A preliminary survey of the estuaries on the south coast of South Africa, Cape St Blaize, Mossel Bay – Robberg Peninsula, Plettenberg Bay, with particular reference to the fish fauna

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The coastal river systems on the south coast of South Africa from Cape St Blaize to Robberg Peninsula were surveyed during October and November 1994. The ichthyofaunal and physico-chemical characteristics of each system are presented and their suitability as estuarine nursery areas is discussed. Five systems (Rooi, Meul, Grooteliland, Kranshoek and Crooks) are outlets of small coastal streams and probably provide little or no habitat for either resident estuarine or migrant marine fishes owing to their small size. Four systems (Maalgate, Gwaing, Skaapkop and Kaaimans) are located within deeply incised valleys and have a permanent connection with the sea. The amount of marginal and intertidal habitat available to fishes, however, is limited due to their morphology. Six systems (Hartenbos, Groot Brak, Touw, Swartvlei, Goukamma and Noetsie) are intermittently open to the sea. Although the Touw and Swartvlei are connected to coastal lake systems, flow within these estuaries is not sufficient to prevent the build up of a sand barrier at the mouth. The Hartenbos, Groot Brak, Goukamma, and Noetsie are also periodically closed by a sand bar. The construction of a dam in the lower catchment of the Groot Brak has affected the hydrology of the system. The two remaining estuaries (Klein Brak and Knysna) are permanently open. In addition to strong tidal currents, the fixing of the mouth of the Knysna Estuary between rocky headlands also serves to maintain a permanent connection with the sea. Mugilidae and Sparidae were represented by the greatest number of species, and also dominated catches numerically and by mass. The fish fauna of all the estuaries surveyed were dominated by the juveniles of estuarine-dependent marine species and estuarine-resident species were also well represented in catches. The estuaries surveyed provide a vital habitat for both marine migrant species and resident species, most of which are endemic to the region. Key words: estuaries, fish, south coast.

INTRODUCTION

The South African coastline extends approximately 3000 km from the Orange (Gariep) River (28°38’S; 16°28’E) on the west (Atlantic Ocean) coast to Kosi Bay (26°54’S; 32°53’E) on the east (Indian Ocean) coast. Some 300 estuarine systems have been identified along the coast of South Africa (Whitfield, 2000). Estuaries are the meeting place of freshwater from rivers and saltwater from the sea and, as such, are dynamic environments characterised by large fluctuations in environmental conditions.

Estuaries are important nursery areas for several species of marine fishes, many of which are exploited in estuaries or coastal fisheries later in their life cycles (Houde & Rutherford, 1993). The role of estuaries as nursery areas is particularly important in southern Africa, as the coastline is exposed and characterised by high-energy wave action, strong ocean currents and a widely fluctuating marine intertidal environment (McLachlan et al., 1981; Beckley, 1985). This is in contrast to areas such as southwestern Australia, where inshore waters are sheltered by reefs and islands and can be used as alternative nursery areas by many marine species (Potter et al., 1990).

Despite the importance of estuaries to fishes, little is known about many of South Africa’s estuarine systems; the state of information of 68% of estuaries is regarded as ‘nil’ or ‘poor’ (Whitfield, 2000). This paper utilises the results of a synoptic fish survey of South Africa’s estuaries and reports on those systems between Cape St Blaize and Robberg Peninsula on the south coast; it represents a continuation of the published series on the estuaries of South Africa (Harrison 1997a,b, 1998, 1999a,b). Basic physico-chemical variables and fish community data are presented and an appraisal of the nursery potential of these systems for fishes is provided.

STUDY AREA

The south coast of South Africa between Cape St Blaize and Robberg Peninsula is characterised by a bimodal precipitation pattern, with rain falling mostly in October/November and March, or almost equally in all seasons (Heydorn & Tinley, 1980; Heydorn, 1991). The coastline borders the Indian Ocean and is influenced by the warm, south-flowing Agulhas Current (Heydorn, 1991). Wind-induced coastal upwelling, which brings cold nutrient rich water to the surface, sometimes occurs during summer (Shannon, 1989). Seventeen river/stream outlets intersect the coast in the region (Heydorn, 1986; Figure 1).

MATERIALS AND METHODS

Physico-chemical properties

The estuaries between Cape St Blaize and Robberg Peninsula were sampled during the period October to November 1994.
Each system was sampled once and took 1–3 days to survey, depending on the size of the system. During each survey, selected physico-chemical parameters were measured at various sites within each system. Water depth was measured using a weighted shotline graduated at 10 cm intervals. Temperature (°C), salinity (‰), conductivity (mS cm⁻¹), pH, dissolved oxygen (mg l⁻¹) and turbidity (NTU) were measured using a Horiba U-10 Water Quality Checker. Where water depth permitted, both surface and bottom waters were measured. The mouth state of each system at the time of sampling was also noted.

Ichthyofauna

The ichthyofauna of each estuary was sampled using a 3.0 m × 1.7 m × 1.5 m mesh seine net with a 5 mm bar mesh purse and a fleet of gill nets. The gill nets were either 10 m or 20 m in length and 1.7 m in depth and consisted of three equal sections of 45 mm, 75 mm and 100 mm stretch meshes. Seine netting was carried out during daylight hours in shallow (<1.5 m deep), unobstructed areas with gently sloping banks. Fish caught were identified and measured to the nearest millimetre standard length (SL) before being released. Specimens that could not be identified in the field were placed in labelled plastic bags and preserved in 10% formalin for transport to the laboratory; where large catches of a species were made, a sub-sample of at least 25 specimens was also kept. Gill netting was carried overnight out in deep (>1 m) open, mid-channel waters, the nets being deployed in the evening (18:00) and lifted the following morning (06:00). In most cases only the larger, deeper systems were sampled using gill nets. Specimens captured in the gill nets were, where possible, identified in the field, measured (mm SL) and weighed to the nearest 1.0 g using a Bonso model 323 balance. Specimens that could not be identified in the field were placed in labelled plastic bags and preserved in 10% formalin for transport to the laboratory. In the laboratory, preserved specimens were identified by reference to Smith & Heemstra (1991) and Skelton (1993). A minimum of 25 specimens of the abundant species were measured (mm SL) and weighed to the nearest 0.01 g using a Mettler PJ 3000 balance. The remaining specimens were counted and the batch weighed.

The total species composition, by number and mass, was calculated for each system. The relative biomass contribution of each species was calculated using actual recorded masses as well as masses derived from length–mass relationships presented in Harrison (2001). Where appropriate, the length frequency

![Figure 1. The location of study estuaries between Cape St Blaize and the Robberg Peninsula on the south coast of South Africa.](image-url)
Hartenbos

The Hartenbos (34°07’S; 22°07’E) is situated approximately 8.5 km northwest of the town of Mossel Bay. The system has a catchment area of 207 km² (Day, 1981) and approximately 20 unnamed tributaries enter the Hartenbos River along its length (Bickerton, 1982). One dam, Hartebeeskuil Dam, is situated in the catchment of the Hartenbos. From the open floodplains of the upper reaches the estuary flows between high (20–30 m) dunes on the southwestern bank and dune vegetation on the northeastern bank. From there to the mouth the estuary forms an S-shape. There are two large sandspits situated on the southwestern and northeastern banks and the estuary mouth is characterised by a large flat sandy bar that is elevated 1–2 m above mean sea level when the mouth is closed (Bickerton, 1982). A weir situated approximately 2.5 km from the mouth delineates the upper reaches of the estuary. A sewage treatment works is also located in the upper reaches on the northern shore, and discharges treated effluent into the estuary. Several bridges cross the estuary; a rail bridge is located about 700 m upstream of the mouth and approximately 1 km further upstream, a dual carriageway road bridge crosses the system. Two additional road bridges cross the estuary about 2 km upstream of the mouth. Although the state of information on the Hartenbos Estuary is moderate, biological/ecological information is lacking (Whitfield, 2000).

**Physico-chemical properties**

Physico-chemical parameters were measured at four sites from the mouth (Site 1) to the upper reaches (Site 4), situated just below the weir. The mouth of the estuary was closed at the time of sampling. The mouth of the Hartenbos is reported to close during dry months and opens in response to heavy rainfall in the catchment (Day, 1981; Bickerton, 1982). The water depth recorded in this survey ranged from 0.8 to 2.0 m (Table 1). The estuary is reported to be very shallow along its length with a depth of 1–3 m reported in the lower reaches (Day, 1981).

Surface water temperatures ranged from 18.8°C to 20.9°C, while bottom water temperatures were generally higher and measured between 18.9°C and 22.1°C (Table 1), indicating a degree of temperature stratification. Bickerton (1982), sampling the estuary in November 1981 when the mouth was open, recorded similar temperatures ranging from 20°C at the mouth to 26°C in the upper reaches, with a mean temperature of 22°C.

Vertical and horizontal salinity stratification was also evident during this survey with surface salinities ranging from 18.8% recorded at the mouth to 12.8% in the upper reaches; bottom salinities ranged from 18.9 to 18.2% (Table 1). Hypersaline conditions have been recorded in the estuary, with salinities of up to 41.8% recorded near the head of the estuary (Day, 1981). During a high spring tide and open-mouth conditions in November 1981, surface salinities of between 36% in the lower reaches to 24% in the upper reaches were recorded, with the equivalent bottom salinities ranging from 36 to 33% (Bickerton, 1982). This indicates that the estuary is well stratified and suggests the presence of a salt wedge in the upper reaches (Bickerton, 1982).

