to the estuary mouth (Whitfield, 1996). The influence of the cross-sectional area on the recorded fish assemblages arises from the effect of estuary depth and width on the otter trawl samples collected. In a deeper system the otter trawl will sample a lower proportion of the water column relative to a wider estuary, while in a wider system a lower proportion of the total habitat available to a species will be sampled compared with a narrower estuary.

The similar results from this study when compared with other otter trawl studies of closed and permanently open systems in South Africa, contradict findings from North America that this technique is difficult to compare if the gears are not identical (Kjelson and Johnson, 1978; DeAlteris *et al.*, 1989). Although otter trawling is a relatively new technique in South African estuarine sampling, it appears to reflect more accurate proportions of demersal species compared with other sampling techniques (Paterson, 1998). Although sampling only a small proportion of the fish communities, otter trawling still identifies distinct differences between the assemblages of open, large closed and small closed estuaries.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

Most research conducted in South African estuaries has focused on larger permanently open systems. This has resulted in very little information being available for smaller estuaries, which comprise the majority of South African systems (Whitfield, 1992). The lack of information, in particular baseline data, is a matter of serious concern as these estuaries are coming under increasing developmental pressures (Avis, 1998). In conjunction with the shortage of information on smaller estuaries, are a lack of comparisons and a consequent misunderstanding of the ecological importance of these systems relative to larger estuaries.

Temporarily open/closed estuaries along the South African coastline are linked to the sea for varying amounts of time. These systems are characterised by a small tidal prism ($<1 \times 10^6$ m^3) when the mouth is open and no tidal prism when closed by a sand bar (Whitfield, 1992). Similarly, a strong horizontal salinity gradient may exist during the tidal phase, while during closed mouth conditions the salinity is more uniform (Begg, 1984a). Additionally, they have small catchments (<500 km^2) and mixing occurs by tidal forces when open, or is wind driven when closed. Conversely, permanently open estuaries have moderate tidal prisms ($1\text{-}10 \times 10^6$ m^3) and the catchments are usually larger than 500 km^2 (Whitfield, 1998). The salinities in these systems often exhibit strong horizontal gradients, and there may be haloclines in deeper regions due to trapping of pockets of sea water (Mackay and Schumann, 1990). Mixing in permanently open estuaries is mostly tidally driven as a result of the strong currents that predominate in the lower and middle reaches.

This study documented ichthyofaunal communities in 10 estuaries along the Eastern Cape coast. The research was aimed primarily at comparing the structural differences between the fish communities in permanently open and intermittently open estuaries. This included an analysis of the environmental variables that may be responsible for the similarities and differences observed.

The correlation of species richness indices with estuary size factors for the seine net and otter trawl data is detailed in Chapter 3. Whitfield (1980b) identified a similar relationship between estuary size and species richness, with a higher richness being found in larger systems. The indication from richness indices that there was a relationship between fish communities and estuary size was confirmed by later community analyses (Chapter 4). The corresponding lack of any trends between diversity indices and estuarine size factors was therefore surprising. However this was as a result of one or two species, namely *Gilchristella aestuaria* and *Atherina breviceps*, dominating the seine net catches in most systems, thereby reducing the calculated diversity. The similarity in rank order between estuary size and the calculated diversity of otter trawl samples was therefore interesting, as these samples were also dominated by one of two species, namely *Glossogobius callidus* and *Solea bleekeri*, depending on estuary type.

Trends in the contribution of species with different origins (marine, estuarine and freshwater) to the diversity and richness of estuarine fish communities are shown in Figure 7.1. This diagram demonstrates the varying ability of marine migrant species to recruit into estuaries depending on the frequency and duration of mouth opening events, and indicates the increase in number of freshwater migrant species with increasing freshwater input into a system. The number of estuarine taxa declines with increased freshwater input, possibly a result of the greater flushing effect on larval and juvenile phases of these small species.

No seasonal (summer/winter) trends were evident in the Eastern Cape fish communities, with similar numbers of individuals and species being caught in each season (Chapter 3). The lack of seasonal trends in the permanently open systems is contrary to the findings of Bennett (1989), who determined that in the permanently open Palmiet Estuary the spring/summer, winter and autumn samples separated into distinct groups due to the migrations of estuarine dependent marine species into and out of this system. Bennett (1989) recorded similar results in the temporarily open Kleinmond Estuary, and Harrison and Whitfield (1995) also identified seasonal trends in three temporarily open/closed KwaZulu-Natal estuaries. Examples of seasonal trends in fish abundance due to migration of marine species into and out of Australian, American and European estuaries, include Barker Inlet in South Australia

(Connolly, 1994), Newark Bay in the United States (Will and Houston, 1992), St Andre Lagoon in Portugal (Da Fonseca *et al.*, 1989) and the upper Thames Estuary in England (Araújo *et al.*, 1999). The lack of seasonal trends in the temporarily closed estuaries during this study may be a result of the extended closed phase preventing the seasonality that would normally occur. In the Bot Estuary, which is often closed for periods in excess of one year, Bennett (1989) did not identify any seasonal trends, and attributed this to the lack of movement of marine migrant species into and out of this system.

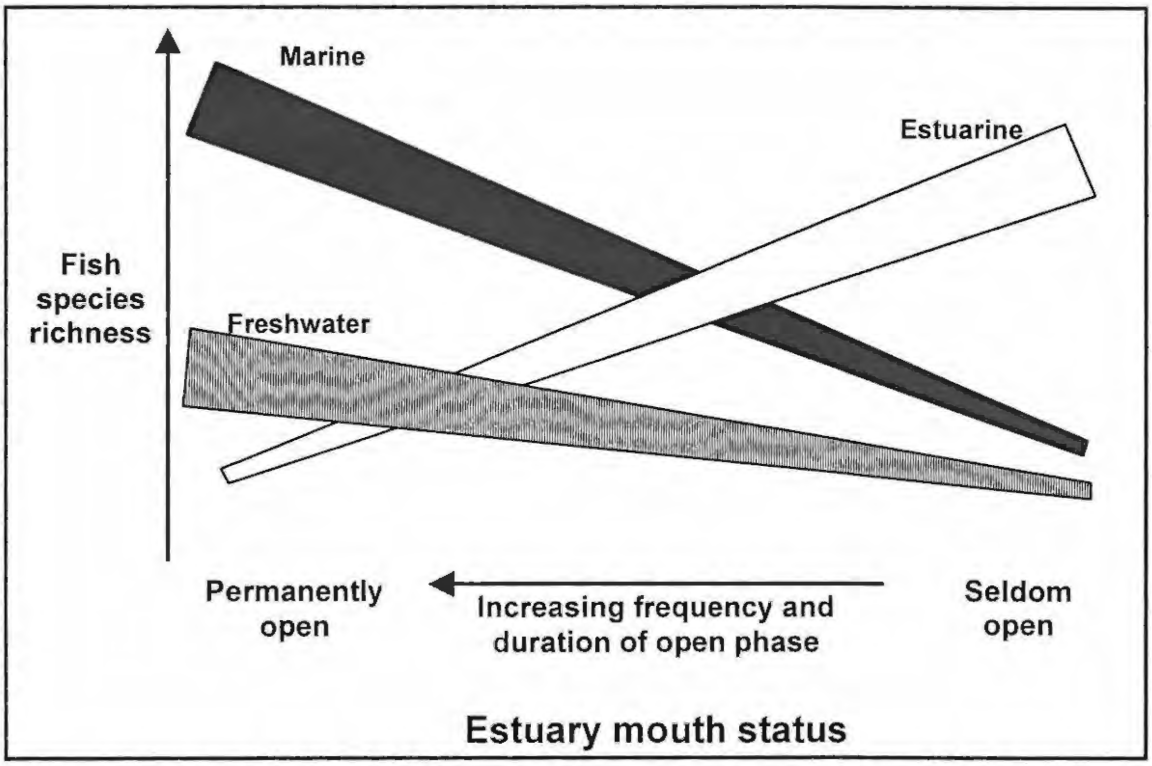


Figure 7.1: Diagrammatic representation of contributions by marine, estuarine and freshwater species to the composition of fish communities in estuaries with different mouth conditions. The thickness of the lines indicates the abundance of each group of fishes.

