
**HOME RANGE DYNAMICS OF SPOTTED GRUNTER,
POMADASYS COMMERSONNII, IN A SOUTH AFRICAN
INTERMITTENTLY OPEN ESTUARY.**

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degree of Master of Science at Rhodes University,
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ABSTRACT

The spotted grunter (*Pomadasys commersonnii*) is an important, estuarine-dependent, fishery species in southern Africa. Since estuaries are essential habitats in the life history of this species, the quantification of area use patterns and movements is important for fisheries management. In this study, acoustic telemetry was used to investigate movements, use of habitat and home range dynamics of spotted grunter in the small intermittently open East Kleinemonde Estuary on the Eastern Cape coast of South Africa.

Nine spotted grunter (range: 326-489mm TL) were surgically equipped with uniquely coded acoustic transmitters. Positional fixes were obtained by manual tracking tagged individuals on six days and six nights during five tracking sessions from March to November 2004. In addition, five stationary data-logging receivers, moored at specific locations from the mouth to the top of the estuary provided additional long-term monitoring.

Kernel home ranges (95% UD) varied in size (26 296-165 321m²) but were all located in a common high use area situated between 300-1 300m from the estuary mouth, which coincided with the highest abundance of prey items. There was no significant variation in home range size [C^2 (N = 9, df = 4) = 4.18; p = 0.38] between the temporally segregated tracking sessions (over nine months). The persistence of these home range estimates were confirmed by the long-term data-logging receivers. There was no significant diel variation in home range size [F(4, 64) = 0.05, p = 0.99] or core area size [F(4, 64) = 1.40, p = 0.25]. Fish length showed negative, although not significant, relationships between home range size (p = 0.225); number of home range areas (p = 0.065); core area size (p = 0.512) and home range length (p = 0.320).

Use of habitat and home range dynamics of spotted grunter in the East Kleinemonde Estuary were consistent over the nine month study period, and they appeared to be influenced more by biotic than abiotic factors. However, when the mouth opened at the end of the study, most tagged fish vacated their home ranges and emigrated to sea.

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CHAPTER 1

GENERAL INTRODUCTION



Spotted grunter (*Pomadasys commersonnii* Lacepede, 1801) is a widespread Indian Ocean species, which occurs in estuaries and coastal waters to depths of 30 metres, eastwards from Cape Point, South Africa, along the African and Asian coastlines to India (Day *et al.* 1981; Van der Elst and Adkin 1991; Smith and Heemstra 2003). It attains approximately 800mm total length (TL) and a weight of about 9kg (Branch *et al.* 1994; Smith and Heemstra 2003). Sexual maturity is reached at about 3 years, with males attaining 50% sexual maturity at 300mm TL and females at 360mm TL (Wallace 1975; Day *et al.* 1981). Spawning occurs in shallow inshore coastal waters during spring and early summer, between August and December (Van der Elst and Adkin 1991; Whitfield 1998; Branch *et al.* 1994; Heemstra and Heemstra 2004). Egg and larval development also take place at sea, after which early juveniles (20-30mm TL) enter estuarine nursery areas during spring and summer, where they remain for the first 2-3 years of their lives (Whitfield 1998; Heemstra and Heemstra 2004). Adults spend most of their lives at sea, but do return to estuaries in a post-spawning condition, mostly to feed (Webb 2002). According to Whitfield's (1994) classification, *P. commersonnii* is a category IIa species, which are wholly dependent on estuaries for juvenile nursery areas.

Spotted grunter is primarily a crepuscular and nocturnal benthic feeder (Whitfield 1998). Juveniles feed on zooplankton, in particular copepods, while larger fish feed on annelids, crustaceans and small bivalves (Heemstra and Heemstra 2004). Within estuaries they can be observed with their tails in the air blowing water into holes in the mud or sand to

uncover prey items, such as sand prawns (*Callinassa kraussi*) and mud prawns (*Upogebia africana*) (Branch *et al.* 1994; Heemstra and Heemstra 2004).

Spotted grunter is euryhaline and has been found in salinities ranging from 0 to 90‰ and can survive at low salinities for extended periods (Deacon and Hecht 1995). Water temperature levels below 13°C have resulted in mass mortalities in the Kosi and St Lucia systems (Blaber and Whitfield 1976). Laboratory experiments have shown the thermal preference of juveniles to be approximately 24 to 25°C (Deacon and Hecht 1995). Spotted grunter has been shown to be unaffected by water turbidity (Hecht and Van der Lingen 1992). Childs (2005) recorded acoustically tagged spotted grunter in turbidities ranging from 4.1 to 567.0 NTU in the Great Fish Estuary.

Throughout its distributional range, spotted grunter is an important and sought after angling species (Branch *et al.* 1994; Whitfield 1998; Smith and Heemstra 2003). It is targeted by recreational beach anglers, estuarine boat and shore anglers and spear fishers (Van der Elst and Adkin 1991). On the southern Cape coast of South Africa this species is primarily caught in estuaries, during the summer months, eastwards of Algoa Bay it is also caught in the inshore marine environment, close to river mouths (Smith and Heemstra 2003; Heemstra and Heemstra 2004). It is also targeted by subsistence trap and net fisheries in KwaZulu-Natal, and is a common bycatch species in the inshore prawn fishery in KwaZulu-Natal (Kerwath *et al.* 2005). Pradervand and Baird (2002) found that spotted grunter was the most commonly caught species in six out of eight estuaries in the Eastern Cape.

Spotted grunter is currently managed by a daily bag limit of 5 fish per person and a minimum size limit of 40cm TL. Spotted grunter is regarded as overexploited and is likely to be under increased pressure in the future, especially as fishing activity in South Africa continues to increase (Lamberth and Turpie 2003). Estuarine-dependency causes a distributional bottleneck in their life history and adds to their vulnerability and further aggravates the problem (Lamberth and Turpie 2003). This is due to the limited area in

which they are being exploited. Increased fishing pressure, especially in estuaries further aggravates the problem.

Aspects of the biology and ecology of spotted grunter have been well studied (Whitfield 1998; Childs 2005; Næsje *et al.* 2007); however information regarding their movement behaviour within estuaries and migrations between estuarine and marine environments are scarce. Characterisation of fish movement and habitat utilization patterns may play a vital role in the understanding of spatial dynamics of fisheries, which in turn can help guide conservation approaches (Childs 2005; Humston *et al.* 2005). Furthermore, information on the spatial distribution and movement patterns, in particular home range size and site fidelity, of individuals within a habitat or ecosystem can aid in the prediction of their response to changes in the environment. Such information also has direct application for fisheries management, specifically for decisions regarding closed areas or seasons (Parsons *et al.* 2003; Humston *et al.* 2005; Kerwath *et al.* 2007).

Biotelemetry has been successfully used as a tool to monitor spatial utilization patterns and guide management; particularly in terms of the determination and implementation of reserves (Meyer *et al.* 2000; Pittman and McAlpine 2001; Kerwath *et al.* 2007). Therefore the use of telemetry methods can provide more information than conventional capture-recapture techniques (Brown and Orians 1970). Although conventional tag and recapture methods allow larger numbers of individuals to be tagged, fine-scale movements of individual fish cannot be studied. Telemetry allows researchers to obtain short-term, high-resolution data on the movement of individual fish, as opposed to capture and recapture locations and times only. Such fine-scale temporal and spatial data is important for answering questions regarding biological, ecological and fisheries aspects of a species (Heupel *et al.* 2006). Telemetry furthermore allows researchers to study individuals in their natural habitat, without requiring direct observation (Arendt *et al.* 2001). This technology is commonly used on species that are can easily be caught and are likely to remain within a specified geographic location (Heupel *et al.* 2006). Telemetry has been used to study the movements of numerous fish species in both the estuarine and marine environments (Meyer *et al.* 2000; Arendt *et al.* 2001; Heupel *et al.* 2006).

Information on the movement of most estuarine-dependent fish species is lacking (Childs 2005; Taylor *et al.* 2006). Such information for spotted grunter is limited to a pilot study and a detailed localized study. Kerwath *et al.* (2005) conducted a tracking experiment in the intermittently open East Kleinemonde Estuary to test the feasibility of telemetry for studying the movements of spotted grunter within an estuarine environment. Childs (2005) and Næsje *et al.* (2007) conducted a study in the permanently open Great Fish Estuary; which showed that daily changes in environmental variables (particularly temperature) played a very important role in the spatial distribution of individual spotted grunter.

Spotted grunter do not only occur in permanently open estuaries, but also utilize temporarily open/closed systems, such as the East Kleinemonde Estuary (Cowley and Whitfield 2001b), which represent approximately 70%, of all South African estuaries (Whitfield 1994). These estuaries are typically small with little or no tidal exchange, and exhibit relatively stable environmental conditions over extended periods. They are, however, subject to rapid changes over short periods (e.g. mouth opening or river flooding events). Based on daily records of the mouth conditions of the East Kleinemonde Estuary from March 1993 to August 1997, the mouth was closed 71.8% of the time and only open on 43 of these days (2.6%) (Cowley and Whitfield 2001b). These mouth opening events are generally associated with periods of high rainfall. This type of estuary, which remains predominantly closed (>50%) throughout the year, is also known as an intermittently open estuary. Investigations of area use and home range estimates of spotted grunter within these smaller, intermittently open estuaries is important because it will enhance our understanding of the ecology of the species, and ultimately contribute towards the better management of this important estuarine-dependent fishery species.

The overall aim of this study was to gain a better understanding of the use of intermittently open estuaries by spotted grunter. The specific objectives were to:

- (1) Quantify the home range size of individual spotted grunter tagged in the East Kleinemonde Estuary.

- (2) Investigate factors that influence the home range size, such as fish length, time of day, time of year (season) and food availability.
- (3) Investigate the long-term behavioural trends of this species within the East Kleinemonde Estuary, especially in terms of their response to estuary mouth opening events.

This thesis is divided into seven chapters, which are outlined below:

Chapter two provides a detailed description of the study area and physico-chemical conditions at the time of this study.

Chapter three provides a detailed description of the materials and methods used in this study.

Chapter four addresses objective one and quantifies the size and location of the kernel home range and core area used by individually tagged spotted grunter within the East Kleinemonde Estuary, over the nine month study period.

Chapter five addresses objective two and investigates several factors that may affect home range size within the East Kleinemonde Estuary. In this chapter, the home range size over different tracking sessions and the diel influence (day versus night) on home range estimates are quantified. Furthermore, the effect of fish size and whether the location of prey items plays a role in determining an individual's home range estimates are investigated.

Chapter six addresses objective three and describes the long-term trends in area use of spotted grunter within the estuary. In addition, data collected by automated data-logging listening stations is used to confirm/validate information recorded while manually tracking tagged individuals.

Chapter seven provides a general discussion in which the principal findings of the study are summarised. Conclusions on the home range parameters of spotted grunter within temporarily open/closed estuaries are discussed and used to provide information for the management of this important fishery species. In conclusion, possible future studies and research needs are presented.

CHAPTER 2

STUDY AREA

2.1 STUDY SITE

The East Kleinemonde Estuary is located in the Eastern Cape Province (South Africa) approximately 15km north-east of the coastal town of Port Alfred and enters the sea at $33^{\circ} 32' S$; $27^{\circ} 03' E$ (Figure 2.1).

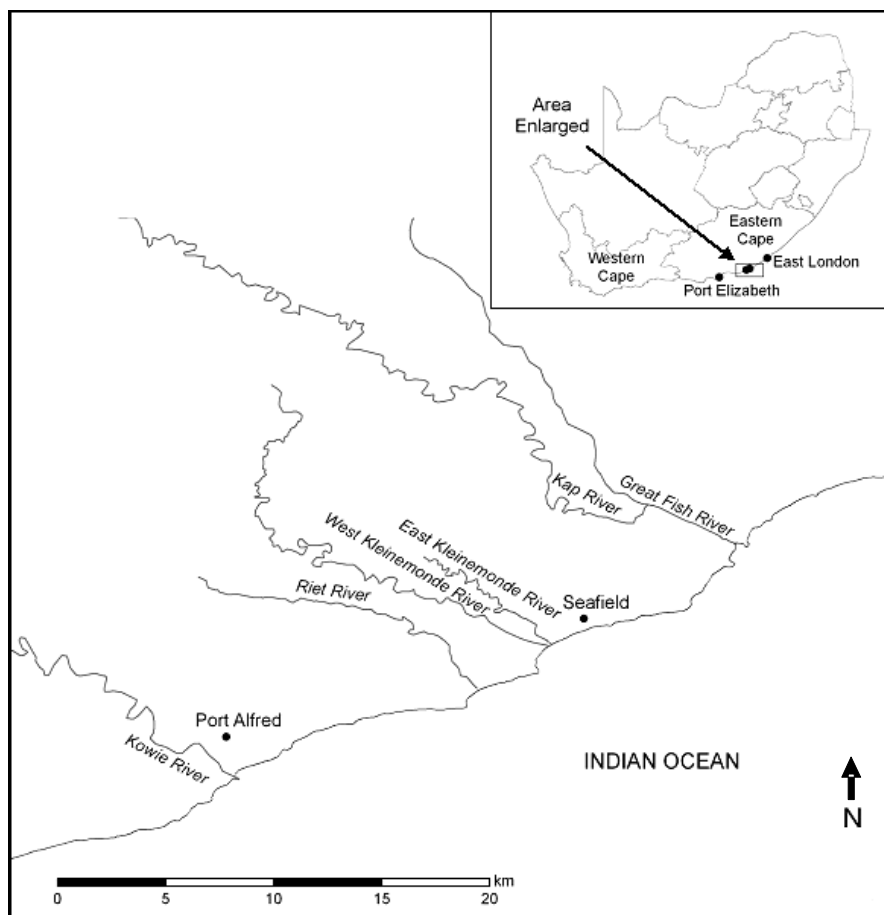


Figure 2.1. Map showing the location of the East Kleinemonde Estuary along the Eastern Cape coastline of South Africa.

According to Whitfield's (1992) classification of estuary types, the East Kleinemonde Estuary is categorized as a temporarily open/closed system. However, an analysis of daily mouth conditions over a 15-year period (1993-present), recorded by Cowley, revealed

that the estuary mouth was closed for approximately 78% of the time (Van Niekerk *et al.* 2007). Consequently, this estuary has also been described as an intermittently open system (Cowley and Whitfield 2001a; Cowley and Whitfield 2001b; Cowley *et al.* 2001; Vorwerk *et al.* 2003). This small estuary is approximately 3.5km long with a maximum width of 250m and has a catchment area of 46.3km². The mean annual runoff is $2 \times 10^6 \text{m}^3$ (Cowley and Whitfield 2001a). The estuary at full state has a surface area of approximately 307 585m² and at its lowest state has a surface area of 205 057m², with perimeter lengths of 9 086m and 7 302m respectively.

The estuary is mostly shallow, with depths of less than two metres. The main channel depth ranges between one and two metres. During times when the mouth remains closed for extended periods, the estuary surface can reach levels of up to 2m higher than the mean sea level ($\pm \text{MSL}+2\text{m}$). This is a result of the formation of a sandbar that develops on the seaward side of the estuary (Cowley and Whitfield 2001b).

The middle and lower reaches of the East Kleinemonde Estuary are surrounded by the small town of Seafielde (Vorwerk *et al.* 2001). The R72 coastal road between Port Elizabeth and East London, crosses over the estuary approximately 500m from the estuary mouth (Figure 2.2).

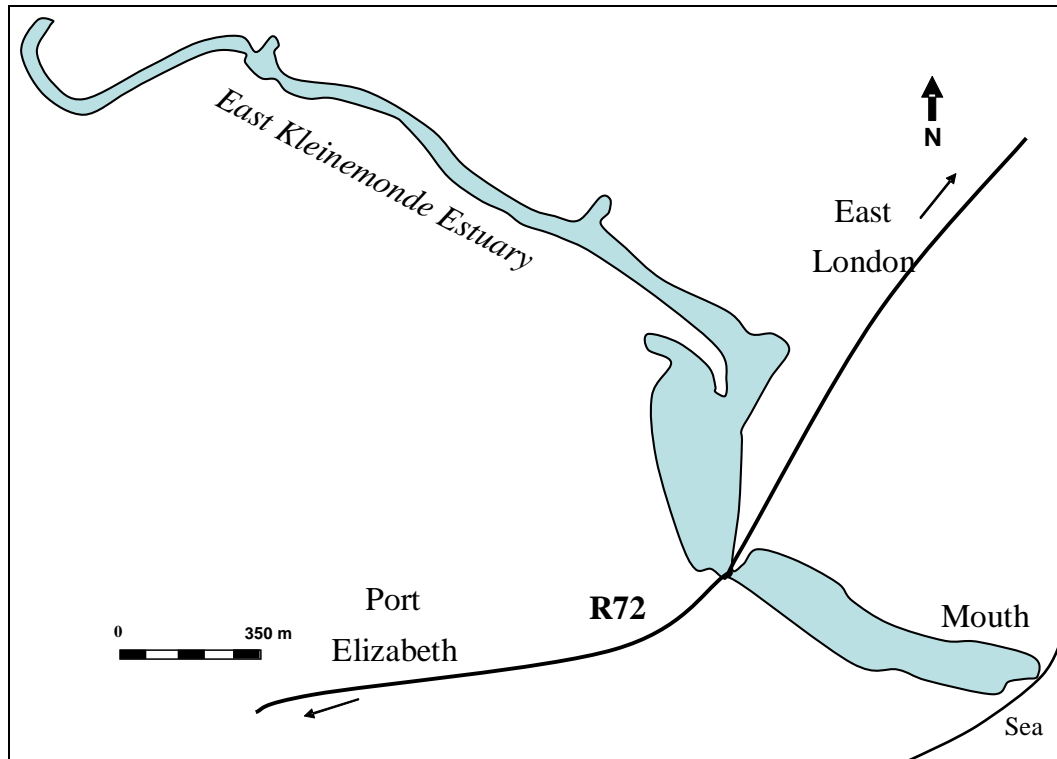


Figure 2.2. Map of the East Kleinemonde Estuary found between East London and Port Elizabeth.

2.2 CLIMATIC CONDITIONS

2.2.1 Temperature and wind

The mild summers and winters experienced along the Eastern Cape coastline are influenced by the cooling and warming effects of the sea. The mean annual minimum and maximum air temperatures recorded by the weather bureau at Port Alfred between January 1993 and July 2007 are shown in Figure 2.3. The lowest mean monthly temperature recorded was 6.4°C in July 2007, with the highest mean monthly temperature recorded being 27.8°C in February 2003.

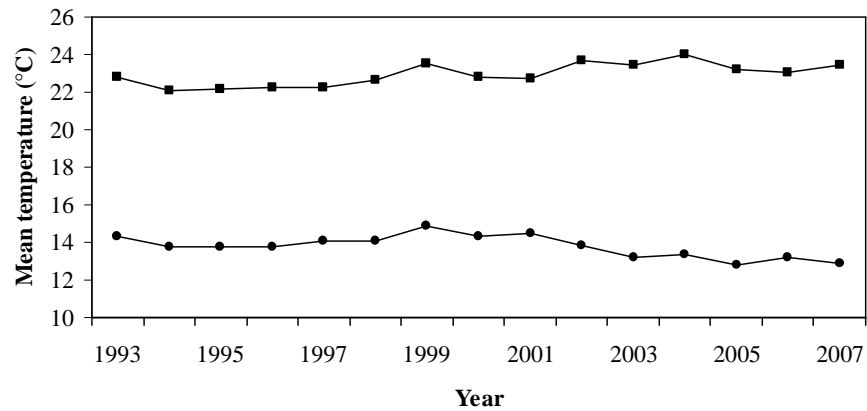


Figure 2.3. Mean annual minimum and maximum air temperatures (°C) recorded at Port Alfred between January 1993 and July 2007 (Data provided by South African Weather Bureau).

The dominant wind direction in this area in summer is north-easterly, while in winter it is south-westerly. This wind contributes to decreasing the heat and humidity found in the Eastern Cape in summer (James 2006). The mean maximum monthly wind speed recorded was $26.6\text{km}\cdot\text{h}^{-1}$ during the afternoon in December 1997. The mean minimum monthly wind speed recorded was $7.6\text{km}\cdot\text{h}^{-1}$, in the early morning in April 2006. Wind speeds recorded were highest in the afternoon, with morning and evening wind speeds being approximately the same, but lower than the afternoon.

2.2.2 Rainfall

The rainfall regime in this area and in the adjacent stretch of coastline is highly variable. Rainfall may occur at any time of the year but generally shows a bimodal pattern (Figure 2.4), with the main peak in spring (James 2006).

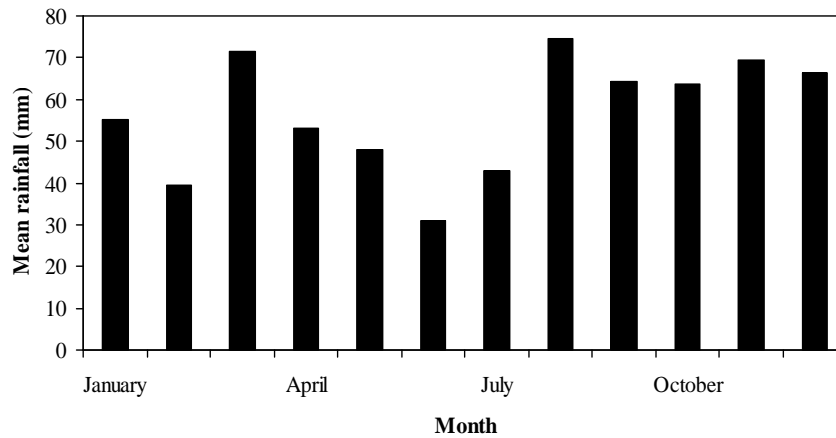


Figure 2.4. Mean monthly rainfall recorded at Port Alfred between January 1993 and May 2007 (Data provided by South African Weather Bureau).

The mean annual rainfall for Port Alfred between January 1993 and May 2007 was 652 ± 222 mm. The lowest annual rainfall for this area was recorded in 1999 (Figure 2.5) with 308mm, while the highest annual rainfall recorded was 1 288mm in 2005 (South African Weather Bureau).

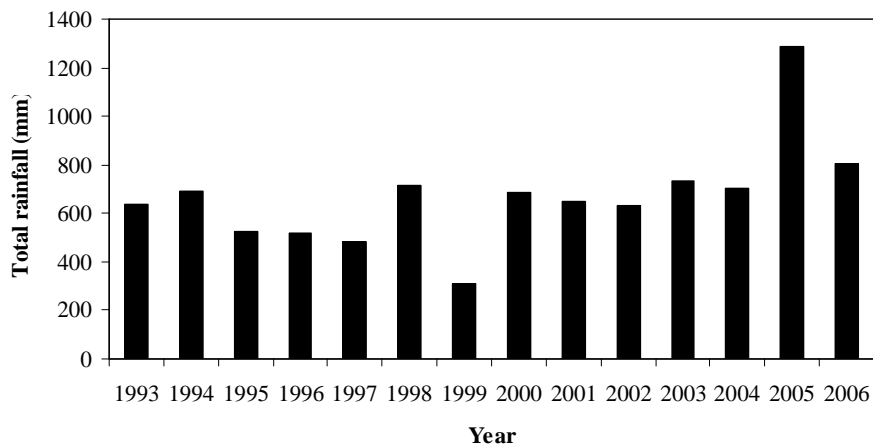


Figure 2.5. Total annual rainfall recorded at Port Alfred between January 1993 and May 2007 (Data provided by South African Weather Bureau).

2.3 PREVIOUS RESEARCH

The East Kleinemonde Estuary has been subject to considerable research attention, mostly ichthyological, over the past decade. More recently as part of a Water Research

Commission (WRC) funded project, the East Kleinemonde Estuary has been subject to an intensive multi-disciplinary study aimed at investigating the functioning of temporarily open/closed estuaries (TOCE's) in the Eastern Cape. The main findings of this detailed study are summarised below:

2.3.1 Mouth dynamics

Van Niekerk *et al.* (2007) reported that mouth opening events seldom lasted more than a few days (from 1-6 days). During these open periods seawater comes into the estuary during high tide and is often prevented from flowing out during low tide due to the height of the sandbar at the mouth. After the mouth closure, water levels slowly increase from marine overwash on high tides or large amounts of rainfall. A summary of estuary mouth conditions from 1993 to 2003 are given in Table 2.1. Small overtopping events are classified as events lasting less than three hours and large overtopping events are those overwash events lasting longer than three hours.

Table 2.1. Mouth conditions (in percentages of total time) of the East Kleinemonde Estuary from 1993 to 2003 (Van Niekerk *et al.* 2007).

Year	Closed	Small overtopping	Large overtopping	Open	Trickling out
1993	86.6	10.7	0.3	2.5	0.0
1994	74.0	21.4	1.4	3.3	0.0
1995	42.2	51.5	4.1	2.2	0.0
1996	87.2	10.4	1.6	0.8	0.0
1997	81.1	14.5	1.4	3.0	0.0
1998	97.0	1.9	0.8	0.3	0.0
1999	100.0	0.0	0.0	0.0	0.0
2000	84.2	6.8	1.1	7.9	0.0
2001	71.0	12.1	0.3	15.1	1.6
2002	76.4	6.0	3.0	13.2	1.4
2003	62.7	14.5	5.2	17.5	0.0
Average	78.4	13.6	1.7	6.0	0.3

2.3.2 Water quality

Taljaard *et al.* (2007) showed that during extended closed periods the horizontal salinity gradient along the length of the estuary is very slight or absent. However, during the open phase the estuary has strong horizontal and vertical salinity gradients, as well as a significant difference in the salinity distribution between low and high tides. Water temperature shows a distinct seasonal pattern, with summer temperatures being higher than winter.

Taljaard *et al.* (2007) found that the East Kleinemonde Estuary did not show a large variation in pH at different salinities along the length of the estuary or between the months sampled (March to November 2006). The pH ranged between 7.7 and 8.3.

Under open mouth conditions the East Kleinemonde Estuary is well oxygenated, with dissolved oxygen (DO) concentrations remaining above 4mg.l^{-1} . During closed mouth phases, although there is greater variation in the bottom water layer, DO rarely drops below 2mg.l^{-1} . Over the monitored period (March to November 2006) there was no obvious variation in turbidity between open and closed phases, although it was noted that levels greater than 100 NTU were generally found during the open phase.

2.3.3 Microalgae and macroalgae

Gama (2007) identified seven major phytoplankton species in the East Kleinemonde Estuary, consisting of four different functional groups, namely diatoms, flagellates, dinoflagellates and microflagellates.

In TOCE's the macrophyte community structure and composition is influenced and dependent on the freshwater inflow, tidal exchange, salinity, water level fluctuations and sediment dynamics (i.e. the response of the macrophytes is event driven). Typically, after mouth closure, submerged macrophyte biomass increases. Analysis of available seeds in sediment samples taken in 2006 indicated that the dominant macrophyte species in the East Kleinemonde Estuary were *Sarcocornia perennis*, *Ruppia cirrhosa* and *Chara vulgaris* (Ridden and Adams 2007). Small amounts of *Potamogeton pectinatus* were also

found, while *Halophila ovalis*, despite being previously reported from this estuary, was not found at all (Ridden and Adams 2007). Since 1995, reed beds (*Phragmites australis*) have become established above the bridge area. Prior to this *R. cirrhosa* occurred in this area at depths of less than 1m.

2.3.4 Invertebrates

Wooldridge and Bezuidenhout (2007) found amphipods, tanaeids, isopods and polychaetes to be the most abundant benthic community groups in the East Kleinemonde Estuary. Species grouping found in the mouth area differed significantly from the rest of the estuary. Wooldridge and Bezuidenhout (2007) observed that the community found in the mouth area tended to be sand associated fauna that did not change throughout the whole study (March to November 2006). Mouth opening events and salinity changes did not affect these species. The communities found above the mouth area were typically mud associated fauna. The two highest sites located in the upper reaches of the estuary developed their own community sub-structures in response to environmental changes after mouth opening events.

The sandprawn, *Callinassa kraussi* is an abundant species on the sand flats and banks of the East Kleinemonde Estuary. Terörde (2005) reported that sandprawns occurred in all areas of the East Kleinemonde Estuary except the very upper reaches, but were most abundant in the lower reaches of this estuary. Terörde (2005) found that the mean prawn density in this estuary was 44 prawns/m² in 2004 and 37 prawns/m² in 2005. The prawn numbers were estimated at 10-12 million individuals or 8-10 tonnes of biomass in the East Kleinemonde Estuary. The main predator of the *C. kraussi* in this estuary is the spotted grunter (*P. commersonii*) (Terörde 2005).