The pH of the water during this survey ranged between 8.9 and 9.2 (Table 1). When the estuary was surveyed in November 1981, pH values ranged from 8.0 to 8.2 and were consistent with the pH of seawater (Bickerton, 1982). Photosynthetic activity by aquatic plants and algae can lead to an increase in the pH of waters (Klein, 1959) and may be responsible for the elevated pH recorded; prolific algal growth was evident in the estuary at the time of this survey.

Surface dissolved oxygen concentrations ranged from 5.7 mg l⁻¹ at the mouth to 7.8 mg l⁻¹ in the upper reaches of the estuary; the equivalent bottom dissolved oxygen concentrations ranged from 7.1 to 9.2 mg l⁻¹ (Table 1). When the mouth of the estuary was closed in July 1978, a mean dissolved oxygen concentration of 6.4 mg l⁻¹ was recorded (Eagle et al., 1979). The water in the estuary was very clear during this survey with turbidities ranging from 1 to 4 NTU (Table 1).

**Ichthyofauna**

Four seine net hauls and five gill nets yielded a total of 609 individuals representing nine species from six families. Mugilidae dominated the taxa, with four species recorded. Gilchristella aestuaria and Atherina breviceps dominated catches, numerically comprising 36.9% and 33.3% of the catch, respectively; Liza richardsonii was the third most important species comprising 19.2% of the catch followed by Lithognathus lithognathus (3.0%), Liza dumerili (2.3%), Mugil cephalus (1.8%), Psammogobius knysnaensis (1.8%) and Pomadasys commersonnii (1.1%) (Table 2). A total species mass of over 15 kg was recorded. Liza richardsonii dominated the biomass, comprising 26.0% of the catch. Other important species included M. cephalus (23.1%), P. commersonnii (17.9%), L. lithognathus (15.7%), Myxus capensis (10.1%), L. dumerili (5.4%) and G. aestuaria (1.4%) (Table 3).

Using a ‘D’ net, gill net and scoop net in the middle and upper reaches of the estuary, Bickerton (1982) recorded a total of 12 fish species when the mouth of the estuary was open in November 1981; six species (50%) were common to this survey. Taxa recorded by Bickerton (1982) included Diplodus capensis, Lichia amia, Monodactylus falciformis, Solea solea, L. lithognathus, G. aestuaria, L. dumerili, L. richardsonii, M. cephalus, Psammogobius knysnaensis, Rhinobatos maculatus and Galichthys felicis. Bickerton (1982) also notes that Argyronomeus japonicus and Orectochromis mossambicus have been recorded by anglers in this estuary. This brings the total number of species recorded in the Hartenbos Estuary to 16.

Liza richardsonii captured during this survey ranged in size between 27 and 325 mm; most of these were small specimens in the 50–60 mm size class. A number of larger specimens in the 80–100 mm size classes were also captured as well as a few very large individuals (>210 mm). Liza richardsonii is an estuarine-dependent marine species that uses estuaries as juvenile nursery areas. Juvenile recruitment into estuaries on the southwestern and southern Cape coasts occurs at about 20 to 50 mm TL (Bennett, 1989; Whitfield & Kok, 1992). A length of about 75 mm FL is attained after a year (Ratte, 1977). The range of sizes captured during this survey indicates regular recruitment and use of the system. Lithognathus lithognathus is another estuarine-dependent species and enters estuaries along the southeastern, southern and southwestern Cape coasts at sizes below 50 mm TL (Bennett, 1993). Most of the individuals captured during this survey were newly recruited and comprised small individuals less than 40 mm; a few larger individuals (>250 mm) were also present. The predominance of small juve-
niles together with the presence of larger individuals also indicates regular recruitment and utilisation of this system. Bickerton (1982) also found that almost all fish captured in the estuary were juveniles or immature, indicating recent recruitment into the estuary. *Gilchristella aestuaria* captured during this survey were all mature individuals between 30 and 50 mm; *G. aestuaria* are estimated to mature at a size of 28 mm SL (Talbot, 1982). By contrast, the majority of *A. breviceps* caught were immature (<30 mm). *Atherina breviceps* is estimated to mature at a size of 40 mm SL (Ratte, 1989). Both *G. aestuaria* and *A. breviceps* are estuarine-resident species and the presence of mature and immature individuals of these species indicates that the Hartenbos is also a viable habitat for estuarine-resident species.

Of the taxa collected during this survey, three were estuarine-resident species that are able to complete their entire life cycle in estuaries; the remaining six species were euryhaline marine species that breed at sea, with juveniles showing varying degrees of dependence on estuaries (Whitfield, 1994). A similar fish community structure was reported by Bickerton (1982) where, of the 12 species caught, 10 (83%) were estuarine-dependent marine species and two (17%) were estuarine-resident species. Estuarine-resident species during this survey comprised 72.1% of the total catch numerically and only 1.7% of the biomass, while estuarine-dependent marine species comprised 28.0% of the catch numerically and 98.3% of the biomass. The dominance of both estuarine-resident and estuarine-dependent marine species in the Hartenbos Estuary indicates that the system supports fishes with very different life cycles.

Klein Brak
The Klein Brak Estuary (34°05' S; 22°08' E) is situated within the southern coastal belt, and is approximately 12 km north of...
Table 2. Relative abundance of fishes captured in south coast estuaries (Cape St Blaise – Robberg Peninsula) in October/November 1994.

<table>
<thead>
<tr>
<th>Species</th>
<th>Hartenbos</th>
<th>Klein Brak</th>
<th>Groot Brak</th>
<th>Maalgat</th>
<th>Gwaing</th>
<th>Meul</th>
<th>Kaaimans</th>
<th>Touw</th>
<th>Swartvlei</th>
<th>Goukamma</th>
<th>Knysna</th>
<th>Noetsie</th>
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<td>4 0.8</td>
<td>1 0.1</td>
<td>212 35</td>
<td>4 0.8</td>
<td>674 30.7</td>
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<td>561 21.9</td>
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<td>Atherina breviceps</td>
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<td>4 0.8</td>
<td>674 30.7</td>
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<td>561 21.9</td>
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<td>Caffrogobius gilchristi</td>
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<td>11 1.1</td>
<td>11 1.1</td>
<td>2 2.1</td>
<td>19 4.0</td>
<td>119 5.4</td>
<td>21 1.7</td>
<td>15 0.6</td>
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<td>122 5.6</td>
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<td>563 44.7</td>
<td>524 20.4</td>
<td>24 1.6</td>
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<td>40 8.4</td>
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<td>109 8.7</td>
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<td>130 100</td>
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<td>120 5.5</td>
<td>161 6.3</td>
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<td>47 3.7</td>
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Table 3. Relative biomass of fishes captured in south coast estuaries (Cape St Blaise – Robberg Peninsula) in September/October 1994.

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<th>Kaaimans</th>
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Mossel Bay. Two major tributaries, the Brandwag River (with a catchment area of 320 km²) and the Moorduik River (with a catchment area of 225 km²) join approximately 3 km from the coast (River Health Programme, 2003). A large flood-tidal delta is situated in the lower reaches of the estuary. A number of bridges cross the estuary. A rail bridge is situated approximately 500 m upstream of the mouth; bridges that carry the dual carriageway motorway across the estuary are located about 1.5 km upstream of the mouth and another road bridge crosses the system about 100 m further upstream. Very little information is available on the Klein Brak Estuary (Whitfield, 2000).

Physico-chemical properties

Physico-chemical parameters were measured at four sites extending from the mouth (Site 1) to the upper reaches of the estuary (Site 4). The estuary was open at the time of sampling. The presence of a well-developed flood-tidal delta in the lower reaches indicates a strong tidal influence and these tidal currents probably serve to maintain a near-permanent connection with the sea (Cooper, 2001). Water depth recorded during this survey ranged from 0.5 to 2.0 m (Table 1). Day (1981) recorded a depth of 2.0 m in the lower reaches of the system.

Surface water temperatures increased from 18.7 °C at the mouth to 19.4 °C in the upper reaches and bottom water temperatures ranged from 18.2 °C to 19.2 °C in the same direction (Table 1). Salinity showed pronounced vertical stratification with surface salinities lower than those recorded at the bottom; surface salinities ranged between 10.6 and 7.0‰ while those at the bottom were between 28.1 to 30.4‰. A horizontal salinity gradient was also evident with values generally decreasing upstream from the mouth (Table 1). Day (1981) also recorded a strong horizontal salinity gradient with a salinity of 34.1‰ recorded near the mouth declining to 60‰ near the head of the system.

As a consequence of the vertical salinity layering, the pH of the bottom water (mean = 8.0) was greater than that of the surface water (mean = 7.9). Surface water dissolved oxygen concentrations ranged from 7.3 to 6.4 mg l⁻¹ and were generally higher than bottom dissolved oxygen concentrations, which measured between 4.7 and 6.7 mg l⁻¹; this is also a reflection of salinity stratification. The water in the estuary was clear, with turbidities not exceeding 14 NTU (Table 1).