No distinctive longitudinal trends in the ichthyofaunal composition of each estuary were measured (Chapter 3). Generally, all three reaches had comparable fish densities per gear type and did not show any major community differences. Changes in fish assemblage composition between the lower, middle and upper reaches was evident, but there were no significant differences between adjacent reaches. This is contrary to reported findings of distinct communities from different estuarine reaches in South Africa (Beckley, 1984; Whitfield, 1988; Ter Morshuizen *et al.*, 1996a; Cowley, 1998). In the intermittently open East Kleinemonde Cowley (1998) found a difference between the fish communities in the mouth region and the rest of the estuary and surmised that this was due to different sediment composition. Similarly, Young *et al.* (1997) found highly significant differences ($p<0.001$) in the densities and number of species found in each region of the intermittently open Moore Estuary in Australia. In the Zeeschelde Estuary in Belgium, Maes *et al.* (1998) reported decreasing species richness and fish abundance with distance upstream and related this to salinity and dissolved oxygen gradients. A similar result was recorded in the Elbe Estuary in Germany, where Thiel *et al.* (1995) found decreased species richness with distance upstream, a trend they related to changing salinity and dissolved oxygen concentrations.

Significant differences in fish composition between estuary types were evident from seine and otter trawl net data, on both a community and density basis (Chapter 4). Conversely, no differences were apparent when the estuary types were compared using gill net data, a result possibly linked to gear selectivity and the small gill net sample sizes (Chapter 4). In addition to the differences between the permanently open and temporarily closed estuaries, a further subdivision of fish communities in the temporarily closed systems into large and small estuaries was established. These differences are similar to those identified by Bennett (1989), Whitfield *et al.* (1989) and Whitfield and Kok (1992). Bennett (1989) recorded differences in diversity and densities of fishes between fish communities in the permanently open Palmiet, seasonally open Kleinmond and the normally closed Bot estuaries. Similarly, Whitfield *et al.* (1989) found that species richness in eelgrass beds in the permanently open Knysna Estuary was twice that of the intermittently open Swartvlei Estuary. In addition, Whitfield and Kok (1992) recorded higher recruitment of juveniles into the Knysna system compared with the Swartvlei Estuary. In a comparison between the permanently open Nornalup-Walpole Estuary and the seasonally closed Wilson Inlet on the southern coast of Australia, the Nornalup-Walpole Estuary had higher diversities and densities of fishes (Potter and Hyndes, 1994). All the above authors attributed the recorded ichthyofaunal differences between estuary types to changes in the marine migrant portion of the fish population.

Begg (1984a, 1984b) postulated that permanently open estuaries in KwaZulu-Natal are important to marine migrant fish species, whereas temporarily open/closed systems supported mainly estuarine resident and freshwater migrant species. These conclusions have been contested by Harrison and Whitfield (1995) who suggested that these findings were the result of using only one gear type during a relatively dry season. Harrison and Whitfield (1995) demonstrated that sampling with a wider range of gear types in temporarily open/closed KwaZulu-Natal estuaries revealed an abundant and diverse marine migrant fish component. This study confirms the findings of Harrison and Whitfield (1995), with several of the temporarily open Eastern Cape systems containing as many marine migrant species as the permanently open estuaries and *vice versa* (Appendix I and II). Potter *et al.* (1990) have linked the higher usage of South African estuaries as nursery areas compared with Australia, to a lack of sheltered marine embayments along the former coastline. In Australia juveniles of marine species have been reported using sheltered marine embayments as nursery areas, whereas in southern Africa, the rough sea conditions encourage juveniles to enter estuarine areas for shelter and protection from predation (Potter *et al.*, 1990).

The different ichthyofaunal communities identified in the various estuary types during this study were analysed in conjunction with a range of variables in an attempt to identify which environmental, physical and chemical factors were responsible for these differences (Chapter 4). Mouth status was identified as the most significant variable accounting for the seine net catch differences, and was the only variable that correlated significantly with the community analyses during both summer and winter. When data from both seasons were combined, additional estuary size factors (e.g. catchment size, mean annual run-off, estuarine area and length) were also significantly correlated to the community analyses. The highest correlation (seine net data) resulted from a combination of mouth status, estuary length, cross-sectional area and bottom salinity (Chapter 4). Otter trawl data revealed significant individual correlations with catchment size, mean annual run-off and the cross-sectional area. The highest correlation from this data resulted when mouth status, cross-sectional area and the percentage cover of submerged macrophytes were combined (Chapter 6). The results from these two separate gear types suggest that estuary size and mouth status are the most important variables influencing Eastern Cape estuarine fish communities.

Many authors (Rebelo, 1992; Thiel *et al.*, 1995; Maes *et al.*, 1998; Araújo *et al.*, 1999) have identified salinity, temperature and dissolved oxygen as the most important variables structuring fish communities in the northern hemisphere. The addition of dissolved oxygen as an important influence could be as result of relatively high pollution levels in European rivers compared with those in this study. Submerged macrophytes contain different estuarine fish communities compared with nearby sandy areas, examples include a range of estuaries along the New South Wales coastline (Gray *et al.*, 1996), Barker Inlet in Australia (Connolly, 1994), Chesapeake Bay (Lubbers *et al.*, 1990), and locally, the Swartkops (Beckley, 1983), Kromme (Hanekom and Baird, 1984) and Swartvlei estuaries (Whitfield, 1986). These authors have related the community differences to different feeding regimes (detritivorous, planktivorous or preying on burrowing arthropods over open sand, and herbivorous or preying on plant associated arthropods in macrophyte regions) and different prey avoidance mechanisms (certain species blend in with the sediment over open sand, while other species use aquatic plants as a refuge in macrophyte regions). Another feature that has been reported to influence fish communities is substratum type, with Walsh *et al.* (1999) reporting different life stages of flatfishes occurring over different sediment types, and Cowley (1998) reporting a different fish community over sandy substrata relative to other substratum types in the East Kleinemonde Estuary. Williams and Zedler (1999) identified different fish communities in channels with different morphology (wide versus narrow) in San Diego Bay. Similarly, Will and Houston (1992) identified the depth of a channel as an important factor influencing the structure of fish communities in Newark Bay.

The effect of size variables on the otter trawl data set should be considered within the context of gear type. The depth and width of the system may influence otter trawl catches, as a larger proportion of the water column will be sampled in a, shallow estuary compared with that in a broader system. Similarly, a larger proportion of the available habitat will be sampled in a narrower estuary relative to a wider system. This trend also extends to the ability of fishes to escape from the net if adopting a flight response. In the smaller estuaries, fishes will have less area to escape to when compared with the larger systems. The otter trawl results may therefore be biased towards certain species, pelagic or demersal, depending on the width and depth of the estuaries (DeAlteris *et al.*, 1989; Rulifson, 1991).

Several authors have identified mouth status as a major influence on fish community structures. Whitfield and Kok (1992) suggested that ichthyofaunal differences between the Swartvlei and Knysna estuaries were due to the deep permanently open mouth in the latter system. Potter *et al.* (1993) similarly identified entrance channel depth as being important in influencing the recruitment of marine migrant species into Wilson Inlet in Australia. Schlacher and Wooldridge (1996) also report much higher ichthyofaunal species diversity in open systems when compared with closed estuaries in South Africa. The study by Bennett (1989) indicated that a lack of contact with the marine environment was the cause of a depauperate ichthyofauna in the Bot River Estuary. Australian temporarily closed systems did not show considerable differences in species diversity and richness relative to permanently open estuaries (Potter and Hyndes, 1994), possibly due to juvenile fish using protected embayments along the Australian coastline instead of entering estuaries (Potter *et al.*, 1990).

The determination of mouth status as the dominant variable may be due to it being an 'umbrella' factor representing an entire range of other variables. The mean annual run-off for the estuaries in this study is directly proportional to catchment size as all the systems fall within the same climatic zone. Schlacher and Wooldridge (1996) identified a direct relationship between estuary mouth status and catchment size (or mean annual run-off) with a certain volume of freshwater input being necessary to keep the estuary mouth permanently open. Mouth status will similarly influence both estuarine area and length, with the marine influence in a system being greater if the mouth is open rather than closed.