2.3.5 Zooplankton and hyperbenthos

Froneman (2007) reported that the total zooplankton abundance and biomass on the East Kleinemonde Estuary decreased following mouth opening events, after which the community was represented by both estuarine and marine spawning species. However,

during the closed phase the community was dominated by estuarine copepod species, such as *Pseudodiaptomus* spp., *Acartia* spp. and *Halicyclops* spp.

Froneman (2007) found that the dominant hypobenthos species in the East Kleinemonde Estuary is the caridean shrimp (*Palaemon peringueyi*) and that there is a clear spatial pattern in the total abundance and biomass of this species within this estuary, with higher numbers occurring in the middle reaches and lower numbers occurring in the lower reaches of the estuary.

2.3.6 Birds

Terörde and Turpie (2007) found significant differences in the mean number of birds between open and closed estuary mouth phases. Eight species were encountered frequently, a further nine species occasionally and 27 species were rarely seen. The Grey Heron (recorded every count) and Great Egret was present year round and used the area mainly for breeding purposes. The pied kingfisher, water thick-knee and great kingfisher were the only resident species. Other species, such as the African spoonbill and yellow-billed duck, used the estuary mainly as a feeding and roosting area, but used alternative areas for breeding.

The dominant avifauna (by numbers) was piscivorous species (70%), followed by invertebrate feeding waders (24%), while waterfowl were scarce (6%).

2.3.7 Fishes

Cowley *et al.* (2007) found that the dominant fish families by number in the East Kleinemonde Estuary were Atherinidae, Clupeidae and Gobiidae. The dominant species within each family were *Atherina breviceps*, *Gilchristell aestuaria* and *Glossogobius callidus* (Vorwerk *et al.* 2003; Cowley *et al.* 2007). *Rhabdosargus holubi* is the dominant species in terms of biomass. The success of this marine-spawning species is attributed to (i) recruitment during overwash events and (ii) an extended breeding season (James *et al.* 2007). Few marine straggler species were found in this estuary and only one freshwater

species, *Oreochromis mossambicus*, was sampled. *O. mossambicus* is most abundant during the closed phase in temporary closed estuaries (James *et al.* 2007).

Collectively these studies indicated that the timing, duration and frequency of the mouth opening events play a critical role in determining the species composition, diversity and abundance in the East Kleinmonde Estuary.

A survey of fishery resource utilization on the East Kleinmonde Estuary by Cowley *et al.* (2003) revealed that most fishing effort (82%) occurred in the lower reaches of the estuary, below the road bridge. The four main species caught in the estuary were spotted grunter (*P. commersonii*), Cape stumpnose (*R. holubi*), white steenbras (*L. lithognathus*) and mullet (*Mugil spp.*).

2.4 ABIOTIC CHARACTERISTICS OF THE EAST KLEINEMONDE ESTUARY DURING THIS STUDY

During this study (March to November 2004) salinity (Atago hand held refractometer), turbidity (Hanna 93703 turbidity meter) and water clarity (secchi disc) were recorded weekly at five fixed stations located 0.24, 0.92, 1.35, 2.53 and 3.28 kilometres from the estuary mouth. Water level was also recorded. In addition, temperature was logged hourly using underwater temperature recorders (VEMCO Minilog) moored at stations 1, 3, 4 and 5 (Figure 2.6).

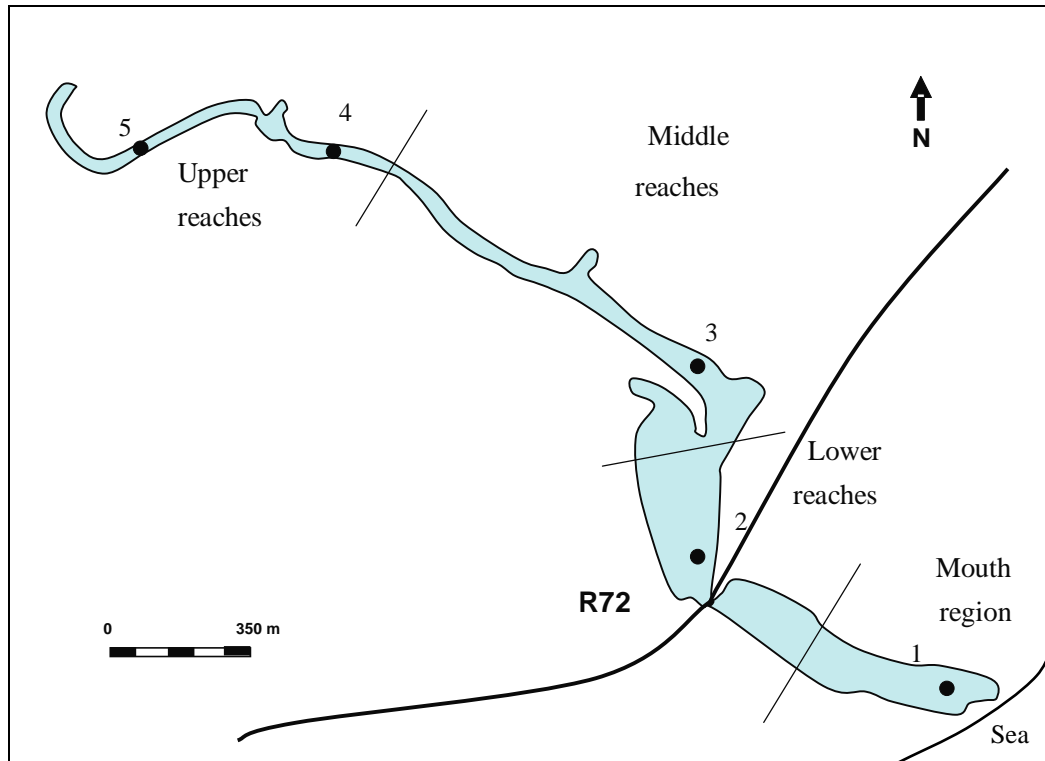


Figure 2.6. Map of The East Kleinemonde Estuary showing the location of the five fixed stations where the water chemistry data was recorded between March and November 2004.

Table 2.2. Location of each of the five fixed stations (km from estuary mouth) showing the mean (\pm standard deviation) salinity and turbidity values for the surface (S) and the bottom (B) of the East Kleinemonde Estuary throughout the study period.

Site	Salinity S (PSU)	Salinity B (PSU)	Turbidity S (FTU)	Turbidity B (FTU)
1 (0.24 km)	31.0 (\pm 4.3)	31.8 (\pm 2.5)	2.8 (\pm 4.2)	2.8 (\pm 2.2)
2 (0.92 km)	31.1 (\pm 3.9)	32.4 (\pm 2.3)	3.6 (\pm 4.0)	8.6 (\pm 6.5)
3 (1.35 km)	31.4 (\pm 2.9)	31.8 (\pm 2.5)	4.7 (\pm 4.3)	5.6 (\pm 3.6)
4 (2.53 km)	30.9 (\pm 3.2)	31.4 (\pm 2.8)	4.0 (\pm 3.8)	10.7 (\pm 20.1)
5 (3.28 km)	29.2 (\pm 5.7)	31.2 (\pm 2.5)	9.2 (\pm 28.0)	6.7 (\pm 6.1)

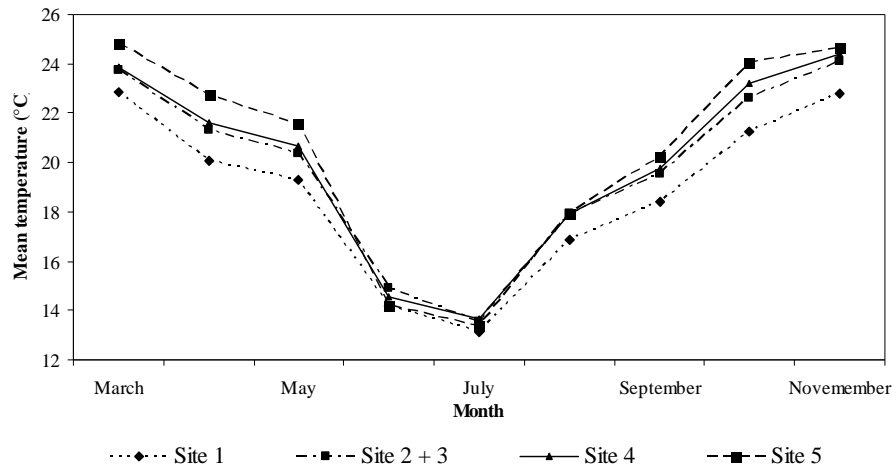


Figure 2.7. Mean monthly water temperatures (°C) at sites 1, 2, 3, 4 and 5 in the East Kleinemonde Estuary between March and November 2004.

There was little variation (ranging from 0.2 to 1.2°C) between water temperature ranges found at the mouth and the upper reaches of the estuary (Figure 2.7). Standard deviation was omitted to aid in clarity of presentation of results. The mean temperature was $19.7 \pm 0.7^\circ\text{C}$. The temperature range found along the length of the estuary during this study, conducted between March and November 2004 is shown in Table 2.3.

Table 2.3. Minimum and maximum temperatures (°C) found at sites 1-5 along the East Kleinemonde Estuary between the study months of March to November 2004.

Site	Minimum (Month)	Maximum (Month)
1	11.8 (July)	26.0 (March)
2 + 3	13.2 (June)	28.9 (March)
4	12.6 (June)	28.5 (March)
5	12.4 (July)	28.9 (March)

During this study, the mouth region had the lowest surface and bottom turbidity values, while the upper region of the estuary had the highest surface and bottom values (Table 2.4). The lowest values for each region of the estuary were recorded during June and July, while the highest values were recorded in September (Table 2.4). This is probably

due to low rainfall in June (9mm) and high rainfall in September (65mm). The mean turbidity values in this estuary between March and November 2004 were 4.86 NTU at the surface and 6.88 NTU on the bottom. The mean water clarity (secchi disc) of the East Kleinemonde Estuary ranged between 28.1cm and 67.3cm during this study period.

Table 2.4. Minimum and maximum turbidity values recorded at each of the five sites along the East Kleinemonde Estuary during this study (March to November 2004).

Site	Minimum (NTU)		Maximum (NTU)	
	Surface	Bottom	Surface	Bottom
1	0.0	0.4	23.0	11.7
2	1.0	2.1	22.2	29.5
3	0.9	2.2	17.7	23.2
4	0.8	1.0	21.6	110.0
5	0.3	0.3	154.0	35.7

Mean salinity in this system was 30.7 PSU at the surface, and 31.7 PSU on the bottom. The lowest salinity was recorded towards the end of September, after a period of high rainfall (65mm in total) (Table 2.5).

Table 2.5. Minimum and maximum salinity values recorded at the five sites along the length of the East Kleinemonde Estuary during this study period (March to November 2004).

Site	Minimum (PSU)		Maximum (PSU)	
	Surface	Bottom	Surface	Bottom
1	12	27	35	35
2	14	26	35	35
3	25	26	35	35
4	24	25	35	35
5	7	25	33	35

The total rainfall for the study period was 347.5mm. The highest rainfall levels were recorded during March (76.5mm) and July (75mm) (Table 2.6). The lowest rainfall was during June (9mm) and August yielded no rainfall (Table 2.6).

Table 2.6. Monthly rainfall recorded at the East Kleinemonde Estuary for each month during the study period.

Month	Rainfall (mm)
March	76.5
April	33.0
May	10.5
June	9.0
July	75.0
August	0.0
September	65.0
October	55.5
November	23.5

During this study the water level was consistently high and the mouth of the estuary remained closed, with 27 small (<3 hours) overwash events and 6 large (>3 hours) overwash events (Table 2.7).

Table 2.7. A summary of estuary mouth status and the number of overwash events (large and small) recorded at the East Kleinemonde Estuary during 2004.

Month	Mouth status	Number of small overwash events (< 3 hrs)	Number of large overwash events (> 3 hrs)
January	Closed	0	0
February	Closed	5	0
March	Closed	3	0
April	Closed	7	1
May	Closed	4	1
June	Closed	0	2
July	Closed	2	2
August	Closed	4	0
September	Closed	0	0
October	Closed	2	0
November	Closed	0	0
December	Open (23 December)		

2.5 SUMMARY

The water level in the East Kleinemonde Estuary was high during 2004. The mouth remained closed for the duration of the study, with some overwash events occurring. The estuary opened on the 23 December 2004 and remained open until 28 January 2005. Water temperatures ranged from 11.8 to 28.9°C. The average salinity for the surface and bottom of the estuary were 30.7 ± 4.0 and 31.7 ± 2.5 PSU, respectively, with a minimum of 7 PSU and a maximum of 35 PSU. The mean surface and bottom turbidity values were 4.9 ± 8.7 and 6.9 ± 7.7 NTU, respectively, with a minimum of 0 NTU and a maximum of 154 NTU. No major physiochemical changes took place during the study period.

CHAPTER 3

MATERIALS AND METHODS

3.1 RESEARCH APPROACH

Acoustic telemetry methods were used to track the movements of eleven spotted grunter (*Pomadasys commersonnii*) in the East Kleinemonde Estuary. Fish were tagged with single frequency (69KHz) transmitters, which allowed for simultaneous tracking of all fish for the entire study period. The uniquely coded transmitter signals were logged using both automated stationary receivers, moored in the estuary, and a hand held manual tracking receiver. Fish movements and area use patterns in the estuary were monitored from March 2004 to January 2005.

3.2 TAGGING OF FISH

On 22 and 23 February 2004, eleven spotted grunter, ranging from 326 to 489mm TL, were caught on rod and line using barbless hooks baited with sand prawn and mud prawn (Table 3.1). The fish were surgically tagged with V8SC-2L-R256 coded transmitter tags (VEMCO[®] Ltd, Halifax, Canada). The tags measured 8.5mm by 28mm, with a weight of 31g in water. The weight of the transmitters did not exceed the recommended maximum of 2% of the mass of the fish (Jepsen *et al.* 2002; Pincock and Voegeli 2002). The tags, with an expected battery life of 136 days (but can last up to 969 days) (D Allen, VEMCO Ltd., Personal communication, 2007) transmitted coded signals at random intervals every 10 to 30 seconds.

Surgery took place immediately after capture on board a motorized boat. Once on board the fish were placed in a container filled with estuary water mixed with an anaesthetic, 2-phenoxyethanol, at a concentration of approximately 1ml.ℓ⁻¹ of estuary water. This anaesthetic has been shown to have no effect on the growth of juvenile spotted grunter (Deacon *et al.* 1997) and has been successfully used during other telemetry studies on this species (Childs 2005; Kerwath *et al.* 2005). Once anaesthetized, the length of each fish was measured to the nearest millimetre (FL and TL) and placed ventral side up in a wet towel on a v-shaped high density foam board (Figure 3.1). Throughout the surgery the

gills were continuously flushed with estuarine water. An incision (15-20mm) was made along the ventral surface posterior to the pelvic girdle. Once the transmitter was inserted into the body cavity, the incision was closed using two independent silk sutures (2/0 Ethicon). Following surgery the fish were placed in a recovery bath filled with fresh estuarine water. As soon as the fish was in a stable upright position and appeared to have recovered from the surgery process, it was released back into the estuary. Following surgery the fish were released at approximately the same location as the catch site (Figure 3.2). Gender could not be determined during surgery or through external characteristics, as spotted grunter do not show display external sexual dimorphic characteristics.

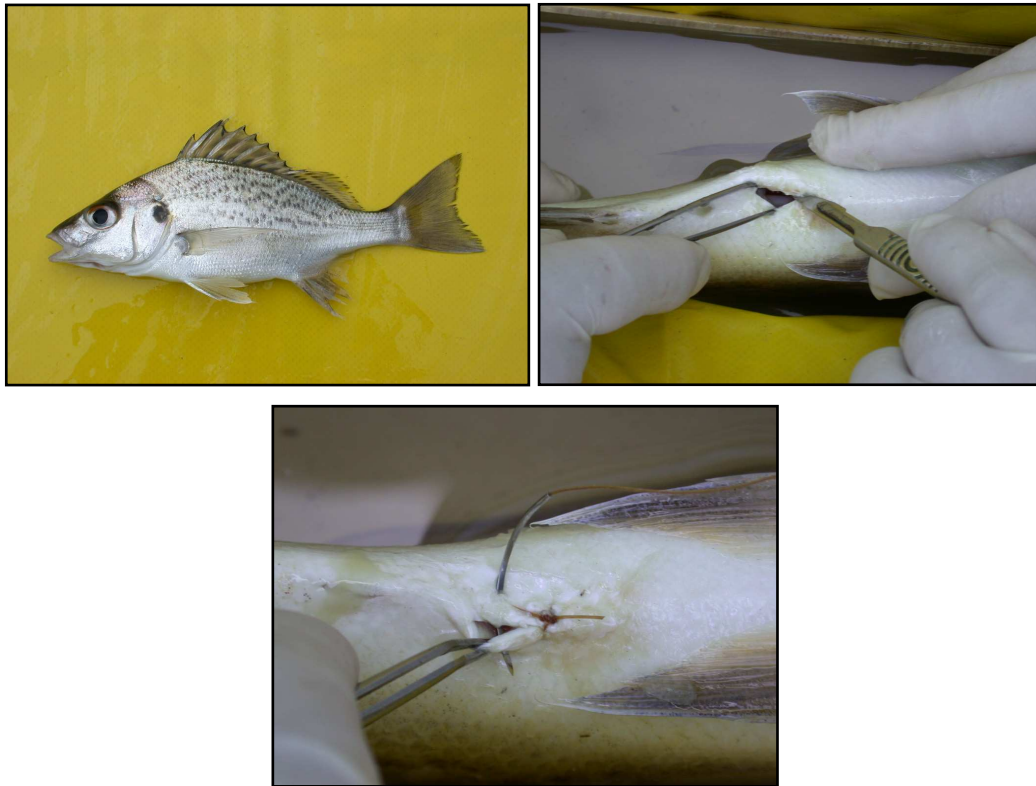


Figure 3.1. Photographs of the tagging procedure done on spotted grunter in the East Kleinemonde Estuary on 22 and 23 February 2004.

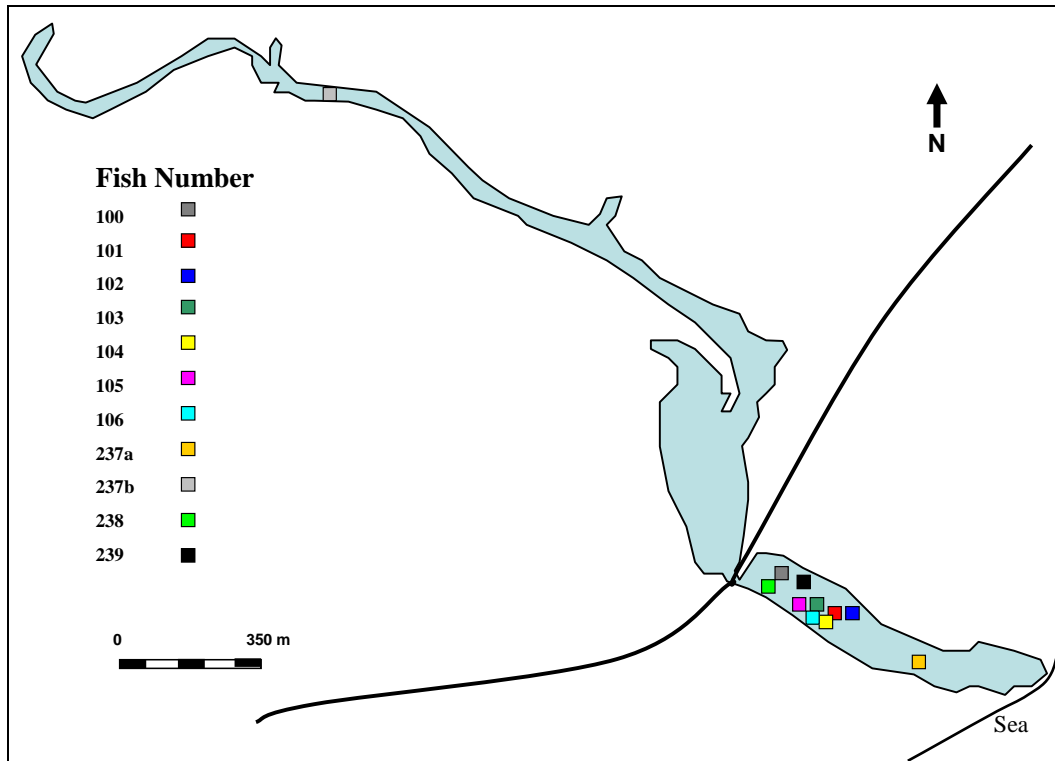


Figure 3.2. Map of the East Kleinemonde Estuary showing the catch and release sites of the eleven acoustically tagged spotted grunter.

None of the tagged fish showed any visible signs of stress or negative post-tagging behaviour. A preliminary experiment conducted on spotted grunter, using the same VEMCO[®] tags, showed no infection, haemorrhaging, post-tagging stress or mortality (Kerwath *et al.* 2005). The average time that the fish was under anaesthetic was 1 minute 35 seconds, while the surgery process took on average 2 minutes 44 seconds. Time to recovery took an average of 1 minute 24 seconds. The overall mean handling time from capture to release was 5 minutes 42 seconds (Table 3.1). Fish 237b showed much longer anaesthesia, surgery and recovery times compared to the other individuals, potentially due to temperature influences (February versus May).

Table 3.1. Tagging information of the eleven spotted grunter tagged with acoustic transmitters in the East Kleinemonde Estuary on 22 and 23 February 2004 (FL = fork length, TL = total length).

Fish ID code	FL (mm)	TL (mm)	Anaesthetic time (min:s)	Surgery time (min:s)	Recovery time (min:s)
100	350	382	01:31	02:25	00:59
101	430	461	01:44	02:01	01:29
102	410	446	00:28	03:28	01:41
103	399	429	02:04	02:27	01:47
104	300	326	01:15	02:19	00:42
105	394	420	01:05	02:23	00:03
106	400	440	01:11	02:21	01:21
237a	408	439	01:30	2:50	1:42
237b	405	-	04:00	04:35	3:35
238	410	449	01:11	02:43	01:01
239	446	489	01:25	02:29	00:59

Fish 237a was caught closest to the mouth region and tagged on 22 February 2004. This fish was recaptured by a fisherman in April 2004 and the tag was re-used on a different individual. The new individual, fish 237b, was tagged and released in the top region of the East Kleinemonde Estuary on 14 May 2004. Fishing effort was evenly distributed along the length of the estuary during the second tagging trip, with fish 237b being the first individual captured.

3.3 TRACKING OF FISH

3.3.1 Manual tracking

A VR60 receiver (VEMCO[®] Ltd, Halifax, Canada), designed to manually track fish from small boats, was linked to a VH10 handheld directional hydrophone (VEMCO[®] Ltd, Halifax, Canada) to collect non-continuous, high resolution positional data on the tagged fish.

The hydrophone was mounted at the base of a stainless steel pipe, which was then attached to a bracket on the side of the boat, in a position that enabled 360 degree rotation. The hydrophone was placed at a depth of approximately 1m below the surface of the water and 20cm below the keel of the boat. Manual tracking followed a fixed track, every session moving from the mouth towards the top of the estuary. As soon as a transmitter signal was detected, the hydrophone was rotated and the strength of the signal monitored to determine the direction of the transmitter (fish). This was continued while the gain was systemically decreased after each code detection, until the gain reached zero and the strength of the signal was equal in all directions. At this point the position of the fish was recorded, using a Garmin GPS12 handheld GPS. Manual tracking continued until all the tagged fish were located. Six day and six night positions were recorded for each fish approximately every second month.

Manual tracking only began eleven days after the fish were tagged, to allow the fish time to acclimate. Fish were tracked during dedicated daytime and night time tracking sessions, from 6 March to 2 November 2004 (Table 3.2). Daytime tracking started one to two hours after sunrise and night time tracking started approximately one hour after sunset.

3.3.2 Automated data-logging listening stations

The VEMCO[®] VR2 is a submersible automated data-logging receiver, which is used to collect long-term data by identifying, logging and storing the information it receives from transmitters within the reception range of the receiver. Each VR2 has an available memory of 2MB, an expected battery life of 15 months and can record over 300 000 detections. The reception range of the VR2 is variable and depends on factors such as depth, salinity and wind. The information stored on the VR2 was downloaded onto a notebook computer in the field, using VEMCO[®] VR2 software. Five VR2s were moored at intervals between the mouth and the top of the East Kleinemonde Estuary, to monitor fish movements throughout the estuary. Water chemistry variables (salinity, temperature and turbidity) were recorded at the surface and bottom of the estuary, at these five fixed

stations. The VR2s were deployed between 1 and 5 March 2004 and were removed between 24 December 2004 and 19 January 2005.

Table 3.2. Summary of manual tracking dates between March and November 2004 in the East Kleinemonde Estuary (Shaded areas are days and nights tracking occurred).

March Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Night	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
April Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Night	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1
May Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Night	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
June Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Night	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1
July Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Night	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
August Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Night	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
September Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Night	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
October Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Night	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
November Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Night	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	

3.3.3 Code collisions

The coded transmitters used in this study randomly emitted a signal between 10 and 30 seconds. Therefore, signal transmission by one or more tags could occur simultaneously, resulting in a code collision. However, the receivers (VR2 and VR60) are only able to positively identify one code at a time. Consequently, the ID codes will not be detected for both tags transmitted simultaneously. However, subsequent code transmissions by the two tags are unlikely to occur simultaneously, due to the random period of 10-30 seconds between signal emissions, and both codes should be detected by the receiver (VEMCO[®] VR2 Receiver Manual, 2007). Code collisions can be clearly heard on the manual tracking receiver (VR60) and are recorded on the display panel as a missed pulse. If code collisions occurred while tracking the fish manually, the tracking team persisted until the individual unique codes were recorded within that area.

Code collisions by one or more transmitters within the reception range of a stationary data-logging receiver (VR2) may be recorded and logged as a false code (i.e. as a transmitter number that does not exist). These “false detections” can easily be recognised on the download data files. All false detections recorded on the download VR2 data files during this study were deleted prior to data analysis.

3.3.4 Range tests

Range testing was conducted at all five of the fixed stations (VR2 sites) on the East Kleinemonde Estuary on 2 and 3 November 2004 and the 9 December 2004 (Figure 3.3). Predetermined sites (approximately 50m apart) were mapped and then transferred to a GPS using Garmin MapSource Software. Two transmitters were attached to a weighted fishing line at 30cm and 45cm above the estuary bottom. They were submerged in the water for a fixed time of 2 minutes at each waypoint. The VR2s were later downloaded to check which sites were within the reception range and which were not. There was a large variability in the detection ranges at each of the five VR2s (Figure 3.3). Range tests showed maximum ranges for each VR2 to be as follows: VR2-1: 308m; VR2-2: 121m; VR2-3: 420m; VR2-4: 107m and VR2-5: 71m. The VR2-3 region showed the greatest detection range, while the VR2-5 showed the smallest detection range. This is probably

due to the physical obstructions (rocky bottom) in this part of the estuary, which would reflect the transmitters' transmissions.

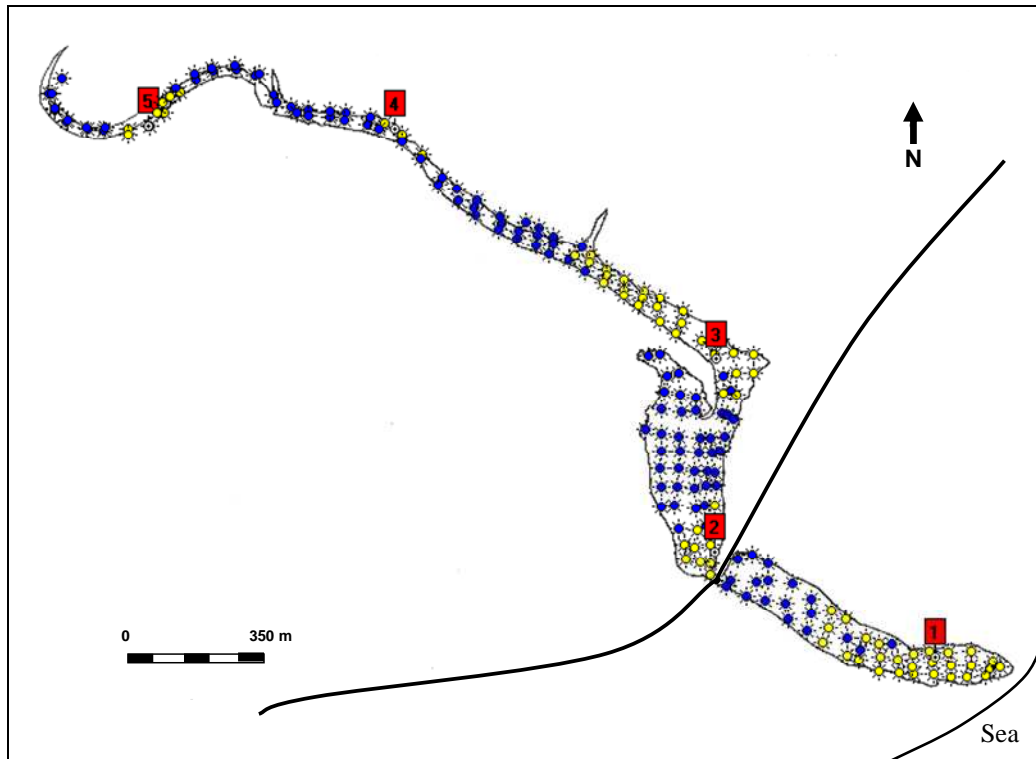


Figure 3.3. Map of East Kleinemonde Estuary showing positions of the moored VR2s (1-5) and the reception range results of the range testing of the five receivers (yellow dots = detected; blue dots = not detected). Water chemistry sites located at fixed stations 1-5.