Ichthyofauna

A total of 500 individuals representing 18 species and 11 families were caught in seven seine net hauls and five gill nets. Mugilidae (4 species), Gobiidae (3 species) and Sparidae (3 species) dominated the taxa in terms of species diversity. *Rhabdosargus holubi* (35.0%) dominated catches by number followed by *C affrogobius gilchristi* (23.6%), *L. dumerili* (7.2%), *P. knysnaensis* (7.0%), *L. lithognathus* (6.2%), *L. richardsonii* (4.2%), *Caffrogobius natalisenis* (3.6%), *P. commersonii* (2.8%), *G. aestuaria* (2.4%), *M. cephalus* (1.4%), *Galeichthys feliceps* (1.2%), *Lichia amia* (1.2%) and juvenile *mugilids* (1.2%) (Table 2). A total fish mass of over 37 kilograms was recorded. The most important species, in terms of mass, was *Argyrosomus japonicus*, which comprised over 20.2% of the catch, followed by *R. holubi* (16.1%), *P. commersonii* (14.5%), *G. feliceps* (11.9%), *L. richardsonii* (9.2%), *L. lithognathus* (7.6%), *M. cephalus* (6.7%), *L. amia* (6.4%), *L. dumerili* (5.5%) and *M. capensis* (1.3%) (Table 3).

*Rhabdosargus holubi* individuals captured during this survey ranged in size from 15 to 139 mm with most individuals in the 70–120 mm size classes. *Rhabdosargus holubi* is an estuarine-dependent marine species. Postflexion larvae and early juveniles recruit into estuaries at a small size of between 9 and 15 mm SL (Cowley et al., 2001) and attain a length of approximately 100 mm SL by the end of their first year (Beckley, 1984). The majority of the individuals captured during this survey were less than one year old; a few small specimens (<30 mm) were also recorded, indicating recent recruitment into the system. *Liza dumerili* is also an estuarine-dependent marine species and individuals during this survey ranged in size from 58 to 224 mm with most specimens between 100 and 150 mm. Recruitment of *L. dumerili* into estuaries on the southern Cape coast occurs at <30 mm TL (Whitfield & Kok, 1992). The presence of a few small individuals in the 50–60 mm size class during this survey suggests recent recruitment into the estuary.

The majority of *L. lithognathus* caught were between 120 and 150 mm. Based on an estimated monthly growth increment of approximately 13 mm for juvenile *L. lithognathus* (Bennett, 1989; Bennett, 1993), most of the individuals captured during this survey were in the 0+ and 1+ year classes. *Liza richardsonii* captured during this survey ranged in size from 66 to 308 mm; most specimens were between 180 and 230 mm. Both larger (>300 mm) and smaller (<70 mm) size classes were also represented. The large numbers of juvenile marine fishes caught in the Klein Brak estuary indicates that it serves a viable nursery function for these species. The range of sizes captured also suggests that the system is utilised on a regular basis.

*Caffrogobius gilchristi* is an estuarine-resident species and matures at a length of approximately 50 mm SL (Bennett, 1989). Specimens captured during this survey were between 27 and 60 mm; most specimens were immature and were in the 30–40 mm size class. *Psammogobius knysnaensis* is also an estuarine-resident species and ranged in size from 24 to 47 mm. The modal size comprised mature individuals in the 30–40 mm size class; *P. knysnaensis* matures at a length of approximately 30 mm SL (Bennett, 1989). The presence of both mature and immature estuarine species indicates that the Klein Brak is also an important habitat for resident fishes.

Of the taxa collected during this survey eleven were estuarine-dependent marine species; these species also dominated the catches both numerically (62.8%) and by mass (99.4%). Five estuarine-resident species and one marine straggler were recorded. Estuarine-resident species comprised 37.0% of the total catch numerically and 0.5% of the total biomass. The occurrence of both estuarine-resident species and estuarine-dependent marine species in the Klein Brak estuary indicates that the system supports fishes with very different life cycles.

Groot Brak

The Groot Brak Estuary (34°03′S; 22°14′E) is situated approximately 5 km southeast of the town of Great Brak River (EMATEK, 1990). The catchment area of the system is estimated at between 131 km² (Morant, 1983) and 192 km² (Day, 1981). The Groot Brak River is approximately 28.5 km in length and arises on the slopes of the Engelsberg in the Outeniqua mountain range (Morant, 1983); the main tributaries of the system are the Perdeberg rivier, Tweeriviere and Vanringsrivier. Two dams, the Ernest Robertson Dam and the Wolwedans Dam, are situated in the catchment of the Groot Brak.

The estuary meanders through a broad floodplain and widens near the coast before discharging to the sea. The lower reaches of the estuary are approximately 1 km wide and a small island, about 500 m long and 300 m wide, is located in this region. The island is developed with residential houses and a small bridge on the northern shore connects it with the mainland. Several bridges cross the estuary; a rail bridge is...
located about 900 m upstream of the mouth and a road bridge crosses the system a further 50 m upstream of this. Bridges that carry the dual carriageway across the estuary are located about 1 km upstream from the mouth and a small road bridge crosses the system near the head of the estuary, approximately 4 km upstream from the mouth. The state of information on the Groot Brak Estuary is considered good; however, biological/ecological information on the system is lacking (Whitfield, 2000).

Physico-chemical properties

Physico-chemical parameters were measured at four sites in the Groot Brak Estuary ranging from the mouth area (Site 1) to the upper reaches of the system (Site 4). The estuary mouth was open at the time of this survey. Day (1981) states that the mouth of the Groot Brak Estuary, which is bounded on the east by a low rocky headland and on the west by a sandspit, is permanently open. The Wolwedans Dam, which was completed in 1990 and is situated approximately 6.5 km upstream from the mouth, however, has affected the hydrology and estuary mouth state (Quinn et al., 1999). The mouth frequently closes and a management plan has been developed to maintain open-mouth conditions during spring and summer; this includes the intermittent release of water from the dam as well as artificial breaching of the mouth when required.

Water depth recorded during this survey ranged from 1.0 m in the mouth region to 2.5 m in the middle reaches (Table 1). Day (1981) reported a depth of 2.0 m in the lower reaches, while Morant (1983) reported mean depths of between 0.2 to 0.8 m in the lower reaches during spring high tides. Both surface and bottom water temperatures increased from the mouth upstream; surface temperatures were also slightly higher than those at the bottom. Surface water temperatures ranged from 19.1 to 23.8°C while those at the bottom were between 18.9 and 22.1°C. By contrast, Morant (1983) found little difference in temperature along the length of the estuary in spring 1981. Water temperatures in winter (August 1978) were, however, warmer in the upper reaches (16.4°C) than at the mouth (12.6°C) (Eagle et al., 1979). The temperature regime recorded during this study is probably a reflection of salinity stratification with warmer fresh waters overlying cooler, more saline bottom waters.

Both horizontal and vertical salinity gradients were recorded during this survey. Surface salinities decreased from 34.9‰ at the mouth to 23.1‰ in the upper reaches. Bottom salinities were higher than those at the surface and ranged from 34.9‰ at the mouth to 30.1‰ in the upper reaches (Table 1). These conditions indicate considerable penetration of seawater into the estuary. Day (1981) also notes that when the mouth of the Groot Brak is open, the whole estuary is tidal. In spring 1981, salinities remained high (36–25‰) throughout most of the estuary and there was evidence of a salt wedge structure in the upper reaches (Morant, 1983). In winter (August 1978) when the mouth was closed salinity values of 23‰ were recorded throughout the estuary (Eagle et al., 1979).

The pH of the water was typically marine and ranged from 8.3 near the mouth to 7.8 in the upper reaches; there was little difference between surface and bottom waters (Table 1). Morant (1983) recorded pH values of around 8.0 throughout the estuary. Both surface and bottom dissolved oxygen concentrations decreased from the mouth upstream (Table 1). Surface dissolved oxygen concentrations ranged from 6.9 to 4.6 mg l⁻¹, while bottom dissolved oxygen concentrations ranged from 6.9 to 2.7 mg l⁻¹ (Table 1). In November 1981, dissolved oxygen concentrations averaged 7.0 mg l⁻¹ and were also lowest in the bottom water of the upper reaches (Morant, 1983). The waters of the Groot Brak were relatively clear and turbidity did not exceed 6 NTU (Table 1).

Ichthyofauna

A total of 996 fish, represented by nine families and 15 taxa were caught in six seine net hauls and five gill nets in the Groot Brak Estuary. In terms of the number of species recorded Mugilidae (eight species), Sparidae (two species) and Gobiidae (two species) were the most important families. In terms of numbers, L. richardsonii (34.7%), G. aestuaria (17%), L. dumerili (14.9%), R. holubi (9.4%), juvenile mugilids (6.5%), L. lithognathus (6.3%), M. capensis (4.2%), M. cephalus (2.3%), Oreochromis mossambicus (1.3%) and C. p. richardi (1.1%) were the most abundant taxa (Table 2). A total fish mass of over 55 kg was recorded. Liza richardsonii (31.2%) was the dominant species followed by L. dumerili (26.0%), G. falciformis (12.4%), O. mossambicus (12.0%), M. capensis (4.7%), M. cephalus (4.5%), R. holubi (2.6%), P. commersonnii (1.8%), Liza tricuspidalis (1.6%) and L. amia (1.5%) (Table 3).

Morant (1983) listed 12 species from the Groot Brak; six species (50%) were common to this survey. Species recorded included Abudelfaf sordidus, G. aestuaria, Glossogobius nudiceps, L. lithognathus, L. dumerili, L. richardsonii, Monodactylus falciformis, M. capensis, P. knysnaensis, R. holubi, S. turbuncii and Syngratinae tenmiokii. The spot damselfish, Abudelfaf sordidus, is a tropical species and was found much further south than its normal range (Morant, 1983). A total of 20 species have now been recorded in this estuary.

