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Great Fish Estuary Programme:

Behaviour and management of important estuarine fishery species

A project within the South Africa / Norway Programme on Research Cooperation

The aim of the programme is to investigate the movement behaviour, migrations and habitat use of important estuarine fishery species (spotted grunter and dusky kob) and local exploitation from fisheries to contribute to the development of a sustainable utilisation strategy.

Background

The utilisation of estuarine fish resources plays a major role in the local economy and food supply in many parts of South Africa. Many fish species that spend parts of their life in estuaries, such as the spotted grunter (*Pomadasys commersonnii*) and dusky kob (*Argyrosomus japonicus*), are exploited for both food (subsistence and small scale fisheries) and recreation. Such estuarine species may also form an important component of commercial coastal fisheries. Due to the poor status of many of the estuarine associated fish stocks, the sustainability of these fisheries is in question. It is therefore urgent to develop sound management practices based on adequate knowledge of the migratory behaviour, population biology, and habitat use of the targeted species.

Project purpose

The purpose of this project is to investigate the movement behaviour of two of South Africa's most important estuarine fishery species, the spotted grunter and dusky kob, the exploitation of these species in estuaries and its implications for management. The movements and activity patterns of the spotted grunter and dusky kob are recorded by making use of acoustic telemetry methods, while the fisheries data are collected using structured visual surveys and on-sight direct contact roving creel (interview) surveys. Results from the project will contribute significantly to ensure sustainable utilization of these heavily targeted species.

Specific objectives

- Describe the movement behaviour of spotted grunter and dusky kob within the Great Fish River estuary and to describe behavioural responses to anomalous natural events and anthropogenic influences.
- Describe habitat utilization of spotted grunter and dusky kob within the estuary.
- Establish the periodicity and duration of the fishes' movements between the estuary and the sea.
- Describe spatial and temporal trends in catch and effort by the different fishery sectors.

Ultimate objectives

- Collate fishery statistics, fishing areas and angler catch data with the observed daily and seasonal movement trends of the fish species in order to assess the species susceptibility to local depletion.
- Explore the effectiveness and consequences of different management measures such as bag limits, minimum legal sizes, estuarine protected areas, and effort restriction as appropriate conservation strategies for the fish species.
- Assist in developing a sustainable exploitation strategy for the different fishery sectors (subsistence, recreational, commercial) and develop recommendatio ns to assist with the overall management of spotted grunter and dusky kob stocks.

Methods

Telemetry enabled us to track the behaviour of individual fish by means of acoustic transmitters attached to the fish. The fish could be continuously tracked for reasonable periods of time, up to a year or longer depending on the setup of the transmitters. Each tag transmitted coded signals on a fixed frequency, allowing for simultaneous tracking of several individual fish. The transmitted coded signals were retrieved by either stationary receivers positioned in the estuary, or by a hand held receiver. In this study, spotted grunter and dusky kob were tagged with surgically implanted transmitters in the Great Fish River estuary. Their movements and habitat utilization were monitored during both summer and winter. The stationary receivers monitored the fish continuously for as long as they were in the estuary, while the hand held receiver was used to monitor the individuals more intensively on shorter time scales.

Aspects of the recreational and subsistence fisheries in the estuary were studied both while manually tracking the fish from a boat and by on-site direct-contact roving creel surveys (interview surveys) conducted on foot on the shore. Observations of number of lines in the water, the number of fishers, classification of anglers (recreational or subsistence), whether they were fishing from land or boat, and their position were done while manually tracking the fish. Information on demographics, resource use sector, area use, catch, and effort were obtained through rowing creel surveys.

Funding and project partners
The following institutions collaborate on the project: the South African Institute for Aquatic Biodiversity (SAIAB), the Norwegian Institute for Nature Research (NINA), Rhodes University, and University of Zululand. It is the intent of the collaborating institutions that the project and relationships established should form the basis for long-term collaborative links between South African and Norwegian scientists and institutions.

The projects were funded by the South Africa / Norway Programme on Research Cooperation (National Research Foundation of South Africa, and the Research Council of Norway), the South African Institute for Aquatic Biodiversity (SAIAB), the Norwegian Institute for Nature Research (NINA), and East Cape Estuaries Management Programme (Marine and Coastal Management). We would like to thank these institutions for their financial support.

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Abstract

Cowley, P.D., Kerwath, S., Næsje, T.F., Childs, A.-R., Gillespie, L.D., Leggitt, C., Thorstad, E.B. and 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. 32 pp.

The space use patterns and horizontal movements of juvenile dusky kob Argyrosomus japonicus, an important fishery species, were studied in the Great Fish Estuary in South Africa (33° 29' 28" S and 27° 13' 06" E) were studied with an array of 11 moored data-logging acoustic receivers (Vemco VR2s). Twenty nine individuals (307 – 400 mm TL) were captured using hook and line methods, surgically equipped with acoustic transmitters, and then released at their catch site within the estuary. Data on 25 individuals was subsequently analysed for up to 195 days (3 March – 14 September 2004). Tagged fish made extensive use of the estuary from the mouth to between 6.4 and 10.3 km upstream. All fish were recorded throughout the lower 5 km of the estuary. Collectively, the tagged fish spent approximately equal proportions of time at each of the seven VR2s located between 0.5 and 6.5 km from the mouth. Periods of limited movements (stationary behaviour) were mostly short and restricted to between 3 and 18 hours. Fifteen fish undertook sea trips with a mean duration of 3.5 days, while four individuals made excursions into freshwater (mean duration = 7.3 days). Observations of daily movements over an arbitrarily chosen one-week period revealed three behavioural patterns (i) stationary behaviour, (ii) one longitudinal excursion either up or down the estuary, and (iii) two longitudinal rhythmic excursions up and down the estuary. The ultimate fate of the fish at the end of the 195 day study period revealed that 16 (64%) left the estuary and never returned; five (20%) were alive and still in the estuary and four (16%) were captured in the fishery during the study period. A comparison between spatial trends in the distribution of fish and angling effort revealed that juvenile dusky kob were most susceptible to capture by recreational boat anglers ($p < 0.05$), while no significant correlations were observed for recreational and subsistence shore angling effort. The dependence on nursery habitat areas and their vulnerability to capture in estuaries can result in reduced catches in coastal and offshore areas. This study emphasizes the importance of establishing estuarine protected areas as a fisheries management objective to assist with the rebuilding of depleted fish stocks such as dusky kob.

Contents

1 Introduction

The dusky kob *Argyrosomus japonicus* is a large Sciaenid, which attains a maximum size of approximately 2 m and a mass of 75 kg. It is an important estuarine, coastal and offshore fishery species targeted by subsistence, recreational and commercial fishery sectors throughout its distributional range (Brouwer *et al.* 1997, Mann et al. 2002, Cowley et al. 2004). The South African dusky kob is managed as a single stock with bag and size limit restrictions. At the time of this study, the bag limit was five fish per person per day and the minimum size limit was 40 cm total length (TL). However, due to recent fishery regulation amendments, the bag and size limit for estuarine and shore caught dusky kob in the Eastern Cape Province are now one fish per person per day and 60 cm TL, respectively.

The life history of dusky kob in South African waters is well understood (Griffiths 1996). Spawning takes place in the nearshore marine environment and early juveniles (20 – 30 mm TL; about 4 weeks old) recruit into estuaries. Early juveniles (<150 mm TL) almost exclusively inhabit the upper reaches of estuaries (Griffiths 1996, 1997a, b; Ter Morshuizen et al. 1996). However, small juveniles (150 – 400 mm TL) occur throughout the estuary and also occur in the nearshore coastal zone. Despite evidence of considerable overlap in the use of estuaries and the nearshore coastal zone by juvenile dusky kob (Griffiths 1996), little is known about the movements between different habitats.

The dusky kob is an estuarine dependent species that is wholly reliant on estuaries as nursery habitats (Whitfield 1998). Due to a high rate of juvenile mortality in estuaries, the spawner biomass per recruit (SB/R) ratio for dusky kob has been reduced to between 1.0 and 4.5% of the pristine value (Griffiths 1997b). Consequently, their dependency on estuarine habitats as juveniles has been viewed as a bottleneck in their life history (Lamberth & Turpie 2003), and alternative management measures, such as estuarine protected areas or area closure within estuaries should be evaluated. However, such an appraisal cannot be done without empirical data on space use patterns and movement behaviour of juvenile dusky kob within estuaries.

The Great Fish Estuary supports large subsistence and recreational line fisheries (Potts et al. 2005). Recreational fishers operate from boats and from shore, while subsistence fishers are restricted to the shore. A recent assessment of the Great Fish estuarine fishery revealed that dusky kob comprised 19% and 20% of the catches in terms of number and mass, respectively. Furthermore, a substantial portion (55%) of the retained catch was below the minimum legal size limit (Potts *et al.* 2005).

The aim of this study was to investigate the movements and space use patterns of juvenile dusky kob in the Great Fish Estuary to contribute to the development of a sustainable utilisation strategy. Fish were tagged with coded acoustic transmitters, and their movements were monitored using a fixed array of automated data-logging receivers. An assessment of the fishery was conducted concurrently (Potts *et al.* 2005) to compare spatial trends of fishing effort in relation to area utilisation by the tagged fish.

2 Materials and methods

2.1 Study site

The 650 km long Great Fish River enters the Indian Ocean approximately half way between Port Elizabeth and East London at 33° 29' 28" S and 27° 13' 06" E on Eastern Cape coast of South Africa (**Figure 1**). The characteristics of the Great Fish River catchment and estuary are summarised in **Table 1**.

Prior to 1975, the river had a highly variable flow regime. Periods of zero flow occurred frequently and caused the river to form a series of discrete pools, and closure of the estuary mouth (Reddering and Esterhuysen 1982, O'Keefe and De Moor 1988). In 1977, the erratic flow of the Great Fish River system was stabilised by the provision of water from the Orange River via an 85 km tunnel. Due to the interbasin transfer system, the river was modified from an irregular seasonal flow to a perennial system (Reddering and Esterhuysen 1982, O'Keefe and De Moor 1988). The tunnel was designed to supply water, primarily for irrigation, to the Fish River valley. The transfer scheme resulted in a 500-800% increase in runoff in the upper regions of the river. However, in recent years water abstraction in the lower Great Fish River has resulted in a considerable reduction in flow. The Great Fish Estuary is presently characterised by large volumes of freshwater derived from the interbasin transfer system, and receives the highest river inflow of any estuary in the Eastern Cape Province (Whitfield 1994). This accounts for continuous nutrient inputs and, hence, elevated phytoplankton production, making the Great Fish Estuary a highly productive system.

The bathymetry of the Great Fish Estuary is uniform. The estuary channel is narrow (30 - 100 m wide), and its depth (0.5 - 3.5 m) is dependent on flooding events (Whitfield et al. 1994). The shallow nature of the estuary is a result of the large fluvial sediment load from the catchment (Grange et al. 2000). These sediments are flushed out to sea during episodic floods, but are gradually replaced during periods of low river flow by sand deposits in the upper reaches and mud in the lower reaches (Reddering and Esterhuysen 1982). The mouth region is often restricted by the presence of extensive sand banks. The turbid nature of the Great Fish Estuary is also a result of the high levels of suspended sediment carried by catchment run-off, particularly during times of flood.