Several authors have used similar equipment as used in this study, in various locations, showing differing reception ranges under different conditions. Some of these are summarised in Table 3.3.

Table 3.3. Equipment used, location, reception ranges seen (in metres) by several previous telemetry researchers.

Reference	Equipment used	Location	Reception range
Næsje <i>et al.</i> (2007)	Four VR2s + handheld directional hydrophone + VR60 + V8SC-2L-R256 transmitters	Great Fish Estuary, Eastern Cape, South Africa	110 – 610
Kerwath <i>et al.</i> (2005)	VR60 + V8SC-2L-R256 transmitters	East Kleinemonde Estuary, Eastern Cape, South Africa	400
Egli and Babcock (2004)	Seven VR2s	Marine reserve, New Zealand	≤500
Hartill <i>et al.</i> (2003)	15 VR1 and VR2s + transmitters	Mahurangi Harbour, New Zealand	300
Carr <i>et al.</i> (1997)	Hydrophones + VR60	Magaguadavic River, New Brunswick	>150

From the above summary (Table 3.3) it is evident that the reception range of the equipment used in this study can be highly variable. However, reception ranges obtained were suitable for addressing the objectives of this study.

CHAPTER 4

HOME RANGE ESTIMATES

4.1 INTRODUCTION

The investigation and analysis of home ranges in fishery species, such as spotted grunter, provide managers with important information on behaviour, movement or displacement efficiency, inter- and intra-specific interactions, and possible resource use patterns (Parsons *et al.* 2003). More specifically, home range estimates provide a better understanding of area use patterns (habitat utilization) of exploited populations. This is vital for designing and formulating management strategies for individual species and for conserving critical habitats (e.g. estuaries) in which they live (Hooge *et al.* 1999; Parsons *et al.* 2003; Humston *et al.* 2005; Stark *et al.* 2005; Taylor *et al.* 2006). Spotted grunter is wholly dependent on estuarine habitats as juveniles and are therefore vulnerable to localized depletion. Fishery surveys conducted on several South African estuaries have revealed that a large portion of the retained catch comprises undersized individuals (Cowley *et al.* 2004; Potts *et al.* 2005; Næsje *et al.* 2007). Consequently, management strategies could consider area closures (protected areas) to prevent recruitment over-fishing and maximize fishery production by emigration of larger individuals from nursery habitats.

Burt (1943), who is widely credited with developing the home range concept, defined an animal's home range as "the area traveled by an individual, while looking for and gathering food, mates and taking care of young". Brown and Orians (1970) defined a home range as "the area in which an animal normally lives, exclusive of migrations, emigrations or unusual erratic wanderings". For this study the home range will be adapted from Brown and Orians (1970) definition, and will be defined as the "area in which the fish normally lives, exclusive of any unusual erratic wanderings".

The home range of an animal is not uniformly utilized and can be divided into the core, intermediate and outer areas (Hooge *et al.* 1999; Crook *et al.* 2004). The core area (often the area within which 50% of all recorded locations occur) is the area in which the animal

spends the majority of its normal activity, such as foraging, resting and hiding from predators. The intermediate areas are where these activities occur less frequently, while the outer areas (often the area within which 95% of all recorded locations occur, including the core area) include occasional investigative behaviours.

Numerous experimental approaches have been used to study the movements of fishes. The use of telemetry is advantageous as it provides fine-scale temporal and spatial data. It allows the tracking and monitoring of real-time movements of individual fish. Telemetry has successfully been used to study the movement patterns of various fish species and different size classes, which utilize a variety of habitats from freshwater rivers, lakes and estuaries to offshore benthic and pelagic marine environments.

Kerwath *et al.* (2005) conducted a tracking experiment on spotted grunter in the East Kleinemonde Estuary to test the feasibility of the use of telemetry to study the movements of estuarine-dependent fish in South Africa. The objectives of their study were to test the effects of the transmitters on fish survival and movement; determine the reception range of the equipment used; investigate interference between tags and how precisely the transmitter is located, and assess how feasible the recovery of accurate and frequent positional data was with surgically implanted transmitters. The results of the study showed that telemetry is a useful tool for studying the movements of estuarine fish species in South Africa. The use of a VEMCO[®] VR60 receiver and VEMCO[®] V8 coded transmitters was found to be a good combination for intensive tracking and movement studies. Successful telemetry studies conducted on estuary associated species have been conducted on members of several families: Sparidae (Hartill *et al.* 2003; Parsons *et al.* 2003); Sciaenidae (Cowley *et al.* 2006; Taylor *et al.* 2006) and Haemulidae (Childs 2005; Kerwath *et al.* 2006).

Home range studies are typically based on short-term investigations (e.g. a few days or weeks) and provide only a ‘snapshot’ of the space use patterns of a species. This is because it is time consuming and expensive to track individuals for extended periods. In contrast, the data set obtained for this study represents one of the longest time-series of

positional fixes, providing data over many months, as well as fixes obtained both during the day and at night. Globally, investigations of home ranges of estuarine-dependent fish species are limited (Childs 2005; Taylor *et al.* 2006). In southern Africa, the only home range study conducted on an estuarine-dependent species was conducted by Childs (2005) in the Great Fish Estuary. The highly turbid, freshwater dominated Great Fish Estuary is permanently open to the sea, and therefore, experiences considerable tidal exchange and highly dynamic environmental variables. Childs' (2005) manual tracking data concluded that smaller spotted grunter generally had a single high-use area located in the lower reaches of the estuary, while larger individuals tended to have two or more high-use areas located both in the lower and upper reaches of the estuary. The home range length of the smaller individuals was also smaller than that of the larger individuals.

In contrast, the East Kleinemonde Estuary is an intermittently open estuary, with no tidal influence during the closed phase and relatively stable environmental conditions (see Chapter 2). Results from this study, presented in the next three chapters, aim to provide a better understanding of the movement and area use patterns of spotted grunter under these different conditions. Thereby providing a better understanding of the ecology of this species, and contribution to the management needs of this important estuarine-dependent fishery species.

The aim of this chapter was to describe the home range parameters, in terms of (i) size and (ii) location, of spotted grunter over an extended period, in the East Kleinemonde Estuary.

4.2 MATERIALS AND METHODS

Methods used to tag and track the fish are described in Chapter 3. Fish 237a and 237b were excluded from analyses in this chapter, as fish 237b replaced fish 237a after being caught by an angler and was, as a result, monitored for a shorter time than the other nine individuals. Home range sizes of the remaining nine individuals were calculated from the data obtained through manual tracking, conducted from 6 March to 2 November 2004.

The estuary was divided into lower, middle and upper reaches based on descriptions provided by the following studies: Kennish 1986; Day *et al.* 1989; Whitfield 1998. The reaches were defined as follows:

Lower: mouth to 1 300m; middle: 1 300 to 2 400m and upper: 2 400 to 3 500m.

4.2.1 Home range estimates

GPS co-ordinates obtained from the positional fixes were used to estimate home range size using the GIS software ArcView[®] GIS 3.2 with the Animal Movement Analysis Extension (AMAE) (Hooge and Eichenlaub 1997). The view projection properties in ArcView[®] GIS 3.2 were set as follows:

Projection: Transverse Mercator

Spheroid: WGS 84

Central meridian: 27

Scale factor: 0.9996

False easting and northing respectively: 500 000 and 10 000 000.

Autocorrelation of positional fixes (data) has been seen to be problematic in telemetry studies (Rooney *et al.* 1998; Otis and White 1999). However, by definition the concept of home range involves autocorrelated data (Otis and White 1999). Rooney *et al.* (1998) defined autocorrelation of positional data as “the phenomenon whereby the position of an animal at time $t + \Delta t$ is not independent of its position at time t ”. If there is a high degree of correlation in the data, the home range size will be underestimated (Rooney *et al.* 1998; Otis and White 1999). It is suggested that autocorrelation should be minimized by the use of non-parametric range estimates (Rooney *et al.* 1998). The kernel estimates used to calculate the density of fish observations in these non-parametric tests may be fixed or adaptive. Fixed kernel estimates may be biased as they often include areas within the home range that are rarely utilized by the animal. It is, therefore, necessary to use adaptive kernels, which vary the smoothing factor, without ‘over-smoothing’ areas of high density and usage (De Solla *et al.* 1999). Eliminating autocorrelation may also limit the biological significance of the data (Rooney *et al.* 1998 and De Solla *et al.* 1999). Few animals move in a random or temporally-independent way, therefore autocorrelated data

is necessary to accurately and sufficiently represent the animals' movement and space use (Rooney *et al.* 1999). It has also been stated by Swihart and Slade (1997) that the “cost of using moderately autocorrelated data with kernel estimates was low and exclusive use of independent observations was unnecessary”. To reduce chances of autocorrelation in this study we (1) only used one day and one night positional fix taken for each fish, which is sufficient time for the fish to have moved a large distance from the previous positional fix, and (2) positional fixes taken every second month. Therefore it was deemed unnecessary to correct for autocorrelation in this study.

Home range estimates were calculated using a non-parametric probabilistic kernel smoother. This is also known as the utilisation distribution (UD). The UD describes how the animal uses the area within its home range (Hooge *et al.* 1999). It is the probability of finding an animal at a particular area and describes the relative amount of time that it spends there (Worton 1989). For this study the 95% and 50% contour or UD was used. The 95% UD represents the fish's home range or the area in which 95% of the fish's activity occurs. The 50% UD represents the core activity area or the area in which 50% of activity occurs (Hooge *et al.* 1999).

According to Worton (1989) the kernel estimator may be described as “the probability density function $f(x)$, or kernel, which is placed over each data point and the estimator, is constructed by adding n components”. Therefore where a large number of points (fish positions) are found the kernel estimator has a higher density, while where there are fewer points, the kernel estimator has a lower density. Using the more sophisticated adaptive kernel approach allows the smoothing factor (h) to be varied.

The UD density estimator is calculated by:

$$F_h(x) = \frac{1}{n} \sum_{i=1}^n \frac{1}{h^2} K\left(\frac{x - X_i}{h}\right)$$

K is the kernel density (unimodal symmetrical bivariate probability density function), h is the smoothing factor that can be varied, X_i is a series of vectors whose coordinates give the location of each observation (X is a random sample of n independent points from the

unknown UD), x is a vector of (x,y) coordinates describing the location where the function is being evaluated, and n is the number of data points.

Using the fixed kernel method with an *ad hoc* value for the smoothing factor resulted in a large amount of the home range estimate falling outside the area of the East Kleinemonde Estuary (i.e. land). Therefore the adaptive kernel method was chosen and the smoothing factor was fixed at $h = 40$. A value of 40 was chosen by trial and error to ensure a more accurate and realistic estimate. However, using this value still produced range areas with slight overlap on the land. To eliminate this, the areas were clipped and the home range sizes recalculated using the outer boundary of the estuary. The home range estimates obtained using this method are expressed in m^2 (i.e. an area estimate).

The length of the home range (m) was also calculated to describe the area use of spotted grunter in the East Kleinemonde Estuary. This was calculated for each fish separately using the two outermost locations of its 95% UD using the measuring tool in ArcView[®] GIS 3.2.

The number of 95% UD areas (home ranges) and 50% UD areas (core areas) for each individual were calculated, as well as the ratio of the one to the other (50% UD: 95% UD). This ratio was calculated by dividing the area of the 50% UD by the area of the 95% UD and multiplying it by 100 to get a percentage. This was done to obtain information on high use areas or critical habitats within the estuary. The overlap of these areas was also calculated.

A map of the bathymetry of the region was obtained and shown below (Figure 4.1).

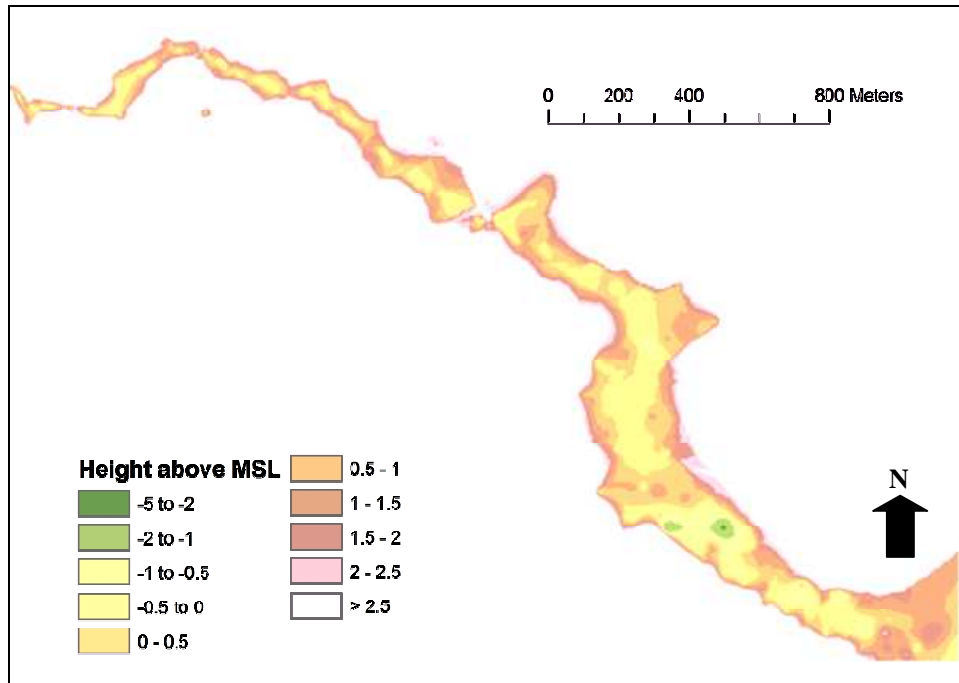


Figure 4.1. Map of the East Kleinemonde Estuary bathymetry.

4.3 RESULTS

4.3.1 Home range estimates

Nine spotted grunter were tagged and tracked over the entire study period (March to November 2004). The calculated home range parameters are summarised in Table 4.1. The number of positional fixes obtained for each fish ranged from 65 to 67, with a total of 596 positional fixes taken. The home ranges of each individual are graphically depicted in Figure 4.2.

Table 4.1. Fish identification (ID) code, fish length, number of positional fixes and home range parameters of spotted grunter (n = 9) in the East Kleinemonde Estuary.

Fish ID code	Length (mm TL)	Number of fixes	Home range: 95% UD (m²)	Core area: 50% UD (m²)	Home range length (m)	Number of 95% UD areas	Number of 50% UD areas	Ratio 50:95% UD
100	382	65	26 296	7 088	567	3	1	27
101	461	66	62 049	16 369	776	3	1	26
102	446	66	51 341	7 912	1 063	4	1	15
103	429	66	88 659	7 825	2 599	4	1	9
104	326	66	165 321	18 830	2 672	7	3	11
105	420	67	61 704	7 166	947	2	1	12
106	440	67	57 054	7 243	860	4	1	13
238	449	66	90 112	12 813	2 594	4	2	14
239	489	67	88 639	11 804	830	3	2	13

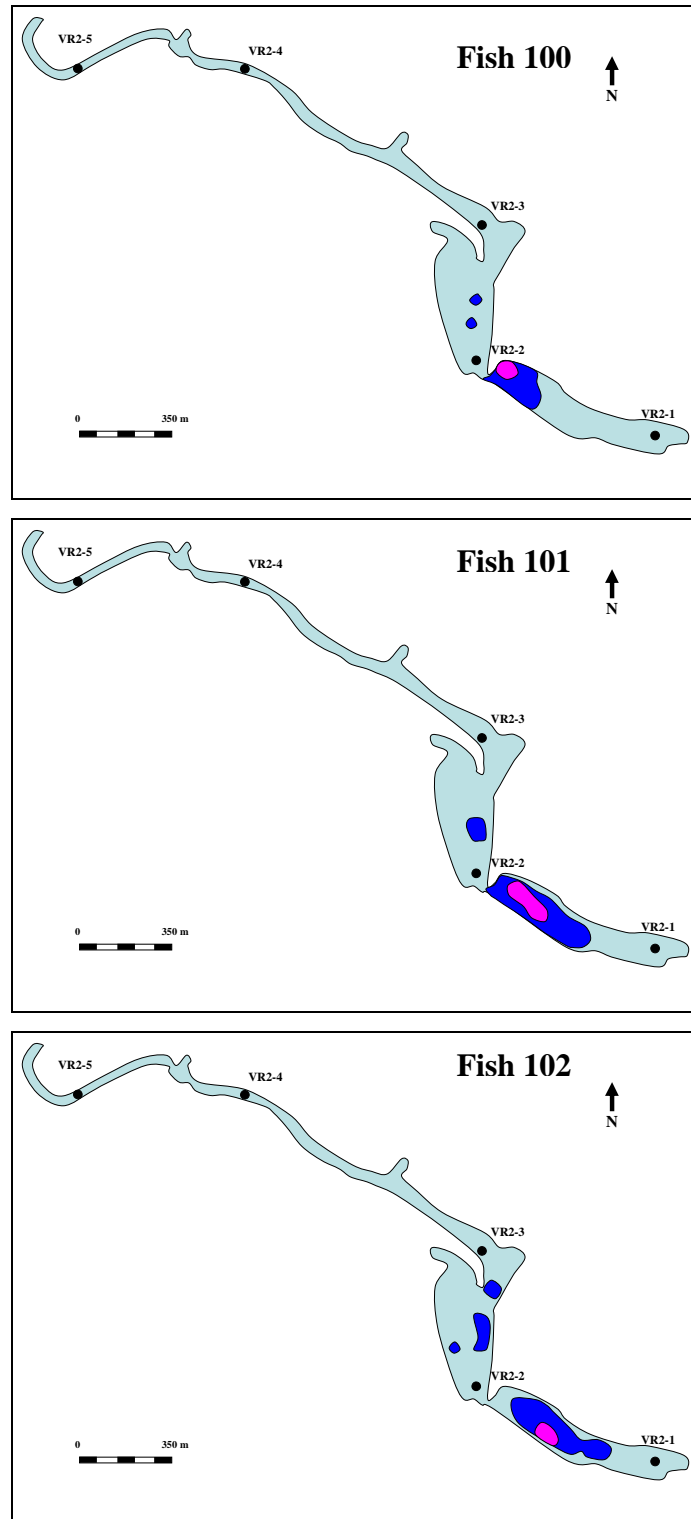


Figure 4.2. Home ranges of tagged spotted grunter ($n = 9$) in the East Kleinemonde Estuary from March to November 2004 (dark blue: 95% UD; purple: 50% UD).

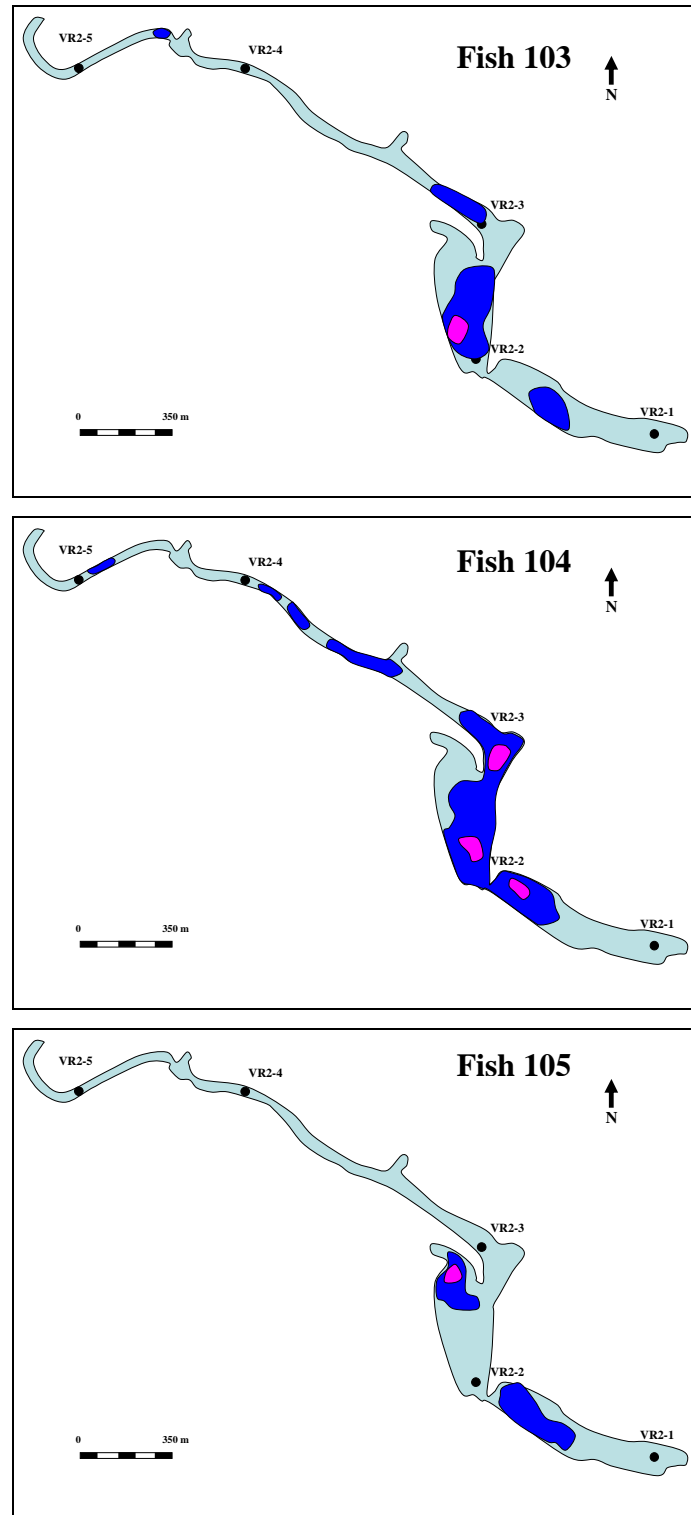


Figure 4.2 cont. Home ranges of tagged spotted grunter ($n = 9$) in the East Kleinemonde Estuary from March to November 2004 (dark blue: 95% UD; purple: 50% UD).

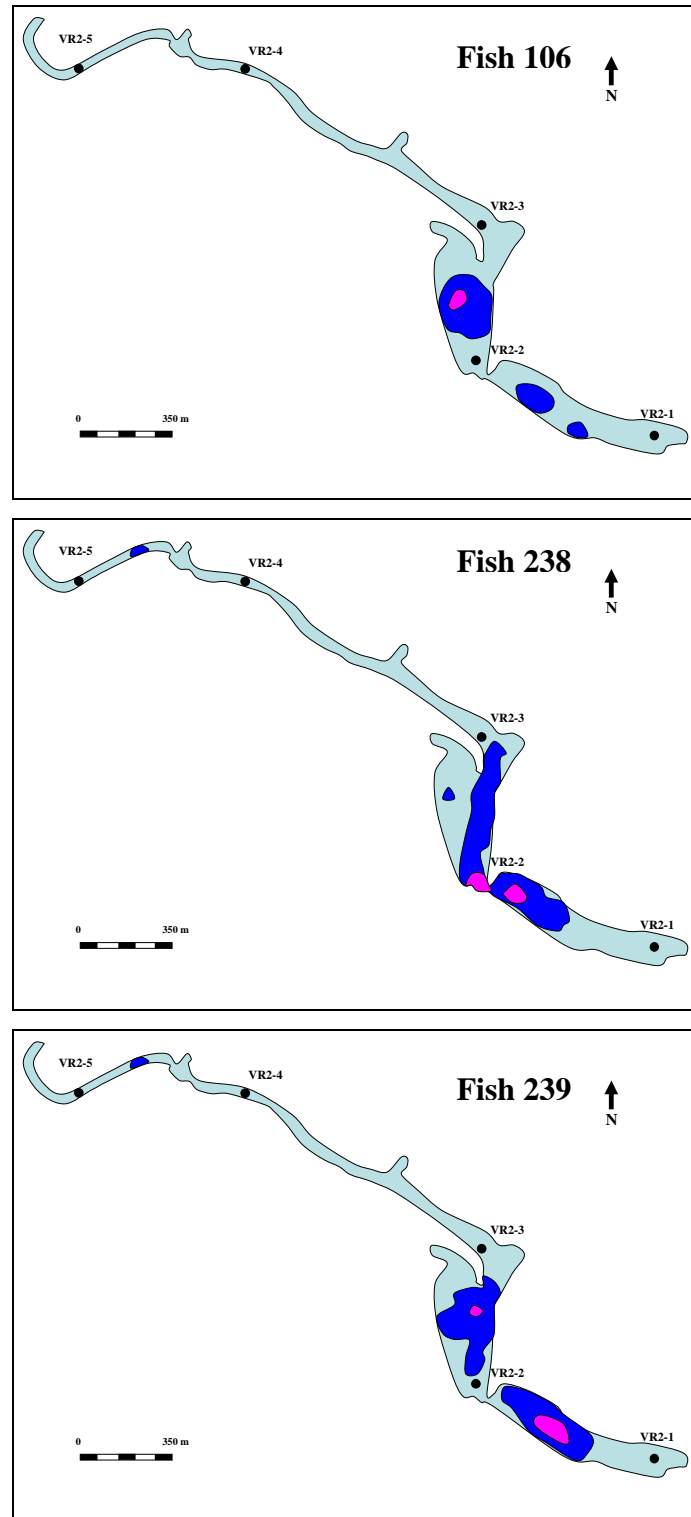


Figure 4.2 cont. Home ranges of tagged spotted grunter ($n = 9$) in the East Kleinemonde Estuary from March to November 2004 (dark blue: 95% UD; purple: 50% UD).

Results from the kernel distribution yielded a mean (\pm standard deviation) home range size (95% UD) of $76\,797 \pm 39\,255\text{m}^2$ for the nine individuals. The home ranges of most individuals ($n = 6$) were confined to the lower reaches of the estuary, while the rest ($n = 3$) extended into the middle and upper reaches of the estuary. Four individuals (Fish 102, 103, 104 and 238) had fragmented home ranges. The number of 95% UD areas was variable and ranged from 2 to 7, with a mean of 3.78 ± 1.39 .

The sizes of the core areas (50% UD) ranged from $7\,088\text{m}^2$ to $18\,830\text{m}^2$, with a mean of $10\,783 \pm 4\,435\text{m}^2$. The number of core areas per individual ranged from 1 to 3, with a mean of 1.44 ± 0.73 . Most ($n = 6$) fish had a single core area, while two fish had two core areas and one fish had three core areas.

Home range lengths ranged from 567m to 2 672m, with a mean length of $1\,434 \pm 900\text{m}$. One individual had an extended home range (into the upper reaches of the estuary), five individuals had moderately short home ranges (extending into the middle reaches) and three individuals had short home ranges (confined to the lower reaches).

A large majority (78%) of the core areas were confined to the lower reaches of the estuary (Figure 4.2). There were no core areas in the upper reaches of the estuary. Overlap of core areas was the highest ($n = 5$) in the lower reaches, between 350 m and 470 m from the estuary mouth, while the core areas of three individuals overlapped between 960m and 1 240m from the estuary mouth. Fish 105 was the only fish that did not have a core area overlapping with other individuals, and was found in the shallow salt marsh area in the middle reaches of the estuary.

The ratio of 50% UD to 95% UD ranged from 9% to 27% (mean = $16\% \pm 6.5\text{ SD}$).