Liza richardsonii caught during this survey ranged between 41 and 336 mm in size; most individuals fell within the 110–150 mm size classes with smaller individuals in the 40–60 mm size classes also well represented. This indicates regular recruitment and utilisation of the system. Liza dumerili individuals ranged from 58 to 225 mm. Most specimens fell within the 170–190 mm size classes; smaller size classes (100–140 mm and 50–70 mm) were also present, which also indicates regular recruitment and use of the estuary. Rhabdosargus holubi were predominantly small, newly recruited individuals less than 30 mm; larger specimens 50–70 mm and 100–110 mm were also represented, indicating regular usage of the system.

Lithognathus lithognathus were between 22 and 176 mm; this species was also dominated by small individuals (<40 mm), which indicates recent recruitment. Myxus capensis and M. cephalus are also estuarine-dependent marine species and both were dominated by newly recruited juveniles <30 mm. Recruitment into estuaries occurs at <20 mm SL for M. capensis (Bok, 1979) and <30 mm TL for M. cephalus (Wallace & van der Elst, 1975). Larger specimens were also captured suggesting regular utilisation of the system. The majority of G. aestuaria caught were mature individuals with a modal size class of 30–40 mm. This indicates that the Groot Brak is also important for estuarine-resident species.

Marine species whose juveniles are dependent on estuaries to varying degrees were the most numerous species recorded (11 species). Three estuarine-resident species and one freshwater species were recorded. Estuarine-dependent marine species dominated catches, comprising 80.0% of the catch numerically and 99.9% by mass; estuarine-resident species comprised 18.6% numerically and only 0.1% by mass. The predominance of estuarine-dependent marine species and estuarine-resident species indicates that the Groot Brak Estuary is an important habitat for fishes with different life-history styles.
Rooi

The Rooi is situated approximately 25 km northwest of Mossel Bay. This system comprises a very small coastal stream that only flows following moderate rains in the catchment. At the coast the stream flows to the sea via a concrete culvert. The stream was not flowing at the time of this survey and the only water in the system was a small pool at the base of the culvert. The Rooi does not appear to function as an estuary and consequently was not sampled during this survey.

Maalgate

The Maalgate (34°03'S; 22°21'E) is situated approximately 32 km northwest of Mossel Bay. The river is located in a deeply incised valley and the system opens to the sea between two rocky headlands. A sandy flood-tidal delta is situated in the lower reaches of the system, which is exposed at low tide; this becomes inundated at high tide, as the valley is flooded with seawater. Very little information exists on the Maalgate system (Whitfield, 2000).

Physico-chemical properties

Physico-chemical parameters were measured at one site in the mouth region of the system. The system was open at the time of sampling. The location of the mouth between rocky headlands and strong tidal currents probably serve to maintain a permanent connection with the sea. The depth recorded at the study site was 1.7 m. There was very little difference between surface and bottom temperatures, which were 18.1°C and 18.4°C, respectively. Similarly, bottom and surface salinities were both close to seawater and measured 34.2‰ and 34.8‰, respectively. The pH of both the surface and bottom waters was close to seawater and measured 8.3. Dissolved oxygen concentrations were above 6.0 mg l–1 and the water was very clear with turbidity values below 3 NTU (Table 1).

Ichthyofauna

Three seine net hauls and three gill nets caught a total of 1170 individuals, representing ten species and seven families. In terms of the number of species recorded Mugilidae (three species) and Soleidae (two species) were the most important families. In terms of numbers, G. aestuaria (78.6%), M. cephalus (17.2%) and P. knysnaensis (2.7%) were the most abundant species recorded (Table 2). A total fish mass of over 5 kg was recorded and this was dominated by L. richardsonii (45.9%), G. aestuaria (26.0%), G. feliceps (14.1%), L. dumerili (10.5%) and R. holubi (1.8%) (Table 3).

All M. cephalus caught had recently recruited into the estuary and were less than 30 mm. Gilchristella aestuaria individuals were all mature with a modal size class of 40–50 mm. A high proportion of the P. knysnaensis were mature, with most specimens belonging to the 30–40 mm size class.

Of the ten taxa collected, eight were estuarine-dependent marine species and two were estuarine-resident species. Resident species comprised 81.3% of the catch numerically and 26.5% by mass. Estuarine-dependent marine species comprised 18.8% of the catch numerically and 73.6% by mass. The presence of both resident species and estuarine-dependent marine species suggests that the Maalgate serves as a viable habitat for these fishes; however, this may be limited due to its location within a small incised valley and restricted marginal habitat.

Gwaing

The Gwaing Estuary (34°03'S; 22°20'E) is located in a deeply incised valley approximately 36 km northwest of Mossel Bay. The mouth region is characterised by an extensive sandy flood-tidal delta, which is exposed at low tide; this becomes inundated at high tide as the valley fills with seawater. The shores of the mouth and lower reaches are protected with concrete walls to facilitate residential and recreational development in the area; a narrow bridge also crosses the system near the mouth. Very little information exists on the Gwaing system (Whitfield, 2000).

Physico-chemical properties

Physico-chemical parameters were measured at two locations in the lower reaches of the estuary. The system was open at the time of sampling. Rocky headlands at the coast and strong tidal currents probably serve to maintain a permanent connection with the sea. Water depth did not exceed 1.0 m (Table 1). Water temperatures ranged from 17.6 to 16.5°C and there was no difference between surface and bottom values. Salinities showed a strong upstream reduction and vertical stratification was also evident. Near the mouth, surface and bottom salinities measured 10.6 and 23.7‰, respectively, while further upstream equivalent measurements were 2.5 and 3.6‰.

The pH of water near the mouth (8.2–8.3) was higher than that recorded further upstream (7.6–7.9). Surface dissolved oxygen concentrations were slightly higher than those at the bottom; values also increased from the mouth upstream. Surface and bottom dissolved oxygen values near the mouth measured 7.9 and 7.1 mg l–1, respectively; further upstream measurements were 8.5 and 8.3 mg l–1. Although the waters were generally clear (<10 NTU), upstream waters were more turbid than those near the mouth; bottom turbidity values were also slightly lower than those at the surface. The physico-chemical parameters recorded during this survey indicate a wedge of saline marine water overlain by more turbid, well-oxygenated estuarine water (Table 1).

Ichthyofauna

Four seine net hauls and three gill nets caught a total of 38 individuals representing six species and four families. Mugilidae and Sparidae were the most important families and were represented by two species each. In terms of numbers, catches were dominated by L. richardsonii, which comprised 96.4% of the catch (Table 2); followed by juvenile mugilids (1.3%) and M. falciformis (1.0%). A total species mass of over 3 kg was recorded, with L. richardsonii comprising 69.9% (Table 3). Other important species in terms of mass included G. feliceps (18.0%), M. falciformis (5.7%), M. capensis (3.1%), L. lithognathus (1.8%) and R. holubi (1.5%).

Liza richardsonii individuals ranged between 40 and 255 mm; most individuals were in the 40–90 mm size classes indicating recent recruitment. Some larger specimens (>210 mm) were also captured suggesting regular utilisation of the system.

Only estuarine-dependent marine species were caught during this survey. This suggests that the Gwaing does not provide a suitable habitat for estuarine-resident taxa and serves a minor nursery function for a limited number of estuarine-dependent marine species because of its restricted marginal habitat.

Skaapkop

The Skaapkop is located approximately 40 km northwest of Mossel Bay. Access to the system was very difficult and as a result it was not sampled during this survey. Based on aerial photographs, the Skaapkop is similar to the Maalgate and Gwaing systems in that the river flows through an incised valley and opens to the sea between rocky headlands. A
sandy flood-tidal delta is also situated in the lower reaches; this appears to be exposed at low tide but is submerged at high tide as the valley is flooded with seawater. The value of the Skaapkop as a habitat for fishes may be limited due to its location in an incised valley and restricted marginal habitat.

**Meul**

The Meul (34°00'S; 22°32'E) is located approximately 51 km northwest of Mossel Bay and comprises a small coastal stream situated in an incised valley. At the coast the system forms a small waterbody about 100 m long situated behind a low sand barrier built up between two rocky headlands; the waterbody is 30 m wide at its widest point.

**Physico-chemical properties**

Physico-chemical parameters were measured at a single site in the waterbody. The system was open to the sea at the time of sampling and was extremely shallow with a depth of only 0.2 m. The water temperature was 19.5°C and the water was slightly brackish (salinity = 0.6‰), indicating little penetration of saltwater into the system. A pH of 8.7 was recorded and the dissolved oxygen was 9.8 mg l⁻¹; turbidity measured 16 NTU (Table 1).

**Ichthyofauna**

A single seine net haul caught only one estuarine-dependent marine species, *Mugil cephalus* (family Mugilidae). A total of 116 individuals were caught with a total mass of 76 g (Tables 2 & 3). Most of these were small individuals (< 40 mm) indicating recent recruitment. The absence of larger individuals or resident estuarine species, however, indicates that the system is of little value as a habitat for estuary-associated fishes.

**Kaaimans**

The Kaaimans (33°59'S; 22°33'E) is situated approximately 47 km west of Knysna. The river is located in an incised valley and opens to the sea between two rocky headlands. The lower reaches of the system is characterised by a sandy flood tidal delta, which is exposed at low tide but is submerged at high tide. A railway bridge spans the mouth region of the estuary. A low road bridge crosses the upper reaches of the system approximately 1.3 km upstream of the mouth and a second road bridge, that carries the national road, crosses the system about 200 m above this. Very little information exists on the Kaaimans system (Whitfield, 2000).