The water chemistry of the Great Fish River is strongly influenced by the underlying rock in the catchment. This has resulted in an increased conductivity. However, the large influx of freshwater derived from the interbasin transfer system dilutes the ions (O'Keefe and De Moor 1988). The flocculation of sediment, which occurs at

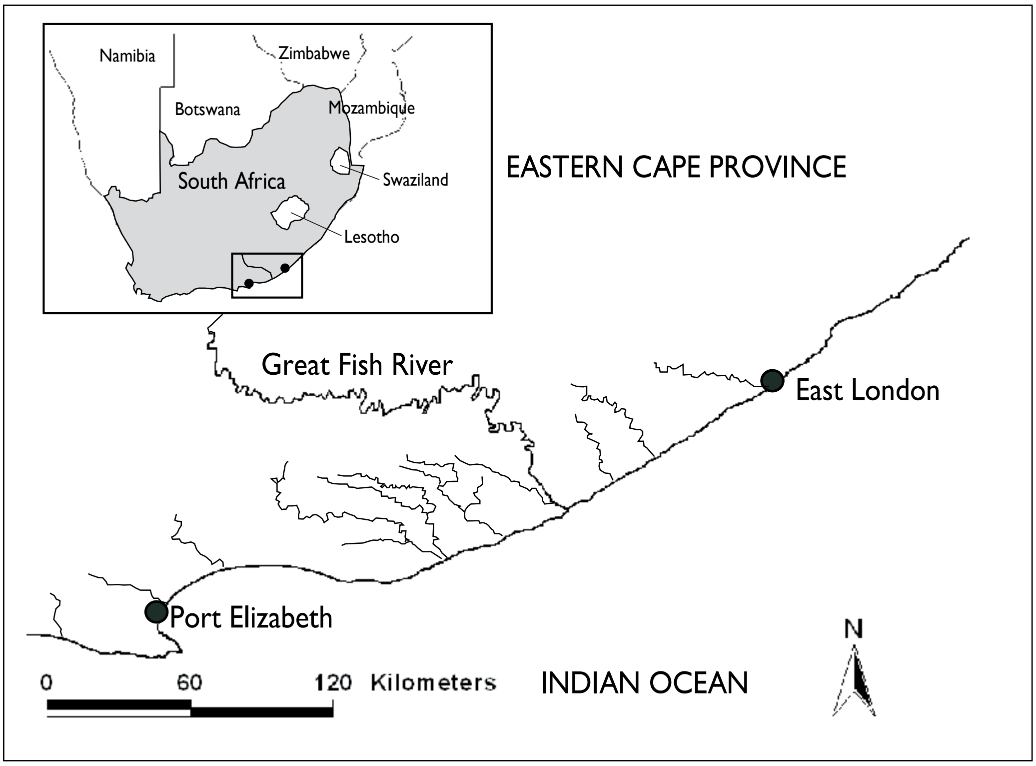


***Figure 1.** Map of South Africa with insert showing the location of the Great Fish and other estuaries along the Eastern Cape coast.*

Table 1. *Characteristics of the Great Fish River catchment and estuary. Adapted from Allanson and Read (1987), Whitfield (1994) and Vorwerk et al. (2003).*

Characteristic	**Value**
Catchment size (km^2)	30 366
Mean annual runoff (m^3)	525 x 10^6
Mean annual river discharge (m^3)	224 x 10^6
Estuarine surface area (ha)	192.7
Estuary volume (m^3)	2.25 x 10^6
Estuarine length (km)	12
Mean depth (m) of estuary	1.4
Mean wide (m) of estuary	122
Tidal cycle (h)	12.4 (SE±0.31)
River Flow per tidal cycle (m^3)	275 x 10^3
Spring tidal prism (m^3)	1.6 x 10^6

the river-estuary interface, decreases the amount of suspended particulate matter in the middle reaches of the estuary. As a result of the net downstream movement of terrestrially-derived sediments, marine sediments are restricted almost entirely to the mouth region of the estuary. Consequently, the lower reaches are mainly marine-dominated, the middle reaches represent the mixing zone between river and sea, and the upper reaches are freshwater dominated (Grange *et al.* 2000).

Perennial river flow together with tidal exchange ensures a permanently open connection to the sea (Grange *et al.* 2000). The spring tidal range is between 1 m and 1.5 m in the lower reaches and decreases towards the head (Whitfield *et al.* 1994). The tidal prism volume exceeds the river water volume by six times during an average tidal cycle. The rapid exchange of water in the estuary, demonstrated by a short flushing time of 0.8 days, is a direct consequence of the magnitude of freshwater discharge into the system (Allanson and Read 1987).

The estuary is riverine in appearance, with few intertidal mudflats or saltmarshes (Ter Morshuizen 1996) and few submerged macrophytes. Reeds and sedges occur intermittently along the banks. The eastern shoreline of the lower and middle reaches of the estuary consists mainly of coastal bushveld. The western shoreline between the estuary mouth and the road bridge forms part of the Great Fish Wetlands Reserve, and approximately 50 m above the road bridge, becomes part of the Kap River Reserve, both of which include saltmarshes. However, these supratidal saltmarshes occurring in the lower reaches are only inundated during periods of high river discharge and/or exceptionally high spring tides (Whitfield *et al.* 1994). Aquatic macrophyte vegetation is dominated by *Phragmites australis* beds in the upper and middle reaches, with a total lack of submerged estuarine plants such as *Zostera capensis* and *Ruppia cirrhosa* (Whitfield *et al.* 1994).

A detailed description of the study site, including infrastructure and access is given by Childs (2005), Næsje *et al.* (2005) and Potts *et al.* (2005).

2.2 Tagging of fish

The transmitters used in this study (V8SC-2L-R256 coded pingers, VEMCO Ltd, Halifax, Canada) were 28 mm in length, 8.5 mm in diameter and weighed 3.1 g in water. These coded transmitters (69 kHz) emitted unique acoustic pulse trains randomly every 20 - 60 seconds (Codes 70 - 89) or 10 - 30 sec (Codes 90 - 99).

Twenty nine juvenile dusky kob were tagged by means of surgical implantation, and released in the Great Fish Estuary in February and March 2004 (**Table 2**).

The fish were caught with rod and line using barbless hooks baited with pilchard (*Sardinops sagax*). Fish were captured and released throughout the estuary (range = 2.4 to 7.0 km from the estuary mouth) (**Table 2**). Surgery took place on-site onboard the small fishing boat. After capture, fish were immediately placed in a 50 litre container with estuary water containing 2-phenoxy ethanol (approximately 0.5 ml per 1 l water). Once anaesthetized, the fish was measured to the nearest millimetre and placed ventral side up in a wet towel on a v-shaped high density foam. During surgery, the gills were continuously flushed with fresh estuarine water. A 15 - 20 mm incision was made along the ventral surface posterior to the pelvic girdle. The transmitter was inserted into the body cavity. The incision was closed using two independent silk sutures (2/0 Ethicon). The total time lapsed from initial capture to release ranged from 5 min 11 sec to 16 min 48 sec (mean = 7 min 36 sec), while the duration of the surgical implantation was on average 2 min 10 sec (range 1 min 20 sec - 3 min 20 sec). Following surgery, the fish were placed in a recovery bath. Once the fish was in a stable upright position and swimming, it was released into the estuary at the catch site.

***Table 2.** Transmitter code, fish lengths, catch and release site with distance from mouth in km, tagging date, date last recorded and the number of days monitored by the VR2 array for dusky kob tagged in the Great Fish Estuary between 3 March and 14 September 2004.*

Transmitter ID code	Total length (mm)	Catch and release site (km)	Date tagged	Last date recorded	Number of study days
70	366	5.05	22/02/2004	14/09/2004	195
71	341	5.05	16/02/2004	18/04/2004	46
72	321	5.94	16/02/2004	28/02/2004	0
73	347	5.76	14/02/2004	12/09/2004	193
74	362	7.00	15/02/2004	04/07/2004	123
75	317	5.05	15/02/2004	18/03/2004	15
76	376	5.81	15/02/2004	29/02/2004	0
77	377	5.05	15/02/2004	19/03/2004	16
78	349	5.72	14/02/2004	22/04/2004	50
79	350	5.04	16/02/2004	13/09/2004	194
80	400	5.05	15/02/2004	10/03/2004	7
81	335	5.05	10/03/2004	19/04/2004	40
82	314	5.04	16/02/2004	29/03/2004	27
83	331	5.94	16/02/2004	30/03/2004	27
84	309	5.04	16/02/2004	10/05/2004	68
85	307	5.04	16/02/2004	19/04/2004	47
86	342	6.97	15/02/2004	17/04/2004	45
87	281	6.98	15/02/2004	15/02/2004	0
88	329	7.00	15/02/2004	13/03/2004	10
89	355	5.76	14/02/2004	14/09/2004	195
90	329	2.41	18/02/2004	28/02/2004	0
91	349	2.44	18/02/2004	09/05/2004	67
92	308	2.40	18/02/2004	19/04/2004	47
94	284	2.41	18/02/2004	11/03/2004	8
95	314	2.39	18/02/2004	22/04/2004	50
96	351	2.44	18/02/2004	19/04/2004	47
97	309	3.16	18/02/2004	18/04/2004	46
98	256	2.38	18/02/2004	18/03/2004	15

Dusky kob attain 50% sexual maturity at lengths of 920 mm (TL) for males and 1070 mm (TL) for females (Griffiths 1996). Therefore, all fish tagged in this study were immature. With the exception of fish 80 (400 mm TL), all the fish were smaller than the minimum legal size limit (400 mm TL) at the beginning of the study.

2.3 Fish movements

Data-logging receivers

Fish movements were monitored using an array of 11 moored automated data-logging receivers (VEMCO VR2s) (**Figure 2**). The VR2 is a submersible, single channel receiver, which identifies, logs and stores information from coded transmitters within the omni-directional reception range, and is designed to collect long-term data. The reception range can be variable and is dependent on wind and wave action, salinity, depth, and physical obstructions (e.g. the road bridge pylons), large rocks, deep holes and substrate type. Due to strong currents and heavy wave action in the mouth region of the estuary, the lowermost VR2 was placed about 200 m upstream. Attempts were made to evenly space the VR2s longitudinally up the estuary, but placement was influenced by depth, substrate type, shore angler access and boating activities. Information stored on the VR2s was downloaded in the field using a notebook computer and VEMCO VR2 software.

Range tests
Reception range tests of the VR2 receivers and the V8SC-2L-R256 transmitters were carried out in the mouth, lower, middle and upper regions of the estuary (**Figure 3**). In addition, range testing was carried out at different phases of the tide at the VR2 situated near the road bridge, approximately 1 km from the mouth (**Figures 4**). During each test, a transmitter was submerged for a fixed period at set distances (every 50 m) from the VR2. As expected, the maximum reception range was highly variable and ranged from 100 m to 610 m.