4.4 DISCUSSION

Animals move according to their needs for survival (e.g. avoiding predators), growth (e.g. finding food) and reproduction (e.g. finding mates) (Matthews 1990; Vincent *et al.* 2005). Movements consume time and energy and we would therefore expect an animal to move

only to the degree at which the benefits outweigh the costs (McNab 1963). Consequently, the less an animal is required to move to fulfil the above needs, the smaller its home range is expected to be (Vincent *et al.* 2005).

The home range parameters of spotted grunter in the East Kleinemonde Estuary were highly variable. This variability was shown in the wide range of home range sizes, core area sizes and the home range lengths. This is in agreement with results from Childs (2005) in the Great Fish Estuary. Spotted grunter tend to have a larger and more variable home range than other species such as whitesaddle goatfish (*Parupeneus porphyreus*) (Meyer *et al.* 2000), snapper (*Pagrus auratus*) (Parsons *et al.* 2003) and giant trevally (*Caranx ignobilis*) (Wetherbee *et al.* 2004). Two behavioural patterns were observed in the variability of these home ranges; roaming behaviour and resident behaviour. Roaming behaviour was seen in three individuals, utilizing fragmented home range areas within the middle and upper reaches. The remaining six individuals displayed resident behaviour, mostly confined to the lower reaches of the estuary. Resident behaviour has been seen to have many associated advantages which include reduced predation risk and higher feeding efficiency due to the familiarity with the chosen area (Eristhee and Oxenford 2002). Spotted grunter presumably remain resident to a specific area as costs of moving are greater than the benefits of remaining, in terms of survival, growth and reproduction (Vincent *et al.* 2005). These behaviour traits have also been observed in the white grunt, *Haemulon plumieri* (Tulevech and Recksiek 1994).

The home range areas of this study ranged between 26 296 and 165 321m² (mean = 76 797 ± 39 255m²). The available area in this estuary at the time of the study was 307 585m², indicating that the fish utilized approximately one quarter of the space available to them.

The majority of fish (n = 6) had a single core area, suggesting a high degree of residency in spotted grunter in the East Kleinemonde Estuary. Of these fish, 78% of core areas were located in the lower reaches of the estuary. The tendency to have only one core area has

also been demonstrated by Bermuda chub *Kyphosus sectatrix* (Eristhee and Oxenford 2001) and snapper *Pagrus auratus* (Hartill *et al.* 2003; Parsons *et al.* 2003).

Spotted grunter in the East Kleinemonde Estuary showed a high degree of overlap of core areas between fish in the lower reaches and part of the middle reaches of the estuary. This overlap occurred predominantly in the lower reaches of the estuary (between 350-470m and 960-1240m from the estuary mouth). There was very little overlap found in the middle reaches and no overlap found in the upper reaches of the estuary. Childs (2005) found a high degree of overlap of spotted grunter core areas in the lower and upper reaches of the Great Fish Estuary. It was suggested that environmental variables, particularly temperature, affected the location of the core areas in this permanently open estuary. In the East Kleinemonde Estuary it would seem that in the absence of changing abiotic factors, the fish did not move up the estuary and remained mostly in the lower reaches of the estuary. It may also be due to there being less food available in the upper reaches of the East Kleinemonde Estuary. Other examples where fish have demonstrated a high degree of overlap include whitesaddle goatfish (Meyer *et al.* 2000), Bermuda chub (Eristhee and Oxenford 2001) and snapper (Parsons *et al.* 2003). The high degree of overlap suggests spotted grunter are not territorial and do not defend their area (Jorgenson *et al.* 2006). Lack of territoriality might reduce the probability of a correlation between home range size and body size (Vincent *et al.* 2005). This is further investigated in Chapter 5.

From the bathymetry map (Figure 4.1), the greatest depth of the estuary (in one hole in the lower reaches) is 5m. Four of the fish have core areas corresponding to the deeper areas or channels (of about 2m) and over the deep hole in the lower reaches. This suggests that spotted grunter spend most of its time in the deeper areas of the lower reaches of the estuary.

As core areas represent the concentrated area use within the home range, it is assumed that these areas are the most important to the fish. The ratio of the core area to the home range area (50:95% UD) represents the level of residency and importance (whether a fish

utilizes its home range area evenly or shows more time spent in the core area). The ratios of core areas to home range areas gave a range of 9 to 27% (mean = $16 \pm 6.5\%$). The small value of this ratio shows that the points were more concentrated or tightly clustered in the core area (Jones 2005), while higher ratios would mean that the fish uses its home range space more evenly. This is an important factor to remember when determining a management strategy (i.e. conservation of smaller areas) for this species in this estuary. Childs (2005) found a broader range of ratios (2 to 37%), but a smaller mean ratio of $11 \pm 8\%$, showing greater clustering in the Great Fish Estuary than in the East Kleinemonde Estuary. Wetherbee *et al.* (2003) and Parsons *et al.* (2003) showed similar values for other species.

This study was conducted during the closed and relatively full state of the estuary. The environmental conditions are considered to be fairly stable in terms of the physico-chemical parameters. Intermittently open estuaries are, however, subject to rapid changes when the mouth opens. These estuary types are also subject to occasional influxes of salt water during overwash events. This would alter the salinity regime of the estuary, and change the water level in the estuary, therefore potentially increasing available habitat into which fish could move (i.e. the salt marsh area on the east bank). Investigating the potential response of the fish to these changes would provide a better understanding of the ecology of the species. As the majority of core areas were located and overlapped over the deeper areas, it is speculated that such increases in water level would have little effect on core area size and location (Figure 4.3). However, it is hypothesized that home range size would increase with increases in water level, as this would allow greater area for exploratory excursions. If these new habitats provide more benefits, such as a higher food availability and decreased risk of predation, it is expected that the home range would change in location as well.

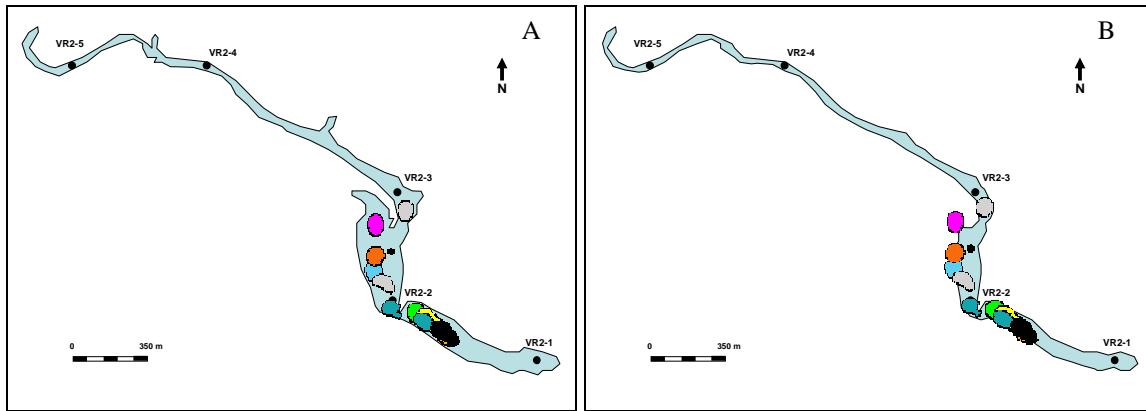


Figure 4.3. Map displaying the core areas (50% UD) of tagged fish ($n = 9$) in the East Kleinemonde Estuary during (A) high water level and (B) superimposed high water level core areas onto low water level estuary boundary.

The estuarine-dependent spotted grunter has come under increased fishing pressure in South African estuaries. Lack of law enforcement and compliance to fishing regulations has resulted in its overexploitation (Cowley *et al.* 2004; Potts *et al.* 2004). Due to its site fidelity and resident behaviour in this estuary, it is suggested that using area closure or zoning within estuaries would be an effective management tool to decrease this overexploitation. Spotted grunter in the East Kleinemonde Estuary has shown resident behaviour, due to the high degree of core overlap and the use of a single core area. The size of the core areas are variable and are mainly located in the lower reaches of the estuary, where the deeper channel is found. It is, therefore, suggested that the ‘critical habitat’ of this species (i.e. areas close to the mouth area incorporating the deeper channel, at depths of about 2m) be considered for management in the form of a small no-take area in the future. This may be sufficient to protect the population of spotted grunter in the East Kleinemonde Estuary.

CHAPTER 5

FACTORS AFFECTING HOME RANGE

5.1 INTRODUCTION

Both abiotic factors, such as temperature, salinity and turbidity, and biotic factors, such as food availability, competition and predation, may influence the size and location of an individual's home range (Heupel and Heuter 2002; Vincent *et al.* 2005). In estuarine species, additional factors such, as estuary mouth state (i.e. open or closed), catchment size, habitat variation, substrate type and parasite loads may also play an important role in determining home range size and location (Marais 1988). The relative importance of one or more of these factors may change over a seasonal cycle (Parsons *et al.* 2003) resulting in variation in diel activity and habitat selection, which are likely to affect individual home range sizes and locations (Hansen and Closs 2005). Intermittently open estuaries display relatively stable physico-chemical conditions during the closed phase (see Chapter 2) (Blaber 1981). However, seasonal variability in temperature and day length may elicit behavioural changes that affect the home range of temporarily resident fish that use these estuaries. Furthermore, when the estuary mouth breaches (opens) rapid changes in the physical state and abiotic conditions are likely to cause individuals to vacate their home ranges and move to sea.

Body size may play an important role in the determination of an individual's home range size (McNab 1963), as it constrains much of an animal's biology (Swihart *et al.* 1988). The morphology of an animal will determine its mobility (McNab 1963). A larger animal will be able to move further within its home range and vacate it much easier than a smaller individual (Macpherson 1988). This may be as a result of a change in their diet, shelter, predation risk or ability to defend resources as individuals grow in size (Kramer and Chapman 1999). As an animals needs and the resources available to them change over time, its home range size may differ temporally (Bradbury *et al.* 1995). A larger individual, however, would require more energy, requiring a larger amount of food to be collected to facilitate the higher energy demand (McNab 1963), requiring a larger home

range. This relationship of increasing home range size with an increase in body size is commonly seen in fish (Jones 2005).

Availability of prey may influence the distributional abundance of predators and determine the location of the home range within a 'stable' estuarine environment (Lowry and Suthers 1998; Vincent *et al.* 2005). According to McNab (1963) home range size will increase as available resources decrease. In estuaries along the south-eastern Cape coast of South Africa, spotted grunter feed mostly on burrowing invertebrates, namely sand prawn (*Callinassa kraussi*) and mud prawn (*Upogebia africana*) (Webb 2002). Spotted grunter extract these prey items by using a 'blowing' method of feeding, in which a jet of water is forced into the prawn burrows and the prey is blown out (Day *et al.* 1981; Webb 2002). This feeding method allows spotted grunter to exploit benthic infaunal species that are not usually available to other fish species within the estuarine habitat. A dietary study conducted in the Great Fish Estuary revealed that the diet of spotted grunter less than 70mm TL was dominated by amphipods and brachyuran species, while fish between 70 and 300mm TL had a diet dominated by amphipods. Fish larger than 200mm TL began to feed on sand prawns, which later became the primary prey item of fish larger than 300mm TL (Webb 2002). Although similar studies have not been conducted on the East Kleinemonde Estuary, spotted grunter are frequently observed blowing sand prawns (PD Cowley, SAIAB, Personal communication, 2006). Based on the dominance of these organisms in the East Kleinemonde Estuary (Wooldridge and Bezuidenhout 2007), it is assumed that sand prawn constitute the primary prey items of large (>300mm TL) spotted grunter in this estuary. A study done by Forbes (1973) showed that the ratio of active burrow to sand prawn number was 1:1 in quieter waters but under turbulent conditions could reach 2:1. In the Swartkops Estuary, Hanekom (1980) found a ratio of one hole per sand prawn. Consequently, such information, together with knowledge of the spatial distribution of sand prawn holes, make it possible to investigate the influence of prey abundance on home range location.

The aim of this chapter was to investigate whether season, day or night, fish length and/or food (sand prawn) availability affects the home range of spotted grunter within the East Kleinemonde Estuary.

It is hypothesized that:

- 1) Spotted grunter in the intermittently open East Kleinemonde Estuary do not shift the location or size of their home ranges in response to season.
- 2) Spotted grunter do not exhibit diel differences in the location or size of their home ranges in response to time of day/night.
- 3) Home range size is positively correlated to fish length.
- 4) Home range location is correlated to availability of prey items.

5.2 METHODS

Details of the methods used to tag and track spotted grunter in the East Kleinemonde Estuary are given in Chapter 3. Positional fixes were collected by manually tracking the nine tagged spotted grunter on six days and six nights during five distinct tracking sessions conducted from March to November 2004 (Table 5.1).

Table 5.1. Manual tracking dates of the tagged spotted grunter (n = 9) in the East Kleinemonde Estuary from March to November 2004.

Tracking session	Month	Daytime Tracking	Night time Tracking
1	March	6, 7, 11, 12, 14, 15	8, 11, 14, 15, 25, 28,
2	May	2, 3, 4, 5, 6, 7	1, 2, 3, 4, 5, 6
3	June	24, 25, 26, 28, 29, 30	23, 24, 25, 28, 29, 30
4	August	28, 29, 30, 31	28, 29, 30, 31
	September	1, 4	3, 6
5	October	26, 27, 28, 29, 30	26, 27, 28, 29, 31
	November	1	1

Home range estimates were generated using the GIS software ArcView[®] GIS 3.2 with the Animal Movement Analysis Extension (AMAE) (Hooge and Eichenlaub 1997). The adaptive kernel method was adopted as it is more sophisticated and allows the user to control the amount of variation in each component of the estimate (Worton 1989). Kernel estimators are sensitive to the choice of the smoothing factor (h) (Gitzen and Millspaugh 2003), with a small smoothing h observing finer detail and large h observing only the prominent features (Worton 1989). Sample size has an effect on the estimate and the degree of smoothing (Seaman and Powell 1996). Areas in which points are more dispersed should use a larger h value, while areas with a higher concentration or more tightly clustered points should use a lower h value (Worton 1989). Based on the above arguments, $h = 40$ was chosen for the seasonal analysis, as the points were less tightly clustered and the sample size of points was larger. In the diel and seasonal analysis combined, $h = 20$ was chosen, as the points were more tightly clustered and had a lower sample size. These h values were selected after initial tests of various options were conducted. The selected values were considered to be suitable as the core areas fell within the estuary (and not on the shore) and provided realistic estimates.

5.2.1 Home range persistence

Five tracking sessions were undertaken approximately every two months between March and November 2004 (Figure 5.1). The dates during each session on which tracking were conducted were influenced by weather conditions and other logistical constraints (e.g. boat engine failure) and hence could not be done on consecutive days. During each tracking session six daytime and six night time positional fixes were obtained for each tagged fish ($n = 9$). Limited battery life of the transmitters used prevented a complete four season (summer, autumn, winter and spring) comparison. Furthermore, based on available water temperature data it was apparent that the tracking sessions could not be confidently assigned to a distinct season (Figure 5.1). Consequently, the home range parameters calculated from each tracking session were treated independently to determine whether changes occurred over the nine month study period. The non-parametric Friedman's Test was used to test for differences in home range and core area sizes between each tracking session.

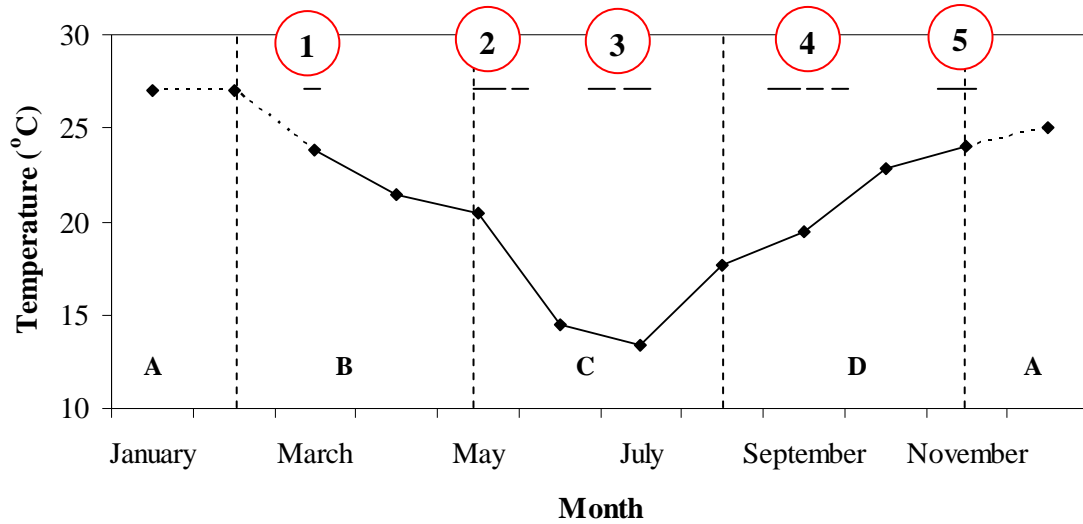


Figure 5.1. Mean surface water temperatures for the East Kleinemonde Estuary, showing the times of the five tracking sessions (red circles and horizontal black lines) and the four seasons (A: summer; B: autumn; C: winter; D: spring), using temperature data from this study (solid line) and data from Cowley and Whitfield (2001b) (dashed line).

5.2.2 Diel home range estimates

Six daytime and six night time positional fixes were obtained from each individual ($n = 9$) during each tracking session. The time at which tracking was initiated was dependent on the sunrise or sunset times during the respective months. Daytime tracking was initiated at least 2 hours after sunrise and the time that positional fixes were made ranged from 06:27 to 15:11. Similarly, night time tracking commenced at least 1 hour after sunset and ranged from 18:24 to 00:32 (Table 5.2).

Table 5.2. Ranges of earliest and latest day and night times when positional fixes were taken for each tagged fish (n = 9) in the East Kleinemonde Estuary during this study (March to November 2004).

Fish ID code	Day	Night
100	06:42 – 13:36	18:45 – 00:32
101	06:42 – 14:22	18:24 – 22:46
102	06:27 – 12:23	18:27 – 23:31
103	07:17 – 15:11	19:02 – 22:04
104	06:44 – 13:19	19:33 – 23:24
105	06:43 – 15:07	18:24 – 20:51
106	06:58 – 15:09	19:03 – 23:03
238	06:53 – 13:41	18:59 – 21:12
239	06:38 – 14:28	18:38 – 21:04

As the assumptions of normality and sphericity were met, a repeated measures ANOVA was used to test the difference in home range and core area sizes between day and night over each tracking session.

5.2.3 Effect of fish length on home range estimates

Spotted grunter attain sexual maturity between 300 and 400mm TL (Wallace 1975; Webb 2002) Based on this, the fish tagged in this study were all mature adults and ranged between 300 and 446mm FL (326 to 489mm TL) (Table 5.3). Linear regression analysis was performed to determine the relationship between fish length and (i) home range size, (ii) core area size, (iii) home range length of each fish and, (iv) number of home range areas.

Table 5.3. Fork length (FL) and total length (TL), to the nearest millimeter, of each tagged spotted grunter (n = 9) in the East Kleinemonde Estuary during this study (March to November 2004).

Fish ID code	FL (mm)	TL (mm)
104	300	326
100	350	382
105	394	420
103	399	429
106	400	440
102	410	446
238	410	449
101	430	461
239	446	489

5.2.4 Effect of food availability on home range estimates

A survey of the distributional abundance of sand prawn burrows was undertaken in September 2004 (during this study) by Terörde (2005). An underwater video camera mounted to a 40cm² frame was placed at 5 random sites at fixed depths (20, 70, 120, 170 and 220cm) along 18 evenly distributed (every 200m) transect lines throughout the estuary (Figure 5.2). Surveys were undertaken during a period when water levels were high, turbidity was low, visibility was very high and the estuary mouth had been closed to the sea for several months. Abundance was calculated as Terörde (2005), by taking the number of prawn holes, multiplying it by 1.05 (prawn hole: prawn factor) and then multiplying it by 6.25 (extrapolating 0.16m² to 1m²). Substrate type was noted to assess the accessibility of the prawns to the fish (Appendix 1). A Spearman Rank Order correlation was done to investigate the relationship between prawn density and distance from the mouth.

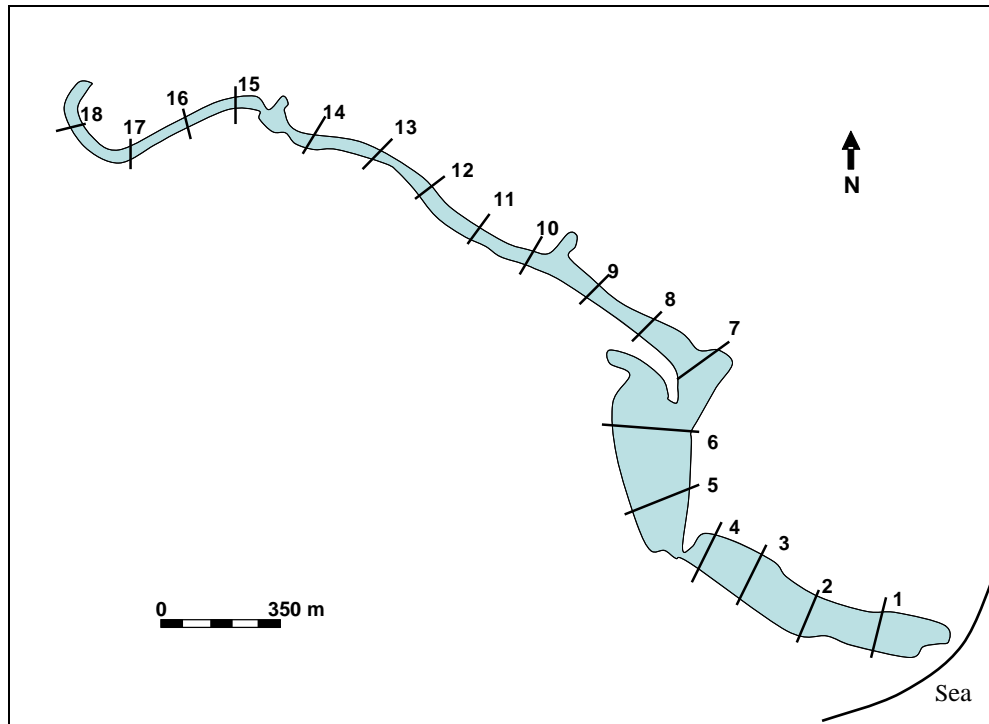


Figure 5.2. Outline of the East Kleinemonde Estuary showing the locations of the 18 transect lines where prawn hole counts were calculated in the East Kleinemonde Estuary in September 2004 (after Terörde 2005).

5.3 RESULTS

5.3.1 Home range persistence

The home range parameters calculated for each of the tagged fish during each tracking session are summarised in Table 5.3.

Table 5.3. Fish identification (ID) code and home range parameters (95% and 50% UD areas) of tagged spotted grunter (n = 9) during each tracking session in the East Kleinemonde Estuary between March and September 2004.

Fish ID code	Tracking session	Home range: 95% UD (m ²)	Core area: 50% UD (m ²)
100	1	27 182	6 624
	2	17 187	6 770
	3	60 119	7 140
	4	29 188	5 651
	5	14 390	5 738
101	1	39 566	14 211
	2	55 137	9 355
	3	66 884	6 494
	4	64 287	6 874
	5	34 565	8 839
102	1	37 495	7 611
	2	29 962	6 453
	3	56 606	7 210
	4	65 728	7 413
	5	26 618	6 871
103	1	37 287	6 475
	2	31 285	6 350
	3	44 653	7 341
	4	41 538	8 229
	5	44 401	12 003
104	1	47 084	7 538
	2	61 931	6 280
	3	43 989	10 718
	4	66 945	6 724
	5	73 834	10 395
105	1	32 452	8 146
	2	43 633	5 889
	3	22 751	6 398
	4	25 301	7 957
	5	76 448	7 326
106	1	37 575	6 254
	2	28 592	6 644
	3	38 166	7 425
	4	32 863	7 669
	5	38 124	9 001
238	1	42 901	7 266
	2	35 587	9 382
	3	78 248	15 336
	4	26 426	5 174
	5	25 565	7 221
239	1	28 770	7 800
	2	52 368	9 509
	3	42 106	10 331
	4	77 279	18 689
	5	57 591	14 058

There was no significant differences in the 95% UD size [Friedman's Test: C^2 (N = 9, df = 4) = 4.18; $p = 0.38$] or the 50% UD size [Friedman's Test: C^2 (N = 9, df = 4) = 3.02; $p = 0.55$] among tracking sessions (Figure 5.3).

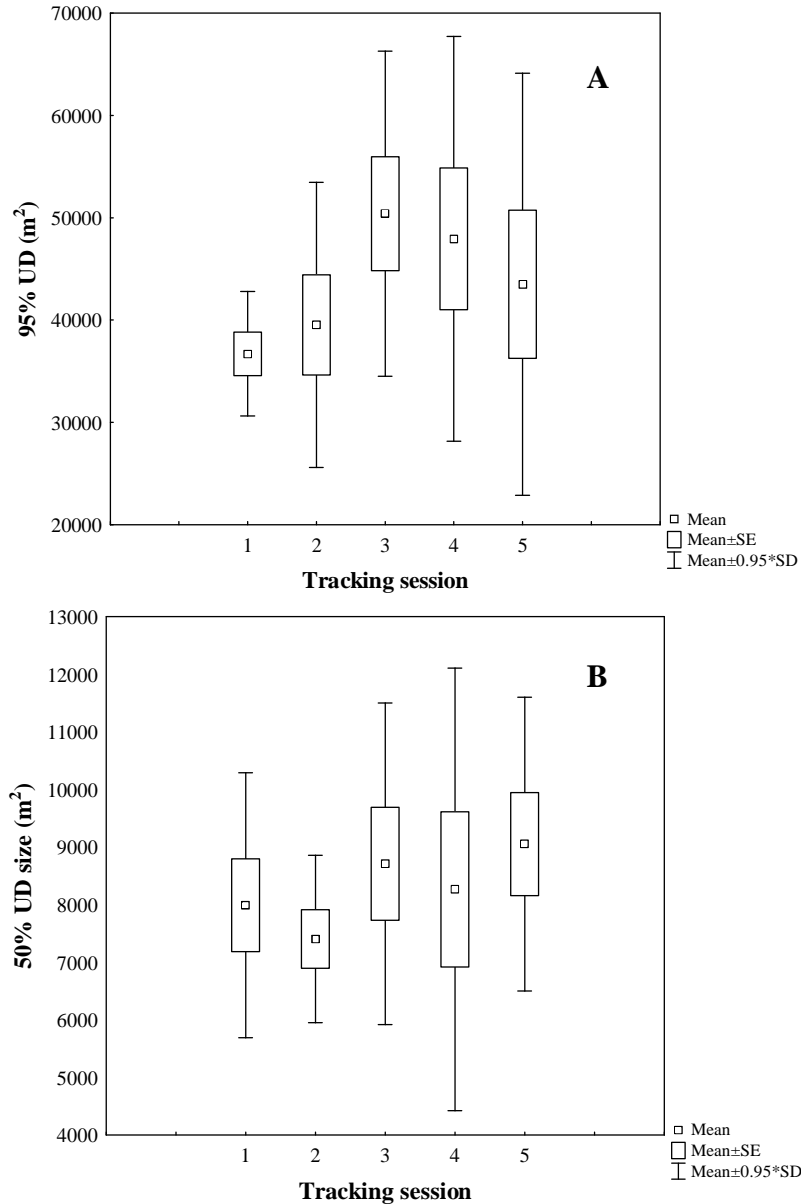


Figure 5.3. Box and whisker plot results for the Friedman's Test conducted on the 95% UD size (A) and 50% UD size (B) of tagged individuals ($n = 9$) in the East Kleinemonde Estuary over the five tracking sessions between March and November 2004.

5.3.2 Diel home range estimates

Diel home range estimates are summarised in Table 5.4.

Table 5.4. Summary of the range of day and night home range and core area sizes, for each tagged spotted grunter (n = 9) in the East Kleinemonde Estuary during the tracking sessions conducted between March and November 2004.