**Physico-chemical properties**

Physico-chemical parameters were measured at two sites in the lower and middle reaches of the estuary. The mouth was open at the time of sampling. The location of the mouth between rocky headlands and strong tidal currents probably serve to maintain a permanent connection with the sea. At high tide the estuary mouth can be over 200 m wide, however, during low tide when the flood-tidal delta is exposed, flow from the estuary is restricted to a narrow inlet. Water depth ranged from 1.2 to 2.6 m (Table 1).

Water temperatures were uniform throughout and measured between 17.6 and 17.8°C. There was evidence of salinity stratification, with bottom salinities higher than those at the surface; surface salinities ranged from 24.1 to 19.6‰ and bottom salinities from 31.3 to 33.2‰. The pH values ranged between 7.8 and 8.2. Dissolved oxygen concentrations in the bottom waters were lower than those at the surface; there was also a slight decrease upstream from the mouth. Surface water dissolved oxygen levels ranged from 6.1 to 5.6 mg l⁻¹ while those at the bottom measured between 5.6 and 4.7 mg l⁻¹. The water was very clear with turbidities of between 1 and 2 NTU recorded (Table 1).

**Ichthyofauna**

Three seine net hauls and three gill nets caught ten species representing six families; Mugilidae, Sparidae and Gobiidae were each represented by two species. A total of 97 individuals were captured and these were dominated by *Heteromycteris capensis* (21.6%), *M. cephalus* (20.6%), *P. knysnaensis* (17.5%), *L. hithognathus* (16.5%), *G. feliceps* (12.4%), *L. richardsonii* (4.1%), *R. holubi* (3.1%), *G. gilchristi* (2.1%), *M. falciformis* (1.0%) and *S. turbynei* (1.0%) (Table 2). A species mass of over 11 kg was recorded with *G. feliceps* (74.3%), *L. richardsonii* (23.6%) and *R. holubi* (1.0%) dominating the catch (Table 3).

*Heteromycteris capensis* is a marine migrant species and recruitment of larvae and post-larvae into warm-temperate estuaries occurs at a length of 5–15 mm BL (Whitfield & Kok, 1992). Individuals captured during this survey were immature and ranged between 25 and 54 mm; most individuals were in the 30–50 mm size classes. *Heteromycteris capensis* attains sexual maturity at about 80 mm SL (Cyrus & Martin, 1991). All the *M. cephalus* captured were newly recruited individuals in the 23–30 mm size class. This suggests that the Kaaimans does serve a nursery function for marine migrant species. *Psammogobius knysnaensis* were mostly mature individuals in the 30–50 mm size classes. This also indicates that the system supports resident fishes.

Two estuarine-resident species were caught during this survey; the remaining species were estuarine-dependent marine species. Estuarine-dependent marine species were the dominant group and comprised 80.3% of the catch numerically and 99.7% of the catch by mass. Estuarine species comprised 19.6% of the catch numerically and only 0.3% by mass. The occurrence of both estuarine-resident species and estuarine-dependent marine species indicates that the Kaaimans serves a viable habitat for these fishes. However, this function may be limited owing to its location in an incised valley and restricted marginal habitat.

**Touws**

The Touws Estuary (33°59'S; 22°34'E) is situated approximately 45 km west of Knysna and falls within the Wilderness National Park. The estuary acts as an intermittent link between the Wilderness lake system and the sea. The Wilderness lake system comprises three estuarine lakes (Rondevlei, Langvlei and Eilandvlei) that are interconnected by shallow channels. The Touws Estuary is connected to Eilandvlei via the narrow Serpentine Channel, which enters the estuary about 3 km upstream of the mouth. Several bridges cross the Touws Estuary and a road and rail bridge are located in the mouth region. Two further rail bridges cross the system approximately 1.6 km and 3.5 km upstream from the mouth, respectively. The Wilderness lakes have been subject to numerous studies and the state of information is regarded as excellent (Whitfield, 2000).

**Physico-chemical properties**

Physico-chemical parameters were measured at four sites in the mouth, lower, middle and upper reaches of the Touws Estuary. The system was closed at the time of sampling. The estuary is characterised by wide variations in hydrology caused by frequent mouth closure, mainly in response to southwesterly wave conditions and longshore and onshore sand transport (Russell, 1996). The sand barrier at the mouth is
often artificially breached to reduce water levels within the estuary. Water depth ranged from 1.2 m to 2.4 m (Table 1), which falls within the range reported by Hall et al. (1987) who recorded depths of between 1 m in the lower reaches to 3.5 m in the vicinity of the Serpentine.

Surface water temperatures decreased from the mouth to the upper reaches of the estuary, and measured between 20.0 and 15.5°C. Bottom temperatures did not exhibit the same longitudinal pattern and were generally warmer than those at the surface; bottom water temperatures ranged from 19.5 to 20.0°C. In addition to thermal stratification, vertical salinity stratification was also evident with bottom salinities being higher than those at the surface. Surface salinities also exhibited a decline as one moved upstream from the mouth and ranged from 3.3‰ at the mouth to 0.3‰ in the upper reaches. Bottom salinities did not exhibit any clear horizontal pattern and ranged between 6.5‰ and 27.5‰ (Table 1). During open phases, salinities tend to increase due to the influx of marine water, and to decrease during closed phases as a result of freshwater inflow (Russell, 1996). Strong axial salinity gradients have been reported during open phases and Russell (1996) found that average salinity during the closed phase was generally below 15‰, with salinities as low as 2‰ recorded on one occasion.

The pH of the waters during this survey ranged from 6.6 to 7.8. Dissolved oxygen concentrations of the surface waters were higher than those recorded at the mouth; this is probably a result of salinity stratification and a lack of mixing. Surface dissolved oxygen values also increased in an upstream direction and ranged between 6.2 mg l^-1 at the mouth to 7.8 mg l^-1 in the upper reaches. Bottom water dissolved oxygen levels were very low, measuring between 0.2 and 3.3 mg l^-1. The estuary water was generally very clear, with turbidities ranging from 1 to 6 NTU (Table 1). Turbidities in the estuary and lakes are generally low, but can increase substantially during periods of high runoff from the catchments (Russell, 1996).

**Ichthyofauna**

Six seine net hauls and five gill nets caught a total of 478 individuals representing 18 species and 11 families. In terms of the number of species recorded, Mugilidae was the most important family (five species), followed by Sparidae and Gobiidae with two species each. In terms of numbers, L. richardsonii (36.8%), R. holubi (18.0%), juvenile mugilids (13.0%), L. dumerili (8.4%), P. knysnaensis (7.3%), C. gilchristi (4.0%), L. tricuspidens (3.6%), M. cephalus (2.9%), H. capensis (1.7%) and L. lithognathus (1.7%) were the most abundant taxa (Table 2). A total species mass of over 22 kg was caught; the most important species, by mass, were L. richardsonii (60.6%), L. dumerili (15.5%), O. mossambicus (7.2%), L. lithognathus (4.4%), P. commersonnii (3.7%), M. cephas (2.5%), L. amia (2.4%), L. tricuspidens (1.7%) and R. holubi (1.4%) (Table 3). Russell (1996) recorded 11 marine species in the Touws Estuary and Wilderness lakes between 1991 and 1993; ten species (91%) were common to this survey. Species recorded by Russell (1996) included L. lithognathus, L. amia, L. dumerili, L. richardsonii, L. tricuspidens, M. falciformis, M. cephalus, M. capensis, P. commersonnii, P. saltatrix and R. holubi.

**Liza richardsonii** showed a polymodal length frequency distribution; the first size class comprised individuals 40–90 mm, the second size class was 110–170 mm and the third size class was 200–330 mm. This indicates regular recruitment of this species into the system. Liza richardsonii individuals caught by Russell (1996) also showed a polymodal length frequency distribution and substantial recruitment was recorded, particularly in 1993. Good recruitment was also evident in R. holubi during this survey; most of the specimens caught were 0+ juveniles between 10 and 30 mm. Liza dumerili ranged between 50 and 218 mm with most individuals greater than 120 mm. Most L. knysnaensis individuals captured were mature and were predominantly in the 30–40 mm size class.

Twelve of the taxa caught were estuarine-dependent marine species whose juveniles are dependent on estuaries to varying degrees. Five estuarine-resident taxa and one freshwater species were also sampled. Estuarine-dependent marine species were the dominant group comprising 87.3% of the catch numerically and 99.6% by mass. Estuarine-residents comprised 12.5% of the catch numerically and only 0.5% by mass. The abundance of estuarine-resident and estuarine-dependent marine species in the Touws Estuary indicates that this system is an important habitat for both groups of fishes.

**Swartvlei**

The Swartvlei Estuary (34°01’S; 22°47’E) is situated on the Cape south coast, approximately 25 km west of Knysna. This system also forms part of the Wilderness National Park. The estuary consists of a 7.2 km winding channel that connects the Swartvlei estuarine lake to the sea. A road bridge and a rail bridge cross the system just below where the lake enters the estuary. Numerous studies have been undertaken on the Swartvlei system, including both the estuary and the lake; the state of information on the Swartvlei is regarded as excellent (Whitfield, 2000).