Other physical and chemical variables that may be influenced by mouth status include salinity, temperature and turbidity. The degree of salinity influence in a system is mainly a function of tidal exchange and riverine input (Schumann *et al.*, 1999). In a closed estuary there will be no tidal prism, while in a permanently open system daily tidal exchanges result in major salinity intrusions up the estuary (Schumann *et al.*, 1999). The temperature of estuarine water is influenced by mouth status through the temperature differentials of riverine, estuarine and marine waters (Read, 1983). This was evident from this study with lower temperature variability occurring between winter and summer in the open systems compared with the temporarily closed estuaries. Mouth status does not directly influence water turbidity, but the effect can be seen in permanently open estuaries where there is often a greater range of turbidity niches from clear seawater to highly turbid riverine water (Whitfield *et al.*, 1994). Conversely, more uniform turbidity gradients prevail in closed estuaries due to the absence of tidal exchange and reduced turbid water inputs from the catchment.

Mouth status also influences the percentage and type of plant cover in an estuary. The reduction or increase in light penetration caused by differing turbidities is a major factor in determining the proportion of an estuary available to submerged macrophyte colonisation (Begg, 1984a, 1984b; Adams *et al.*, 1999; Bell and Westoby, 1986; Buzzelli *et al.*, 1998). Open mouth conditions facilitate the tidal inundation and exposure of salt marshes, whereas in closed systems salt marsh plants such as *Spartina maritima* are absent due to a lack of tidal cycles (Day, 1981). Talbot *et al.* (1990), and Howard-Williams and Liptrot (1980) have also commented on the importance of tidal currents in preventing smothering of *Zostera capensis* beds by deposition of muddy sediments and excessive filamentous algal growth. Another macrophyte genus, *Ruppia*, is more commonly found in temporarily closed estuaries due to the weaker stems and a lack of supporting tissues preventing their survival in stronger currents (Adams *et al.*, 1992).

Mouth status similarly affects the sediment type and distribution within an estuary. Tidal water currents have a direct effect on the flocculation process and consequent sedimentation of particles, thereby affecting the distribution of substrata within an estuary (Kennish, 1986). In a closed system the deposition and distribution of sediments will be influenced by the reduction in water velocity as turbid riverine water enters the estuarine environment (Reddering, 1988; Reddering and Rust, 1990).

In addition to influencing a variety of physico-chemical variables, mouth status also determines fish assemblage composition via its impact on recruitment. Several authors (Bennett, 1989; Marais, 1981, 1983; Harrison and Whitfield, 1995; Kok and Whitfield, 1986; Schlacher and Wooldridge, 1996; Whitfield and Kok, 1992) have found that the frequency and duration of mouth opening events has a direct influence on the species richness in different estuaries along the South African coastline. Similarly, this study has identified greater species richness and diversity in the large permanently open systems relative to the temporarily closed estuaries. It is possible that permanently open systems provide stronger cues to juvenile fish in the marine environment, thereby offering greater recruitment opportunities to a wider variety of fish (Whitfield, 1998). Temporarily closed estuaries provide weaker cues for recruitment, as these can only enter the marine environment via seepage through the sandbar under closed mouth conditions. Additionally, in a permanently open estuary the nature of the mouth allows for recruitment to occur throughout the year, while in temporarily closed estuaries the juvenile fish have to wait in the surf zone for either an overwash or mouth opening event before recruitment can occur.

The length frequency composition of various fish species also appears to be influenced by estuarine size factors and mouth status. Estuarine resident taxa demonstrated a larger modal size class in the permanently open estuaries when compared with the intermittently open systems (Chapter 5). Conversely, the largest individuals of marine migrant species were found in temporarily closed estuaries, probably a result of the inability of these species to migrate back to sea at an earlier stage. The larger modal size class of estuarine resident taxa in permanently open systems, is possibly due to the larvae and juveniles of these weak swimming taxa being flushed out of such estuaries (Beckley, 1985; Harris and Cyrus, 1997). Neira and Potter (1992) reported supporting results in the Wilson Inlet, a poorly-flushed seasonally closed system in Australia, which was dominated by the larvae of estuarine resident species. A flushing effect was also reported by Dew (1995) in the Hudson River Estuary with *Microgadus tomcod* larvae. These larvae where found in a size-distribution gradient down the Hudson Estuary before and after flooding events, with high flow rates resulting in very few larvae being captured within the system (Dew, 1995).

All estuary types offer resources and functions to the estuarine and marine fish communities that utilise them. The benefits of open systems to ichthyofaunal communities include permanent access for marine migrant species and a large variety of niches due to a wide range of turbidities, salinities and temperatures (Marais, 1988; Whitfield, 1996). Intermittently open estuaries offer other benefits to the fish that enter them, including an enhanced nursery function due to the inundation of surrounding intertidal and supratidal zones (Kok and Whitfield, 1982). These newly submerged areas increase the available nursery area (Bennett *et al.*, 1985), as they are often shallow and vegetated, thus providing a greater degree of protection from predators. In addition, these areas increase the available food resources due to the inundation of floodplain habitats with a high detrital mass (Whitfield, 1980c).

In conclusion this study has demonstrated that the various Eastern Cape estuary types, from the large permanently open systems to the small intermittently open estuaries, have different fish communities. These differences do not render any estuary type unimportant to ichthyofaunal populations; on the contrary they seem to complement each other, offering different resources and functions to the fish species that utilise them. It is this complementary effect that should be taken into account when any proposals regarding estuarine reserves are assessed. In addition, no estuary type should be sacrificed for development in an attempt to protect other estuary types from developmental pressures. An estuary from each size category and type should be included in any proposed system of estuarine reserves, to firstly conserve a representative fish community from each estuary type, and secondly to maintain the variety of estuarine functions that each estuary type provides for resident and migrant fish species.

> "When one tugs at a single thing in nature,
> he finds it attached to the rest of the world."
>
> John Muir (1838 – 1914)
> *Famous American Naturalist and Conservationist*

REFERENCES

ADAMS, J.B. Unpublished. Botanical survey of the Mpekweni and East Kleinemonde estuaries, January 1997.

ADAMS, J.B., Knoop, W.T. and Bate, G.C. 1992. The distribution of estuarine macrophytes in relation to freshwater. *Botanica Marina* **35**: 215-226.

ADAMS, J.B., Bate, G.C. and O'Callaghan, M. 1999. Primary producers: estuarine macrophytes. In: *Estuaries of South Africa.* Allanson, B.R. and Baird, D. Cambridge University Press, Cambridge. pp. 100-117.

ARAúJO, F.G., Bailey, R.G. and Williams, W.P. 1999. Spatial and temporal variations in fish populations in the upper Thames estuary. *Journal of Fish Biology* **55**: 836-853.

AVIS, A.M. 1998. Coastal zone management and development. In: *Field Guide to the Eastern and Southern Cape Coasts.* Lubke, R. and de Moor, I. (Eds). University of Cape Town Press, Cape Town. pp. 446-458.

BADENHORST, P. 1988. Report on the dynamics of the Kleinemonde West and East estuaries (CSE 13 & 14). CSIR Report EMA/T 8805. 19 pp.

BAIRD, D., Marais, J.F.K., and Daniel, C. 1996. Exploitation and conservation of angling fish in two South African estuaries. *Aquatic Conservation: Marine and Freshwater Ecosystems* **6**: 319-330.

BARKLEY, R.A. 1972. Selectivity of towed-net samplers. *Fishery Bulletin* **70**: 799-819.

BECKLEY, L.E. 1983. The ichthyofauna associated with *Zostera capensis* Setchell in the Swartkops estuary, South Africa. *South African Journal of Zoology* **18**: 15-24.

BECKLEY, L.E. 1984. The ichthyofauna of the Sundays Estuary, South Africa, with particular reference to the juvenile marine component. *Estuaries* 7: 248-258.

BECKLEY, L.E. 1985. Tidal exchange of ichthyoplankton in the Swartkops Estuary mouth, South Africa. *South African Journal of Zoology* **20**: 15-20.

BEGG, G.W. 1984a. The comparative ecology of Natal's smaller estuaries. *Natal Town and Regional Planning Commission Report* **62**: 1-182.

BEGG, G.W. 1984b. The estuaries of Natal (part II). *Natal Town and Regional Planning Commission Report* **55**: 1-631.

BELL, J.D. and Westoby, M. 1986. Variation in seagrass height and density over a wide spatial scale: effects on common fish and decapods. *Journal of Experimental Marine Biology and Ecology* **104**: 249-274.

BELL, K.N.I., Cowley, P.D., and Whitfield, A.K. In Press. Seasonality in frequency of marine access to an intermittently open estuary: implications for recruitment strategies. *Estuarine, Coastal and Shelf Science.*

BENNETT, B.A. 1989. A comparison of the fish communities in nearby permanently open, seasonally open and normally closed estuaries in the south-western cape, South Africa. *South African Journal of Marine Science* **8**: 43-55.