	95% UD area size (mean ± SD)	50% UD area size (mean ± SD)
Fish 100 Day	7 613 – 17 082 (10 604 ± 3 710)	1 454 – 2 120 (1 746 ± 293)
Night	7 352 – 10 746 (9 698 ± 1 342)	1 500 – 2 277 (1 936 ± 324)
Fish 101 Day	11 364 – 18 150 (14 836 ± 2 660)	1 521 – 6 250 (3 172 ± 1 902)
Night	13 348 – 22 735 (17 941 ± 3 714)	2 197 – 8 920 (4 945 ± 3 117)
Fish 102 Day	9 590 – 15 922 (13 131 ± 2 861)	1 566 – 2 649 (2 152 ± 410)
Night	11 512 – 19 931 (13 665 ± 3 527)	1 832 – 4 614 (2 850 ± 1 120)
Fish 103 Day	6 382 – 14 813 (11 137 ± 3 744)	1 526 – 3 777 (2 761 ± 984)
Night	11 430 – 19 485 (14 753 ± 2 920)	1 768 – 3 569 (2 548 ± 691)
Fish 104 Day	11 109 – 22 347 (16 295 ± 4 599)	2 193 – 8 626 (4 335 ± 2 566)
Night	8 710 – 14 702 (11 672 ± 2 693)	1 672 – 3 340 (2 567 ± 692)
Fish 105 Day	9 569 – 22 165 (13 592 ± 5 377)	1 563 – 8 391 (4 102 ± 2 973)
Night	7 773 – 12 387 (10 983 ± 2 016)	2 022 – 3 233 (2 406 ± 489)
Fish 106 Day	8 731 – 13 761 (10 165 ± 2 119)	1 673 – 3 059 (2 348 ± 548)
Night	8 054 – 16 835 (13 421 ± 3 355)	1 600 – 3 456 (2 640 ± 736)
Fish 238 Day	7 211 – 16 637 (12 471 ± 4 043)	1 486 – 3 504 (2 633 ± 873)
Night	7 345 – 19 229 (13 824 ± 4 483)	1 505 – 3 667 (2 654 ± 899)
Fish 239 Day	10 251 – 18 337 (14 737 ± 3 160)	1 745 – 3 730 (2 926 ± 740)
Night	13 932 – 17 383 (15 771 ± 1 302)	1 689 – 3 665 (2 505 ± 830)

There was no significant diel differences in the 95% UD size [Repeated measures ANOVA: $F(4, 64) = 0.05$, $p = 0.99$] or the 50% UD size [Repeated measures ANOVA: $F(4, 64) = 1.40$, $p = 0.25$] (Figure 5.4).

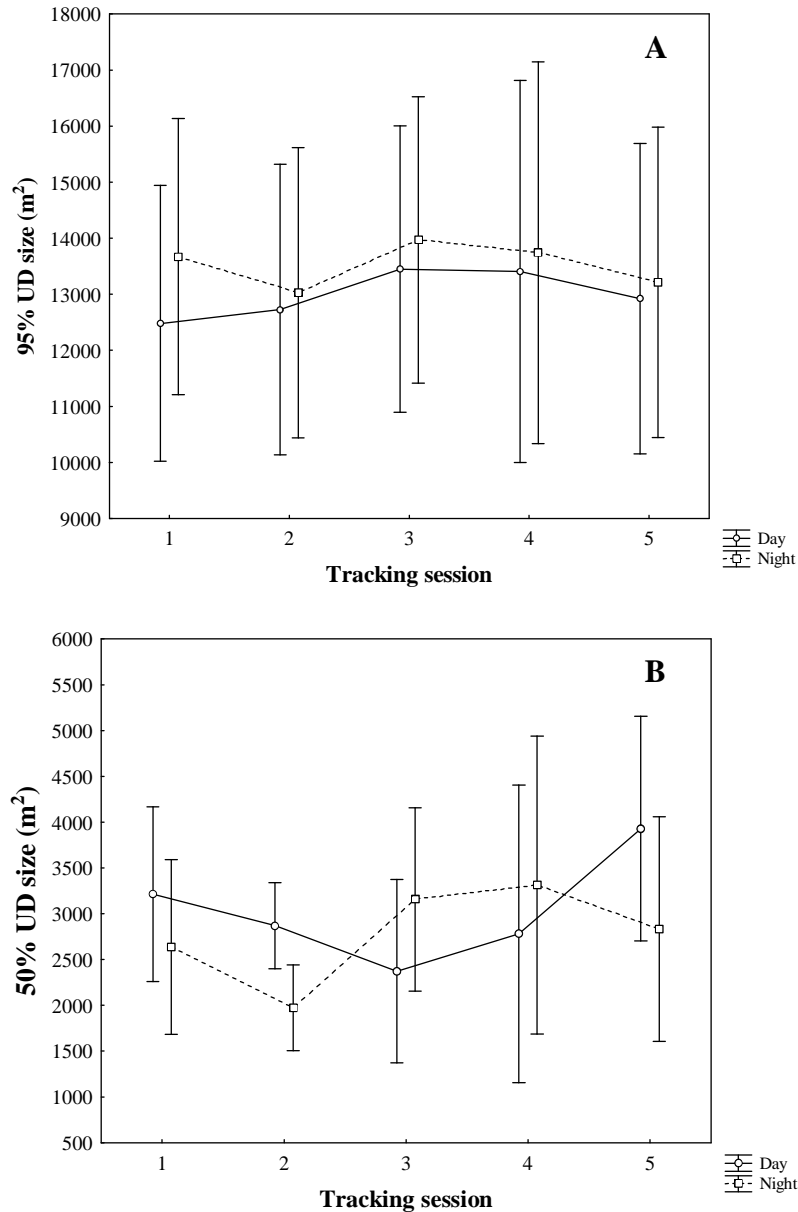


Figure 5.4. Box and whisker plot results of the repeated measures ANOVA conducted on the daytime and night time 95% UD (A) and the 50% UD (B) areas during each of the five tracking sessions conducted in the East Kleinemonde Estuary between March and November 2004.

5.3.3 Effect of fish length on home range estimates

The effect of fish length on the size and number of home range areas, size of the core areas and home range length all showed a negative slope with no significant relationship (Figure 5.5). The relevant statistics for each relationship were as follows:

Home range size: $P = 0.225$; $R^2 = 0.2023$; $f(1, 7) = 1.77$ (Figure 5.5a).

Number of home range areas: $P = 0.065$; $R^2 = 0.4068$; $f(1, 7) = 4.80$ (Figure 5.5b).

Core area size: $P = 0.512$; $R^2 = 0.064$; $f(1, 7) = 0.48$ (Figure 5.5c).

Home range length: $P = 0.320$; $R^2 = 0.1404$; $f(1, 7) = 1.14$ (Figure 5.5d).

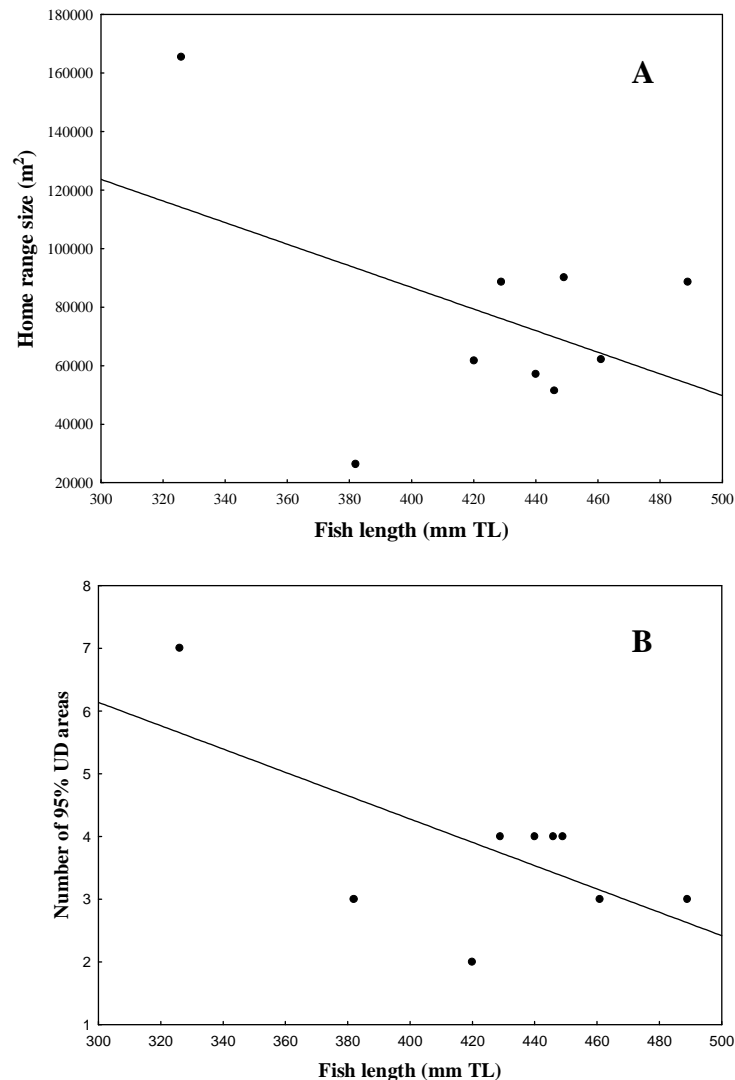


Figure 5.5. Effect of fish length on home range size (A), number of 95% UD areas (B), core area size (C) and home range length (D) of spotted grunter ($n = 9$) in the East Kleinemonde Estuary.

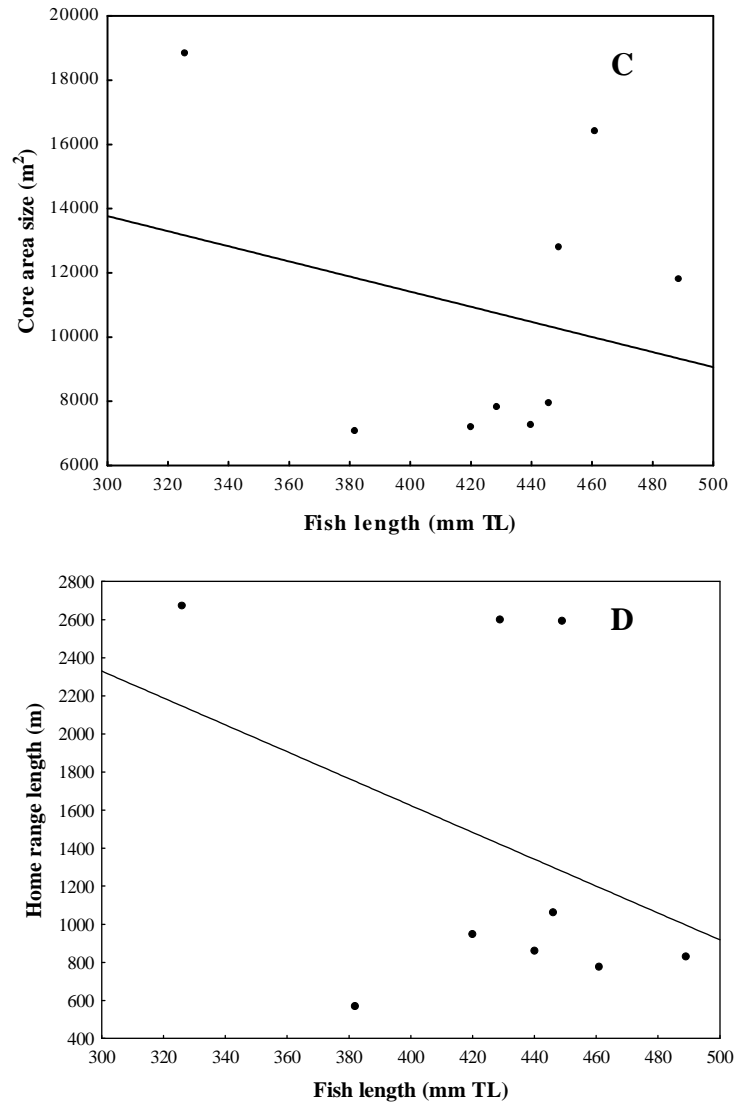


Figure 5.5 cont. Effect of fish length on mean home range size (A), number of 95% UD areas (B), mean core area size (C) and home range length (D) of spotted grunter ($n = 9$) in the East Kleinemonde Estuary.

5.3.4 Effect of food availability on home range estimates

A summary of distributional abundance of sand prawns in the East Kleinemonde Estuary during September 2004 is shown in Appendix 1. No prawns were found at the head of the estuary (last two transects). Prawn densities were generally highest at water depths of 120 and 170cm (Appendix 1). There was a significant negative correlation (Figure 5.6) between prawn densities and distance from mouth (Spearman rank order correlation: $p < 0.05$; $r = -0.38$). Overall, prawn abundance along each transect was highly variable.

The highest sand prawn abundance was seen 800m from the estuary mouth. Prawn abundance decreased with increasing distance from the mouth. The 95% UD areas of the nine tagged individuals coincided with the location of the higher prawn abundance found in the lower reaches of the East Kleinemonde Estuary (Figure 5.6).

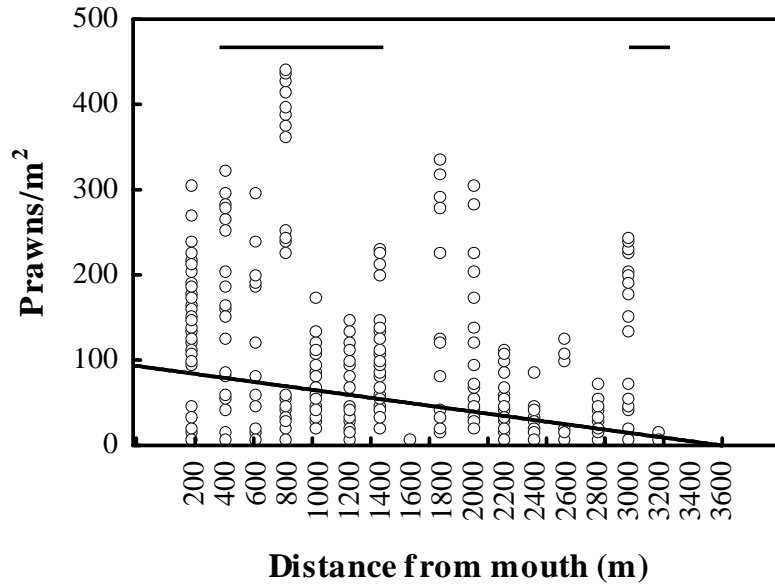


Figure 5.6. The correlation between prawn densities and distance from the East Kleinemonde Estuary mouth in September 2004 (after Terörde 2005) and the locations of 95% UD areas of the tagged spotted grunter (solid black line).

5.4 DISCUSSION

This is the first study to describe the home range of spotted grunter in an intermittently open estuary, over temporally segregated tracking sessions and during the day and night, over an extended period of nine months. Intermittently open estuaries are known to have little or no horizontal temperature gradient, a result of a small catchment size that limits input of freshwater and coastal winds that promote increased mixing of the water column (Lukey *et al.* 2006). The long term persistence of home range parameters is likely, considering the relatively stable conditions found in this estuary type during the closed mouth phase. The benefits of home range persistence are area familiarity and efficient utilization of its prey resources (Litvaitis *et al.* 1987; Eristhee and Oxenford 2002).

Lowry and Suthers (1998) found that red morwong (*Cheirodactylus fuscus*) showed seasonal variation in home range, which they suggested was linked to changes in habitat quality. Similarly, Matthews (1990) found changes in habitat quality over different seasons to cause a variation in both the home range size and location of *Sebastes* spp. Bradbury *et al.* (1995) found that female cunner (*Tautogolabrus adspersus*) changed home range size over season. This was possibly due to changing requirements associated with spawning and reproductive behaviour. Spotted grunter is a marine-spawning species and therefore reproductive activity would not have influenced the home range parameters during this study.

Although a number of environmental factors were relatively stable during this study (e.g. water level and salinity), water temperatures ranged from 11.2 to 28.9°C. The distribution of fishes within estuaries is dependent on and affected by fluctuations in temperature (Blaber 1981). Temperature has been suggested as the most controlling abiotic factor in fish (Beitinger and Fitzpatrick 1979). It controls key physiological, biochemical and life-history processes of fish (Deacon and Hecht 1995). Most fish species depend on the behavioural control of their body temperatures and, therefore, need to find appropriate water temperatures in which to live (Beitinger and Fitzpatrick 1979). Generally, fish have a thermal preference at which their physiological processes are optimized. In nature, however, fish are not always found in their preferred optimal temperature, even though it may be available to them. This is possibly due to one or more other factors overriding their behaviour, which may include non-thermal environmental factors such as season, light intensity, biotic interactions and age (Deacon and Hecht 1995). The thermal preference for 0+ juvenile spotted grunter under laboratory conditions was found to be between 24 and 25°C (Deacon and Hecht 1995). This shows that spotted grunter have adapted to and are tolerant of a wide range of temperatures.

There were no significant differences in home range and core area size among tracking sessions for any of the nine individuals, during this study. The home range area of certain individuals (e.g. fish 100 and 101), however, extended slightly (both towards the top and mouth area of the estuary) during the colder months (June and August). This suggests

more exploratory behaviour, perhaps in search of optimal (less stressful) conditions. This was to be expected, as the fish would attempt to locate themselves in their preferred optimal temperatures, as shown by Deacon and Hecht (1995). In October, when warmer water temperatures returned (Figure 5.1), fish occupied approximately the same home range sizes observed in March 2004.

Fish 103, 104, 105 and 106 all changed their home range in May 2004. This may have been due to a slight increase in water level and therefore increased habitat availability. There were one large and seven small overwash events recorded prior to their move. During March and April there was also a cumulative total rainfall of 109.5mm. The resultant rise in water level increased habitat availability, for example, on the salt marsh area along the east bank of the estuary. Fish 105 moved into this area (i.e. relocation of home range) and stayed there for the remainder of the study.

Despite apparent deviation in the home range parameters in response to temperature and water level, there were no significant differences over the nine month study period. Therefore, due to the long-term persistence of the home range parameters, the null hypothesis that spotted grunter do not shift the location and size of their home range in response to season, was not rejected.

Many fish species undertake regular excursions, often more extensive at night, to different habitats (Lowry and Suthers 1998; Meyer *et al.* 2000; Eristhee and Oxenford 2001), including haemulids (Ogden and Ehrlich 1977; Tulevech and Recksiek 1994). It is suggested that nocturnal and crepuscular activity usually occurs to reduce predation risk, to optimize foraging strategies, and is an adaptation to prey availability (Jadot *et al.* 2002). Work done by Lowry and Suthers (1998) showed that *Cheilodactylus fuscus*, had larger home range and core area sizes at night compared to daytime. Jadot *et al.* (2002) showed that *Sarpa salpa* in the Mediterranean Sea was less mobile during the day, with increased activity during dusk and early night. Adult tautog, *Tuatoga onitis*, showed a decline in activity during mid-day hours, possibly due to the fish resting during maximum sunlight hours (Arendt *et al.* 2001). Whitesaddle goatfish, *Parupeneus porphyreus*, were

found to be quiescent during the day, becoming active and moving to feeding grounds at sunset, where they remained active throughout the night, returning to their daytime habitat at sunrise (Meyer *et al.* 2000). Laboratory experiments by Du Preez *et al.* (1996) showed a nocturnal peak in oxygen consumption of spotted grunter, suggesting this is the period of greater activity.

Members of the Haemulidae (grunts) are considered to be nocturnal feeders (Tulevech and Recksiek 1994; Deacon and Hecht 1995; Kramer *et al.* 1997). This is because they have increased visual perception under low light conditions (Kendall *et al.* 2003). It has also been suggested certain species feeding solitarily at night, utilize the same foraging areas on successive nights (Kendall *et al.* 2003). The dominant prey item of spotted grunter was shown to be distributed along the length of this estuary, but with significantly higher abundance in the lower reaches, indicating no need for the fish to move to different localities to feed. Tagging studies conducted on the white grunt (*Haemulon plumieri*) showed that they also remain associated with a particular location (Moe 1966).

Childs (2005) found that spotted grunter maintained consistent home range parameters for extended periods and that home range location in the permanently open Great Fish Estuary coincided with the area of highest prey density. However, regular movements, in response to daily tidal rhythmic changes in environmental variables, were observed. The findings of this study revealed that spotted grunter in the East Kleinemonde Estuary did not alter their home ranges diurnally and therefore we failed to reject the null hypothesis (spotted grunter do not exhibit diel differences in location and size of their home range in response to time of day/night).

It is accepted that the size of an animal can affect the maximum area or distance it can cover, and would therefore influence the size of the home range (Vincent *et al.* 2005). Generally, the larger the individual, the larger its home range would need to be in order to locate more food to support its higher energy demands (McNab 1963; Jones 1995; Meyer *et al.* 2000; Travnichek 2004). This is true unless there is superabundance in available food. As a fish grows larger in size, it is also able to increase its swimming speed

enabling them to cover more area (Macpherson 1998; Kramer and Chapman 1999) and thus increasing the size of its home range. In contrast, this study revealed no significant relationships between fish length and home range size, number of home range sites, core area size and home range length. Other authors that have found home range to decrease with increasing fish length are Miller and Menzel (1986), Fish and Savitz (1983), Todd and Rabeni (1989) and, Lowry and Suthers (1998). Lowry and Suthers (1998) noted that home ranges may be determined by physical characteristics (such as size, metabolic rate and ontogenetic development), together with environmental factors (such as distribution, abundance of food and intra- and interspecific interactions). The metabolic relationship between size and home range area, with larger terrestrial mammals having a larger home range is not as applicable to poikilothermic animals in the marine or estuarine environment (Lowry and Suthers 1998). More complex factors determine fish home range sizes, than the resource-budget models used to explain mammals home range sizes (Lowry and Suthers 1998). Therefore, contrary to what was expected, spotted grunter home range size within the East Kleinemonde Estuary was not positively correlated to fish length and thus the null hypothesis (home range size is positively correlated to fish length) was rejected. This is probably largely due to the high abundance in prey items available to them.

Location, size and activity within a home range are often concentrated into activity centres containing important resources such as optimal habitats (for resting and refuge) and available food resources. Since these needs and the energy requirements and availability change over time, changes in the home ranges are expected (McNab 1963; Bradbury *et al.* 1995). Animals assess prey density and directly adjust their territory or home range size to include resources that are sufficient for their current energetic needs (Hansen and Closs 2005). It is assumed that an animal would situate its home range as close to its foraging area as possible to optimize its resource use and therefore minimize the energy needed to acquire food. When food availability is limited, home range areas would need to be increased or the location changed (McNab 1963; Hansen and Closs 2005). Sand prawn abundance within the East Kleinemonde Estuary was significantly different along the length of the estuary, with the lower reaches showing a higher

abundance of prawns. No prawns were found at the head of the estuary (transect lines 17 and 18). The area 600m upwards of the estuary mouth was the area of highest overlap of spotted grunter home ranges and core areas. This region of the estuary is characterised by a sandy substrate with reed bed margins and also had the highest sand prawn densities at depths of 120-170 cm. This substrate type would allow the spotted grunter to obtain its prey (prawns) more easily. Areas with rock, mud or submerged macrophytes make the prawns much less accessible to the spotted grunter, limiting them to the larger sandy areas. These large areas of soft bottom substrate would be expected to support a larger number of grunts (Kendall *et al.* 2003). Cowley *et al.* (2006) hypothesized that a strong selection exists for estuary associated fishes preying on non-mobile benthic organisms, such as prawns, to exhibit station-keeping behaviour and occupy areas that provide optimal prey availability.

Childs (2005) showed that spotted grunter home ranges within the Great Fish Estuary coincided with the highest abundance of their preferred prey item. Hansen and Closs (2005) found that drift-feeding stream fish adjusted their home range in response to availability of food. Humston *et al.* (2005) showed that the bonefish (*Albula vulpes*) stayed only a few days in the area released, due to a change in foraging grounds. Similarly to the results of other studies done, spotted grunter within the East Kleinemonde Estuary did locate their home ranges in areas of highest prey abundance of prey items, and therefore the null hypothesis (spotted grunter home range location was correlated to the availability of prey items) could not be rejected.

In conclusion, it was found that although spotted grunter made slight movements when more habitats were available or temperatures dropped, home range parameters remained relatively constant throughout the study period, both across tracking sessions and diurnally in the East Kleinemonde Estuary. Contrary to what may be expected, fish size had no effect on the home range parameters of this species within this intermittently open estuary. It was found that the only factor to influence spotted grunter home range was the location, availability and accessibility of sand prawns.

CHAPTER 6

LONG-TERM TRENDS IN AREA USE

6.1 INTRODUCTION

Home range studies are largely based on short-term observations, commonly a few days or weeks (Parsons *et al.* 2003). This is mainly due to the expense and time required to track individuals over extended periods (Egli and Babcock 2004). However, short-term monitoring periods often underestimate the extent of a fish's movements and hence its home range size (Parsons *et al.* 2003; Heupel *et al.* 2004). Therefore, there is a need for long-term data in order for more accurate estimation of home ranges. The home range estimates from this study were based on snapshots in time, and data were collected by manually tracking the tagged fish on 30 days during five temporally segregated tracking sessions over a nine month period.

The development of passive acoustic monitoring (i.e. moored automated data-logging listening stations) has enabled long-term simultaneous observations of the movements of numerous individuals (Heupel *et al.* 2004). Consequently, the use of data-logging receivers is becoming increasingly more popular amongst biotelemetry researchers (Arendt *et al.* 2001; Egli and Babcock 2004; Heupel *et al.* 2004). In this study five automated data-logging listening stations were spaced along the length of the East Kleinemonde Estuary enabling long-term (>10 months) monitoring of tagged spotted grunter within this estuary. Despite known differences in reception range, the data downloaded from each listening station allowed for the confirmation of the snapshot data used to estimate home range parameters during the same extended period.

The aims of this chapter were to (1) investigate the long-term area use patterns of spotted grunter in the East Kleinemonde Estuary; (2) confirm the home range estimates reported in earlier chapters; (3) identify any deviations or excursions taken outside of the calculated home range areas and to quantify the frequency, duration and extent of these exploratory excursions, and (4) determine whether the tagged fish emigrated to sea after the estuary mouth opened on 23 December 2004.

6.2 MATERIALS AND METHODS

6.2.1 Automated data-logging listening receivers

Fish movements were monitored over a period of 294 days, using five automated data-logging listening receivers (VEMCO® VR2s), moored 240m, 915m, 1 350m, 2 525m and, 3 280m, respectively, from the mouth of the closed East Kleinemonde Estuary (Figure 6.1). The VR2 is a submersible single channel receiver that logs and stores information from coded transmitters within the reception range of the receiver (Pincock and Voegeli 2002). The reception range of the VR2 is variable and depends on factors such as depth, salinity, wind and physical obstructions (e.g. rocks). Extensive range testing was conducted throughout the East Kleinemonde Estuary. A computer generated grid map (50m²) of the entire estuary was used to identify fixed points at which reception ranges were tested (OziExplorer). Two transmitters, equivalent to those used in the study, were attached 30cm and 45cm from the bottom of a weighted line. The transmitters were submerged at 192 identified fixed sites which were transferred from the computer generated grid map to a GPS. At each site the transmitters were submerged for 2 minutes. To prevent “time of day” errors the PC clock was calibrated to the time recorded on the GPS. The maximum reception ranges were as follows: VR2-1: 308m; VR2-2: 121m; VR2-3: 472m; VR2-4: 107m and VR2-5: 88m. The five VR2s were deployed on 5 March 2004 and three (VR2-3; VR2-4 and VR2-5) were removed following a mouth breaching event on 23 December 2004. The remaining two receivers (VR2-1 and VR2-2) were left in the estuary until 19 January 2005 to confirm whether the fish left the estuary after the breaching event on the 23 December 2004 (Figure 6.1).