**Physico-chemical properties**

Physico-chemical parameters were measured at six sites from the mouth to the head of the estuary. The mouth of the system was open at the time of sampling. The Swartvlei Estuary opens seasonally and is normally closed during winter and open in summer (Whitfield, 1989). Water depth ranged from 0.8 m in the upper reaches to a maximum recorded depth of 2.7 m in the middle reaches (Table 1). Kok & Whitfield (1986) report that the estuary is normally very shallow, with a maximum recorded depth of 4 m and a narrow central channel that is bordered on each side by intertidal sand flats. Water levels are primarily governed by mouth phase and river inflow (Whitfield et al., 1983).

There was little difference between surface and bottom water temperatures during this study and values ranged between 21.2 and 23.3°C. Seasonal water temperatures range from 10–14°C in mid-winter to 25–29°C in mid-summer (Whitfield et al., 1983). Salinity stratification was evident during this study with surface values less than those at the bottom. Surface waters also exhibited an axial gradient with salinities decreasing upstream from the mouth. Surface salinities recorded between 10.4 and 31.5‰. When the estuary mouth was open, Whitfield & Kok (1992) recorded salinities of between 15–35‰ in the middle and upper reaches. In the lower reaches salinities fluctuated between 25–35‰. Salinities tend to decline during the closed phase (Whitfield & Kok, 1992).

There was little difference between surface and bottom pH measurements, which ranged between 7.7 and 8.4. Surface dissolved oxygen concentrations were generally higher than those recorded at the bottom, reflecting the stratified salinity conditions. Surface dissolved oxygen values ranged between 7.0 and 8.2 mg l^-1 while bottom values measured between 5.5 and 8.1 mg l^-1. The water in the estuary was very clear, ranging between 0 and 3 NTU (Table 1).
Ichthyofauna

Ten seine net hauls and six gill nets caught a total of 2192 individuals represented by 20 species from 11 families. Mugilidae and Sparidae were the most important families, with five species each; Gobiidae were represented by two species. Numerically, catches were dominated by A. breviceps (30.7%), Sarpa salpa (23.8%), L. richardsonii (10.5%), R. holubi (8.5%), Clinus superciliosus (5.6%), juvenile mugilids (5.5%), C. gilchristi (5.4%), D. sargus (3.1%), P. knysnaensis (3.0%) and S. temminckii (1.2%) (Table 2). A total species mass of over 47 kg was caught and was dominated by L. richardsonii (69.2%), P. commersonii (15.3%), G. feliceps (2.7%), R. holubi (2.6%). L. lithognathus (1.8%), M. cephalus (1.5%), A. breviceps (1.3%) and M. capensis (1.1%) (Table 3). Russell (1996) caught 12 marine species in the Swartvlei estuary and lake between 1991 and 1993; ten species (83%) were common to this survey. Taxa recorded comprised specimens 270–330 mm. The predominance of small 0+ individuals in the Swartvlei estuary and species comprised 46.4% of the catch numerically and 97.3% of the biomass. Estuarine-resident species comprised 53.5% of the catch. Specimens captured ranged between 62 and 171 mm; most specimens were immature and were between 60 and 80 mm. Syngnathus temminckii matures at about 120 mm SL (Bennett, 1989). The presence of representatives of both juvenile and adult estuarine-resident species indicates that the Swartvlei Estuary is an important habitat for these fishes. Estuarine-dependent marine species comprised 53.5% of the catch numerically and 2.4% by mass. The predominance of estuarine-dependent marine species and estuarine-resident species, together with the range of size classes recorded, indicates that the Swartvlei Estuary is an important habitat for these fishes.

Goukamma

The Goukamma Estuary (34°04’S; 22°57’E) is situated approximately 12 km west of Knysna and lies within the Goukamma Nature Reserve. The Goukamma Nature Reserve also includes an offshore marine protected area and the Groenvlei coastal lake (van der Merwe, 1970). At the coast the estuary is diverted parallel to the shore by sand dunes and the mouth is situated behind a low sand barrier. A railway bridge crosses the estuary approximately 8.5 km upstream of the mouth and a further 200 m above this, bridges that carry the dual carriageway road cross the system. Another road bridge is located about 8.8 km upstream of the mouth. The state of information on the Goukamma Estuary is poor (Whitfield, 2000).

Physico-chemical properties

Physico-chemical parameters were measured at four sites in the mouth, lower, middle and upper reaches of the estuary. The mouth of the system was open at the time of this survey. Very little information exists on the frequency of mouth opening in the Goukamma Estuary. Examination of aerial photographs indicate that the system does periodically close behind a sand barrier built up at the mouth. Water depth varied between 0.4 m at the mouth to 3.1 m in the upper reaches (Table 1).

Surface water temperatures declined in an upstream direction and ranged from 19.8°C at the mouth to 18.5°C in the upper reaches. Bottom water temperatures followed a similar trend and were generally slightly lower than those at the surface; bottom water temperatures measured between 18.5 and 17.7°C (Table 1). Vertical salinity stratification was pronounced, with surface salinities not exceeding 6.0‰ and bottom salinities greater than 27.0‰. Surface salinities also exhibited a horizontal gradient from 5.9‰ recorded near the mouth to 0.7‰ in the upper reaches.

Surface water pH declined from 7.2 to 6.6 in an upstream direction. The pH of the bottom water was slightly higher than that at the surface and ranged from 7.8 to 7.9; no horizontal gradient, however, was apparent (Table 1). The water in the Goukamma River is reported to be brown in colour and highly acidic (van der Merwe, 1970), and this probably accounts for the lower pH values recorded in the brackish surface waters.

Surface dissolved oxygen concentrations (6.7–7.0 mg l–1) were higher than those recorded at the bottom (3.0–3.5 mg l–1) and are probably a result of salinity stratification and a lack of mixing. The estuary water was very clear, with turbidities not exceeding 3 NTU. The turbidity of the surface waters (3 NTU), however, was slightly higher than those at the bottom (1–2 NTU) (Table 1).
Ichthyofauna

A total of five seine net hauls and five gill nets caught 1313 individuals represented by 16 species and nine families. In terms of the number of species recorded Mugilidae with four species and Gobiidae with three species were the most important families, followed by Sparidae and Soleidae with two species each. Gilchristella aestuaria was the dominant species numerically, comprising 44.7% of the catch, followed by Rhabdosargus holubi (18.1%), L. lithognathus (17.5%), L. richardsonii (8.7%), M. cephalus (3.9%), P. knysnaensis (3.7%) and C. gilchristi (1.7%) (Table 2). A total species mass of 33 kg was recorded. The biomass was dominated by Liza richardsonii (52.9%), A. japonicus (17.0%), P. commersonii (12.8%), L. lithognathus (12.5%) and M. capensis (2.6%) (Table 3). Rhabdosargus holubi mostly comprised recently recruited 0+ juveniles 10–30 mm. L. lithognathus also comprised mainly juveniles below 40 mm that had recently entered the estuary; a few larger specimens (mostly 230–280 mm) were also present, suggesting regular utilisation of the system. Liza richardsonii ranged between 53 and 328 mm and exhibited a complementary length frequency distribution. One size class comprised individuals mostly between 70 and 90 mm, the second size class included specimens 150–180 mm, and the third class comprised individuals between 230 and 300 mm; this indicates regular recruitment and use of the estuary by L. richardsonii. All M. cephalus captured comprised recently recruited individuals in the 20–30 mm size class. The presence of a wide size range of marine species in the Goukamma Estuary indicates that this system is functioning as an important nursery habitat for these species.

Gilchristella aestuaria in the Goukamma Estuary were mostly in the 20–40 mm size classes and both juvenile and adult specimens were well represented. Pammogobius knysnaensis ranged between 25 and 40 mm in length; most specimens were mature and occurred within the 30–40 mm size class. Cafrrogobius gilchristi captured during this survey were mostly immature and fell within the 30–50 mm size classes. The Goukamma appears to serve a viable habitat for resident fish species.

Estuarine-dependent marine species dominated the fishes of the Goukamma Estuary; 11 species belonged to this group and comprised 49.9% of the catch numerically but only 1.0% by mass. Five estuarine-resident species were recorded; this group comprised 50.3% of the catch numerically but only 1.0% by mass. The results of this survey indicate that the Goukamma Estuary appears to serve a viable function for both marine migrant and estuarine-resident fishes.

Knysna

The Knysna Estuary (34°04’S; 23°03’E) is situated in the town of Knysna on the south coast of South Africa. The Knysna River is 64 km long (Day et al., 1952), with a catchment area of between 315 and 337 km² (Grindley, 1985). The estuary is approximately 19 km long and falls within the Knysna National Lake Area, which is a National Park. The lower reaches of the estuary broaden to approximately 3 km wide and are characterised by extensive intertidal sand flats. A permanent connection with the sea is fixed between two rocky headlands approximately 200 m apart. Two islands, Thesen Island and Leisure Island, are also situated in the lower reaches and both islands are developed. Thesen Island, which is about 2 km long and 1.5 km wide, is connected to the mainland by a bridge on the north shore while Leisure Island, which is approximately 1.8 km long and 0.6 km wide, is connected to the mainland by a narrow bridge on the eastern shore. A railway bridge crosses the estuary approximately 5.5 km upstream of the mouth and a road bridge is located about 12 km upstream from the mouth. A second road bridge (Westford Bridge) crosses the system about 2.5 km above this. The head of the estuary is marked by rapids (Charlesford Rapids). The Knysna system has been well studied and the state of information on the estuary is regarded as excellent (Whitfield, 2000).