Study period
Fish were caught and tagged on various dates after 14 February 2004 (**Table 2**), while the positioning, mooring and initiation of the VR2s was finalised on 3 March 2004, which was defined as the start of the study period. The final data download was performed on 14 September 2004. Therefore, this study reports on the monitoring of acoustically tagged fish over a 195 day study period.

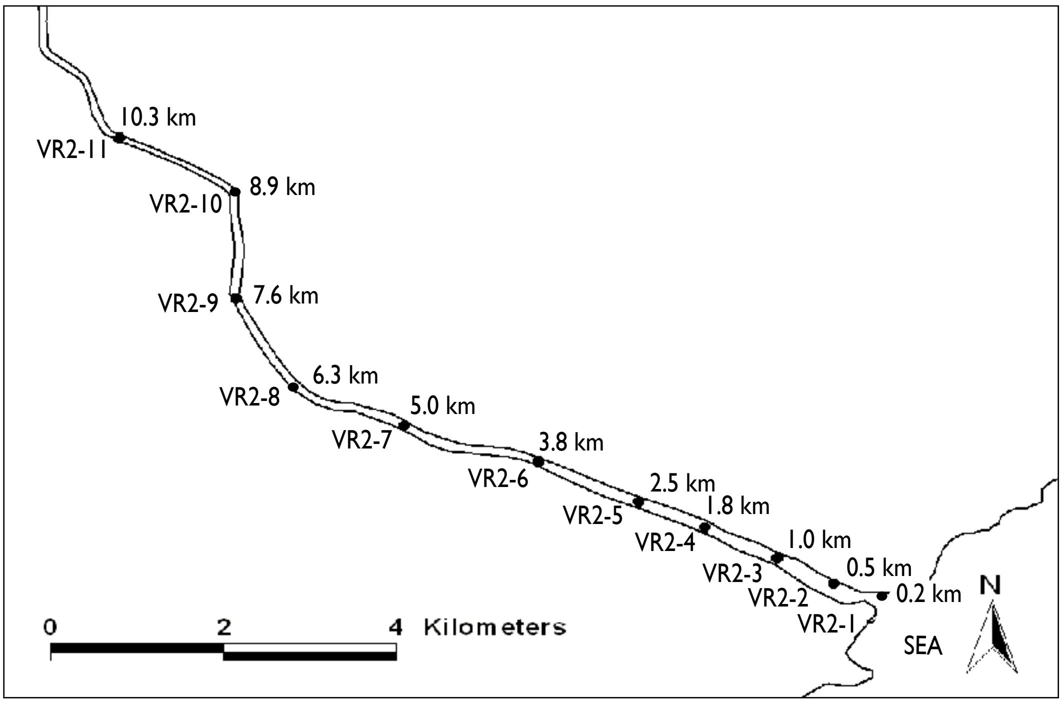
Data analysis
All data files downloaded from the VR2s were initially screened for false codes, which were subsequently deleted.

Due to the high variability in reception ranges at different locations in the estuary (**Figures 3** and **4**), fish movements could not be inferred by the proportion (percentage frequency) of code detections at each VR2 within the array. Consequently, the whereabouts of each fish was determined by calculating the time each individual spent at or near each VR2 placed in different regions of the estuary.

To gain information on the degree of residency, the maximum time each individual was continuously detected by a particular VR2 was determined. The 'residency period' was taken as the time during which consecutive code detections were recorded at a single VR2. Absence periods of less than 60 min were ignored if the individual was not recorded on any other VR2 during this period.

To determine possible site preferences and to investigate movement patterns within the estuary, the time each tagged fish spent in the vicinity of each VR2 was calculated. A fish was assumed to be in the vicinity of a particular VR2 when two (or more) consecutive

__Figure 2.__ Location and distance from the mouth of the 11 moored VR2 receivers used in the Great Fish Estuary between March and September 2004.



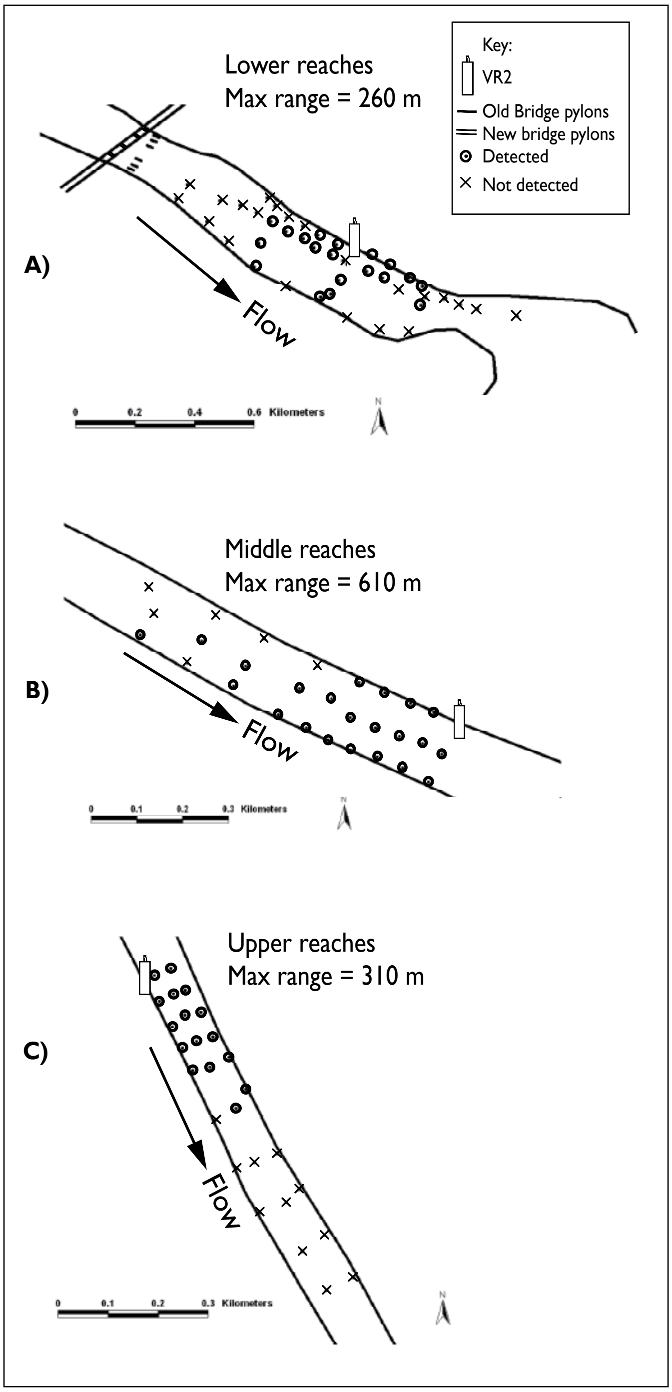


Figure 3. *Results from reception range tests conducted in the (A) lower, (B) middle and (C) upper reaches of the Great Fish Estuary.*

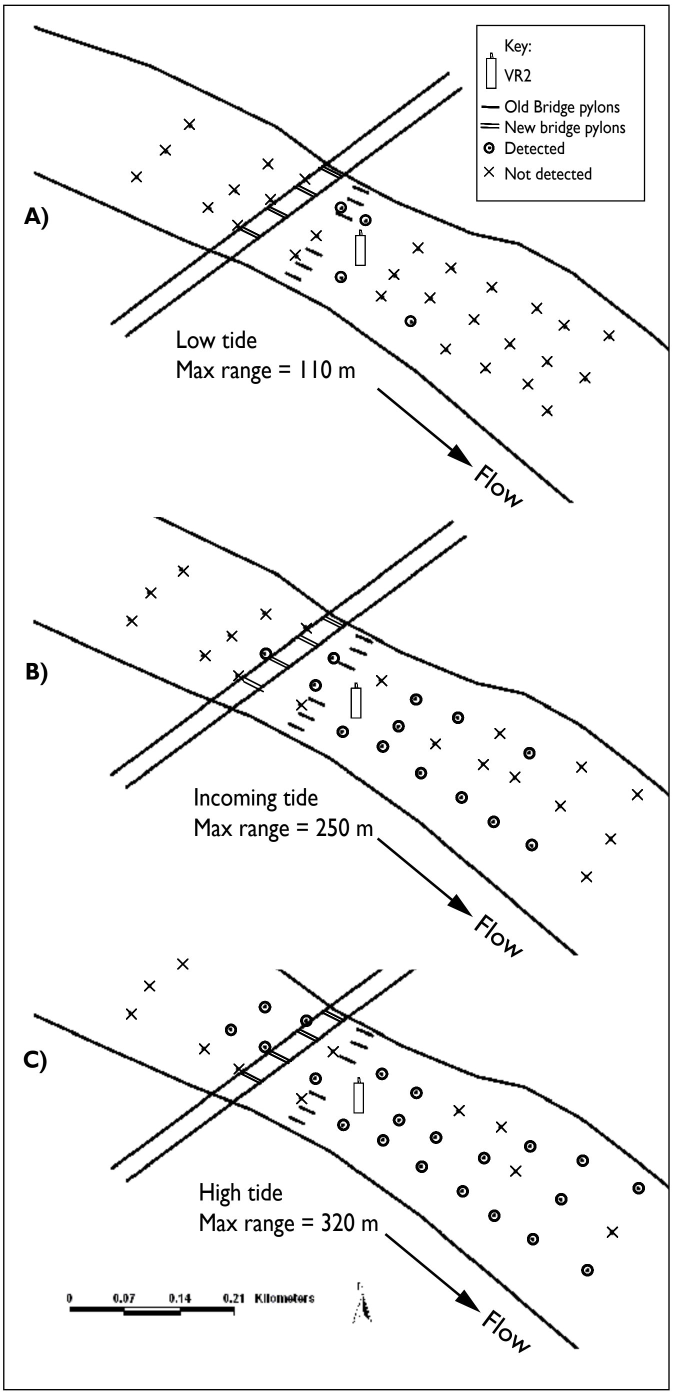


Figure 4. *Results from reception range tests conducted at the VR2 near the road bridge during (A) low, (B) incoming and (C) high tides in the Great Fish Estuary.*

detections occurred within 60 min. Absence times of more then 60 min were assigned in equal proportions to the VR2 before and the VR2 after the absence period. Absence times exceeding 24 hours were treated in the same way as for the sea trip analysis (see below). If detections before and after an absence period were made on one of the two lowermost VR2s, the time period was allocated to a sea trip, and if the detections were made on the uppermost VR2, the time was logged as river-time.

Downloaded data was also analysed to investigate the periodicity and duration of sea trips. Continuous detection of individual codes was not always possible due to (i) variable reception range for any given VR2, (ii) code collisions, and (iii) the spacing of VR2s along the estuary. Consequently, fish could be 'absent' from the array but still present in the estuary. Tagged fish were considered to be present in the estuary if two or more consecutive code detections were recorded by any one of the VR2s in the array within 24 hours.

When a fish was not detected for a period exceeding 24 hours it was assumed to be either (i) in the estuary but stationary between two VR2s, (ii) in the river, upstream of the VR2 array, or (iii) at sea, downstream of the VR2 array. The whereabouts of tagged fish were defined as follows:

Estuary: The presence of a fish in the estuary was confirmed if it was either continuously detected by the array or detected by the same VR2 or an adjacent VR2 following an absence period exceeding 24 hours.