BENNETT, B.A and Branch, G.M. 1990. Relationships between production and consumption of prey species by resident fish in the Bot, a cool temperate South African estuary. *Estuarine, Coastal and Shelf Science* **31**: 139-155.

BENNETT, B.A., Hamman, K.C.D., Branch, G.M., and Thorne, SC. 1985. Changes in the fish fauna of the Bot River Estuary in relation to opening and closure of the estuary mouth. *Transactions of the Royal Society of South Africa* **45**: 449-464.

BLABER, S.J.M. 1974. The population structure and growth of juvenile *Rhabdosargus holubi* (Steindachner) (Teleostei: Sparidae) in a closed estuary. *Journal of Fish Biology* **6**: 455-460.

BLABER, S.J.M. 1979. The biology of filter feeding teleosts in Lake St Lucia, Zululand. *Journal of Fish Biology* **15**: 37-59.

BLABER, S.J.M. 1981. The zoogeographical affinities of estuarine fishes in South-East Africa. *South African Journal of Science* **77**: 305-307.

BLABER, S.J.M. 1985. The ecology of fishes of estuaries and lagoons of the Indo-Pacific with particular reference to Southeast Africa. In: *Fish Community Ecology in Estuaries and Coastal Lagoons: Towards an Ecosystem Integration.* Yanez-Arancibia, A. UNAM Press, Mexico. pp. 274-266.

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

BLABER, S.J.M. and Whitfield, A.K. 1976. Large scale mortality of fish at St Lucia. *South African Journal of Science* **72**: 218.

BLABER, S.J.M., Cyrus, D.P., and Whitfield, A.K. 1981. The influence of zooplankton food resources on the morphology of the estuarine clupeid *Gilchristella aestuarius* (Gilchrist, 1914). *Environmental Biology of Fishes* **6**: 351-355.

BLACK, C.A. 1965. *Methods of Soil Analysis, Part I, Physical and Mineralogical Properties, including Statistics of Measurement and Sampling.* American Society of Agronomy, Wisconsin.

BOULLÉ, D.P. 1989. *Aspects of biology and ecology of a small stream fish community.* B.Sc. (Hons), Rhodes University, Grahamstown. 45pp.

BUZZELLI, C.P., Wetzel, R.L. and Meyers, M.B. 1998. Dynamic simulation of littoral zone habitats in lower Chesapeake Bay. II. Seagrass habitat primary production and water quality relationships. *Estuaries* **21**: 673-689.

CHITTENDEN, M.E. and Van Engel, W.A. 1972. Effect of a tickler chain and tow duration on trawl catches of the blue crab, *Callinectes sapidus*. *Transactions of the American Fisheries Society* **101**: 732-734.

CLARKE, K.R. and Ainsworth, M. 1993. A method of linking multivariate community structure to environmental variables. *Marine Ecology Progress Series* **92**: 205-219.

CLARKE, K.R. and Warwick, R.M. 1994. *Change in Marine Communities: An approach to Statistical Analysis and Interpretation.* Bourne Press Limited, Bournemouth.

COETZEE, D.J. 1982. Stomach content analyses of *Gilchristella aestuarius* and *Hepsetia breviceps* from the Swartvlei system and Groenvlei, southern Cape. *South African Journal of Zoology* **17**: 59-66.

COLLOTY, B.M. 2000. *The botanical importance rating of the estuaries of Ciskei / Transkei*. Ph.D., University of Port Elizabeth. 230pp.

CONNOLLY, R.M. 1994. a comparison of fish assemblages from seagrass and unvegetated area of a Southern Australian estuary. *Australian Journal of marine and Freshwater Research* **45**: 1033-1044.

COSTA, M.J., Costa, J.L., de Almeida, P.R., and Assis, C.A. 1994. Do eel grass beds and salt marsh borders act as preferential nurseries and spawning grounds for fish? An example of the Mira estuary in Portugal. *Ecological Engineering* **3**: 187-195.

COWLEY, P.D. 1998. *Fish population dynamics in a temporarily open/closed South African estuary.* Ph.D., Rhodes University. 145pp.

COWLEY, P.D., Whitfield, A.K. and Bell, K.N.I. In Press. Surf zone ichthyoplankton adjacent to an intermittently open estuary, with evidence of recruitment during overwash events. *Estuarine Coastal and Shelf Science*.

CYRUS, D.P. 1992. Turbidity gradients in two Indo-Pacific estuaries and their influence on fish distribution. *Southern African Journal of Aquatic Sciences* **18**: 51-63.

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

CYRUS, D.P. and Blaber, S.J.M. 1987b. The influence of turbidity on juvenile marine fishes in estuaries. Part 1. Field studies at Lake St Lucia on the southeastern coast of Africa. *Journal of Experimental Marine Biology and Ecology* **109**: 53-70.

CYRUS, D.P. and Blaber, S.J.M. 1992. Turbidity and salinity in a tropical northern Australian estuary and their influence on fish distribution. *Estuarine, Coastal and Shelf Science* **35**: 545-563.

CYRUS, D.P. and McLean, S. 1996. Water temperature and the 1987 fish kill at lake St Lucia on the south eastern coast of Africa. *Southern African Journal of Aquatic Sciences* **22**: 105-110.

CYRUS, D.P., Wellman, E.C., and Martin, T.J. 1993. Diet and reproductive activity of the estuarine roundherring *Gilchristella aestuaria* in Cubhu, a freshwater coastal lake in northern Natal, South Africa. *Southern African Journal of Aquatic Sciences* **19**: 3-13.

DA FONSECA, L.C. Costa, A.M. and Bernado, J.M. 1989. Seasonal variation of benthic and fish communities in a shallow land-locked coastal lagoon (St. Andre, SW Portugal). *Scientia Marina* **53**: 663-669.

DAY, J.H. 1980. What is an estuary? *South African Journal of Science* **76**: 198-198.

DAY, J.H. 1981. The estuarine flora. In: *Estuarine ecology with particular reference to Southern Africa.* Day, J.H. A.A. Balkema, Cape Town. pp. 251-331.

DEALTERIS, J.T., Recksiek, C.W., Fahfouhi, A, and Liuxiong, X. 1989. Comparison of the performance of two bottom-sampling trawls. *Transactions of the American Fisheries Society* **118**: 119-130.

DE VILLIERS, G. 1987. Harvesting harders *Liza richardsonii* in the Benguela upwelling region. *South African Journal of Marine Science* **5**: 851-862.

DEW, C.B. 1995. The nonrandom size distribution and size-selective transport of age-0 Atlantic tomcod (*Microgadus tomcod*) in the lower Hudson River estuary. *Canadian Journal of Fisheries and Aquatic Sciences* **52**: 2353-2366.

DEWET, P.S. and Marais, J.F.K. 1990. Stomach content analysis of juvenile cape stumpnose *Rhabdosargus holubi* in the Swartkops estuary, South Africa. *South African Journal of Marine Science* **9**: 127-133.

DUNDAS, A. 1994. *A comparative analysis of fish abundance and diversity in three semi-closed estuaries in the Eastern Cape.* M.Sc., University of Port Elizabeth. 81pp.

FORBES, A.T. and Cyrus, D.P. 1993. Biological effects of salinity gradient reversals in a southeast African estuarine lake. *Netherlands Journal of Aquatic Ecology* **27**: 483-488.

FRONEMAN, P.W. *Pers. comm.* Information on plankton densities in the Kasouka estuary. E-mail: "Re: Density of plankton in closed estuaries": w.froneman@ru.ac.za.

FRONEMAN, P.W. In press. Preliminary investigation of food web structure in contrasting estuaries. *Southern African Journal of Aquatic Sciences.*

GRAY, C.A., McElligot, D.J. and Chick, R.C. 1996. Intra- and inter-estuary differences in assemblages of fishes associated with shallow seagrass and bare sand. *Marine and Freshwater Research* **47**: 723-735.

GRIFFITHS, M.H. 1997. Influence of prey availability on the distribution of dusky kob *Argyrosomus japonicus* (Sciaendae) in the Great Fish River estuary, with notes on the diet of early juveniles from three other estuarine systems. *South African Journal of Marine Science* **18**: 137-145.