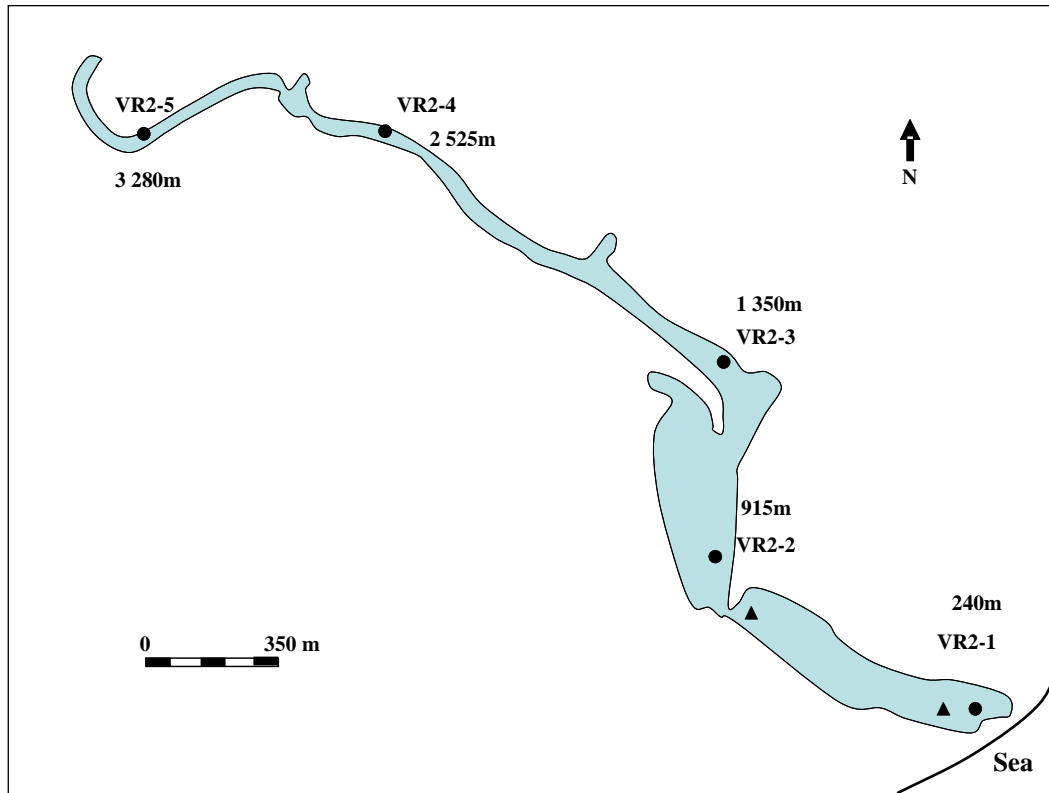


Figure 6.1. Location of the five VR2s moored in the East Kleinemonde Estuary between 5 March and 24 December 2004, indicating their distance from the mouth. The locations of the two VR2s that were moved following the mouth breaching are indicated by triangles.

6.2.2 Data analysis

6.2.2.1 Area use patterns

The VR2s recorded the presence or absence of tagged individuals within the reception range around each receiver. Although the reception ranges between each VR2 were highly variable, each VR2 was strategically placed (i.e. on bends) to log the fish when they moved up and down the estuary. It was assumed that when a tagged fish moved past a VR2 it was recorded. Consequently, this provided continuous information on the location (within specific zones of the estuary) of each fish for the 294 days. The downloaded data was screened for false detections (discussed in Chapter three) and then analysed to quantify the time spent in the vicinity of each VR2 over the entire study period of 294 days (7 056 hours). The presence of a fish in the vicinity of a VR2 was taken when two or more detections occurred consecutively, within 60 minutes. The total

time was then converted to the proportion of time spent at each VR2. This calculation was influenced by the variability in reception ranges of the five VR2s.

6.2.2.2 Confirmation of manual tracking home range estimates

The screened, downloaded VR2 data was used to quantify the time spent in the vicinity of each VR2 on the days when manual tracking occurred (total period = 720 hours, approximately 10% of the study duration) and was compared with the proportion of time spent in the vicinity of each VR2 over the entire study period (7 056 hours), using a Kolmogorov-Smirnov significance test. Consequently, it could be tested whether data collected on manual tracking days (snapshots taken on 30 days), represented a true reflection of the spatial behaviour of the tagged individuals over the nine month period.

6.2.2.3 Frequency, duration and extent of exploratory excursions

Frequency and duration of exploratory excursions for each fish were calculated over the entire study period. An excursion was defined as any exploratory or investigative movement out of the home range over the nine month period in which the fish were manually tracked. If the home range occurred in the vicinity of a VR2, that VR2 was excluded from the excursion analysis (VR2-2 was excluded for all fish and VR2-3 was excluded for four fish). The numbers of excursions were calculated as the number of times a single, continuous return trip was undertaken either i) up the estuary and recorded on one or more of the top two or three VR2s, or ii) down the estuary (to VR2-1). The duration of an excursion was calculated as the total amount of time from when it was detected on a VR2 outside its home range to the time it was last recorded on the VR2 closest to its home range (Figure 6.2). Excursions were placed into time intervals of three hours and analysed using a repeated measures ANOVA to investigate temporal patterns. The number of excursions taken each month were analysed using a repeated measures ANOVA. The distance of each excursion, for each individual tagged fish, was taken as the distance from the outermost edge of the home range containing the core area to the location of the furthestmost VR2 reached (Figure 6.2). Fish 104 was excluded from these analyses as its home range extended the length of the estuary.

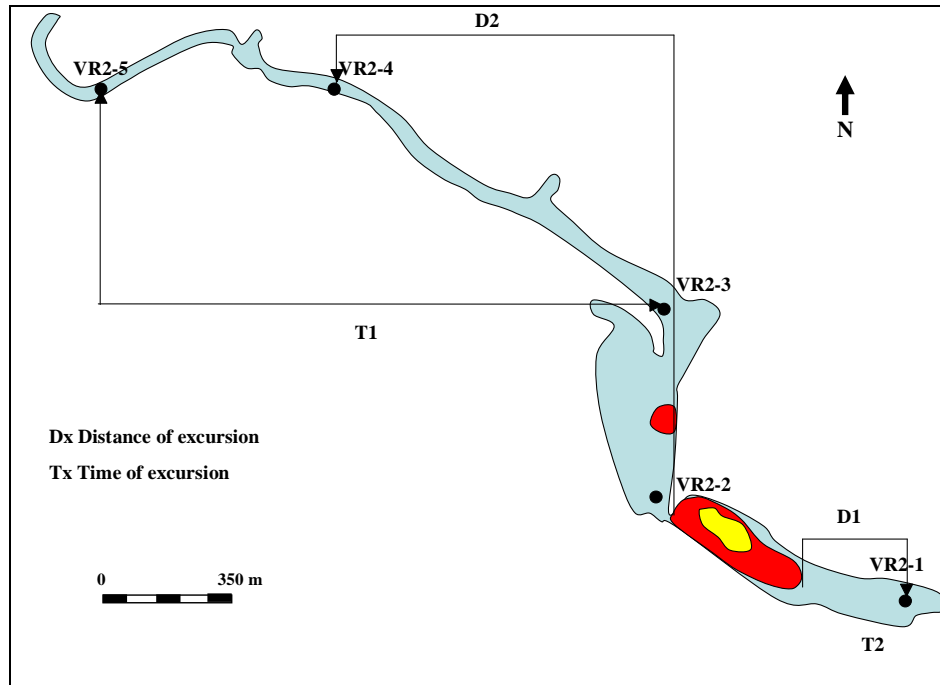


Figure 6.2. Example of time and distance calculations of exploratory excursions undertaken by tagged spotted grunter in the East Kleinemonde Estuary (yellow: 50% UD; red: 95% UD).

6.3 RESULTS

6.3.1 Area use patterns and confirmation of home range estimates

A total number of 410 710 detections were logged on the five VR2s. Most detections were recorded on VR2-2 (64.4%), while VR2-4 (0.6%) had the fewest. All fish were recorded on VR2-1, VR2-2 and VR2-3; while two individuals (fish 101 and 239) were not detected on VR2-4 and VR2-5 and one individual (fish 105) was not detected on VR2-5. Fish 239 had the fewest detections (5 377), while fish 238 had the highest number of detections (189 967) (Figure 6.3).

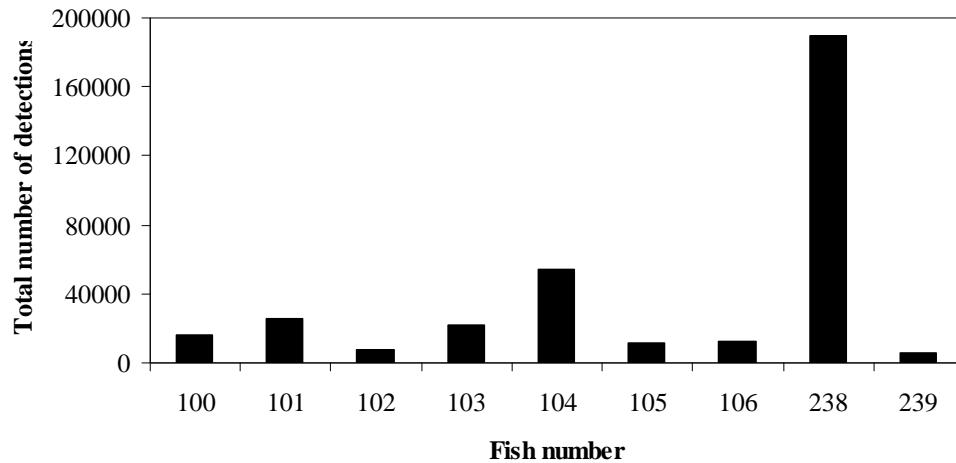


Figure 6.3. Total number of detections (on all five VR2s) for each of the tagged spotted grunter in the East Kleinemonde Estuary between March and December 2004.

On average the tagged fish spent most time (87.9%; 6 205 hours) during the 294 day study period in parts of the estuary outside of the reception range of the VR2 array. Similarly, the fish spent most time (82.9%; 597 hours) outside of the VR2 array during the 720 hour manual tracking period.

The distribution and proportion of peaks in the total amount of time spent at each VR2 during the manual tracking period (30 days) and the entire study period (294 days) were similar for all fish and corresponded closely with the calculated 95% and 50% UD areas (Figure 6.4). For all fish the amount of time spent in the vicinity of each VR2 during the 720 hour manual tracking period was not significantly different to the entire 7 056 hour study period (Kolmogorov-Smirnov, Table 6.1).

Certain fish (fish 100 at VR2-3; fish 103 at VR2-3 and fish 239 at VR2-1) showed much larger peaks (number of detections) at certain VR2s during the entire study period compared to the manual tracking period (Figure 6.4). This could be ascribed to the increased exploratory behaviour to those areas of the estuary, and hence were only logged on the VR2s during the extended period and not over the manual tracking (snapshot) period.

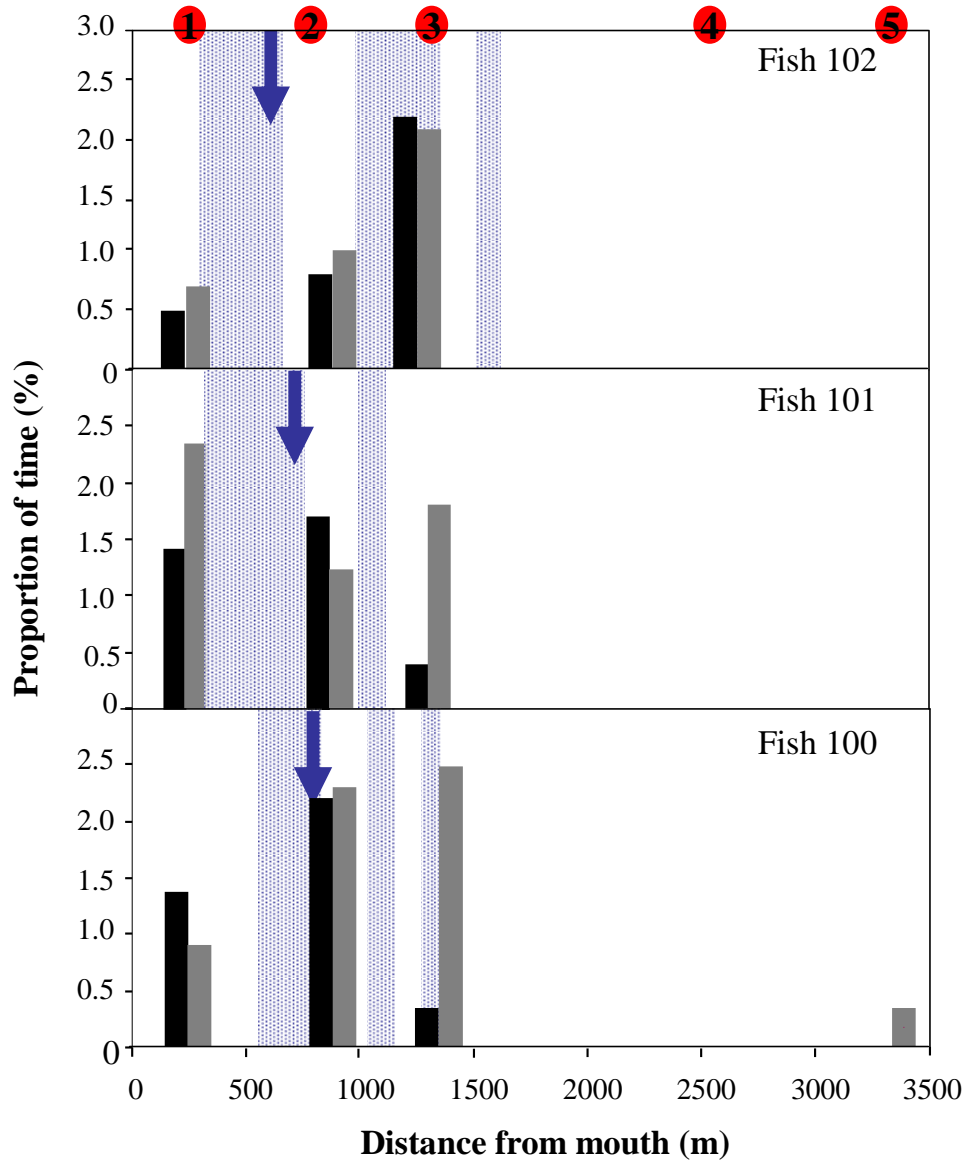


Figure 6.4a. Proportion of time (percentage frequency) tagged spotted grunter spent in the vicinity of each VR2 (numbered red dots) during (i) the entire 294 day study period (grey shaded bar) and (ii) the specified 720 hour period when manual tracking was conducted (black shaded bar). The stipple blue shaded areas indicate the extent of the 95% UD and the arrows indicate the location of the 50% UD.

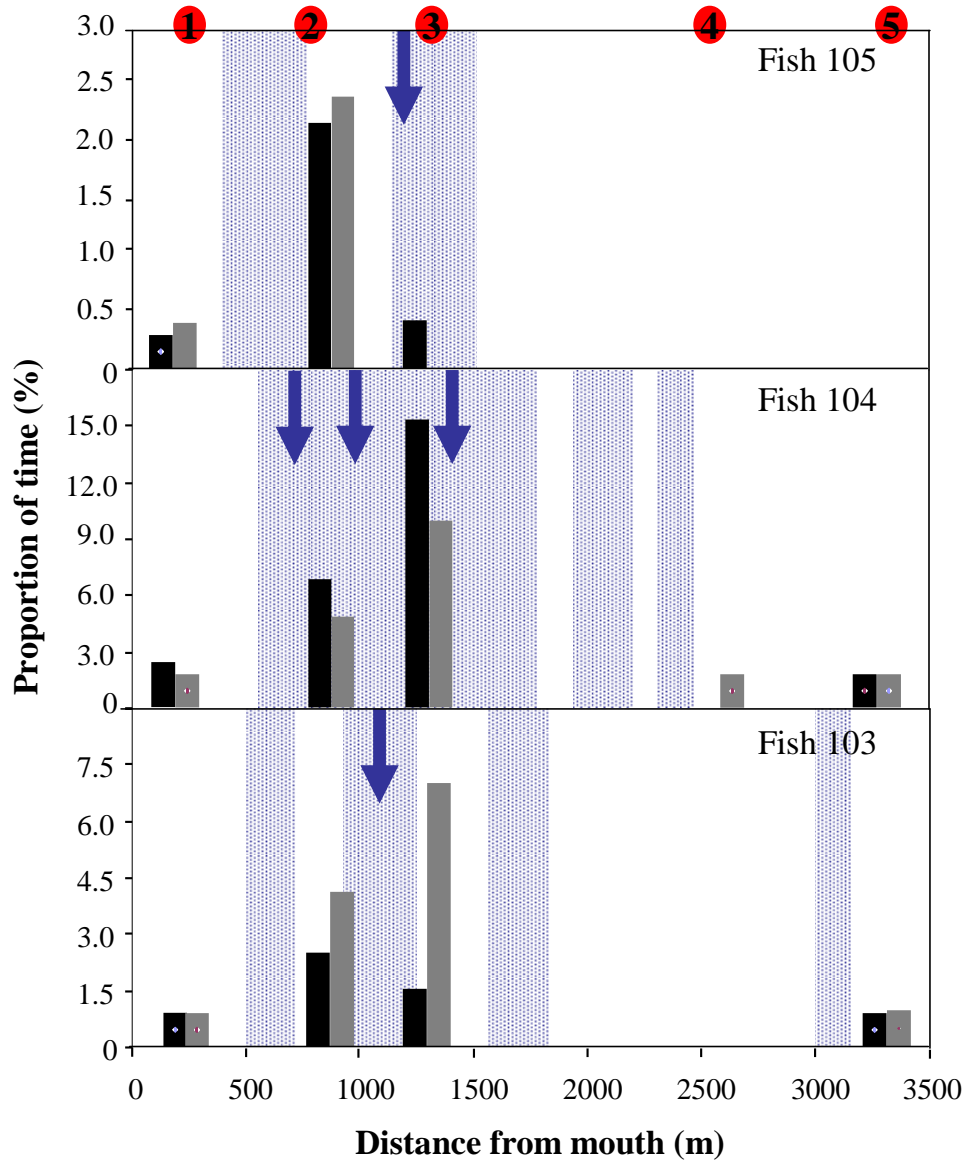


Figure 6.4b. Proportion of time (percentage frequency) tagged spotted grunter spent in the vicinity of each VR2 (numbered red dots) during (i) the entire 294 day study period (grey shaded bar) and (ii) the specified 720 hour period when manual tracking was conducted (black shaded bar). The stipple blue shaded areas indicate the extent of the 95% UD and the arrows indicate the location of the 50% UD.

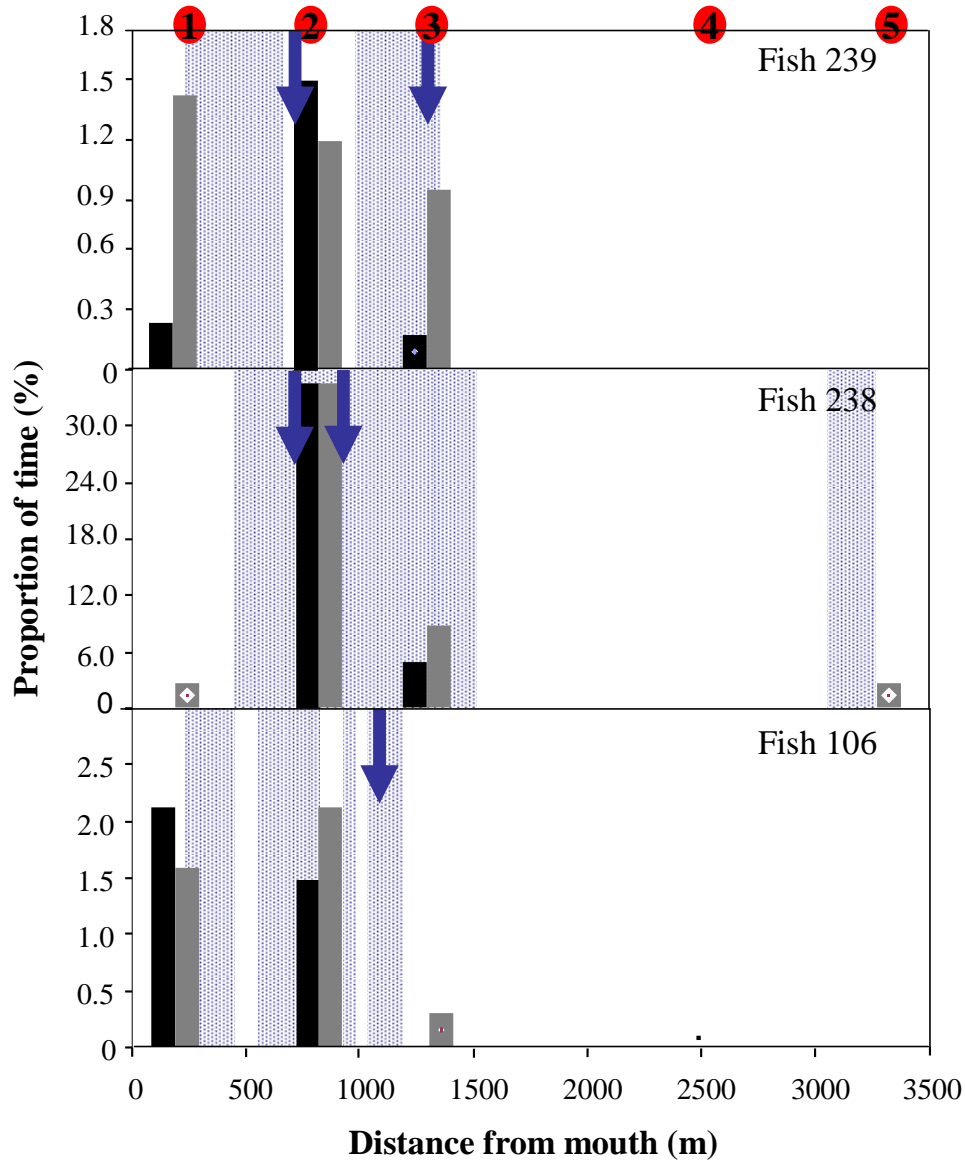


Figure 6.4c. Proportion of time (percentage frequency) tagged spotted grunter spent in the vicinity of each VR2 (numbered red dots) during (i) the entire 294 day study period (grey shaded bar) and (ii) the specified 720 hour period when manual tracking was conducted (black shaded bar). The stipple blue shaded areas indicate the extent of the 95% UD and the arrows indicate the location of the 50% UD.

Table 6.1. Results of the Kolmogorov-Smirnov significance test showing the mean and standard deviation of manual tracking (MT) and VR2 data at a significance level of $p < 0.05$. All cases were not significantly different at $p > 0.1$.

Fish ID code	Mean MT	Mean VR2	Standard deviation MT	Standard deviation VR2
100	0.6	1.2	0.9	1.0
101	0.6	1.0	0.7	1.0
102	0.7	0.7	0.9	0.8
103	0.9	2.4	0.1	3.2
104	5.0	3.7	6.3	4.6
105	0.5	0.6	0.9	1.0
106	0.7	0.8	0.9	0.9
238	7.7	8.8	15.3	14.9
239	0.4	0.7	0.6	0.7

6.3.2 Exploratory excursions

Excursions undertaken by each individual fish are summarised in Table 6.2. Fish 104 was excluded because it displayed exploratory behaviour throughout the study period (i.e. its home range extended across the length of the estuary). All fish made excursions ($n = 46-110$) with durations ranging from 60 minutes to 51 hours 04 minutes. All fish ventured to the mouth region (VR2-1). Most excursions (50%) were short ($< 500\text{m}$), while 41% of excursions were between 501 and 1 500m. Excursions of between 1 501 and 2 500m were taken 9% of the time, with only 1% of all excursions being over 2 500m (Figure 6.5). The pattern of excursions was similar for all fish. Only fish 105 and 239 did not make excursions to the head of the estuary (VR2-5). On average, excursions to the mouth region were more frequent (61%) than excursions up the estuary (25% to VR2-3; 5% to VR2-4 and 9% to VR2-5).

Table 6.2. Total number of excursions undertaken over the entire study period (1 March to 24 December 2004), total number of excursions taken to each VR2 (excluding VR2-2) and the longest excursion undertaken by each tagged spotter grunter ($n = 8$) and the month in which it took place in the East Kleinemonde Estuary.

Fish ID code	Total excursions	Excursions to VR2-1 only	Excursions to VR2-3 only	Excursions to VR2-4 only	Excursions to VR2-5 only	Longest excursion time (month)
100	104	44	49	0	11	51h 04min (August)
101	109	68	41	0	0	15h 39min (August)
102	55	46	-	4	5	3h 56min (October)
103	46	21	-	7	18	6h 43min (April)
104	-	-	-	-	-	-
105	68	39	29	0	0	4h 34min (August)
106	110	69	34	5	2	16h 18min (November)
238	65	33	-	15	17	19h 36min (August)
239	48	48	-	0	0	7h 06min (June)

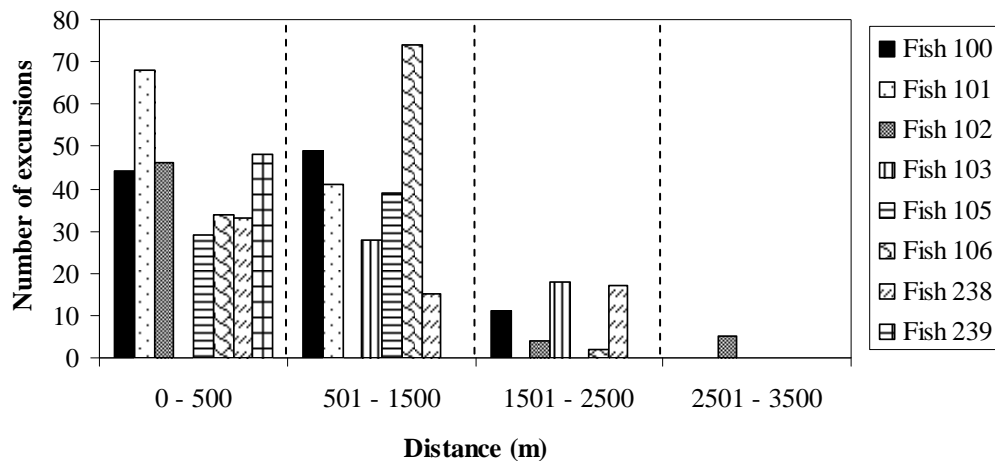


Figure 6.5. Number of excursions undertaken by the tagged spotter grunter ($n = 8$) in the East Kleinemonde Estuary at distances of 0 - 500m; 501 - 1 500m; 1 501 - 2 500m and 2 501 - 3 500m away from their home range area.

The overall diurnal pattern of exploratory excursions throughout the year was investigated by calculating the number of excursions taken during each month during the study period. No significant differences were found among months (Repeated Measures ANOVA: $F_{9, 63} = 1.33$; $p = 0.24$) (Figure 6.6).

Fish undertook excursions during daylight hours on 52% of the time, while excursions during night time hours were undertaken on 48% of the time (Figure 6.7). Five fish (fish 100, 101, 102, 103 and 105) undertook more daytime excursions, while the other three fish (fish 106, 238 and 239) undertook more night time excursions. The overall pattern of excursions was investigated by dividing day- and night time hours into three-hour intervals. No significant differences were found among the three-hour intervals (Repeated Measures ANOVA: $F_{7, 49} = 1.95$; $p = 0.81$) (Figure 6.7).

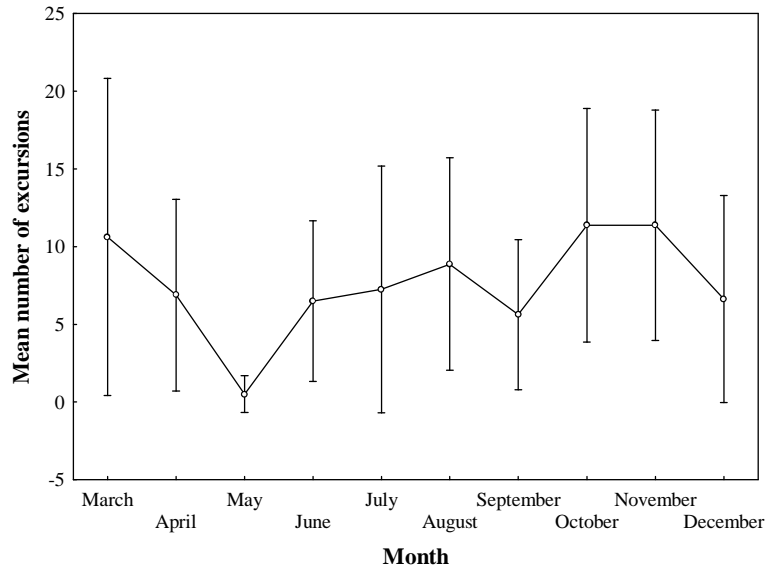


Figure 6.6. Mean number (+ SD) of exploratory excursions undertaken by tagged spotted grunter ($n = 8$) in the East Kleinemonde Estuary during each month of the study period in the East Kleinemonde Estuary.