River: A visit to upstream riverine habitats was confirmed if a fish was last and first detected on one of the two uppermost VR2s (VR2-10 or VR2-11) following an absence period exceeding 24 hours.

Sea: A sea trip was confirmed if detections were recorded on one of the two lowermost VR2s (VR2-1 or VR2-2) before and after an absence period exceeding 24 hours.

Possible sea: Due to poor reception range in the mouth region it was also considered possible for a fish to have undertaken a sea trip if it was last recorded on VR2-3 prior to an absence period and subsequently first recorded on either VR2-1 of VR2-2.

Caught: Tagged fish were vulnerable to capture in the fishery. The loss of these fish was confirmed by the return of the captured fish (tag) by an angler. The recovery of tags was assisted by an angler awareness campaign and a tag reward system. A fish was also assumed to have been captured, if the last signal was picked up by any of the receivers from VR2-4 to VR2-8, and never recorded again.

Dispersed detections were also recorded by the VR2 array. In rare cases when a fish was detected by a VR2 that was far away from the VR2 that last detected it (following an extended absence period), the data was carefully scrutinised to explain these anomalies. These anomalies could be attributed to code collisions (fish shoaling), bad weather (strong winds) and tidal influences (strong currents).

2.4 Fishery data

A comprehensive on-site fishery survey was conducted at the time of the present study (Potts *et al.* 2005). A combination of roving creel and point access surveys were conducted during six days each month, comprising two weekdays (Tuesday – Thursday), two Fridays and two Saturdays. Survey days were selected to include both spring and neap tidal cycles. The distribution of fishing effort by each of the fishery sectors was analysed for 0.5 km intervals from the estuary mouth to 3.5 km upstream. A detailed account of the survey procedure and data analysis is given by Potts *et al.* (2005). To be able to compare the distribution of fish and fishers in the estuary, the number of hits on each VR2 was taken as a rough proxy for distribution (space use) of the tagged fish. The values for each VR2 were then assigned to the 0.5 km zones where fishing effort was recorded. If a VR2 was positioned at a boundary between two zones, the value was split between the two zones. Data from the VR2s beyond 3 km from the mouth were pooled. Correlation (Spearman Rank) between the distribution of fishing effort and tagged fish was used to assess their susceptibility to being captured.

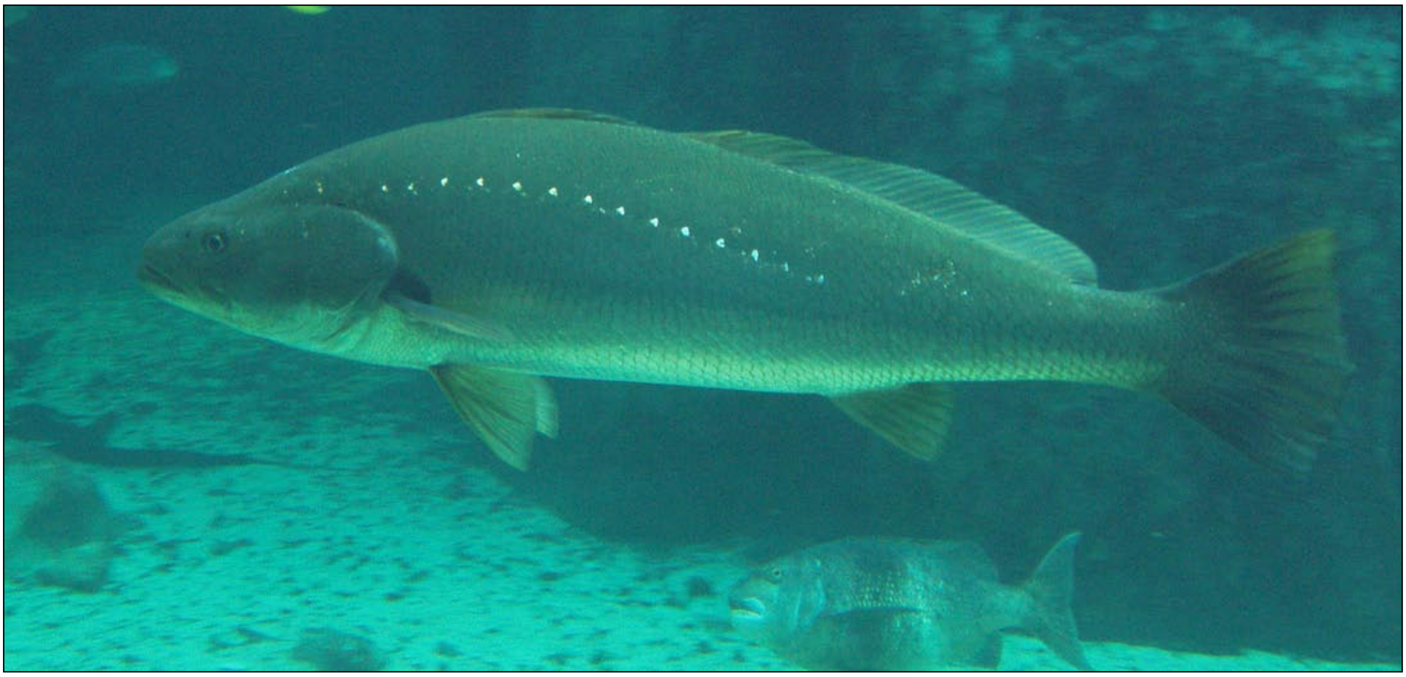
The mouth area of the Great Fish Estuary.

Clear seawater pushing into the mouth of the Great Fish Estuary.

Turbid water in the upper part of the Great Fish Estuary.

Recreational boat-fishing in the lower part of the Great Fish Estuary.

Recreational fishers in the caravan park at the mouth of the Great Fish Estuary.



A dusky kob approximately 1 m long.

A very large dusky kob of approximately 50 kg which was caught in the Great Fish Estuary in 2004.

The dusky kob is an important resource for the subsistence fishers along the Grest Fish Estuary.

Subsistence fishers with spotted grunter (left) and dusky kob (right), the two most important fishery species in the Great Fish Estuary.

Rod and line were used to catch juvenile dusky kob for tagging with acoustic transmitters in this study.

The transmitters were 28 mm long and implanted into the body cavity of the fish.

The automated data loggers (VR2s) were moored at the bottom of the estuary.

Automated data logger being placed in the upper part of the estuary.

Downloading data from an automated data logger.

3 Results

3.1 Efficiency of the receiver array

Detailed coverage of the tagged fish was successfully achieved by the VR2 array. After filtering the raw data for false codes a total of 199225 confirmed detections were recorded. All 25 fish were detected by the receiver array during the study period. However, not all fish were recorded by every receiver (**Figure 5**). VR2 numbers 2 to 8 registered all 25 fish, where as the two uppermost VR2s (number 10 and 11) registered the least number of fish (4-5 fish). The proportion of total number of detections was also not evenly distributed among the VR2s in the array. Most detections were recorded on VR2-8 (19%), VR2-2 (17%), VR2-3 (17%) and VR2-5 (14%) (**Figure 6**).

Passing of VR2s within the estuary were observed on a few occasions. Thirteen times fish passed one or more VR2s during an absence period. On the majority of occasions "absent" fish only passed one or two VR2s without detection. However, on three occasions tagged individuals migrated upstream, from the mouth to the top end of the array without being detected. Two of these occasions coincided as fish with ID code 70 and 79 were both absent from 19 to 28 April 2004. The arrival times at the uppermost and the second uppermost VR2, respectively, were synchronous (within an hour). It is suggested that these fish, possibly in a shoal, moved rapidly through the VR2 array and spent considerable time in the riverine environment before being detected by the two uppermost VR2s.

The number of days that each fish was monitored ranged from 7 to 195 (**Table 2**). On average, tagged individuals were detected by VR2s on 74% of the days that they were present in the estuary (range = 25 to 100%) (**Figure 7**).

__Figure 5.__ Number of tagged dusky kob recorded at each VR2 receiver in the Great Fish Estuary between 3 March and 14 September 2004. For positions of the receivers see __figure 2__.

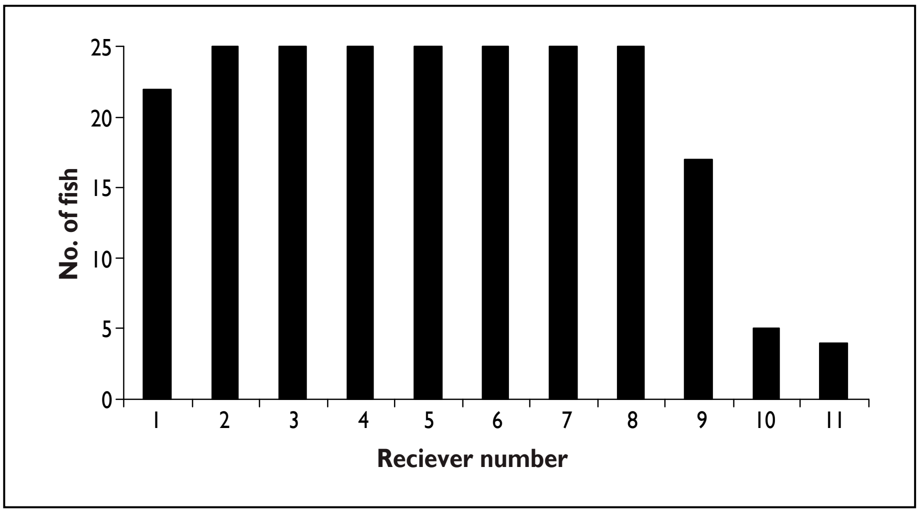


__Figure 6.__ The proportion of total detections (percentage frequency) recorded on each VR2 receiver in the Great Fish Estuary between 3 March and 14 September 2004. Due the possibility of different reception ranges of the various VR2, this figure may give an inaccurate illustration of fish dispersal. For positions of the receivers see __figure 2__.