GRIFFITHS, S.P. and West, R.O. 1999. Preliminary assessment of shallow water fish in three small intermittently open estuaries in south-eastern Australia. *Fisheries Management and Ecology* **6**: 311-321.

HALL, C.M., Whitfield, A.K. and Allanson, B.R. 1987. Recruitment, diversity and the influence of constrictions on the distribution of fishes in the Wilderness lakes system, South Africa. *South African Journal of Zoology* **22**: 163-169.

HANEKOM, N. and Baird, D. 1984. Fish community structure in *Zostera* and non-*Zostera* regions of the Kromme estuary, St Francis Bay. *South African Journal of Zoology* **19**: 295-301.

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

HARRISON, T.D. and Whitfield, A.K. 1990. Composition, distribution and abundance of ichthyoplankton in the Sundays River estuary. *South African Journal of Zoology* **25**: 161-168.

HARRISON, T.D. and Whitfield, A.K. 1995. Fish community structure in three temporarily open/closed estuaries on the Natal coast. *Ichthyological Bulletin of the J.L.B. Smith Institute of Ichthyology* **64**: 80 pp.

HARRISON, T.D., Cooper, J.A.G., Ramm, A.E.L., and Singh, R.A. 1996. Health of South African Estuaries: Groot (Wes) - Great Fish Executive Report. Project No: QH102.

HARRISON, T.D., Cooper, J.A.G., Ramm, A.E.L., and Singh, R.A. 1997. Health of South African Estuaries: Old Womans - Great Kei. Project No: JEH01.

HARTMAN, R.D. and Herke, W.H. 1987. Relative selectivity of five coastal marsh sampling gears. *Contributions in Marine Science* **30**: 17-26.

HOWARD-WILLIAMS, C. and Liptrot, M.R.M. 1980. Submerged macrophyte communities in a brackish South African estuarine-lake system. *Aquatic Botany* **9**: 101-116.

JUBB, R.A. 1978. Sharp-tooth catfish, *Clarias gariepinus*, in the Great Fish River, Eastern Cape. *Piscator* **102**: 24-27.

KENNISH, M.J. 1986. *Ecology of Estuaries.Volume 1. Physical and Chemical Aspects.* CRC Press, Boston.

KJELSON, M.A. and Johnson, G.N. 1978. Catch efficiencies of a 6.1-meter otter trawl for estuarine fish populations. *Transactions of the American Fisheries Society* **107**: 246-254.

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

KOPKE, D. 1988. The climate of the Eastern Cape. In: *Towards an Environmental Plan for the Eastern Cape*. Bruton, M. and Gess, G. (Eds). Rhodes University, Grahamstown. pp. 44-52.

LAURENSON, L.J.B. and Hocutt, C.H. 1984. The introduction of the rock catfish, *Gephyroglanis sclateri*, into the Great Fish River via the Orange/Fish Tunnel, South Africa. *Naturalist* **28**: 12-15.

LAURENSON, L.J.B. and Hocutt, C.H. 1986. Colonisation theory and invasive biota: The Great Fish River, a case history. *Environmental Monitoring and Assessment* **6**: 71-90.

LAURENSON, L.J.B., Hocutt, C.H., and Hecht, T. 1989. An evaluation of the success of invasive fish species of the Great Fish River. *Journal of Applied Ichthyology* **5**: 28-34.

LUBBERS, L., Boynton, W.R. and Kemp, W.M. 1990. Variations in structure of estuarine fish communities in relation to abundance of submersed vascular plants. *Marine Ecology Progress Series* **65**: 1-14.

LUBKE, R.A. 1988. Descriptions of the coastal regions. In: *A Field Guide to the Eastern Cape Coast*. Lubke, R., Gess, G., and Bruton, M. (Eds). The Grahamstown Centre of the Wildlife Society of Southern Africa, Grahamstown. pp. 3-8.

LUTJEHARMS, J.R.E. 1998. Coastal hydrography. In: *Field guide to the Eastern and Southern Cape coasts*. Lubke, R. and de Moor, I. (Eds). University of Cape Town Press, Cape Town. pp. 50-61.

MACKAY, H.M. and Schumann, E.H. 1990. Mixing and circulation in the Sundays River Estuary, South Africa. *Estuarine, Coastal and Shelf Science* **31**: 203-216.

MAES, J., van Damme, P.A., Taillieu, A. and Ollevier, F. 1998. Fish communities along an oxygen-poor salinity gradient (Zeeschelde Estuary, Belguim). *Journal of Fish Biology* **52**: 534-546.

MARAIS, J.F.K. 1981. Seasonal Abundance, Distribution, and Catch Per Unit Effort Using Gill-Nets, of Fishes in the Sundays Estuary. *South African Journal of Zoology* **16**: 144-150.

MARAIS, J.F.K. 1983. Seasonal abundance, distribution and catch per unit effort of fishes in the Krom Estuary, South Africa. *South African Journal of Zoology* **18**: 96-102.

MARAIS, J.F.K. 1988. Some factors that influence fish abundance in South African estuaries. *South African Journal of Marine Science* **6**: 67-77.

MARAIS, J.F.K. 1990. Body composition of ten marine migrants and one freshwater fish species caught in estuaries of the Eastern Cape, South Africa. *South African Journal of Marine Science* **9**: 135-140.

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

MELVILLE-SMITH, R and Baird, D. 1980. Abundance, distribution and species composition of fish larvae in the Swartkops estuary. *South African Journal of Zoology* **15**: 72-78.

MELVILLE-SMITH, R, Baird, D, and Wooldridge, T. 1981. The utilization of tidal currents by the larvae of an estuarine fish. *South African Journal of Zoology* **16**: 10-13.

NEIRA, F.J. and Potter, I.C. 1992. The ichthyoplankton of a seasonally closed estuary in temperate Australia. Does an extended period of opening influence species composition? *Journal of Fish Biology* **41**: 935-953.

NEIRA, F.J., Beckley, L.E., and Whitfield, A.K. 1988. Larval development of the Cape silverside, *Atherina breviceps* Cuv. & Val., 1835 (Teleostei, Atherinidae) from southern Africa. *South African Journal of Zoology* **23**: 176-183.

PATERSON, A.W. 1998. *Aspects of the ecology of fishes associated with salt marshes and adjacent habitats in a temperate South African estuary.* Ph.D., Rhodes University. 200pp.

PATERSON, A.W. and Whitfield, A.K. 1996. The fishes associated with an intertidal salt marsh creek in the Kariega estuary, South Africa. *Transactions of the Royal Society of South Africa* **51**: 195-218.

POTTER, I.C. and Hyndes, G.A. 1994. Composition of the fish fauna of a permanently open estuary on the southern coast of Australia, and comparisons with a nearby seasonally closed estuary. *Marine Biology* **121**: 199-209.

POTTER, I.C., Beckley, L.E., Whitfield, A.K. and Lenanton, R.C.J. 1990. Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and Southern Africa. *Environmental Biology of Fishes* **28**: 143-178.

POTTER, I.C., Hyndes, G.A. and Baronie, F.M. 1993. The fish fauna of a seasonally closed Autralian estuary. Is the prevalence of estuarine spawning species high? *Marine Biology* **116**: 19-30.

PRITCHARD, D.W. 1967. What is an estuary: physical viewpoint. In: *Estuaries*. Lauff, G. American Association for the Advancement of Science, Washington, D.C. pp. 3-5.

RATTE, T.W. 1989. *Population structure, production, growth, reproduction and the ecology of* Atherina breviceps *Valenciennes, 1935 (Pisces, Atherinidae) and* Gilchristella aestuaria *(Gilchrist, 1914) (Pisces, Clupeidae), from two southern Cape coastal lakes*. Ph.D., University of Port Elizabeth. 319pp.

READ, G.H.L. 1983. The effect of a dry and a wet summer on the thermal and salinity structure of the middle and upper reaches of the Keiskamma Estuary, Ciskei. *Transactions of the Royal Society of South Africa* **45**: 45-62.

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

REBELO, J.E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries* **15**: 403-413.

REDDERING, J.S.V. 1988. Prediction of the effects of reduced river discharge on the estuaries of the south-eastern Cape Province, South Africa. *South African Journal of Science* **84**: 726-730.

REDDERING, J.S.V. and Rust, I.C. 1990. Historical changes and sedimentary characteristics of Southern African estuaries. *South African Journal of Science* **86**: 425-428.