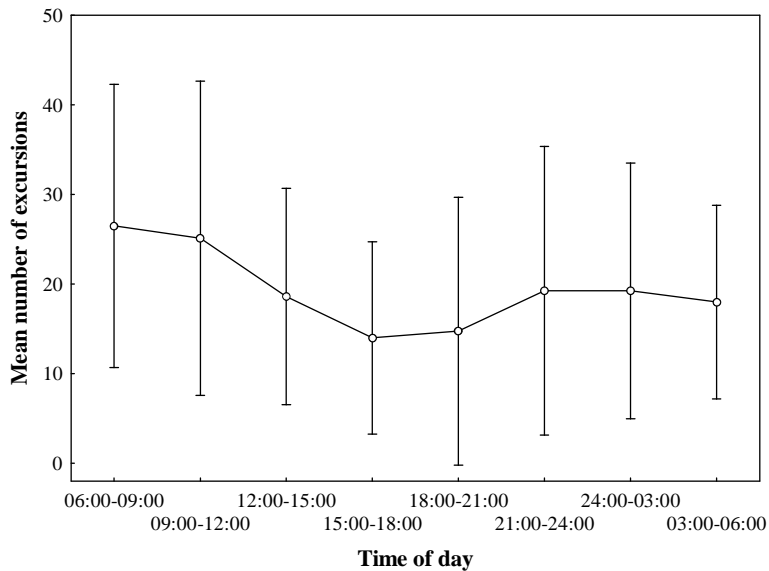


Figure 6.7. Mean (+ SD) number of exploratory excursions undertaken by tagged spotted grunter ($n = 8$) in the East Kleinemonde Estuary during 3-hourly intervals in the East Kleinemonde Estuary.

6.3.3 Fish movements after mouth breaching event

Following heavy rainfall, the estuary mouth opened (breached) on 23 December 2004 at approximately 11:30, and by 04:00 the following morning the surface area of the estuary was reduced from 307 585m² to approximately 205 000m². For this reason VR2-2 was taken out and repositioned (Figure 6.1) and VR2-3; VR2-4 and VR2-5 were removed on 24 December 2004. Even though the location of the VR2 was changed, it was apparent the fish remained in the region of the estuary that corresponded with the home range area.

The ultimate fate of the nine tagged fish following the mouth opening event on 23 December 2004 is described below. Fish 104 was last recorded in the mouth region on 29 November 2004 at 08:23, at which point the battery of the transmitter seemed to die and become inactive. Fish 105 was last recorded in the same area on the 23 December 2004 at 19:26, after which it is not recorded on the VR2 array again (i.e. went to sea). Fish 101 was last detected on the 23 December 2004, located on VR2-1 at 20:11, after which it left the estuary. Fish 239 was last recorded on 26 December 2004 at 16:01. Fish 238 was last located in the vicinity of VR2-1 on 27 December 2004 at 03:23. Fish 102 and 100 were last recorded in the mouth area of the estuary on 28 December 2004 at 05:03 and 14:47 respectively. Fish 103 was the longest remaining fish before leaving the estuary after being recorded last on 10 January 2005 at 01:28. It is assumed fish 106 remained in the estuarine environment for the entire study period as it was last recorded on the 19 January 2005 in the region of VR2-2 at 12:20. On this day the remaining VR2s were removed.

In summary it can be noted that seven fish left the East Kleinemonde Estuary after the mouth opening event, while one fish remained in the estuary. The fate of one individual (fish 104) is unknown, due to the inactive transmitter towards the end of the study. Fish 238 was subsequently recorded on a VR2 in the neighbouring Great Fish Estuary (approximately 15km away) in February and March 2005 (PD Cowley, SAIAB, Personal communication, 2006).

6.4 DISCUSSION

Long-term observations and information on the movement of the tagged spotted grunter along the length of the East Kleinemonde Estuary were successfully achieved by the array of five VR2s positioned strategically within the estuary. This study showed that the area use of individual fish remained fairly similar over an extended nine month period. These findings were mirrored by a study conducted by Childs (2005) in the Great Fish Estuary, using manual tracking data and a three month period after manual tracking (using automated data-logging listening stations), which showed that the peaks in the distribution and proportion of the total detections at each automated listening station (ALS) corresponded with the location of the core areas. It also concluded that the peaks in abundance and distribution during the manual tracking period and the three month period were similar. Childs (2005) found no significant difference between the proportions of detections recorded at each ALS for each fish during the two periods.

Daily movements of spotted grunter within the intermittently closed East Kleinemonde Estuary showed various behavioural patterns, namely (a) stationary behaviour within a specific area; (b) a single excursion of up to 2.5km in distance and (c) occasionally two excursions in a day, which ranged between 0.1 and 2.5km. The latter behavioural pattern was not common. Individual variation was relatively small over the study period, however, variation between individuals was seen. This variation is most likely due to individual biological differences, such as the fish size or possibly to phenotypic (learnt behaviour) or genotypic (genetic) behavioural variability (Egli and Babcock 2004). The variation may also reflect feeding and non-feeding periods of activity, with fish resting during certain periods of the day and becoming more active while searching for prey and feeding. Despite behavioural differences among individuals, the general movement and area use within the estuary was similar (Figure 6.4). Spotted grunter within the East Kleinemonde Estuary seemed to restrict their movement to the lower reaches (up to 1 300m from the mouth) with few excursions to the upper reaches. The total time spent by all individuals within each region of the estuary was not evenly distributed, but was highest (416 hours) at VR2-2 and lowest (5 hours) at VR2-4. This could possibly be due to the low detection range in the region of VR2-4 (see Chapter three), although based on

the location of the calculated home ranges (see Chapter four) suggests the outcome is correct. The home ranges of the tagged fish were not located near VR2-4 and therefore it is expected that there would be few detections in this area. Similar to Childs (2005) results, most core areas in the East Kleinemonde Estuary overlapped in areas which showed the highest proportion of time spent in the vicinity of the VR2s. This was especially true at VR2-2, which logged the highest proportion of detections. This confirmed the home range characteristics described in earlier chapters were maintained for extended periods (i.e. the nine month VR2 monitoring period).

It has been hypothesized that there would be an evolutionary advantage in the frequent use of a limited area (Bradbury *et al.* 1995; Kramer and Chapman 1999; Eristhee and Oxenford 2001). It allows the fish to become extremely familiar with the area and therefore improve their feeding efficiency. Childs (2005) showed that juvenile spotted grunter in the Great Fish Estuary displayed resident behaviour and a high use area in the lower reaches of this estuary, which coincided with the highest abundance of their preferred food, mud prawn (*Upogebia Africana*) and sand prawn (*Callinasa kraussi*). Snapper (*Pagrus auratus*) were found to be highly resident in a New Zealand marine reserve, with some individuals remaining faithful to their home range areas for over a year (Parsons *et al.* 2003). Lowe *et al.* (2003) found that kelp bass (*Paralabrax clathratus*) remained in their home range location for as long as three years. The white grunt (*Haemulon plumieri*) has also been shown to display resident behaviour and remain associated with a particular location for 200 days (Bardach 1958). Spotted grunter in the East Kleinemonde Estuary also displayed resident behaviour for extended periods. This was seen by the unimodal peaks seen in the proportion of time spent in the vicinity of each VR2. Fish 238 showed a high degree of residency to a particular area of the estuary, being continuously recorded on only two of the VR2s for the entire study period (294 days). Some individuals, however, showed limited roaming behaviour (e.g. fish 102 and fish 239), with more evenly distributed peaks of detections on the VR2s. Coupled with the resident behaviour of spotted grunter within this estuary, was the aspect of site preference. Eight tagged individuals preferred the high-use area (around VR2-2), high in abundance of easily accessible prey (as shown in chapter five). Although prawns were

evenly distributed along the length of the estuary, this area is characterised by sandy substrate bottom, which would make it easier for the fish to access the prawns. Lepage *et al.* (2005) conducted a study on juvenile sturgeon (*Acipenser sturio*), which showed restricted movement in the Gironde Estuary, due to the distribution and location of its prey item, polychaete worms. The remaining individual (fish 104) had its home range extended across the length of the estuary. This individual was the smallest fish (300mm FL; 326mm TL) and may have utilized the entire estuary to avoid competition with larger individuals.

Area utilization based on the ‘snapshot’ home range estimates were not significantly different (Kolmogorov-Smirnov significance test) to that observed from the continuous VR2 data from the same period. A similar trend in distribution and abundance was seen, with occasional larger peaks in the VR2 data, probably due to increased exploratory excursions to those areas of the estuary that would not have been detected during the manual tracking.

Spotted grunter in the permanently open Great Fish Estuary, have been shown to undertake excursions into the marine environment at various times (Childs 2005). Prior to leaving the estuary, the fish undertook short sea trips, lasting up to one day. Most trips in this permanently open estuary were undertaken at night (84%) and most returned between midday and midnight (77%). The most important environment cue which appeared to influence the spotted grunter trips in the Great Fish Estuary was temperature. Childs (2005) also found a significant relationship between the tidal phase and the trip being taken, with fish leaving on the outgoing tide and returning on the incoming tide. Tidal movements have been reported in other species such as European flounder (*Platichthys flesus*) (Wirjoatmodjo and Pitcher 1984) and thin-lipped mullet (*Liza ramada*) (Almeida 1996). Unlike these other studies, the exploratory excursions displayed by the tagged fish in the East Kleinemonde Estuary followed no rhythmic pattern (in relation to time of day or year), possibly due to the lack of daily tidal influence (as seen in permanently open estuaries). Adult white grunt (*Haemulon plumieri*) movements have also been shown to

be variable, with excursions being undertaken at various times of the day or night (Tulevech and Recksiek 1994).

The longest excursions undertaken by each of the tagged fish occurred in the months of April (one fish), June (one fish), August (four fish), October (one fish) and November (one fish). All of these months, except June, correspond with periods of increased rainfall (see Chapter 2). These high amounts of rain would result in the estuary water level rising, making more habitat available to the fish, therefore allowing for increased exploratory behaviour. These adult fish may also have been seeking a way out of the estuary in order to spawn (spawning season occurs between August and November).

Spotted grunter, within the Great Fish Estuary, mostly undertook short excursions with durations of 6 to 24 hours (Childs 2005). Similarly, the majority of excursions undertaken by the tagged spotted grunter in the East Kleinemonde Estuary were short (<500m, with durations of approximately 1 to 25 hours on average) in a downstream direction. Long excursions were rarely undertaken in the East Kleinemonde Estuary. It is well understood that individuals select suitable home range areas, based on the biotic and abiotic factors that demand the least amount of energy to be expended (McNab 1963). The longer the excursion that is taken, the more the energy that is expended, and therefore the individual would need to find more food to facilitate this loss in energy. It has been shown that grunts form resting schools in mangrove and reef habitats (Tulevech and Recksiek 1994) and migrate from these areas to seagrass or sand flats to feed. Short excursions were probably more common as there was little need to leave their home range area, as they were located in areas where food was easily available and the habitat did not change (i.e. the channel), nor influenced by physico-chemical (e.g. salinity) changes.

There was, however, some evidence of associative behaviour, with occasional trips of different individual fish occurring at the same time to the same location. The possible benefits of this behaviour are (a) increased defence against predators by being in a group, (b) defence by the group of valuable feeding grounds and (c) increased profitability of the foraging success of other individuals within the group (Brown and Orians 1970).

Detections on the VR2s confirmed that seven fish chose to leave the estuary after the mouth opened in December 2004. It is interesting to note that subsequent to this study, fish 238 was recorded in the Great Fish Estuary. This highlights the importance of estuarine environments throughout the life-history of this species. Estuaries provide abundant resources as well as turbid waters in which juvenile and adult fish can avoid predators. The use of multiple estuaries by this one individual fish may also be attributed to low sea water temperatures. It has been suggested by several authors that many fish move into estuaries to seek warmer water temperatures (Deacon and Hecht 1995; Childs 2005). Additionally, it has also be found that catches of ragged tooth sharks (*Carcharias taurus*), one of spotted grunters predators, are higher after upwelling events have occurred, bringing cold water close to the coastline (Childs 2005). Therefore, it is also possible that this individual moved back into an estuarine environment to seek refuge and avoid predation.

This study showed that the area use of spotted grunter within the East Kleinemonde Estuary remained similar over an extended period. The results of the VR2 data can be used to infer area use patterns of spotted grunter over an extended period, as well as confirm the home range estimates calculated from the manual tracking data. The use of continuous tracking data also provided additional insight into the behaviour (e.g. exploratory excursions) of spotted grunter within this intermittently open estuary. The use of long-term data as an additional method to manual tracking, as suggested by Lowry and Suthers (1998) and Parsons *et al.* (2003), has successfully been used in this study, showing the importance of using two telemetric methods.

CHAPTER 7

GENERAL DISCUSSION

Studying the movement behaviour, and especially the home range, of fishery species, such as spotted grunter, is vital to gain a better understanding of their area use patterns, habitat utilization and their dependency on estuaries, as essential habitats in their life history. This information is essential for designing and formulating a corrective management strategy for this overexploited species, as well as for the conservation of the estuarine environment in which they live (Hooge *et al.* 1999; Parsons *et al.* 2003; Taylor *et al.* 2007). Spotted grunter has come under increased fishing pressure in South African estuaries, mainly due to the lack of law enforcement and compliance to fishing regulations, which has resulted in its overexploitation (Cowley *et al.* 2004; Potts *et al.* 2004). Information on the movement of most estuarine-dependent fish species is lacking (Childs 2005; Taylor *et al.* 2007), and in the case of spotted grunter is confined to only a few studies. A pilot study was conducted to test the feasibility of telemetry for studying the movements of spotted grunter in the estuarine environment (Kerwath *et al.* 2005) and a detailed study conducted in Great Fish Estuary, providing information on the effect of environmental variables on the spatial movement of this species (Childs 2005; Næsje *et al.* 2007).

The spawning area of spotted grunter is thought to be in the marine inshore waters off the KwaZulu-Natal coast of South Africa (Webb 2002). It is thought the eggs and larvae are transported southwards in the Agulhas current and early juveniles recruit into estuaries at 20-50mm TL. They remain in these nursery habitats until sexual maturity is reached, at about 300-400mm TL (usually between one and three years of age), after which they move back into the marine environment (Wallace 1975; Webb 2002). It may also be possible that the eggs and larvae are not transported southwards in the Agulhas current but are rather transported south inshore of the current due to the predominantly north-easterly winds occurring during spring. There is further evidence to suggest that the eggs and larvae may be kept within close proximity of where they were spawned by near-shore circulation (Beckley and Connell 1996).

Childs (2005) studied the movement behaviour of spotted grunter in the permanently open Great Fish Estuary, and described the life cycle of this species using Harden Jones' (1968) classical 'Migration Triangle'. The steps in this triangle consist of the following: (1) the movements of the early stages (eggs and larvae) from their spawning ground to estuarine nursery habitats, then, (2) following their estuarine-dependent phase and the onset of sexual maturity, they move from their natal estuary back to the marine environment and finally, (3) the adults migrate back to the spawning ground, completing their life cycle. Childs (2005) found adolescent spotted grunter in the Great Fish Estuary were highly resident, exhibiting station-keeping behaviour and occupying a fixed small home range, generally confined to a single core area. This common high-use area was located in the lower reaches of the estuary, which was characterised by high food availability, possibly reduced predation and wide abiotic fluctuations. The second step in the triangle involved the maturing adolescent fish beginning to undertake short-term sea trips. These movements were strongly influence by the tide, as well as time of day. Long-term sea trips were characterised by the fish permanently leaving the estuary and moving into the marine environment (representing the end of the juvenile estuarine-dependent phase).

Unlike fish in the permanently open Great Fish Estuary, the second step of the triangle (emigration to sea) cannot be undertaken during the closed mouth phase in the East Kleinemonde Estuary. The mouth can stay closed for several years, limiting movement out of the estuary and recruitment into the estuary. Mouth opening events are not seasonal and are often determined by rainfall, which in turn may influence the way in which marine-spawning estuarine-dependent fish species utilize these estuarine systems (Cowley and Whitfield 2001b). However, the closed phase provides an ideal opportunity for researchers to investigate the home range dynamics of fish populations trapped in these intermittently open estuaries.

During this study, adult spotted grunter tagged and acoustically monitored in the East Kleinemonde Estuary were highly resident, with the majority of individuals utilizing a single core area. Home ranges displayed by spotted grunter in this estuary were small,

with a mean size of $76\,797 \pm 39\,255\text{m}^2$. The majority of home ranges were confined to the lower reaches of the estuary, with no core areas being located in the upper reaches. The high-use, lower reaches of the estuary were characterised by a high abundance of prey items. The main area of overlapping core areas was located in the main channel (deeper section of the estuary), at about 2m in depth. Home range sizes did not change throughout the study period (i.e. no variation over the various tracking sessions). However, home range sizes extended slightly after periods of increased water level (rainfall) and cooler temperatures, indicating that fish may alter their home ranges characteristics in response to slight fluctuations in water temperature and level (Chapter 5). No diel variation in the home range parameters of the tagged fish were noted in this estuary. In addition, fish size showed no positive correlation with the home range parameters (home range size, number of home range areas, core area size and home range length) in this study. The home range dynamics and temporal space use patterns of spotted grunter in the East Kleinemonde Estuary are summarised in Figure 7.1.

Station-keeping behaviour has been reported from other members of the grunt (Haemulidae) family. Moe (1966) revealed white grunt (*H. plumieri*) remained associated with a particular location for extended periods. Bardach (1958) showed that *Haemulon sciurus* occupied the same reef areas in Bermuda for a period of up to 200 days. Site fidelity has also been reported in other estuarine associated species. Hartill *et al.* (2003) reported that snapper (*Pagrus auratus*) were observed to have a high degree of overlap in space use patterns and displayed resident and mobile behavioural patterns. Snapper undertook seas trips leaving the estuary in the morning and returning in the afternoon (exhibiting tidal biorhythms). Sea trips undertaken by snapper were in part related to fish size, with larger individuals taking more seas trips. Similar to Childs' (2005) study, striped white bass (*Morone saxatilis*) undertook coastal migrations but some individuals exhibited resident behaviour in the Hudson River and never undertook coastal migrations (Zlokovitz *et al.* 2003).

Food availability appears to be the dominant factor affecting the home range parameters of spotted grunter within the intermittently open East Kleinemonde Estuary. Griffiths

(1997) suggested that juvenile dusky kob (*Argyrosomus japonicus*) in the Great Fish Estuary were distributed according to prey availability. Taylor *et al.* (2006) found that dusky kob (mulloway) in an Australian estuary maintained home ranges that were significantly correlated to fish size and that periods of greatest movement coincided with their preys' most active period (diel pattern of feeding).

The exploratory excursions undertaken by the tagged individuals in this estuary followed no rhythmic pattern. This is possibly due to the lack of daily tidal influence, characteristic of permanently open estuaries. The majority of excursions by the tagged individuals were short (<500m), and were undertaken to the mouth region of the estuary. It was noted, however, that the longest excursions tended to occur after periods of high rainfall. This exploration is probably due to changes in the physico-chemical parameters (e.g. salinity).

During this study the use of both manual tracking and automated data-logging listening station data, provided a clear understanding of the area use patterns and movements of spotted grunter in the closed East Kleinemonde Estuary over an extended period, highlighting the value of using two different telemetric methods. The continuous automated tracking component of the study was important to identify potential masking of short-term movements (e.g. at night or exploratory excursions) and provided confirmation and validation of the home range estimates that were calculated using 'snapshot' data obtained by manual tracking.

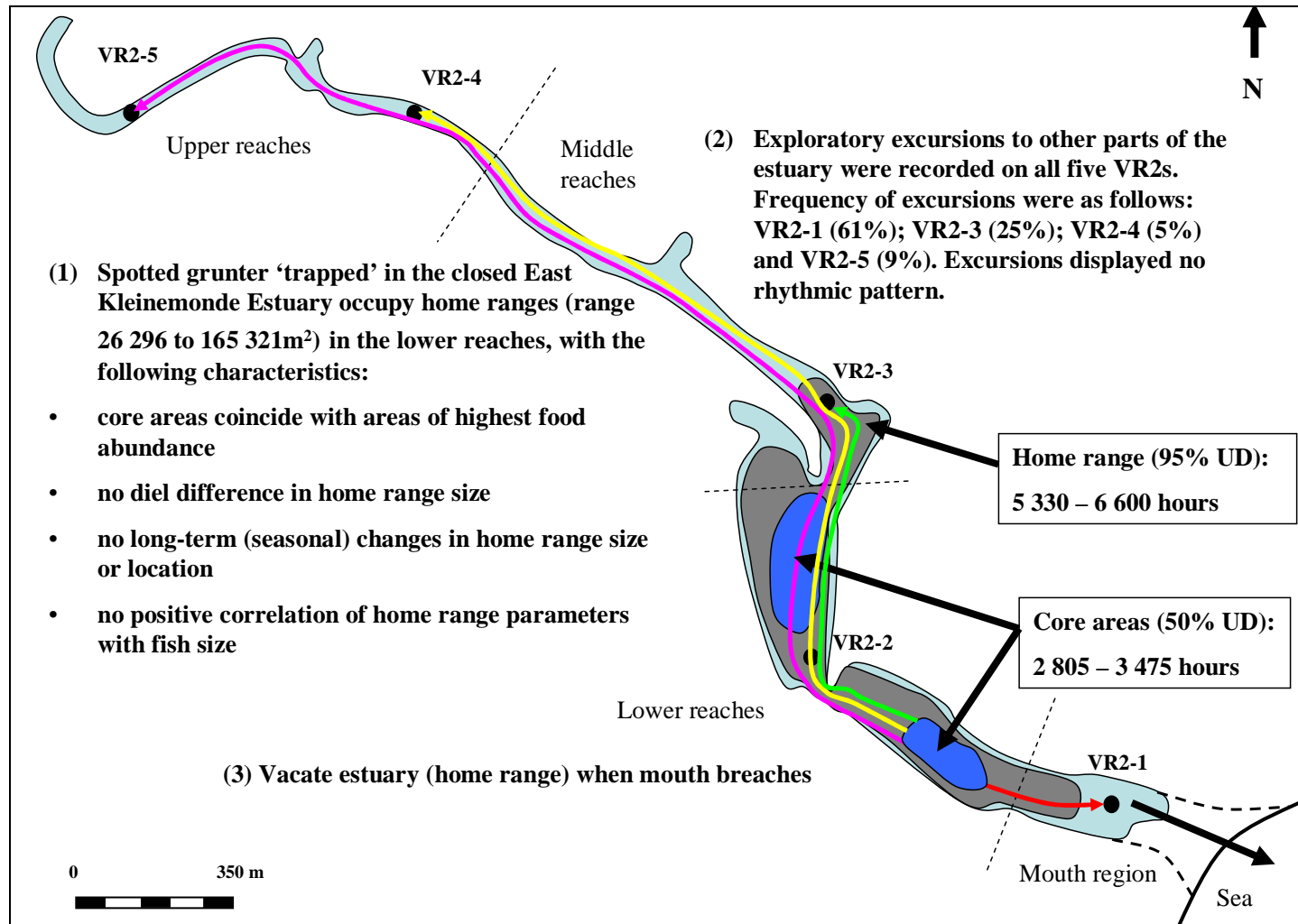


Figure 7.1. A graphical summary of the temporal area use patterns of the tagged spotted grunter in the East Kleinemonde Estuary during the closed mouth phase between March and December 2004 (Total time = 7 056 hours).

MANAGEMENT IMPLICATIONS

Spotted grunter is regarded to be maximally or overexploited (Fennessey 2000) and is likely to be under increased fishing pressure in the future due to an increase in fishing effort, as well as improved fishing gear and techniques. Lamberth and Turpie (2003) suggested that the conservation of estuarine associated fishery species must include management actions for both nursery area (estuarine) and marine stocks. The findings of a nationwide fishery survey by Brouwer *et al.* (2002) revealed that spotted grunter is not a dominant species in the catches of marine (coastal) fisheries. In contrast, this species is very important in estuarine fisheries throughout its distribution range (James *et al.* 2001; Pradervand and Baird 2002; Cowley *et al.* 2003). Therefore, the sustainability of the South African spotted grunter stock hinges on the implementation of appropriate management actions within estuarine environments. It is proposed that the management of this important fishery species requires two actions: (1) improved management of estuarine habitats and (2) improved fisheries management approaches.

The management of the estuarine habitats requires a legal framework or policy that mandates the implementation of Integrated Management Plans (IMPs). Such management plans must take into consideration: land-use planning (what activities should happen where), infrastructure development (housing plans and services such as water and electricity), finance and investment planning (resources for projects and programmes) and sector planning (to incorporate issues such as coastal management and tourism). Such plans are based on co-management approaches, with guidelines being divided into four main issues: resource management, ecosystem management, socio-economic factors and institutional structuring. Resource management includes controlling access to bait collection areas; restriction of collection of bait (such as mud prawn and sand prawn) to daylight hours and within legal limits; prohibiting capture of fish during mouth breaching events (in temporarily open/closed systems) and prohibiting capture of linefish species (e.g. grunter) with cast nets, seine nets, gill nets and traps. Ecosystem management includes minimizing impacts to sensitive areas adjacent to bait collecting areas (e.g. salt marshes); restriction of boat access to the carrying capacity of the estuary; adopting a holistic approach to management (including marine and terrestrial spheres); identifying

potential Estuarine Protected Areas (EPAs) for conservation of overexploited linefish species (which should include the mouth area and adjacent marine environment) and the protection of the riparian habitats (with reference to boat launching sites and access to vehicles). Socio-economic factors that need to be incorporated include zonation of estuarine areas for different user groups; the promotion of community involvement, mitigation of impacts from urban developments and the promoting of sustainable use of the estuarine environment and its resources (for example the use of catch and release fisheries and ecotourism). Institutional structuring (e.g. via municipalities) need to be put into place for the implementation and monitoring of such IMPs. Such monitoring includes controlling pollution, waste emissions and urban and agricultural runoff (overall health of the estuary); enforcement through compliance monitoring and the existing legislation (e.g. permits) and imposing severe penalties for non-compliance; prevention of illegal poaching of estuarine resources (particularly fish) and the implementation of research and monitoring programmes within estuarine environments.

In terms of managing the species, the life history of spotted grunter dictates that juveniles have an obligatory estuarine-dependent phase. Several studies have reported that a large portion of spotted grunter caught and retained in estuarine fisheries are undersized (less than the minimum legal size limit of 400mm TL) (Cowley *et al.* 2004; Potts *et al.* 2004). Therefore, it is vital that an improvement in law enforcement occurs. As part of this, compliance may also be improved by awareness (e.g. sign boards) and angler education programmes. The failure of conventional fisheries management approaches (e.g. minimum size and bag limit restrictions) have been highlighted by several authors (Griffiths 1997; Cowley *et al.* 2002). Although Marine Protected Area's (MPA's) form an integral part of the operational management procedure for linefish species in South Africa, the potential benefits of Estuarine Protected Area's (EPA's) has received little attention. Based on available information (Childs 2005 and this study), it appears that fishing mortality on resident spotted grunter may be abated by the establishment of no-take zones within estuaries. Such a management recommendation, however, cannot be based solely on the findings of two studies. Further research is essential for the effective design and implementation of closed areas or reserves within estuaries. Furthermore,

future studies should include larger sample sizes and should be conducted over longer periods in order to investigate inter-annual trends. Research on a variety of estuaries is also important to ensure a better understanding of the home range dynamics, movement patterns and migrations of spotted grunter. Lastly it is important that research on the spatial management needs of spotted grunter is not conducted in isolation. Instead, such research should adopt a multi-species approach and also address the needs of other important estuarine-dependent fishery species, such as dusky kob (*Argyrosomus japonicus*), white steenbras (*Lithognathus lithognathus*) and leervis (*Lichia amia*).

Appendix 1. Prawn transect lines showing the total and average number of prawns on the East and West bank of the East Kleinemonde Estuary, in varying depths of water and substrate type in September 2004 (after Terörde 2004).