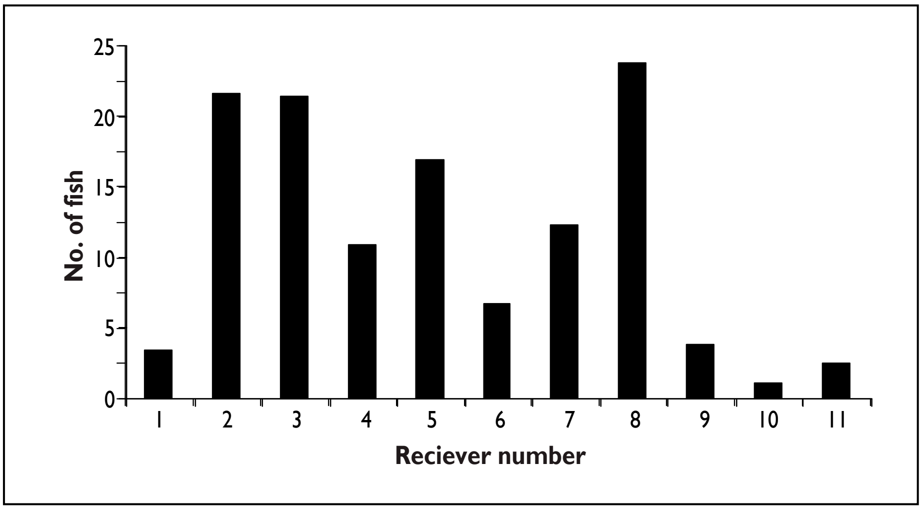
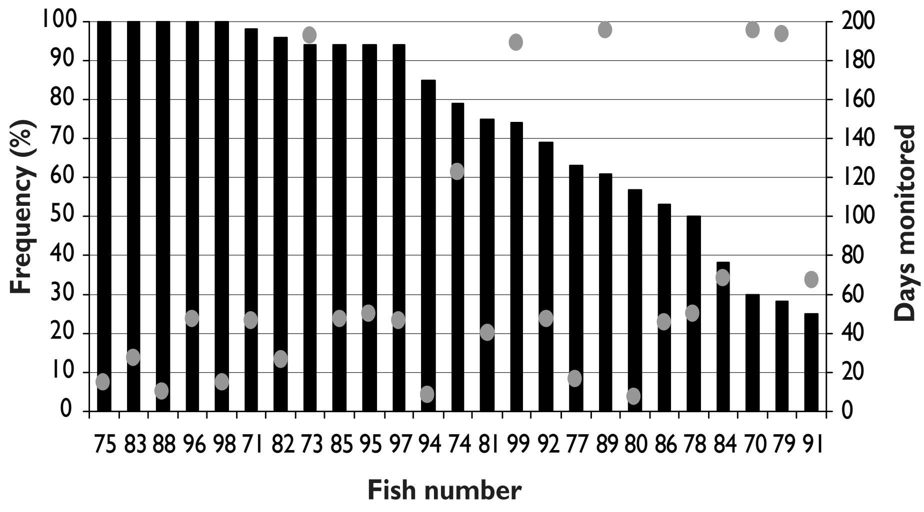


Figure 7. Histogram showing the proportion of days (percentage frequency) each fish was detected by the VR2 array. Grey dots indicate the total number of days each fish was monitored in the Great Fish Estuary between 3 March and 14 September 2004.



3.2 Area use and movements in the estuary

All tagged juvenile dusky kob made extensive horizontal movements up and down the estuary, using a minimum of 6 km and up to more than 10 km of the estuary (**Figure 8**). Many of the tagged fish also moved into the sea and/or the river. A description of the space use patterns and ultimate fate of each tagged fish is outlined below (**Figure 8**):

Fish 70. Fish 70 was recorded 8789 times on the 10 lowermost VR2s and spent approximately 16% of the time in the sea. It made use of approximately 9 km of the estuary, but most time was spent in the vicinity of VR2-4 (22%) and VR2-10 (16%). This fish was monitored for 195 days and was still alive at the end of the study.

Fish 71. Fish 71 was recorded 6527 times. The detections were distributed over the 8 lowermost VR2s (6.4 km of the estuary) with the longest time spent around VR2-5. It was last detected on VR2-3 on 18 April 2004, when it was assumed to have left the study area.

Fish 73. Fish 73 was detected 8410 times. It was recorded on all VR2s and made use of approximately 10.3 km of the estuary, showing a bimodal time distribution with longest time periods spent around VR2-3 (18%) and VR2-8 (22%). It was last recorded in the upper reaches of the estuary on 12 September 2004 and was still alive at the end of the study period.

Fish 74. Fish 74 was recorded 10883 times on the VR2 array. Although this individual made use of approximately 9 km of the estuary, it spent most of its time around VR2-2 (57%). It was last recorded on VR2-3 on 4 July 2004, when it emigrated to sea.

Fish 75. Fish 75 was recorded 3049 times during the 15 days that it was present in the study area. It made use of approximately 6.4 km between VR2-2 and VR2-8, with most time spent at VR2-4 (37%). It was caught on 18 March 2004.

Fish 77. Fish 77 was only recorded 426 times. It made use of approximately 7.5 km of the estuary and was last detected on VR2-3 on 19 March 2004. Similar to Fish 71 and 74 it possibly left the study site (to sea) after only 16 days of monitoring.

Fish 78. Fish 78 was recorded 5031 times on the 8 lowermost VR2s and made use of approximately 6.4 km of the estuary. It was last detected on 22 April 2004 at VR2-1 in the estuary mouth, which confirmed that it emigrated to sea after 50 days of monitoring.

Fish 79. Fish 79 was recorded 8141 times. It was detected throughout the estuary (10.3 km), but it spent most of its time beyond the range of VR2-11 in the riverine environment (68%). It was last recorded on 13 September 2004 on VR2-11 and still alive at the end of the study period.

Fish 80. Fish 80 was recorded 1775 times on the 8 lowermost VR2s. Although it made use of approximately 6.4 km of the estuary, most time was spent around VR2-2 (31%). It also spent a third of its time (34%) at sea. It was last recorded at VR2-1 on 10 March 2004, when it finally left the estuary.

Fish 81. Fish 81 was recorded 10134 times over 40 days. It made use of approximately 7.5 km of the estuary, but it spent most of its time around VR2-8 (26%). It was last recorded at VR2-1 on 19 April 2004, when it emigrated to sea.

Fish 82. Fish 82 was recorded 5745 times on the 9 lowermost VR2s. It made use of approximately 7.5 km of the estuary and detections were fairly evenly distributed between VR2-2 and VR2-9. However, it spent approximately one third of its time (35%) at sea. It was monitored for 26 days, after which it was confirmed to have emigrated to sea on 29 March 2004.

Fish 83. Fish 83 was recorded 9782 times over 27 days. It was recorded on all VR2s (10.3 km of estuary), but spent most time (27%) around VR2-8. This fish was caught on 30 March 2004.

Fish 84. Fish 84 was recorded 10316 times on the 9 lowermost VR2s. It made use of approximately 7.5 km of the estuary, with a high percentage of time spent at sea (23%). Within the estuary, most time was spent around VR2-6 (20%). This fish was caught on 10 May 2004 after 68 days of monitoring.

Fish 85. Fish 85 was recorded 11162 times on the 9 lowermost VR2s. It made use of approximately 7.5 km of the estuary, spending most time around VR2-4 (21%) and VR2-7 (23%). It was last detected on 19 April 2004 at VR2-1 in the estuary mouth, which confirmed that it emigrated to sea after 47 days of monitoring.

Fish 86. Fish 86 was recorded 6407 times over 45 days. It made use of approximately 7.5 km of the estuary, spending most time around VR2-2. However, it also spent considerable time at sea (21%). It emigrated to sea on 17 April 2004 after being last detected at VR2-1. Interestingly, this fish was captured in the mouth of the Great Fish Estuary on 21 January 2006, 16 months after the study period.

Fish 88. Fish 88 was recorded 4294 times over 10 days. It made use of approximately 7.5 km of the estuary with most time spent around VR2-2 (28%). It emigrated to sea on 13 March 2004.

Fish 89. Fish 89 was recorded 12927 times on the 9 lowermost VR2s. Although it used approximately 7.5 km of the estuary, it spent more than half of its time around VR2-2 (53%). It was alive and last recorded on VR-7 at the end of the 195 day study period. This fish was captured in the estuary (1 km from the mouth) on 5 March 2005, six months after the study period.

Fish 91. Fish 91 was recorded 897 times over 67 days of monitoring. It used approximately 6.4 km of the estuary, but spent most time around VR2-3 (61%). This individual either emigrated to sea or was caught in the estuary as it was last recorded on VR2-3.

Fish 92. Fish 92 was recorded 3414 times on the 9 lowermost VR2s. It made use of approximately 7.5 km of the estuary, favouring the area around VR2-5 (30% of the time). It was last detected on 19 April 2004 at VR2-1 in the estuary mouth, which confirmed that it emigrated to sea after 47 days of monitoring.

Fish 94. Fish 94 was recorded 1627 times on the 8 lowermost VR2s. It used approximately 6.4 km of the estuary and emigrated to sea after only 8 days of monitoring.

Fish 95. Fish 95 was recorded 14994 times and on all VR2s over 50 days of monitoring. It made use of approximately 10.3 km of the estuary with most time spent around VR2-5 (37%). This individual either emigrated to sea or was caught in the estuary as it was last recorded on VR2-3.

Fish 96. Fish 96 was recorded 14987 times on the 8 lowermost VR2s, but spent a large proportion of time (50%) around VR2-5. This individual emigrated to sea on 19 April 2004.

Fish 97. Fish 97 was recorded 11987 times on the 9 lowermost VR2s. It made use of approximately 7.5 km of the estuary, but most time was spent around VR2-3 (43%). This individual emigrated to sea on 18 April 2004 after 46 days of monitoring.

Fish 98. Fish 98 was recorded 3452 times on VR2-2 to VR2-9. Prior to being caught on 18 March 2004, it used approximately 7 km of the estuary, favouring the area from VR2-3 to VR2-4 (35% and 25% of time, respectively).

Fish 99. Fish 99 was recorded 24078 times on the 10 uppermost VR2s. It used approximately 10.3 km of the estuary, favouring the area around VR2-6 (32% of time), and was last recorded (still alive) on VR2-10 at the end of the study period.