RIBBINK, A.J. 1994. Biodiversity and speciation of freshwater fishes with particular reference to African cichlids. In: *Aquatic Ecology, Scale, Pattern and Process*. Giller, P., Hildrew, A., and Raffaelli, D. (Eds). Blackwell Scientific Publications, Oxford. pp. 261-288.

ROBSON, D.S. and Regier, H.A. 1964. Sampling size in Peterson mark-recapture experiments. *Transactions of the American Fisheries Society* **93**: 215-226.

ROSS, G.J.B. 1988. Coastal Hydrography. In: *A Field Guide to the Eastern Cape Coast*. Lubke, R., Gess, G., and Bruton, M. (Eds). The Grahamstown Branch of the Wildlife Society of Southern Africa, Grahamstown. pp. 31-34.

RULIFSON, R.A. 1991. Finfish utilization of man-initiated and adjacent natural creeks of South Creek Estuary, North Carolina, using multiple gear types. *Estuaries* **14**: 447-464.

RUSSELL, I.A. 1996. Fish Abundance in the Wilderness and Swartvlei lake systems: changes relative to environmental factors. *South African Journal of Zoology* **31**: 1-9.

SCHUMANN, E.H., Largier, J.L. and Slinger, J.H. 1999. Estuarine hydrodynamics. In: *Estuaries of South Africa*. Allanson, B.R. and Baird, D. Cambridge University Press, Cambridge. pp. 100-117.

SCHLACHER, T.A. and Wooldridge, T.H. 1996. Ecological responses to reductions in freshwater supply and quality in South Africa's estuaries: lessons for management and conservation. *Journal of Coastal Conservation* **2**: 115-130.

SMAKTHIN, V. 1999. *Pers. comm.* Information on mean annual run-off and catchment sizes for estuaries. Email: "Re:Hydrography of Ciskeian Estuaries": vsmakthin@csir.co.za.

SMITH, M.M. and Heemstra, P.C. 1995. *Smith's Sea Fishes.* Southern Book Publishers, Johannesburg.

STOKESBURY, K.D.E., Bichy, J.B., and Ross, S.W. 1999. Selectivity and efficiency of two otter trawls used to assess estuarine fish and macroinvertebrate populations in North Carolina. *Estuaries* **22**: 882-888.

STONE, A.W. 1988. Climate and Weather. In: *A Field Guide to the Eastern Cape Coast.* Lubke, R., Gess, G., and Bruton, M. (Eds). The Grahamstown Branch of the Wildlife Society of Southern Africa, Grahamstown. pp. 19-30.

STONE, A.W., Weaver, A.vB., and West, W.O. 1998. Climate and Weather. In: *Field guide to the Eastern and Southern Cape coasts.* Lubke, R. and de Moor, I. (Eds). University of Cape Town Press, Cape Town. pp. 41-49.

TAKEUCHI, I. and Hino, A. 1997. Community structure of caprellid amphipods (Crustacea) on sea greases in Otsuchi bay, northeastern Japan, with reference to the association of *Caprella japonica* (Schurin) and *Phyllospadix iwatensis* (Makino). *Fisheries Science* **63**: 327-331.

TALBOT, M.M.J. 1982. *Aspects of the ecology and biology of* Gilchristella aestuarius *(G & T) (Pisces: Clupeidae) in the Swartkops estuary, Port Elizabeth.* M.Sc., University of Port Elizabeth. 128 pp.

TALBOT, M.M.B., Knoop, W.T. and Bate, G.C. 1990. The dynamics of estuarine macrophytes in relation to flood/siltation cycles. *Botanica Marina* **33**: 159-164.

TER MORSHUIZEN, L.D. 1996. *Distribution patterns of fishes in the head region of a turbid Eastern Cape estuary.* M.Sc., Rhodes University. 71pp.

TER MORSHUIZEN, L.D. and Whitfield, A.K. 1994. The distribution of littoral fish associated with eelgrass *Zostera capensis* beds in the Kariega estuary, a Southern African system with a reversed salinity gradient. *South African Journal of Marine Science* **14**: 95-105.

TER MORSHUIZEN, L.D., Whitfield, A.K., and Paterson, A.W. 1996a. Distribution patterns of fishes in an eastern Cape estuary and river with particular emphasis on the ebb and flow region. *Transactions of the Royal Society of South Africa* **51**: 257-280.

TER MORSHUIZEN, L.D., Whitfield, A.K., and Paterson, A.W. 1996b. Influence of freshwater flow regime on fish assemblages in the Great Fish River and estuary. *Southern African Journal of Aquatic Sciences* **22**: 52-61.

THIEL, R., Sepúlveda, A., Kafemann, R. and Nellen, W. 1995. Environmental factors as forces structuring the fish community of the Elbe Estuary. *Journal of Fish Biology* **46**: 47-69.

VAN DER HORST, G. and Erasmus, T. 1981. Spawning time and spawning grounds of mullet with special reference to *Liza dumerilii* (Steindachner, 1869). *South African Journal of Science* **77**: 73-78.

VAN DER ELST, R.P. and Wallace, J.H. 1976. Identification of the juvenile mullet of the east coast of South Africa. *Journal of Fish Biology* **9**: 371-374.

WALLACE, J.H. 1975a. The estuarine fishes of the east coast of South Africa. Part IV. Occurrence of juveniles in estuaries. Part V. Ecology, estuarine dependence and status. *South African Association for Marine Biological Research Investigative Report* **42**: 63 pp.

WALLACE, J.H. 1975b. The estuarine fishes of the east coast of South Africa. Part I. Species composition and length distribution in the estuarine and marine environments. Part II. Seasonal abundance and migrations. *South African Association for Marine Biological Research Investigative Report* **40**: 1-72.

WALLACE, J.H., Kok, H.M., Beckley, L.E., Bennett, B., Blaber, S.J.M. and Whitfield, A.K. 1984. South African estuaries and their importance to fishes. *South African Journal of Science* **80**: 203-207.

WALSH, J.H., Peters, D.S., and Cyrus, D.P. 1999. Habitat utilization by small flatfishes in a North Carolina estuary. *Estuaries* **22**: 803-813.

WALTON, C. 1984. *Readers Digest Atlas of Southern Africa.* Readers Digest Association of South Africa, Cape Town.

WHITE, P.N. and Bruton, M.N. 1983. Food and feeding mechanisms of *Gilchristella aestuarius* (Pisces: Clupeidae). *South African Journal of Zoology* **18**: 31-36.

WHITFIELD, A.K. 1980a. Factors influencing the recruitment of juvenile fishes into the Mhlanga estuary. *South African Journal of Zoology* **15**: 166-169.

WHITFIELD, A.K. 1980b. A checklist of fish species recorded from Maputaland estuarine systems. In: *Studies on the Ecology of Maputaland.* Bruton, M. and Cooper, K. (Eds). Rhodes University, Grahamstown. pp. 204-209.

WHITFIELD, A.K. 1980c. A quantitative study of the trophic relationships within the fish community of the Mhlanga estuary, South Africa. *Estuarine, Coastal and Shelf Science* **10**: 417-435.

WHITFIELD, A.K. 1983. Factors influencing the utilization of Southern African estuaries by fishes. *South African Journal of Science* **79**: 362-365.

WHITFIELD, A.K. 1986. Fish community structure response to major habitat changes within the littoral zone of an estuarine coastal lake. *Environmental Biology of Fishes* **17**: 41-51.

WHITFIELD, A.K. 1988. The fish community of the Swartvlei estuary and the influence of food availability on resource utilization. *Estuaries* **11**: 160-170.

WHITFIELD, A.K. 1989a. Fish larval composition, abundance and seasonality in a southern African estuarine lake. *South African Journal of Zoology* **24**: 217-224.

WHITFIELD, A.K. 1989b. Ichthyoplankton interchange in the mouth region of a southern African estuary. *Marine Ecology Progress Series* **54**: 25-33.

WHITFIELD, A.K. 1989c. Ichthyoplankton in a southern African surf zone: nursery area for the postlarvae of estuarine associated fish species? *Estuarine, Coastal and Shelf Science* **29**: 533-547.

WHITFIELD, A.K. 1990. Life-history styles of fishes in South African estuaries. *Environmental Biology of Fishes* **28**: 295-308.

WHITFIELD, A.K. 1992. A characterization of Southern African estuarine systems. *South African Journal of Aquatic Sciences* **18**: 89-103.