Physico-chemical properties

Physico-chemical parameters were measured at six sites in the Knysna Estuary, from the lower reaches (Site 1) to the upper reaches (Site 6). The mouth was open at the time of the survey. The location of the mouth between rocky headlands prevents the longshore drift of sand into the estuary and serves to maintain a permanent connection with the sea (Day, 1981).

Water depth measured during this survey ranged between 1.3 and 3.1 m but generally exceeded 2.0 m at most sites (Table 1). In the upper reaches, between the two road bridges, depths of 2.0–3.0 m were recorded; between the rail bridge and the road bridge the depth varied between 1.8 and 5.0 m, while below the rail bridge depths of between 3.6 and 14.0 m were recorded (Day, 1981). Depths of up to 16 m have also been reported in the mouth channel by Grindley (1985).

There was little difference between surface and bottom water temperatures; values did, however, increase upstream from the mouth. Surface and bottom temperatures ranged between 17.9 and 17.8°C at the lower site (Site 1) to 23.7 and 23.9°C at the uppermost site (Site 6) (Table 1). Day et al. (1952) recorded a maximum temperature of 29.0°C at the top of the estuary in summer and a minimum of 12.0°C in winter; temperatures at the mouth ranged from 13.9°C in winter to 21.8°C in summer. Similarly, Whitfield & Kok (1992) recorded temperatures in the upper reaches of between 13.0°C (winter) and 28.0°C (summer). In the lower reaches of the estuary, the sea moderated water temperatures, which ranged from 15–23°C (Whitfield & Kok, 1992). Wind-induced upwelling in summer can occasionally result in cold water (10–15°C) entering the estuary with the flood tide (Grindley, 1985).

Both surface and bottom salinities decreased from the lower to the upper reaches, with very little vertical stratification. Surface salinities ranged from 34.5 to 22.7‰ while bottom salinities measured between 34.8 and 23.1‰ (Table 1). Normal river discharge is weak compared with tidal exchange and consequently salinities of 30–35‰ are recorded at the rail bridge, and seaward of this point there is little vertical stratification (Day, 1981). At the head of the estuary (Charlesford Rapids) the water column is well stratified, with salinities of 0.4‰ on the surface and approximately 5.1‰ at the bottom (Day, 1981).

Surface and bottom pH values during this survey were similar to that of seawater and ranged between 7.9 and 8.1 (Table 1). Day et al. (1952) recorded pH values of 8.3–8.4 in the lower reaches and 7.2–8.0 in the upper reaches. At the head of the estuary the pH drops to between 6.6 and 7.0, and above that the river water is acidic. There was little difference between surface and bottom dissolved oxygen concentrations indicating that the waters are well mixed. Dissolved oxygen values generally decreased upstream from the mouth. Surface and bottom dissolved oxygen concentrations ranged between 5.8 and 6.7 mg l⁻¹ (Table 1). Day (1981) reported high dissolved oxygen concentrations throughout the estuary, with the exception of the narrow channel near Thesen Island, which was near a sewage outfall. Turbidity during this survey ranged between 2 and 18 NTU. The waters were generally clear with turbidities mostly below 7 NTU. Day et al. (1952) noted that a feature of the Knysna estuary is the clarity of the water. This may be attributed to a strong marine influence on the
system and the inflow of freshwater with low suspensoid levels.

Ichthyofauna
A total of 2564 individuals representing 33 species from 18 families were caught in 26 seine net hauls and nine gill nets. In terms of the number of species recorded Mugilidae and Sparidae were the most important families with seven species each, followed by Gobiidae with five species. In terms of numbers, catches were dominated by *A. breviceps* (21.9%), *G. aestuaria* (20.4%), *R. holubi* (14.0%), *L. richardsonii* (10.8%), *S. salpa* (7.1%), juvenile mugilids (6.3%), *D. sargus* (4.3%), *L. dumerili* (2.0%), *C. natalensis* (1.8%), *P. knysnaensis* (1.8%), *Rhabdosargus globiceps* (1.6%), *Hemiramphus far* (1.1%), *L. lithognathus* (1.1%) and *P. commersonii* (1.0%) (Table 2). A total species mass of over 82 kg were caught. Catches were dominated by *L. richardsonii* (26.8%), *L. dumerili* (13.4%), *S. salpa* (13.2%), *Elops machnata* (6.9%), *L. tricuspidens* (6.9%), *H. far* (6.6%), *P. commersonii* (5.2%), *Myliobatis aquila* (4.2%), *R. holubi* (3.9%), *L. ania* (3.6%), *Pomatomus saltatrix* (1.6%), *Amblyrhynchotes honckenii* (1.3%), *A. breviceps* (1.2%) and *M. cephalus* (1.1%) (Table 3).

Almost 200 species of fish have been recorded in the Knysna Estuary (Grindley, 1985). The high number of species recorded is probably a reflection of the numerous studies that have been undertaken in the system. The strong marine influence may also contribute toward the high species richness; almost 20% of the taxa recorded during this survey were marine stragglers, which do not depend on estuaries. Of particular interest is the occurrence of the endangered Knysna seahorse, *Hippocampus capensis*; Knysna Estuary represents a key habitat for this species.

Two size classes of *R. holubi* were caught; the first comprised individuals mostly between 20–30 mm and the second size class consisted of larger specimens mostly in the 70–100 mm size classes. The majority of fish sampled were less than one year old indicating good recruitment of 0+ individuals into the estuary. *Liza richardsonii* captured during this survey were mostly newly recruited individuals in the 40–60 mm size classes; a few larger specimens in the 140–160 mm size classes were also represented as well as those in the 240–290 mm size classes. This indicates regular recruitment and utilisation of the estuary by this species.

*Sarpa salpa* was represented by two main size groups. Most individuals were small, between 30 and 60 mm; larger specimens were mostly in the 210–230 mm size classes. The majority of fish, however, were large individuals (>130 mm). The two main sizes included individuals in the 140–160 mm and the 250–280 mm size classes. Although smaller individuals were not captured, the bimodal size distribution suggests regular recruitment into the estuary. It is probable that the smaller, recently recruited individuals may be included among the juvenile mullet captured in this estuary.

*Rhabdosargus globiceps* is an estuarine-dependent marine species and recruitment into estuaries occurs at <40 mm TL (Whitfield & Kok, 1992). Specimens collected during this survey were represented by small, recently recruited individuals; all specimens were less than 40 mm and were mostly in the 20–40 mm size classes. *Lithognathus lithognathus* were predominately small individuals, mostly in the 30–50 mm size classes; a few larger specimens, 120–140 mm and 200–220 mm were also captured. The range of sizes captured indicates regular recruitment and utilisation of the estuary. *Hemiramphus far* is an estuarine-dependent marine species and ranged between 162 and 410 mm; the vast majority were mature individuals exceeding 310 mm in length. *Hemiramphus far* attains sexual maturity at a length of approximately 250 mm SL (Whitfield, 1998). *Pomadasyis commersonii* is also a marine migrant species, which recruits into estuaries at between 20–30 mm TL (Wallace & van der Elst, 1975). Specimens captured during this survey were predominantly newly recruited individuals in the 20–30 mm size class. These results show that the Knysna estuary is an important nursery area for estuarine-dependent marine species.

*Atherina breviceps* were mostly mature individuals in the 40–70 mm size classes; a few smaller individuals were also captured, indicating that the estuary is also important for estuarine-resident species. All *G. aestuaria* caught were mature individuals greater than 30 mm, with most individuals within the 30–40 mm size class. *Callionymus natalensis* is an estuarine-resident species and specimens captured during this study ranged between 30 and 66 mm with most individuals within the 30–60 mm size classes. Most *P. knysnaensis* were mature, with a modal size class of 30–40 mm. *Syngnathus temminckii* ranged in size from 46 to 190 mm, with most specimens being immature (60–80 mm size classes). The Knysna Estuary also appears to be an important habitat for estuarine-resident fishes.

Overall, the estuarine-dependent marine species predominated, represented by 17 species. Estuarine-resident species were represented by nine species and seven marine stragglers were recorded. Estuarine-dependent marine species comprised 51.1% of the catch numerically and 91.9% by mass. Estuarine species comprised 47.9% numerically and 1.9% by mass, while marine stragglers comprised 0.9% numerically and 6.1% by mass. The high proportion of marine stragglers, relative to other estuaries in the region, is probably a reflection of the strong marine influence in the system. The predominance of estuarine-dependent marine species, together with the range of size classes recorded highlights the importance of this system as a nursery habitat for certain marine fishes. The high contribution of resident species also highlights its importance as a suitable habitat for this group of fishes.

Noetsie
The Noetsie Estuary (34°04’S; 23°07’E) is situated approximately 7 km southeast of Knysna. At the coast the system comprises a relatively small waterbody situated behind a wide, low sand barrier. Very little information exists on the Noetsie system (Whitfield, 2000).

Physico-chemical properties
Physico-chemical parameters were measured at two sites in the mouth (Site 1) and lower reaches (Site 2) of the Noetsie Estuary. The mouth of the system was open at the time of sampling. The Noetsie is a small estuary and river flow is probably insufficient to maintain a permanent connection with the sea and the system is periodically closed by the development of a sand barrier at the mouth (Table 1). The estuary was very shallow with depths ranging between 0.6 and 1.1 m.