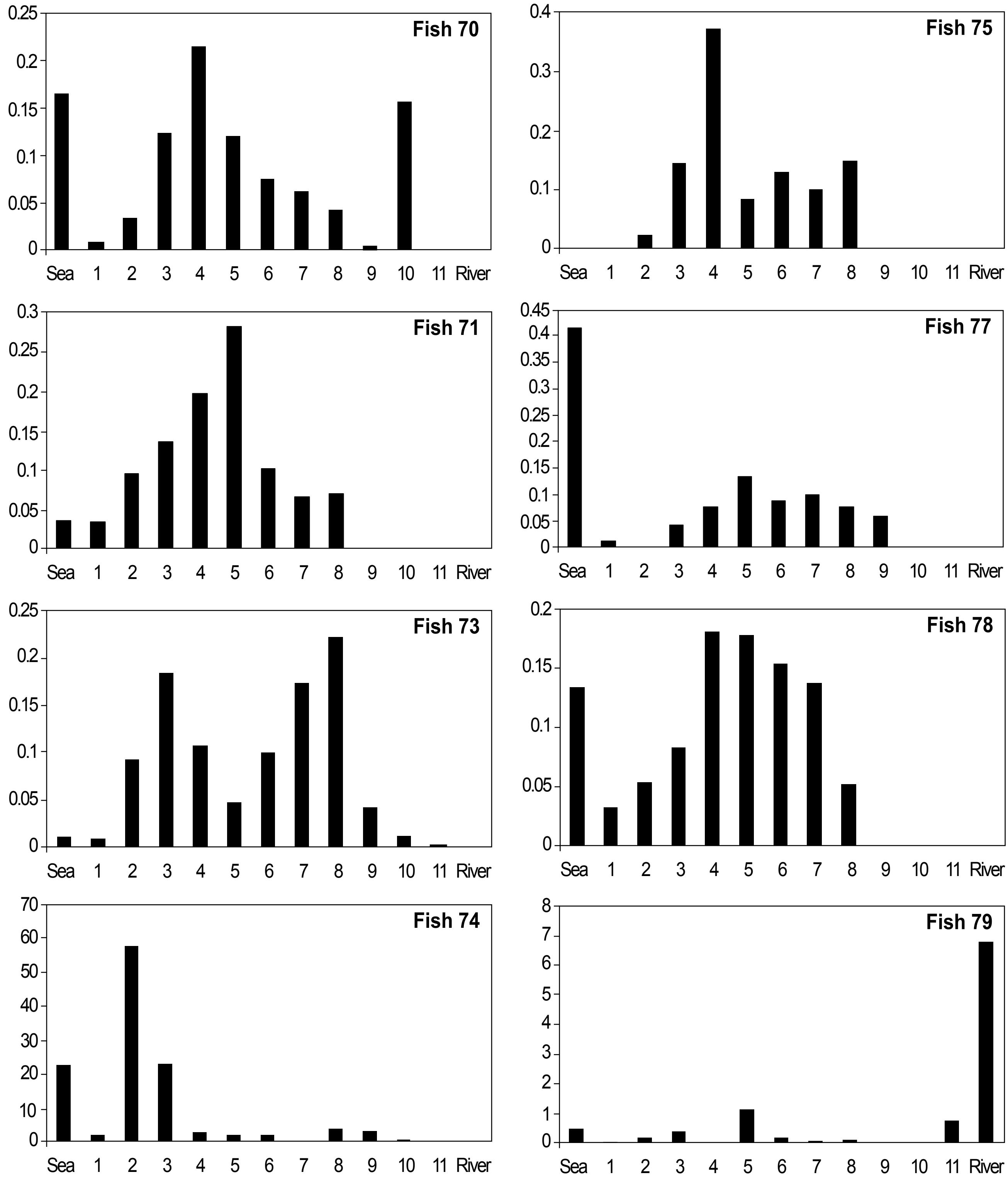


Figure 8. *Proportion of time (percentage frequency) spent in the vicinity of each VR2, at sea or upriver by tagged dusky kob (n = 25) in the Great Fish Estuary between 3 March and 14 September 2005. Numbers 1 to 11 on the X axis refer to the VR2 number.*

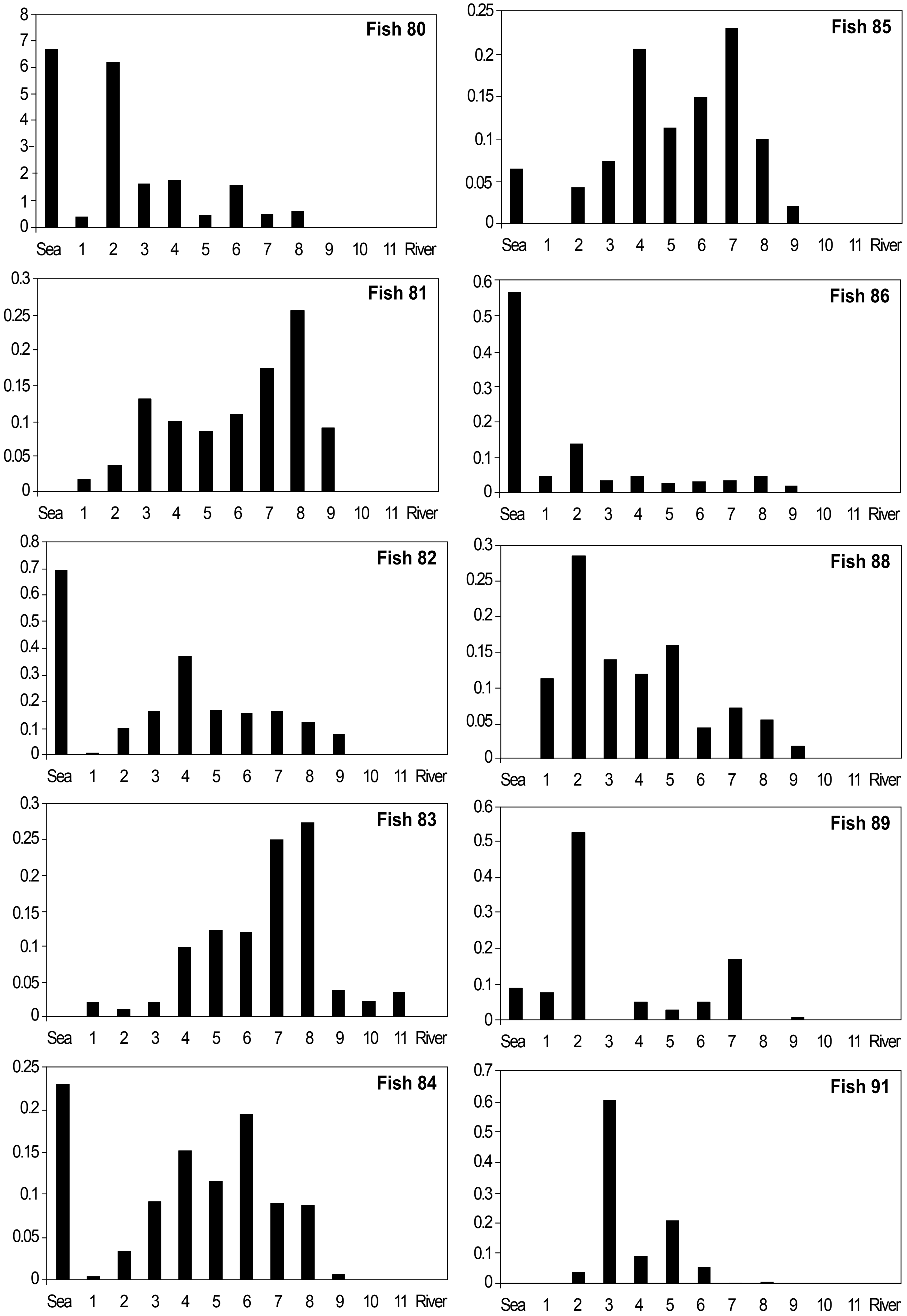


Figure 8 continue

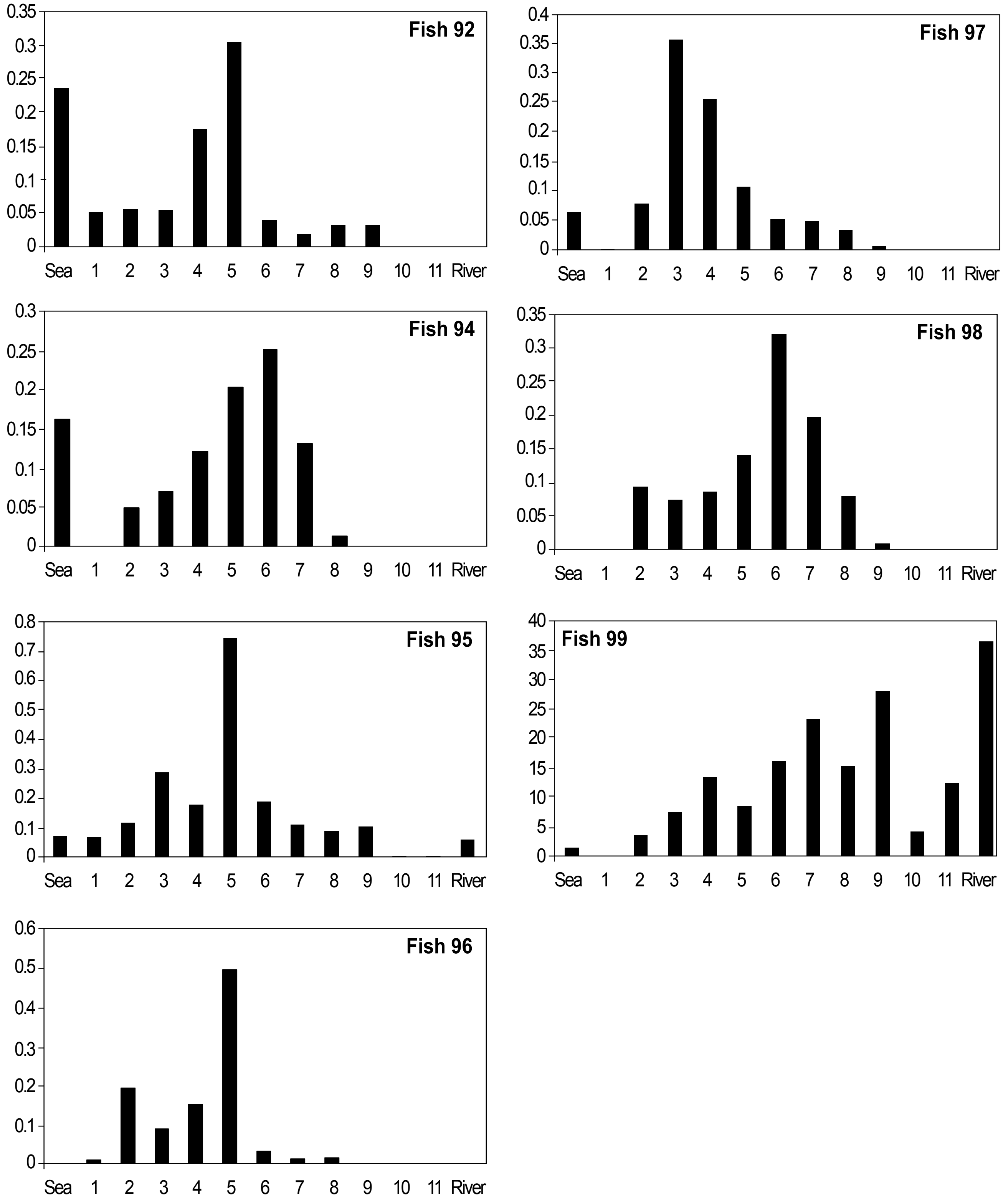


Figure 8 continue

Collectively, the tagged dusky kob (n = 25) spent most time (77%) between VR2-2 and VR2-8, approximately 0.5 km and 6.5 km from the estuary mouth, respectively (**Figure 9**). In this area, the time spent in the vicinity of each of the 7 VR2s was similar, varying between 7% and 14%. The upper 4 km of the estuary (VR2s: 9, 10 and 11) was less frequently used (total time = 5%). Prior to leaving the estuary permanently or being caught, the tagged fish collectively spent 13% and 4% of the time at sea or upriver, respectively (**Figure 9**).