WHITFIELD, A.K. 1994. Abundance of larval and 0+ juvenile marine fishes in the lower reaches of three southern African estuaries with differing freshwater inputs. *Marine Ecology Progress Series* **105**: 257-267.

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

WHITFIELD, A.K. 1998. Biology and Ecology of Fishes in Southern African Estuaries. *Ichthyological Monographs of the J.L.B. Smith Institute of Ichthyology* **2:** 223 pp.

WHITFIELD, A.K. 2000. *Available scientific information on individual South African estuarine systems.* Water Research Commission, South Africa.

WHITFIELD, A.K. and Blaber, S.J.M. 1979. The distribution of the freshwater cichlid *Sarotherodon mossambicus* in estuarine systems. *Environmental Biology of Fishes* **4**: 77-81.

WHITFIELD, A.K and Harrison, T.D. 1996. *Gilchristella aestuaria* (Pisces: Clupeidae) biomass and consumption of zooplankton in the Sundays estuary. *South African Journal of Marine Science* **17**: 49-53.

WHITFIELD, A.K. and Kok, H.M. 1992. Recruitment of juvenile marine fishes into permanently open and seasonally open estuarine systems on the southern coast of South Africa. *Ichthyological Bulletin of the J.L.B. Smith Institute of Ichthyology* **57**: 39 pp.

WHITFIELD, A.K. and Paterson, A.W. 1995. Flood-associated mass mortality of fishes in the Sundays Estuary. *Water SA* **21**: 385-389.

WHITFIELD, A.K., Beckley, L.E., Bennett, B.A., Branch, G.M., Kok, H.M., Potter, I.C. and Van der Elst, R.P. 1989. Composition, species richness and similarity of ichthyofaunas in eelgrass *Zostera capensis* beds of southern Africa. *South African Journal of Marine Science* **8**: 251-259.

WHITFIELD, A.K., Paterson, A.W., Bok, A.H., and Kok, H.M. 1994. A comparison of the ichthyofaunas in two permanently open eastern Cape estuaries. *South African Journal of Zoology* **29**: 175-185.

WILL, R. and Houston, L.J. 1992. Fish distribution survey of Newark Bay, New Jersey, May 1987-April 1988. In: *Estuarine Research in the 1980s: The Hudson River Environmental Society, Seventh Symposium on Hudson River Ecology*. Lavett Smith, C. (Ed). State University of New York, New York. pp. 428-445.

WILLIAMS, G.D. and Zedler, J.B. 1999. Fish assemblage composition in constructed and natural tidal marshes of San Diego Bay: relative influence of channel morphology and restoration history. *Estuaries* **22**: 702-716.

WOOLDRIDGE, T. and Bailey, C. 1982. Euryhaline zooplankton of the Sundays estuary and notes on trophic relationships. *South African Journal of Zoology* **17**: 151-163.

YOUNG, G.C., Potter, I.C., Hyndes, G.A. and de Lestang, S. 1997. The ichthyofauna of an intermittently open estuary: implications of bar breaching and low salinities on faunal composition. *Estuarine, Coastal and Shelf Science* **45**: 53-68.

ZAR, J.H. 1996. *Biostatistical Analysis.* Prentice-Hall International, London.

Appendix I: The percentage species contribution and number of estuarine resident species caught in each estuary using the small seine net.

Family	**Species**	**Common Name**	**Bira**	**East Kleinemonde**	**Gqutywa**	**Great Fish**	**Keiskamma**	**Klein Palmiet**	**Mgwalana**	**Mpekweni**	**Mtati**	**Ngculura**
Ambassidae	*Ambassis natalensis*	Slender glassy				0.9						
Atherinidae	*Atherina breviceps*	Cape silverside	56.5	20.4	88.8	0.5	1.7	59.5	24.0	16.5	50.1	46.4
Clinidae	*Clinus superciliosus*	Super klipfish					0.2					
Clupeidae	*Gilchristella aestuaria*	Estuarine roundherring	29.0	73.3	8.1	92.1	89.3	31.3	70.2	81.0	48.0	22.5
Gobiidae	*Caffrogobius gilchristi*	Prison goby				1.4	4.0					
	Caffrogobius natalensis	Baldy	0.1									
	Caffrogobius nudiceps	Barehead goby	0.5				3.5		0.3			
	Glossogobius callidus	River goby	13.8	5.2	2.9	0.6	0.1	9.2	5.6	2.5	1.9	30.9
	Oligolepis acutipennis	Sharptail goby				0.2						
	Oligolepis keiensis	Speartail goby					0.1					
	Psammogobius knysnaensis	Speckled sandgoby	0.3	1.0	0.2	5.1	1.1		0.1	0.1	0.1	0.1
Hemiramphidae	*Hyporhamphus capensis*	Cape halfbeak	0.1	0.1						0.1	0.5	
Syngnathidae	*Syngnathus acus*	Longsnout pipefish		<0.1	<0.1	0.2	<0.1		<0.1	<0.1	<0.1	
	Syngnathus watermeyeri	Estuarine pipefish		0.1								
		Total individuals	7834	4539	7110	642	2171	1455	8378	17521	10998	825
		Total species	7	7	5	8	9	3	6	6	6	4

Appendix II: The percentage marine and freshwater species contribution to the large seine net catch in each system, including a total number of species recorded in each estuary.

Family	**Species**	**Common Name**	**Bira**	**East Kleinemonde**	**Gqutywa**	**Great Fish**	**Keiskamma**	**Klein Palmiet**	**Mgwalana**	**Mpekweni**	**Mtati**	**Ngculura**
Anguillidae	*Anguilla mossambica*	Longfin eel				0.2						
Ariidae	*Galeichthys feliceps*	White seacatfish				0.2	2.4		0.1			
Carangidae	*Caranx sexfasciatus*	Bigeye kingfish				1.1	0.9		0.2	0.1		
	Lichia amia	Leervis								0.1		
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	1.5	4.7	0.7	0.7			9.6	7.6	1.1	0.7
Clariidae	*Clarius gariepinus*	Sharptooth catfish				0.4						
Clinidae	*Fucomimus mus*	Mousey klipfish					0.2					
Cyprinidae	*Barbus aeneus*	Smallmouth yellowfish				0.2						
	Cyprinus carpio	Carp				0.2						
Elopidae	*Elops machnata*	Ladyfish					0.4		0.1	0.1	0.1	
Gerreidae	*Gerres acinaces*	Smallscale pursemouth			0.1							
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	1.2	0.1	2.5	8.2	19.1		6.2	0.3	0.8	
	Pomadasys olivaceum	Piggy			2.9				0.2			
Hemiramphidae	*Hemiramphus far*	Spotted halfbeak							0.4			

Appendix II continued…

Family	Species	Common Name	Bira	East Kleinemonde	Gqutywa	Great Fish	Keiskamma	Klein Palmiet	Mgwalana	Mpekweni	Mtati	Ngculura
Monodactylidae	*Monodactylus falciformis*	Oval moony	3.3	9.0	0.4			3.8	1.1	5.9	3.1	0.9
Mugilidae	Mugilidae <50 mm SL	Juvenile mullet		0.6		0.5						
	Liza dumerilii	Groovy mullet	9.4	3.2	3.9	4.7	16.2		5.6	7.4	20.3	0.2
	Liza macrolepis	Largescale mullet	0.1									
	Liza richardsonii	Southern mullet	7.2	5.1	8.7	43.6	19.5	17.7	5.0	1.3	17.3	33.6
	Liza tricuspidens	Striped mullet	0.2	0.1	2.0	0.9	0.7		0.1	1.5	0.2	0.3
	Mugil cephalus	Flathead mullet	3.7	0.3	0.3	4.0	5.7	5.1	1.1	1.1	0.2	2.5
	Myxus capensis	Freshwater mullet	2.0	13.5	0.3	0.9	0.2		1.7	3.9	11.3	23.5
	Valamugil cunnesius	Longarm mullet	0.6	0.1	0.5	0.9					0.2	
Notocheiridae	*Iso natalensis*	Surf sprite					2.0					
Pomatomidae	*Pomatomus saltatrix*	Elf			7.1				0.1	0.8		
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	0.1			1.5	5.5		0.3	0.1	0.1	
Serranidae	*Epinephelus andersoni*	Catface rockcod					0.4					
Soleidae	*Heteromycteris capensis*	Cape sole		0.3	4.6	2.2	0.2		0.1	0.4	0.1	0.1
	Solea bleekeri	Blackhand sole		0.2	5.4	15.6	4.6		1.4	1.4	0.2	
Sparidae	*Acanthopagrus berda*	Estuarine bream	0.1			0.4	0.7			0.1		