Surface water temperatures ranged from 18.4 to 21.7°C in an upstream direction and bottom water temperatures ranged from 18.2 to 18.8°C in the same direction. Bottom water temperatures were slightly lower than those at the surface, particu-
larly at the upper site (Site 2). Surface salinities decreased in an upstream direction from 34.6 to 14.2‰, while bottom salinities ranged from 34.8 to 31.2‰. Vertical stratification was evident with bottom salinities higher than those at the surface. Salinities suggest some seawater penetration, particularly at high tide when seawater washes into the estuary across the beach.

Surface water pH ranged from 8.2 to 7.6, while bottom water pH ranged from 8.3 to 8.2. The higher bottom pH recorded at the upper site (Site 2) is probably a result of salinity stratification. Salinity stratification probably also accounted for the slightly lower bottom dissolved oxygen readings relative to those at the surface. Surface dissolved oxygen measured 6.6–6.2 mg l⁻¹, while those at the bottom were 6.4–6.1 mg l⁻¹. Dissolved oxygen values also decreased slightly upstream from the mouth. The waters of the Noetsie were clear, with turbidities of between 2 and 10 NTU (Table 1).

**Ichthyofauna**

A total of four seine net hauls and three gill nets caught 1501 individuals representing seven species from four families. In terms of the number of species recorded, Mugilidae (two species) and Sparidae (two species) were the most important families. Numerically, catches were dominated by mugilids, with *M. capensis* comprising 51.9% of the catch followed by *M. cephalus* (41.6%), *L. richardsonii* (3.9%) and *G. aestuaria* (1.6%) (Table 2). A total species mass of 9 kg was caught, with *L. richardsonii* (48.6%), *M. cephalus* (41.4%) and *M. capensis* (9.7%) dominating (Table 3).

The Noetsie Estuary appears to serve a nursery function for marine species, especially mugilids. This is supported by the predominance of newly recruited cohorts of *M. capensis* (20–30 mm) and *M. cephalus* (20–30 mm) during this survey. *Liza richardsonii* was represented by a range of size classes, which indicates regular recruitment and use of the system. Recently recruited individuals were mostly in the 30–50 mm size classes; larger individuals between 70 and 100 mm were the dominant size class, with a few specimens in the 170–220 mm and 270–300 mm size classes also present. *Gilchristella aestuaria* were all mature individuals (>40 mm) and were mostly in the 40–50 mm size class.

Estuarine-dependent marine species were the dominant group, comprising 98.4% of the catch numerically and 99.7% by mass. Estuarine-resident species comprised only 1.7% numerically and 0.3% by mass. This survey indicates that, although the Noetsie Estuary is a relatively small system and is often closed to the sea, it does appear to serve a viable nursery function for marine species; the system also supports estuarine-resident taxa.

**Grooteland**

The Grooteland is situated within the Harkervill State Forest and lies about 13 km east of Knysna. This system is a small coastal stream that seeps through to the sea via a boulder and lies about 13 km east of Knysna. This system is a small coastal stream that seeps through to the sea via a boulder barrier. The system comprises a small coastal stream that lies behind a boulder barrier. One set of physico-chemical measurements were made during this survey. The system was very shallow with a maximum depth of only 0.1 m recorded. The water temperature was 18.5°C. Salinity was low (0.1‰) indicating little or no seawater input. The lack of marine input was reinforced by a pH recording of 4.8. Dissolved oxygen levels were low and measured 4.8 mg l⁻¹. A turbidity of 14 NTU was recorded (Table 1).

No fish were observed in the shallow water and no sampling was conducted in the Kranshoek. Owing to its small size, this coastal stream is unlikely to provide suitable habitat for either estuarine-dependent marine species or estuarine-resident species.

**Crooks**

The Crooks lies approximately 18 km east of Knysna and falls within the Harkervill State Forest. This system is a small coastal stream that flows to the sea through a boulder barrier at the mouth. Physico-chemical measurements were made at one site during this survey. A depth of 0.5 m was recorded and the water temperature measured 22.7°C. The salinity at the site was 29.6‰ which indicates some seawater input into the system. The pH of the water was 8.1 and dissolved oxygen measured 6.9 mg l⁻¹ (Table 1).

No fish were observed in the shallow water and no sampling was conducted during this survey. The system is very small and is unlikely to provide suitable habitat for either estuarine-dependent marine species or estuarine-resident species.

**GENERAL DISCUSSION**

Seventeen rivers intersect the coast between Cape St Blaize and Robberg Peninsula (Figure 1). Five systems (Rooi, Meul, Grooteland, Kranshoek and Crooks) are outlets of coastal streams and probably provide little or no habitat for either resident or marine fishes owing to their very small size and limited connection with the sea. Four larger systems (Maalgate, Gwaing, Skaapkop, and Kaaimans) are located within deeply incised valleys and have stronger marine connections. The mouths of these systems are fixed between rocky headlands and, although sand does accumulate in the mouth region and in the lower reaches, a permanent connection with the sea is usually maintained. The sandy flood-tidal delta deposits in the lower reaches are typically exposed at low tide but are submerged at high tide as the river valleys become flooded with seawater. Both marine migrant and estuarine-resident species were recorded from these systems, indicating a viable habitat for these fishes. The amount of marginal and intertidal habitat available to fishes, however, is probably limited due to their morphology.

Six systems (Hartenbos, Groot Brak, Touws, Swartvlei, Goukamma, and Noetsie) were intermittently open to the sea. Although the Touws and Swartvlei are connected to estuarine lake systems, flow within these estuaries is not sufficient to prevent the build up of a sand barrier at the mouth. The Hartenbos, Groot Brak, Goukamma, and Noetsie are also periodically closed by a sand bar. In the case of the Groot Brak, the construction of a major dam in the lower catchment has affected the hydrology of the system such that it is unable to maintain a permanent connection with the sea. In the two remaining estuaries (Klein Brak and Knysna) strong tidal currents probably serve to maintain a near-permanent connection with the sea. The location of the mouth between rocky
headlands in the Knysna Estuary also serves to maintain a permanent connection with the sea. The fish fauna of all the estuaries studied were dominated by the juveniles of estuary-dependent marine species. Marine-spawning teleosts usually dominate the ichthyofauna (in terms of the number of species and mass) of temperate estuaries of the northern and southern hemispheres (Loneragan et al., 1989; Potter et al., 1997; Griffiths, 2001; Castillo-Rivera et al., 2002; Harrison, 2005). Mugilidae and Sparidae were represented by the greatest number of species, and also dominated catches numerically and by mass. Mugilidae are abundant in temporarily open/closed estuaries in South Africa (e.g. Marais & Baird, 1980; Marais, 1981; 1983; Kok & Whitfield, 1986; Vorwerk et al., 2001) with a total of 10 species recorded from the cool- and warm-temperate regions (Harrison, 2005). Dominant mugilid species during this survey included L. dumerillii, L. richardsonii, L. tricuspidens, M. cephalus and M. capensis. Sparidae are also represented by a large number of species in temperate South African estuaries, with a total of 14 species recorded (Smith & Heemstra, 1991). Dominant sparids during this survey included L. lithognathus, R. holubi, and S. salpa. Other important taxa were A. japonicus (Sciaenidae), G. felceps (Ariidae), L. amia (Carangidae) and P. commersonnii (Haemulidae).

Estuarine-resident species were also well represented in catches. Although there are only a few species that are able to breed and complete their entire life cycle within estuaries (Day et al., 1981), these species are well adapted to these environments and often occur in large numbers. In terms of estuarine resident fishes, the dominant species included A. breviceps, C. gilchristi, G. aequata, and P. knysnaensis. All of these species are endemic to southern Africa (Smith & Heemstra, 1991).

Marine stragglers that are not dependent on estuaries are typically more abundant in the lower reaches of estuaries and were particularly prevalent in the Knysna Estuary. Oreochromis mossambicus was the only freshwater species recorded in this study. Oreochromis mossambicus is endemic to southern Africa, but does not occur naturally south of the Bushmans Estuary in the Eastern Cape, although it has been introduced extensively into systems south of the Bushmans Estuary (Whitfield & Blaber, 1979).

Both the dominant estuarine-dependent marine taxa as well as the estuarine-resident component breed primarily during spring/summer. Resident species have reproductive specialisations that enhance the chances of their eggs being retained within estuaries (Bennett, 1989). Atherina breviceps, C. gilchristi, and P. knysnaensis all attach their eggs to some fixed substratum (Bennett, 1989; Whitfield, 1998); G. aequata spawns in the upper reaches of estuaries and as the larvae grow, their distribution extends toward the mouth (Melville-Smith & Baird, 1980; Talbot 1982). Recruitment of juvenile estuarine-dependent marine species from the marine environment takes place mainly in summer. The advantage of spring/summer spawning and recruitment is that maximum cover and food are available, which together with the higher water temperatures, optimise growth of larvae and juveniles (Bennett, 1989). The majority of the dominant fishes recorded during this study are endemic species, thus highlighting the important role these systems perform in the maintenance of the ichthyofaunal diversity within the region.

The coastal sector between Cape St Blaize and Robberg Penninsula contains some 17 coastal outlets. Of the systems assessed by Whitfield (2000) within this coastal sector, the state of available information on over 50% was regarded as poor; furthermore, no biological/ecological information existed on over 70% of the systems. As a result of this survey, basic physico-chemical and biological (fishes) information now exists on most systems.

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