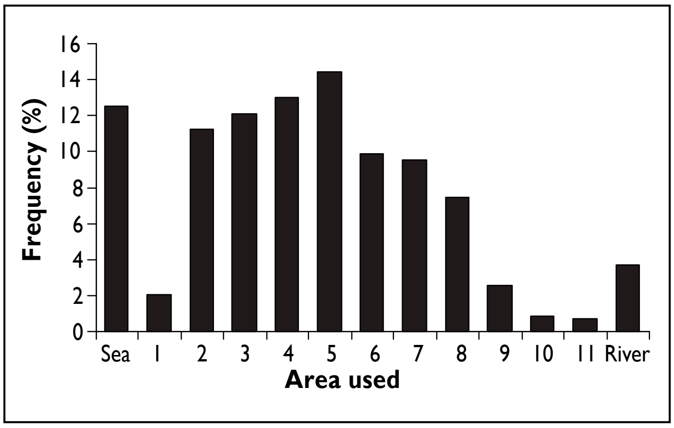


Figure 9. *Proportion of time (percentage frequency) spent in the vicinity of each VR2, at sea or upriver by all tagged dusky kob (n = 25) in the Great Fish Estuary between 3 March and 14 September 2005. Numbers 1 to 11 refer to the VR2 number.*

3.3 Movements to sea and upriver

During their respective monitoring periods, 19 of the 25 tagged dusky kob were absent from the VR2 array for periods exceeding 24 hours. The absence periods for 15 fish (60 %) were ascribed to sea trips, while four fish (16 %) ventured into the riverine environment. The duration of both sea and river trips were mostly short (**Figure 10**). The maximum duration of a sea trip was 22 days (mean = 3.5 days), while the maximum duration of a river trip was as long as 76 days (mean = 7.3 days).

A common behavioural pattern was observed when tagged fish emigrated to sea. Nine of the tagged fish left the estuary between the 18th and 22nd April 2004 and never returned (**Figure 11**), and interestingly, four

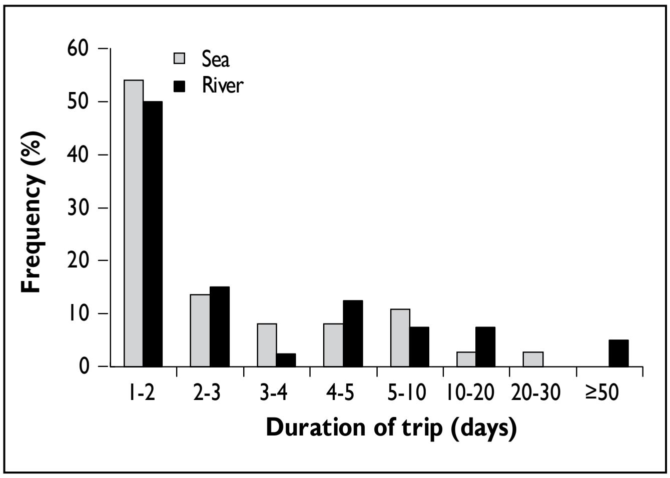
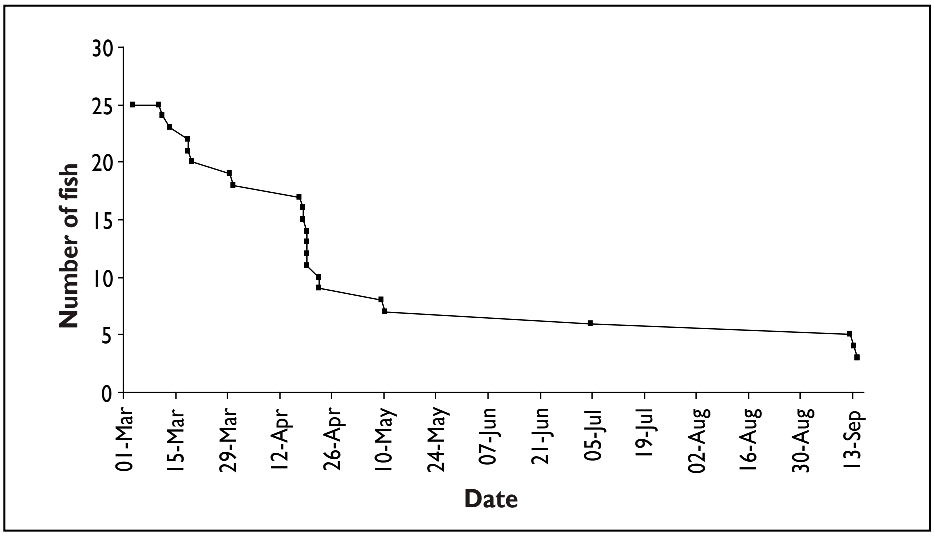


Figure 10. *The frequency of sea and river trips of various durations by tagged dusky kob (sea trips n = 15 fish; river trips n = 4 fish) in the Great Fish estuary between 3 March and 14 September 2004.*

Figure 11. *Attrition of acoustically tagged dusky kob in the Great Fish Estuary over the 195 days study period between 3 March and 14 September 2004.*



of these fish left on the same day (19th April 2004). A similar pattern was observed for the other fish that emigrated to sea; often more than one fish left the estuary within a few days (**Figure 11**).

3.4 Daily movements

Although tagged fish often used several kilometres of the estuary in a day, periods of restricted movements in discrete areas within the estuary were also observed (see **figure 12**). When absence times exceeding 1 hour were assigned to the closest VR2, periods of restricted movements ranged between 5 hours and 22 days (mean 3.5 days). However, most fish (64%) had periods of restricted movements (i.e. time staying close to a VR2) of less than one day.

Examples of short-term movements over an arbitrarily chosen one-week observation period (3 – 10 March 2004) are provided in **Figure 12**. Four fish (ID codes: 70, 79, 84, and 94) have been chosen to exemplify movement patterns. Daily (within 24 hours) movements resembled one of the following patterns: (i) no longitudinal movements (stationary behaviour) lasting from approximately 14 hours (e.g. Fish 84 & 94; 3-5 March) to more than one day (e.g. Fish 79; 8-10 March), (ii) a single longitudinal excursion of up to 6 km either up or down the estuary (e.g. Fish 70; 5 March), and/or (iii) two longitudinal excursions up and down a 3 to 5 km stretch of the estuary.

The latter pattern was observed simultaneously for three of the tagged fish (fish 70, 84 and 94) between the 6 and 10 March. These fish displayed rhythmic movements up and down the estuary, mostly with two distinct trips within a 24 hour period. The direction of the rhythmic movements for these three fish corresponded with the tides (unpublished results); fish moved upstream during rising and high tide and downstream during falling and low tide. The time and location data for these three fish suggests that they were at times swimming together (shoaling). However, over the same period fish number 79, following an excursion of about three km up river on 7 March, remained stationary until 11 March (**Figure 12**).

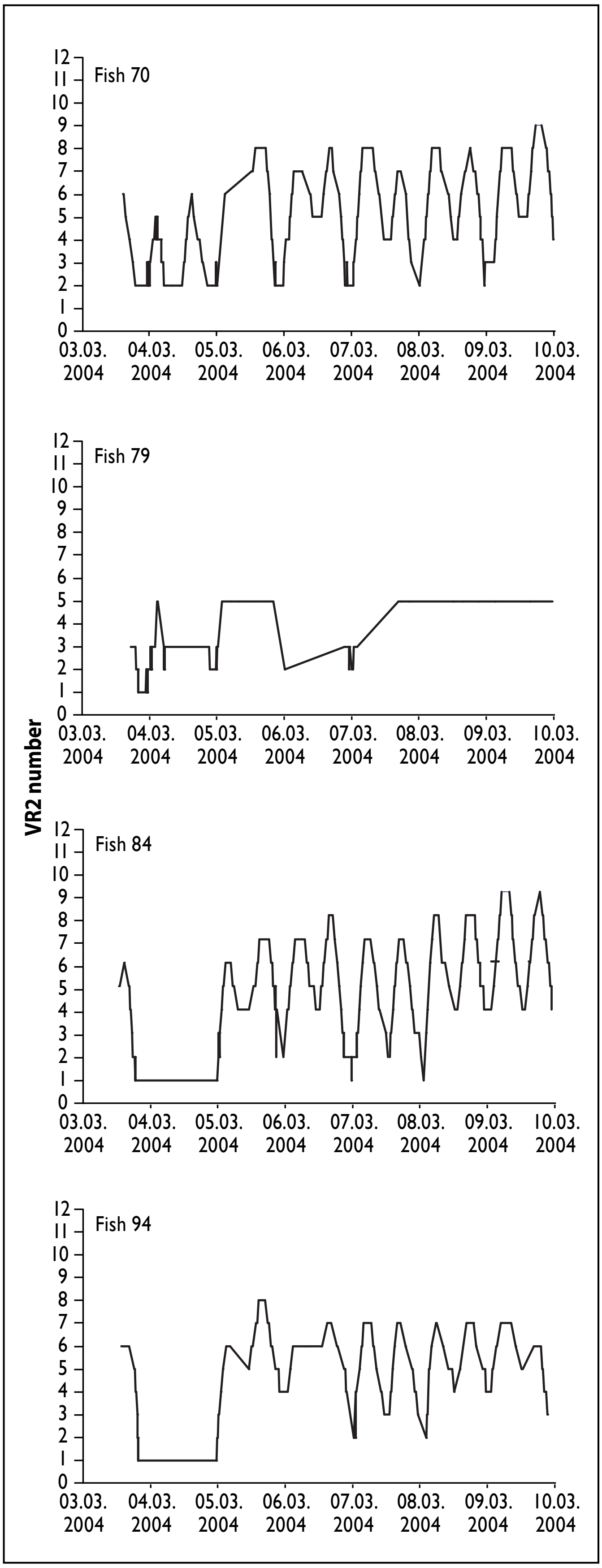


***Figure 12.** Examples of short-term (one week) movements of five tagged dusky kob (ID codes 70, 79, 84 and 94) in the Great Fish Estuary.*

3.5 Distribution of fishing effort vs. dusky kob area use

shore-based recreational and subsistence fishers, as well as boat-based recreational fishers operate on the Great Fish Estuary. Catch and effort trends of the various fishery sectors were documented by Potts et al. (2005) and used here to assess the susceptibility of juvenile dusky kob to capture in the fishery. The distribution of fishing effort by shore anglers (subsistence and recreational) was not correlated to the longitudinal distribution of tagged fish in the estuary (Spearman Rank Correlation, $p = 0.305$) (**Figure 13**). However, there was a significant relationship between the distribution of recreational boat fishing effort and distribution of tagged fish (Spearman Rank Correlation, $p = 0.003$).

4 Discussion

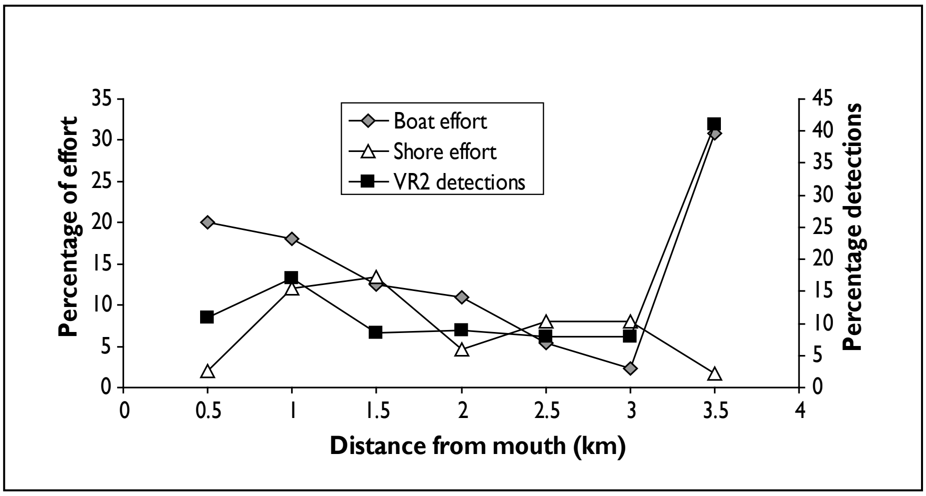
This report presents the findings of the first telemetry study on dusky kob in South Africa, as well as the first detailed study on the localised movements of this species within an estuary. Detailed coverage of acoustically tagged fish in the Great Fish Estuary was successfully achieved by the array of 11 VR2s. The whereabouts (area use) of each fish was confirmed by the presence (or absence) of unique code detections on the VR2s over a 195 day study period. Fish positions were categorised as either being in the estuary, at sea, in the river (upstream) or lost by capture in the fishery.