Transect	Side of estuary (East/West)	Depth (cm)	Substrate type	Total number of prawn holes	Abundance of prawn holes
1	E	20	Sand + sticks	8	10.5
	E	70	Sand	52	68.3
	E	120	Sand	173	227.1
	E	170	Sand	171	224.4
	E	220	Sand	119	156.2
	W	220	Sand	113	148.3
	W	170	Sand	114	149.6
	W	120	Sand	115	150.9
	W	70	Sand	85	111.6
	W	20	Sand	12	15.8
2	E	20	Rocks	0	0.0
	E	70	Rocks	0	0.0
	E	120	Sand	136	178.5
	E	170	Sand	206	270.4
	E	220	Sand	190	249.4
	E	270	Sand	61	80.1
	W	270	Sand	57	74.8
	W	220	Sand	8	10.5
	W	170	Weed + rock	0	0.0
	W	120	Weed + rock	3	3.9
3	W	70	Rocks	0	0.0
	W	20	Rock + thin sand	0	0.0
	E	20	Grass + mud	0	0.0
	E	70	Sand	1	1.3
	E	120	Sand	168	220.5
	E	170	Sand	55	72.2
	E	220	Weed + sand	8	10.5
	W	220	Mud + weed	0	0.0
	W	170	Mud + weed	0	0.0
	W	120	Rock + weed	0	0.0
4	W	70	Weed + sand	5	6.6
	W	20	Weed + rock	0	0.0
	E	20	Reed + algae	0	0.0
	E	70	Sand	207	271.7
	E	120	Sand	280	367.5
	E	170	Sand	285	374.1
	E	220	Weed + sand	23	30.2
	E	270	Weed + sand	27	35.4
	W	270	Weed + sand	27	35.4
	W	220	Weed + rock	0	0.0
5	W	170	Weed + rock	1	1.3
	W	70	Weed + rock	0	0.0
	W	20	Weed + rock	0	0.0
	E	20	Reeds	0	0.0
	E	70	Sand	79	103.7
	E	120	Sand	33	43.3

	E	170	Sand	39	51.2
	W	170	Sand	30	39.4
	W	120	Sand	85	111.6
	W	70	Sand	51	66.9
6	W	20	Sand + weed	0	0.0
	E	20	Algae	0	0.0
	E	70	Reeds + algae	1	1.3
	E	120	Sand + algae	7	9.2
	E	170	Sand	7	9.2
	E	220	Sand + algae	7	9.2
	E	270	Sand	2	2.6
	W	270	Sand	15	19.7
	W	220	Sand	68	89.3
	W	170	Sand	17	22.3
	W	120	Sand	76	99.8
	W	70	Sand	32	42.0
	W	20	Grass + weed	0	0.0
7	E	20	Weed + algae	0	0.0
	E	70	Sand	16	21.0
	E	120	Sand	32	42.0
	E	170	Sand	89	116.8
	W	170	Sand	70	91.9
	W	120	Sand	163	213.9
	W	70	Sand	72	94.5
	W	20	Reed	0	0.0
8	E	20	Grass + weed	0	0.0
	E	70	Grass + weed	0	0.0
	E	120	Sand	2	2.6
	W	120	Sand	3	3.9
	W	70	Mud + grass	0	0.0
	W	20	Algae	0	0.0
9	E	20	Sand	0	0.0
	E	70	Algae	15	19.7
	E	120	Sand	228	299.3
	W	120	Sand	103	135.2
	W	70	Sand	21	27.6
	W	20	Grass + weed	0	0.0
10	E	20	Weed	0	0.0
	E	70	Sand	23	30.2
	E	120	Sand	180	236.3
	W	120	Sand	71	93.2
	W	70	Sand	25	32.8
	W	20	Algae + grass	0	0.0
11	E	20	Algae + weed	0	0.0
	E	70	Sand	16	21.0
	E	120	Sand	14	18.4
	E	170	Sand	19	24.9
	W	170	Sand	31	40.7
	W	120	Sand	34	44.6
	W	70	Sand	76	99.8
	W	20	Weeds	0	0.0
12	E	20	Rocks	0	0.0
	E	70	Rocks	0	0.0
	E	120	Rocks, Sticks + Sand	1	1.3
	E	170	Sand	3	3.9

	E	220	Sand	10	13.1
	W	220	Sand	24	31.5
	W	170	Sand	13	17.1
	W	120	Sand	13	17.1
	W	70	Sand	10	13.1
13	W	20	Algae + Weed	0	0.0
	E	20	Algae	0	0.0
	E	70	Sand	8	10.5
	E	120	Sand	82	107.6
	W	120	Sand	8	10.5
	W	70	Sand	6	7.9
14	W	20	Reeds + algae	0	0.0
	E	20	Reeds	0	0.0
	E	70	Reeds	0	0.0
	E	120	Sand	34	44.6
	E	170	Sand	20	26.3
	W	170	Sand + rocks	11	14.4
	W	120	Sand	10	13.1
	W	70	Sand	0	0.0
15	W	20	Sand	0	0.0
	E	20	Grass + algae	0	0.0
	E	70	Grass + algae	0	0.0
	E	120	Reeds	4	5.3
	E	170	Reeds	158	207.4
	W	170	Reeds	151	198.2
	W	120	Reeds	52	68.3
	W	70	Reeds	5	6.6
16	W	20	Reeds	0	0.0
	E	20	Reeds	0	0.0
	E	70	Reeds	0	0.0
	E	120	Reeds	0	0.0
	E	170	Rock + sand	0	0.0
	W	170	Sand	1	1.3
	W	120	Sand	3	3.9
	W	70	Sand	4	5.3
17	W	20	Grass + algae	0	0.0
	E	20	Rock	0	0.0
	E	70	Rock	0	0.0
	E	120	Rock	0	0.0
	E	170	Rock	0	0.0
	W	170	Rock	0	0.0
	W	120	Rock	0	0.0
	W	70	Rock bed	0	0.0
18	W	20	Rock bed	0	0.0
	E	20	Grass	0	0.0
	E	70	Grass + reeds	0	0.0
	E	120	Sand + sticks	0	0.0
	E	170	Sand + sticks	0	0.0
	W	170	Sand + sticks	0	0.0
	W	120	Sand + sticks	0	0.0
	W	70	Sand + sticks	0	0.0
	W	20	Sand + sticks	0	0.0

REFERENCES

Almeida PR (1996) Estuarine movement patterns of adult thin-lipped grey mullet, *Liza ramada* (Risso) (Pisces, Mugilidae), observed by ultrasonic tracking. *Journal of Experimental Marine Biology and Ecology* **202**: 137-150.

Arendt MD, Lucy JA, Evans DA (2001) Diel and seasonal activity patterns of adult tautog, *Tautoga onitis*, in lower Chesapeake Bay, inferred from ultrasonic telemetry. *Environmental Biology of Fishes* **62**: 379-391.

Bardach JE (1958) On the movements of certain Bermuda reef fishes. *Ecology* **39**(1): 139-146.

Beckley LE, Connell AD (1996) Early life history of *Pomatomus satrix* off the East coast of South Africa. *Marine and Freshwater Research* **47**: 319-322.

Beitinger TI, Fitzpatrick LC (1979) Physiological and ecological correlates of preferred temperature in fish. *American Zoologist* **19**(1): 319-329.

Blaber SJM (1981) The zoological affinities of estuarine fishes in South-East Africa. *South African Journal of Science* **77**: 305-307.

Blaber SJM, Whitfield AK (1976) Large scale mortality of fish at St Lucia. *South African Journal of Science* **72**: 218.

Bradbury C, Green JM, Bruce-Lockhart M (1995) Home ranges of female cunner, *Tautoglabrus adspereus* (Labridae), as determined by ultrasonic telemetry. *Canadian Journal of Zoology* **73**: 1268-1279.

Branch GM, Griffiths CL, Branch ML, Beckley LE (1994) *Two Oceans: a guide to the marine life of Southern Africa*. David Philip Publishers, Cape Town. 360pp.

Brouwer SL, Buxton CD (2002) Catch and effort of the shore and skiboat linefisheries along the South African Eastern Cape coast. *African Journal of Marine Science* **24**: 341-354.

Brown JL, Orians GH (1970) Spacing patterns in mobile animals. *Annual Review of Ecology and Systematics* **1**: 239-262.

Burt WH (1943) Territoriality and home range concepts as applied to mammals. *Journal of Mammology* **24**: 346-352.

Carr JW, Lacroix GL, Anderson JM, Dilworth T (1997) Movements of non-maturing cultured Atlantic salmon (*salmo salar*) in a Canadian river. *Journal of Marine Science* **54**: 1082-1085.

Childs AR (2005) Movement patterns of spotted grunter, *Pomadasys commersonni* (Haemulidae), in the Great Fish Estuary, South Africa. Msc Thesis, Rhodes University, South Africa. 151pp.

Cowley PD, Brouwer SL, Tilney RL (2002) The role of the Tsitsikamma National Park in the management of four shore-angling fish along the south-eastern Cape coast of South Africa. *South African Journal of Marine Science* **24**: 27-35.

Cowley PD, Kerwath S, Næsje TF, Childs A-R, Gillespie LD, Leggitt C, Thorstad EB, Økland F (2006) Space use patterns and movements of juvenile dusky kob *Argyrosomus japonicus* in the Great Fish Estuary (South Africa): implications for management. Nina Report 119. 32pp.

Cowley PD, Muller CM, James NC, Strydom NA, Whitfield AK (2007) Water Research Commission: Cape intermittently open estuary research programme. Appendix J: Fish. Unpublished Report. 164pp.

Cowley PD, Whitfield AK (2001a) Fish population size estimates from a small intermittently open estuary in South Africa, based on mark-recapture techniques. *Marine and Freshwater Research* **52**: 283-290.

Cowley PD, Whitfield AK (2001b) Ichthyofaunal characteristics of a typical temporarily open/closed estuary on the south-east coast of South Africa. *Ichthyological Bulletin* **71**: 1-17.

Cowley PD, Whitfield AK, Bell KNI (2001) The surf zone ichthyoplankton adjacent to the intermittently open estuary, with evidence of recruitment during marine overwash events. *Estuarine, Coastal and Shelf Science* **52**: 339-348.

Cowley PD, Wood AD, Corroyer B, Nsubuga Y, Chalmers R (2003) A survey of fishery resource utilization on four Eastern Cape estuaries (Great Fish, West Kleinemonde, East Kleinemonde and Kowie). *Protocols Contributing to the Management of Estuaries in South Africa, with a Particular Emphasis on the Eastern Cape Province. Volume III. Project C, Supplementary Report C5*. pp 129-165.

Crook DA (2004) Is the home range concept compatible with the movements of two species of lowland river fish? *Journal of Animal Ecology* **73**: 353-366.

Day Jr. JW, Hall CAS, Kemp WM, Yáñez-Arancibia A (1989) Estuarine ecology. A Wiley-Interscience publication. United States. 558pp.

Day JH, Blaber SJM, Wallace JH (1981) Estuarine Fishes. In *Estuarine Ecology with particular Reference to Southern Africa*. A.A Balkema, Cape Town. pp 197-221.

Deacon N, Hecht T (1995) Observations on the thermoregulatory behaviour of juvenile spotted grunter, *Pomadasys commersonnii* (Haemulidae: Pisces). *Journal of Applied Ichthyology* **11**: 100-110.

Deacon N, White H, Hecht T (1997) Isolation of the effective concentration of 2-phenoxyethanol for anaesthesia in the spotted grunter, *Pomadasys commersonnii*, and its effect on growth. *Aquarium Sciences and Conservation* **1**: 19-27.

De Solla SR, Bonduriansky R, Brooks RJ (1999) Eliminating autocorrelation reduces biological relevance of home range estimates. *Journal of Animal Ecology* **68**: 221-234.

Du Preez HH, McLachlan a, Marais JFK (1986) Oxygen consumption of shallow water teleost, spotted grunter, *Pomadasys commersonnii* (Lacepde, 1802). *Comparative Biochemistry and Physiology* **84**: 67-70.

Egli DP, Babcock RC (2004) Ultrasonic tracking reveals multiple behavioural modes of snapper (*Pagrus auratus*) in a temperate no-take marine reserve. *ICES Journal of Marine Science* **61**(7): 1137-1143.

Eristhee N, Oxenford HA (2001) Home range size and use of space by Bermuda chub *Kyphosus sectatrix* (L.) in two marine reserves in the Soufrière Marine Management Area, St Lucia, West Indies. *Journal of Fish Biology* **59**: 129-151.

Fennessey ST (2000) *Stock assessment and management of spotted grunter in KwaZulu-Natal (Final report)*. Oceanographic Research Institute, Durban. 9pp.

Fish PA, Savitz J (1983) Variations in home ranges of largemouth bass, yellow perch, bluegills and pumpkinseeds in Illinois Lake. *Transactions of the American Fisheries Society* **112**: 147-153.

Forbes AT (1973) A study of the burrowing sandprawn *Callianassa kraussi* Stebbing (Crustacea: Decapoda: Thalassinidea). PhD Thesis. Rhodes University, Grahamstown. 164pp.

Froneman PW (2007) Water Research Commission: Cape intermittently open estuary research programme. Appendix I: Zooplankton and hyperbenthos. Unpublished Report. 164pp.

Gama P (2007) Water Research Commission: Cape intermittently open estuary research programme. Appendix F: Plants: Microalgae. Unpublished Report. 164pp.

Gitzen RA, Millspaugh JJ (2003) Comparison of least-squares cross-validation bandwidth options from kernel home-range estimation. *Wildlife Society Bulletin* **31**(3): 823-831.

Griffiths MH (1997) Influence of prey availability on the distribution of dusky kob *Argyrosomus japonicus* (Sciaenidae) 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.

Hanekom NM (1980) A study of two thalassinid prawns in the non-*Spartina* regions of the Swartkops estuary. PhD. Thesis. University of Port Elizabeth, Port Elizabeth, South Africa.

Hansen EA, Closs GP (2005) Diel activity and home range size in relation to food supply in a drift-feeding stream fish. *Behavioural Ecology* **16**: 640-648.

Harden Jones (1968) *Fish migrations*. Edward Arnold Ltd, London. 325pp.

Hartill BW, Morrison MA, Smith MD, Boubée J, Parsons DM (2003) Diurnal and tidal movements of snapper (*Pagrus auratus*, Sparidae) in an estuarine environment. *Marine and Freshwater Research* **54**: 931-940.

Hatin D, Fortin R, Caron F (2002) Movements and aggregation areas of adult Atlantic sturgeon (*Acipenser oxyrinchus*) in the St. Lawrence River Estuary, Quebec, Canada. *Journal of Applied Ichthyology* **18**(4-6): 586-594.

Hecht T, Van der Lingen CD (1992) Turbidity- induced changes in feeding of fish in estuaries. *South African Journal of Zoology* **27**: 95-107.

Heemstra P, Heemstra E (2004) *Coastal fishes of southern Africa*. South African Institute of Aquatic Biodiversity (SAIAB) and National Inquiry Service Centre (NISC), Grahamstown. 488pp.

Heupel MR, Heuter RE (2002) Importance of prey density in relation to the movement patterns of juvenile blacktip sharks (*Carcharhinus limbatus*) within a coastal nursery area. *Marine and Freshwater Research* **53**: 543-550.

Heupel M, Simpfendorfer C, Collins A, Tyminski J (2006) Residency and movement patterns of bonnethead sharks, *Sphyrna tiburo*, in a large Florida estuary. *Environmental Biology of Fish* **76**: 47-67.

Heupel MR, Simpfendorfer CA, Heuter RE (2004) Estimation of shark home ranges using passive monitoring techniques. *Environmental Biology of Fishes* **71**: 135-142.

Hightower JE, Jackson JR, Pollock KH (2000) Use of telemetry methods to estimate natural and fishing mortality of striped bass, in Lake Gaston, North Carolina. *Transactions of the American Fisheries Society* **130**(4): 557-567.

Hooge PN, Eichenlaub B (1997) Animal movement extension to ArcView. Version 2.0. Alaska Biological Science Centre, United States Geological Survey, Anchorage, Alaska.

Hooge PN, Eichenlaub WM, Solomon EK (1999) Using GIS to analyze animal movements in the marine environment. United States Geological Survey and National Park Service, Gustavus, Alaska. 20pp.

Humston R, Auld JS, Larkin MJ, Luo J (2005) Movements and site fidelity of the bonefish *Albula vulpes* in the northern Florida Keys determined by acoustic telemetry. *Marine Ecology Progress Series* **291**: 237-248.

Jadot C, Ovidio M, Voss J (2002) Diel activity of *Sarpa salpa* (Sparidae) by ultrasonic telemetry in a *Posidonia oceanica* meadow of Corsica (Mediterranean Sea). *Aquatic Living Resources* **15**: 343-350.

James NC (2006) Trends in fish community structure and recruitment in a temporarily open/closed South African estuary. PhD Thesis. Rhodes University, Grahamstown. 170pp.

James NC, Beckley LE, Mann BQ, Kyle R (2001) The recreational fishery in the Kosi estuarine lake system, South Africa. *African Zoology* **36**(2): 217-228.

James NC, Cowley PD, Whitfield AK, Lamberth SJ (2007) Fish communities in temporarily open/closed estuaries from the warm- and cool-temperate regions of South Africa: A review. *Reviews in Fish Biology and Fisheries* **17**(4): 565-580.

Jellyman DJ, Sykes JRE (2003) Diel and seasonal movements of radio-tagged freshwater eels, *Anguilla* spp., in two New Zealand streams. *Environmental Biology of Fishes* **66**: 143-154.

Jepsen N, Koed A, Thorstad EB, Baras E (2002) Surgical implantation of telemetry transmitters in fish: how much have we learnt? *Hydrobiologia* **483**: 239-248.

Jones KMM (2005) Home range areas and activity centres in six species of Caribbean wrasses (Labridae). *Journal of Fish Biology* **66**: 150-166.

Jorgensen SJ, Kaplan DA, Klimley AP, Morgan SG, O'Farrell MR, Botsford LW (2006) Limited movement in blue rockfish *Sebastes mystinus*: internal structure of home range. *Marine Ecology Progress Series* **327**: 157-170.

Kendell MS, Christensen JD, Hillis-Starr Z (2003) Multi-scale data used to analyze the spatial distribution of French grunts, *Haemulon flavolineatum*, relative to hard and soft bottom in a benthic landscape. *Environmental Biology of Fishes* **66**: 19-26.

Kennish MJ (1986) Ecology of estuaries. CRC Press, Inc. United States. 254pp.

Kerwath SE (2005) Empirical studies of fish movement behaviour and the implication in spatially explicit models for marine conservation. PhD Thesis. Rhodes University, Grahamstown. 227pp.

Kerwath SE, Götz A, Attwood CG, Sauer WHH, Wilke CG (2007) Area utilization and activity patterns of roman *Chrysoblephus laticeps* (Sparidae) in a small marine protected area. *African Journal of Marine Science* **29**(2): 259-270.

Kerwath SE, Götz A, Cowley PD, Sauer WHH, Attwood C (2005) A telemetry experiment on spotted grunter, *Pomadasys commersonnii*. *African Journal of Marine Science* **27**(2): 389-394.

Kramer DL, Chapman LJ (1999) Implications of fish home range size and relocation for marine reserve function. *Environmental Biology of Fishes* **55**: 65-79.

Kramer DL, Rangeley RW, Chapman LJ (1997) *Habitat selection: patterns of spatial distribution from behavioural decisions*. Behavioural Ecology of Teleost Fishes. Ch 3: pp 37-80. Oxford University Press, Oxford.

Lamberth SJ, Turpie JK (2003) The role of estuaries in South African fisheries: economic importance and management implications. *African Journal of Marine Science* **25**: 131-157.

Lepage M, Taverny C, Piefort S, Dumont P, Rochart E, Brosse L (2005) Juvenile sturgeon (*Acipenser sturio*) habitat utilization in the Gironde estuary as determined by acoustic telemetry. In: Spedicato MT, Lembo G and Marmulla G (eds). *Aquatics telemetry: advances and applications. Proceedings of the Fifth Conference on Fish Telemetry held in Europe, Ustica, Italy, 9-13 June 2003. Rome, FAO/COISPA. 2005. pp 169-177.*

Litvaitis JA, Major JT, Sherburne JA (1987) Influence of season and human-induced mortality of spatial organization of bobcats (*Felis rufus*) in Maine. *Journal of Mammalogy* **68**(1): 100-106.

Lowe CG, Topping DT, Cartamil DP, Papastamatiou YP (2003) Movement patterns, home range, and habitat utilization of adult kelp bass *Paralabrax clathratus* in a temperate no-take marine reserve. *Marine Ecology Progress Series* **256**: 205-216.

Lowry MB, Suthers IM (1998) Home range, activity and distribution patterns of a temperate rocky-reef fish, *Cheilodactylus fuscus*. *Marine Biology* **132**: 569-578.

Lukey JR, Booth AJ, Froneman PW (2006) Fish population size and movement patterns in a small intermittently open South African estuary. *Estuarine, Coastal and Shelf Science* **67**: 10-20.

Macpherson E (1998) Ontogenetic shifts in habitat use and aggregation in juvenile sparid fishes. *Journal of Experimental Marine Biology and Ecology* **220**: 127-150.

Marais JFK (1988) Some factors that influence fish abundance in South African estuaries. *South African Journal Marine Science* **6**: 67-77.

Matthews KR (1990) An experimental study of the habitat preferences and movement patterns of copper, quillback and brown rockfishes (*Sebastes* spp.). *Environmental Biology of Fishes* **29**(3): 161-178.

McNab BK (1963) Bioenergetics and the determination of home range size. *The American Naturalist* **97**: 133-141.

Meyer CG, Holland KN, Wetherbee BM, Lowe CG (2000) Movement patterns, habitat utilization, home range size and site fidelity of whitesaddle goatfish, *Parupeneus porphyreus* in a marine reserve. *Environmental Biology of Fishes* **53**(3): 235-242.

Miller ML, Menzel BW (1986) Movements, homing and home range of muskellunge *Esox masquinongy* in West Okoboju Lake, Iowa. *Environmental Biology of Fish* **16**: 243-255.

Moe Jr. MA (1966) Tagging fishes in Florida offshore waters. *Technical Series Florida Board of Conservation* **5**(49): 1-40.

Næsje TF, Childs AR, Cowley PD, Potts WM, Thorstad EB, Økland F (2007) Movements of undersized spotter grunter (*Pomadasyds commersonii*) in the Great Fish Estuary, South Africa: implications for fisheries management. *Hydrobiologia* **582**: 25-34.

Ogden JC, Ehrlich PR (1977) The behaviour of heterotypic resting schools of juvenile grunts (Pomadasyidae). *Marine Biology* **42**: 273-280.

Otis DL, White GC (1999) Autocorrelation of location estimates and the analysis of radiotracking data. *The Journal of Wildlife Management* **63**(3): 1039-1044.

Parsons DM, Babcock RC, Hankin RKS, Willis TJ, Aitken JP, O'Dor RK, Jackson GD (2003) Snapper *Pagrus auratus* (Sparidae) home range dynamics: acoustic tagging studies in a marine reserve. *Marine Ecology Progress Series* **262**: 253-265.

Pincock DG, Voegeli FA (2002) Quick course in underwater telemetry systems. VEMCO Limited, Shad Bay. 31pp.

Pittman SJ, McAlpine CA (2001) Movements of marine fish and decapod crustaceans: Process, Theory and Application. *Advances in Marine Biology* **44**: 206-272.

Potts WM, Cowley PD, Corroyer BF, Næsje TF (2004) Trends in fishery resource utilization on the Great Fish Estuary. *Interim report October 2003-2004*. South African Institute for Aquatic Biodiversity. 26pp.

Potts WM, Cowley PD, Corroyer B, Næsje TF (2005) Trends in fishery resource utilization on the Great Fish Estuary. *Nina Report* 50. 34pp.

Pradervand P, Baird D (2002) Assessment of the recreational line fishery in selected Eastern Cape estuaries: trends in catches and effort. *South African Journal of Marine Science* **24**: 87-101.

Ridden T, Adams JB (2007) Water Research Commission: Cape intermittently open estuary research programme. Appendix G: Macrophytes. Unpublished Report. 164pp.

Rooney SM, Wolfe A, Hayden TJ (1998) Autocorrelated data in telemetry studies: time to independence and the problem of behavioural effects. *Mammal Review* **28**(2): 89-98.

Seaman DE, Powell RA (1996) An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology* **77**(7): 2075-2085.

Smith MM, Heemstra PC (2003) *Smiths' Sea Fishes*. Struik Publishers, Cape Town. pp 569.

Stark KE, Jackson GD, Lyle JM (2005) Tracking arrow squid movements with automated acoustic telemetry system. *Marine Ecology Progress Series* **299**: 167-177.

Stone KD, Heidt GA, Caster PT, Kennedy ML (1997) Using Geographic Information Systems to determine home range of the southern flying squirrel (*Glaucomys volans*). *American Midland Naturalist* **137**: 106-111.

Swihart RK, Slade NA (1997) On testing for independence of animal movements. *Journal of Agricultural, Biological and Environmental Statistics* **2**: 48-63.

Swihart RK, Slade NA, Bergstrom BJ (1988) Relating body size to the rate of home range use in mammals. *Ecology* **69**(2): 393-399.

Taljaard S, Gama P, Snow G (2007) Water Research Commission: Cape intermittently open estuary research programme. Appendix D: Water quality. Unpublished Report. 164pp.

Taylor MD, Laffan SD, Fielder DS, Suthers IM (2006) Key habitat and home range of mulloway *Argyrosomus japonicus* in a south-east Australian estuary: finding the estuarine niche to optimize stocking. *Marine Ecology Progress Series* **328**: 237-247.

Terörde AI (2005) A study of distribution and abundance patterns of the burrowing sandprawn, *Callinassa kraussi* Stebbing, using a non-invasive sampling technique. Rhodes University, Honours Thesis 30pp.

Terörde AI, Turpie JK (2007) Water Research Commission: Cape intermittently open estuary research programme. Appendix K: Birds. Unpublished Report. 164pp.

Todd BL, Rabeni CF (1989) Movement and habitat use by steam-dwelling smallmouth bass. *Transactions of the American Fisheries Society* **118**: 229-242.

Travnichek VH (2004) Movement of flathead catfish in the Missouri River: examining opportunities for managing river segments for different fisheries goals. *Fisheries Management and Ecology* **11**: 89-96.

Tulevech SM, Recksiek CW (1994) Acoustic tagging of adult white grunt, *Haemulon plumieri*, in Puerto Rico and Florida. *Fisheries Research* **19**: 301-319.

Van der Elst RP, Adkin F (1991) *Marine linefish: priority species and research objectives in southern Africa*. Oceanographic Research Institute, Durban. 132pp.

Van Niekerk L, Cowley PD, Bornman T (2007) Water Research Commission: Cape intermittently open estuary research programme. Appendix C: Physical dynamics. Unpublished Report. 164pp.

VEMCO VR2 receiver manual: operating manual (2007) Version 1.21. 39pp.

Vincent ACJ, Evans KL, Marsden AD (2005) Home range behaviour of the monogamous Australian seahorse, *Hippocampus whitei*. *Environmental Biology of Fishes* **72**: 1-12.

Vorwerk PD, Whitfield AK, Cowley PD, Paterson AW (2001) A survey of selected Eastern Cape estuaries with particular reference to the ichthyofauna. *Ichthyological Bulletin* **72**: 1-52.

Vorwerk PD, Whitfield AK, Cowley PD, Paterson AW (2003) The influence of selected environmental variables on fish assemblage structure in a range of south-east African estuaries. *Environmental Biology of Fishes* **66**: 237-247.

Wallace JH (1975) The estuarine fishes of the east coast of Southern African. Part III. Reproduction. *Investigational Report of the Oceanographic Research Institute* **41**: 1-48.

Webb (2002) Biology and demography of the spotted grunter *Pomadasys commersonnii* (Haemulidae) in South African waters. MSc Thesis. Rhodes University, Grahamstown. 134pp.

Wetherbee BM, Holland KN, Meyer CG, Lowe CG (2004) Use of a marine reserve in Kaneohe Bay, Hawaii by the giant trevally, *Caranx ignobilis*. *Fisheries Research* **67**: 253-263.

Whitfield AK (1992) A characterization of southern African estuarine systems. *South African Journal of Aquatic Science* **18**: 89-103.

Whitfield AK (1994) An estuary-association classification for the fishes of southern Africa. *South African Journal of Science* **90**: 411-417.

Whitfield AK (1998) Biology and ecology of fishes in southern African estuaries. J.L.B. Smith Institute of Ichthyology, Grahamstown. 223pp.

Wirjoatmodjo S, Pitcher TJ (1984) Flounders follow the tides to feed: evidence from ultrasonic tracking in an estuary. *Estuarine, Coastal and Shelf Science* **19**: 231-241.

Wooldridge T, Bezuidenhout K (2007) Water Research Commission: Cape intermittently open estuary research programme. Appendix H: Benthic invertebrates of the East Kleinemonde Estuary. Unpublished Report. 164pp.

Worton BJ (1989) Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* **70**(1): 164-168.

Wynberg RP, Branch GM (1991) An assessment of bait-collecting for *Callinassa kraussi* Stebbing in Langebaan Lagoon, Western Cape, and of associated avian predation. *South African Journal of Marine Science* **11**: 141-152.

Zamora L, Moreno-Amich R (2004) Quantifying the activity and movement of perch in a temperate lake by integrating acoustic telemetry and a geographic information system. *Hydrobiologia* **438**: 209-218.

Zlokovitz ER, Secor DH, Piccoli PM (2003) Patterns of migration in Hudson River striped bass as determined by otolith microchemistry. *Fisheries Research* **63**: 245-259.