Appendix II continued…

Family	Species	Common Name	Bira	East Kleinemonde	Gqutywa	Great Fish	Keiskamma	Klein Palmiet	Mgwalana	Mpekweni	Mtati	Ngculura
Sparidae	*Diplodus cervinus*	Zebra	0.1									
	Diplodus sargus	Blacktail	0.1									
	Lithognathus lithognathus	White steenbras		2.7	3.3	4.5		41.8	0.7	2.4	0.9	
	Rhabdosargus globiceps	White stumpnose	0.1		0.1							
	Rhabdosargus holubi	Cape stumpnose	70.0	59.9	57.3	7.5	21.3	31.6	66.0	65.4	43.5	38.3
	Rhabdosargus sarba	Tropical stumpnose							0.1	0.1		
	Rhabdosargus thorpei	Bigeye stumpnose							0.1			
	Sarpa salpa	Strepie	0.4									
Teraponidae	*Terapon jarbua*	Thornfish			0.1				0.1			
Tetraodontidae	*Amblyrhynchotes honckenii*	Evileye puffer/blaasop				0.7						
Torpedinidae	*Torpedo fuscomaculata*	Blackspotted electric ray	0.1									
		Total individuals	2513	946	762	550	457	79	2354	2088	1588	1509
		Total species	18	14	18	22	17	5	22	19	15	9

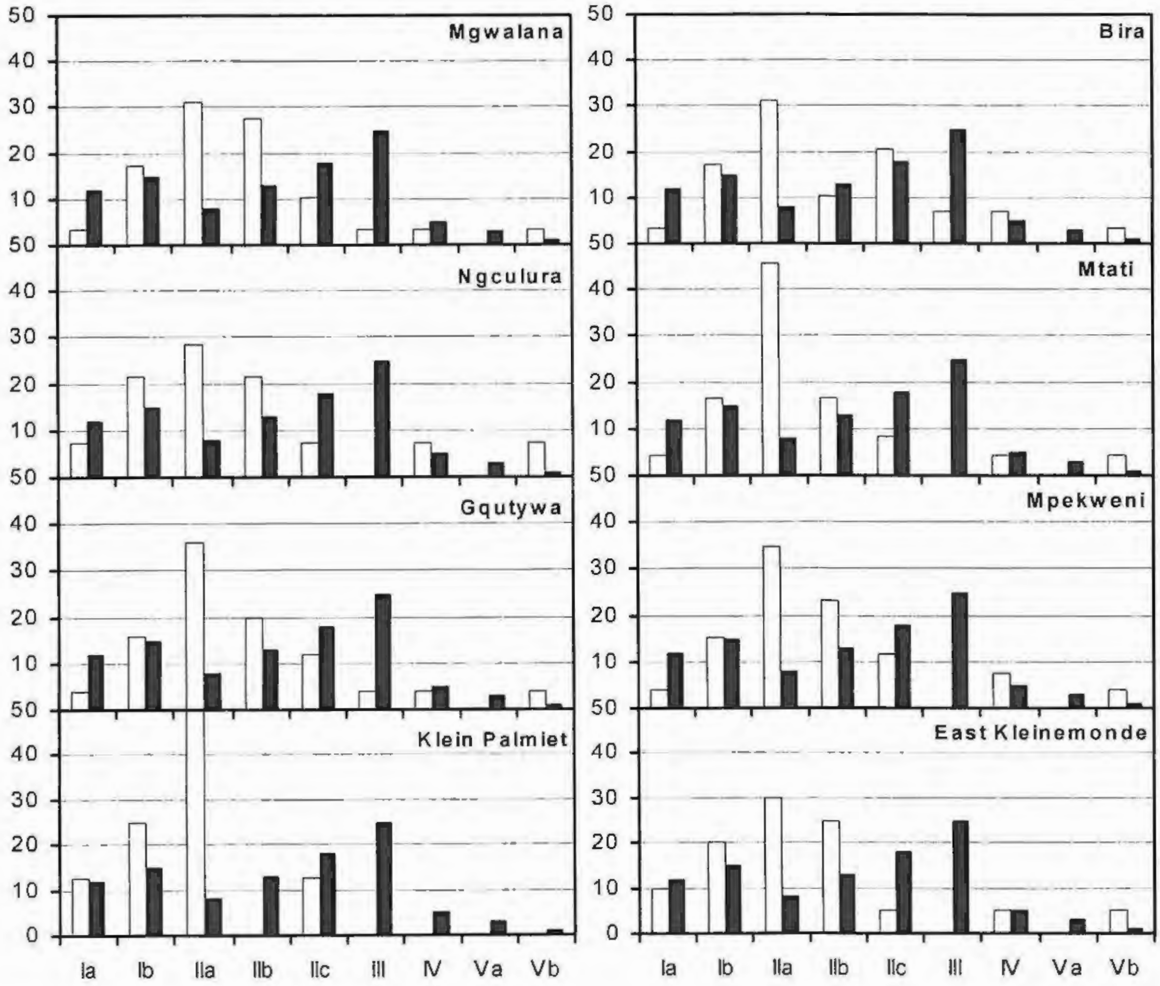
Appendix III: The percentage species contribution to the gill net catch in each system, including a total number of species recorded in each system.

Family	Species	Common Name	Bira	East Kleinemonde	Gqutywa	Great Fish	Keiskamma	Mgwalana	Mpekweni	Mtati	Ngculura
Ariidae	*Galeichthys feliceps*	White seacatfish					8.6	1.3			
Carangidae	*Lichia amia*	Leervis		1.4	8.9		3.9	3.8	1.9	0.7	
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia		3.5	2.2			13.8	0.6		4.7
Cyprinidae	*Barbus aeneus*	Smallmouth yellowfish				3.8					
Elopidae	*Elops machnata*	Ladyfish	16.8	0.2			0.6	1.3	5.7	39.2	
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	8.9	4.9	6.7	7.7	5.6	17.6	8.2	10.0	
Monodactylidae	*Monodactylus falciformis*	Oval moony	2.0	33.3	1.1				1.6	12.6	2.9
Mugilidae	*Liza dumerilii*	Groovy mullet	2.0	2.0	3.3	1.5	0.4	5.7	1.9	2.8	2.3
	Liza richardsonii	Southern mullet	12.9	3.0	17.8		22.2	5.3	6.3	3.0	4.7
	Liza tricuspidens	Striped mullet	4.0	0.5	1.1		8.3	1.3	6.9		9.3
	Mugil cephalus	Flathead mullet	26.7	22.9	11.1	75.4	1.5	1.7	22.1	1.4	41.9
	Myxus capensis	Freshwater mullet	3.0	7.1			16.5	9.4	11.3	7.7	2.3
	Valamugil buchanani	Bluetail mullet					0.6			0.7	
	Valamugil cunnesius	Longarm mullet	6.9	3.0						0.7	
Pomatomidae	*Pomatomus saltatrix*	Elf	1.0		16.7						

Appendix III continued…

Family	Species	Common Name	Bira	East Kleinemonde	Gqutywa	Great Fish	Keiskamma	Mgwalana	Mpekweni	Mtati	Ngculura
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	13.9	1.6	12.2	12.4	23.2	24.5	8.1	18.9	
	Johnius dorsalis	Small kob					0.4				
Sparidae	*Acanthopagrus berda*	Estuarine bream							0.6		
	Lithognathus lithognathus	White steenbras		3.6	4.4		0.4	0.6	2.5	1.4	7.0
	Rhabdosargus holubi	Cape stumpnose	2.0	13.2	14.4		0.4	5.3	13.8	0.7	7.0
Teraponidae	*Terapon jarbua*	Thornfish								3.0	
		Total individuals	101	130	90	65	324	159	159	143	43
		Total species	12	14	12	5	15	13	15	14	9

Appendix IV: The proportion of species in each estuarine dependence category for individual closed estuaries. The clear bars represent the proportions recorded during this study, while the dark bars represent the proportion for southern African estuaries in general (after Whitfield, 1998).



Appendix V: The proportion of species in each estuarine dependence category for individual open estuaries. The clear bars represent the proportions recorded during this study, while the dark bars represent the proportion for southern African estuaries in general (after Whitfield, 1998).