A range of behavioural patterns were observed among the 25 individuals studied: 15 fish (60 %) made return-trips to sea, 4 fish (16%) ventured into the riverine habitat and 5 fish (20%) remained in their estuarine nursery habitat for the entire study period (195 days). Furthermore, 9 fish left and never returned to the estuary; while a further 5 individuals either left the estuary (unconfirmed emigrant) or were caught in the lower reaches of the estuary.

Area use and movements in the estuary

Despite clear evidence of behavioural differences among individuals, the general movement patterns and area used by all tagged individuals was similar. Each fish used a minimum of 6 km of the estuary, and all of them spent a large proportion of time (~80%) between 0.5 km and 6.5 km from the estuary mouth. Furthermore, the time spent within this region was fairly evenly distributed (see **Figure 9**), indicating that

__Figure 13.__ The longitudinal distribution (distance from mouth) of fishing effort and tagged dusky kob in the Great Fish Estuary between February and September 2004. Fishery data above 3 km are pooled.



dusky kob make frequent and extensive movements within the Great Fish Estuary.

A number of biotic (e.g. predation, food availability) and abiotic (e.g. temperature, salinity, turbidity) factors may induce behavioural responses in estuary associated fishes and impact on their distribution and abundance within estuaries (Whitfield 1994, 1998). Marais (1988) reported that dusky kob favoured turbid estuaries that have large freshwater inputs, such as the Great Fish Estuary. Cardona (2000) demonstrated that salinity was a key determinant for understanding the distributional abundance of juvenile flathead mullet in the estuaries on the island of Minorca (Balearic archipelago), and concentrated in fresh and oligohaline (0.5 – 4.9‰) waters. In an earlier telemetry study on the Great Fish Estuary, Næsje *et al.* (2006) used salinity as a proxy for a number of correlated variables (e.g. temperature and turbidity) and showed that the distribution of small spotted grunter *Pomadasys commersonnii* was significantly influenced by abiotic factors. These authors showed that spotted grunter were distributed further upriver on days with a high influx of marine water. Although physico-chemical variables such as salinity and turbidity were not recorded during this study, the high use area of dusky kob corresponded with the mesohaline (5 – 17.9‰) and polyhaline (18 – 29.9‰) regions of the estuary (physico-chemical data after Childs 2005). However, juvenile dusky kob are known to be salinity tolerant and capable of surviving in salinities ranging between 0 and 66‰ (Ter Morshuizen *et* al. 1996, Wallace 1975). Based on the observed variation of behavioural patterns, it is doubtful that a single environmental variable can adequately explain the distribution of dusky kob in the Great Fish Estuary. Marshall and Elliot (1998) showed that environmental variables only partly explained the variance in the distribution of fishes in the Humber Estuary (UK).

A telemetry study on juvenile sturgeon *Acipenser sturio* revealed that they exhibited restricted movements in the Gironde Estuary (France), due to the spatial distribution of polychaete worms, which is their favourite prey (Lepage et al. 2005). Erickson *et al.* (2002) showed that green sturgeon *Acipenser medirostris* also occupied small home ranges in the Rogue River (USA). Juvenile spotted grunter (< 400 mm TL) in the Great Fish Estuary displayed home range behaviour and a common high use area in the lower reaches of the estuary coincided with the highest abundance of their preferred prey (Childs *et al.* in prep.). Based on this, it is hypothesized that strong selection exists for estuary associated fishes, which prey on non-mobile benthic organisms (e.g. worms and prawns), to exhibit station-keeping behaviour and occupy areas of optimal food availability. In other words, their distribution is primarily determined by biotic variables. However, what behaviour can be expected from estuarine dependent species, such as dusky kob, that prey on mobile organisms?

Griffiths (1997b) showed that dusky kob (200 - 400 mm TL) in the Great Fish Estuary feed predominantly on teleosts, especially small mugilids and *Gilchristella aestuaria*, and suggested that the distribution of dusky kob was mainly determined by prey availability. An independent study showed that these shoaling prey species are abundant and widely distributed in the Great Fish Estuary (Ter Morshuizen *et al.* 1996). Therefore, the observed space use patterns (i.e. extensive horizontal movements and limited station keeping behaviour) support Griffiths' suggestion that the distributional abundance of dusky kob is determined by biotic factors (i.e. prey availability). Nonetheless, further detailed investigations on how these fish respond to different abiotic conditions and environment events will be worthwhile. This is especially important in dynamic estuarine environments that are exposed to significant daily changes in abiotic conditions such as temperature, salinity and turbidity as well as unpredictable freshwater intrusions following periods of high rainfall.

Observations over a short time period (one day) revealed three distinct behavioural patterns (*viz*. stationary behaviour, a single longitudinal excursion or two longitudinal excursions up or down the estuary; examples given in **Figure 12**). Given that behaviour is a comprise between costs and benefits, it is suggested that these patterns are most likely ascribed to individual biological differences. Therefore the variation in, for example, the observed duration of stationary behaviour by tagged dusky kob may reflect periods of feeding and non-feeding activity. At times, however, the longitudinal excursions up and/or down the estuary were rhythmic (see **Figure 12**) and may have corresponded with the rise and fall of the tide. Rhythmic movements associated with the tides has been reported in other estuarine fishes such as European flounder *Platichthyes flesus* (Wirjoatmodjo & Pitcher 1984), thin-lipped mullet *Liza ramada* (Almeida 1996) and the spotted grunter *Pomadasys commersonnii* (Childs 2005).

In addition to the observed individual behavioural patterns, there were indications that dusky kob can adopt associative (shoaling) behaviour. During the week we studied daily movement of four fish (as an example), at least three individuals were simultaneously recorded making rhythmic longitudinal movements up and down the estuary between the 6th and 10th March (**Figure 12**). Furthermore, between 18th and 22nd April 2004, fish congregated in the mouth region (lower reaches), possibly in response to a common environmental cue, and 9 of the tagged individuals emigrated to sea, of which 4 left on the same day (**Figure 11**). According to Brown and Orians (1970) shoaling species benefit by (i) group defence against predators, (ii) group defence of feeding areas, (iii) ability to exploit a resource not readily captured by solitary individuals, and (iv) the ability to profit from the foraging success of other individuals by observing where they find food. Considering that the main prey items of juvenile dusky kob (200 – 400 mm TL) comprise small mobile shoaling species, the benefits of associative behaviour would include an increased ability to capture prey compared to solitary individuals and possibly predator avoidance. Although dusky kob are the dominant piscivores in the Great Fish Estuary they are known to be cannibalistic (Griffiths 1997a, Marais 1984). Associations of individuals prior to and during the emigrating phase would also be favourable in terms of predator avoidance.

Sea and river trips

Whitfield (1998) showed that estuarine dependent fish species are more tolerant to lower than higher salinities. The use of the freshwater dominated upper reaches of estuaries (or river-estuarine interface - REI) by fishes, particularly during their early juvenile stages, is well documented (e.g. Ter Morhuizen *et al.* 1997, Whitfield *et al.* 2003). Griffiths (1996) showed that early juvenile dusky kob (<150 mm TL) are confined to the upper reaches of the Great Fish Estuary, while larger juveniles (150 – 400 mm TL) are found throughout the system, but larger individuals are mostly in the lower and middle reaches. Fish larger than 150 mm also occur in nearshore marine habitats, and results from conventional tagging studies have revealed that immature individuals (< 1200 mm TL: size at 100% sexual maturity) remain close to their natal estuary (i.e. exhibit limited dispersal).

During this study, 15 (60%) of the tagged fish made return trips to sea with a mean duration of 3.5 days (max. = 22 days). The reason for these sea trips is uncertain, but was probably in response to an environmental cue and/or some biological or physiological requirement. Sea trips are common to other estuary associated fishes. Næsje *et al.* (2006) revealed that with the onset of sexual maturity (~ 400 mm TL) spotted grunter made frequent sea trips, possibly in preparation for a spawning migration. Similarly, Hartill *et al.* (2003) showed that larger snapper *Pagrus auratus* from the Maruhangi Estuary (New Zealand) made more frequent sea trips than smaller individuals. Therefore, unlike dusky kob that only attain sexual maturity at 1200 mm TL, sea trips made by spotted grunter and snapper may represent a transition phase prior to the marine-dominated adult phase of their life history.

The large number of tagged dusky kob (9 confirmed and 4 unconfirmed) that left the estuary and never returned during the 195 day study period suggests that the connectivity with their natal estuary diminishes with size (age). However, the recapture of Fish 86 six months after the study period and Fish 89 sixteen months after the study period, revealed that they remain associated with their natal estuary. Fish 86 left the estuary after 45 days of the study period, while Fish 89 stayed in the estuary the whole study period (195 days). This finding suggests that juveniles in the marine environment exhibit limited longshore dispersal and, hence, agree with results from conventional tagging studies (Griffiths 1996).

Griffiths (1997a) suggested that the confinement of small dusky kob (<150 mm TL) to the upper reaches, despite reduced availability of the favoured prey item (*Mesopodopsis slabberi*: Mysidacea), was attributed to both predator avoidance and food availability. Ter Morhuizen et al. (1997) showed that 0+ juveniles of several species (including dusky kob) are attracted to freshwater head reaches of permanently open estuaries, while older juveniles are more common in the lower and middle reaches. During this study, four (16%) of the tagged fish ventured into the river-estuarine interface (REI region), while one individual (Fish 79) spent a large proportion (68%) of the 195 day study period in the freshwater reaches. Childs (2005) showed that adult spotted grunter (> 400 mm TL) also made frequent use of the REI in the Great Fish Estuary and suggested that these visits were used to rid parasite loads. In the absence of high food availability, the reasons why post early-juvenile fishes undertake extended visits to low salinity environments is not fully understood. The possibility of physiological adaptations and physiological responses to environmental factors (e.g. salinity) cannot be ignored, and is currently receiving some research attention (Bernatzeder *in prep*.).

Implications for fisheries management

Tagged dusky kob used much of the available estuarine area (6 – 10 km) over relatively short periods. The lack of prolonged station keeping behaviour precluded any significant correlation between the distributions of fishing effort by shore anglers and the area used by juvenile dusky kob. However, a positive correlation was observed for the more mobile boat anglers that utilised more of the estuarine area. Nonetheless, the findings of this study have implications for fisheries management and questions whether estuarine dependency represents a demographic bottleneck for juvenile dusky kob. The nursery role of South African estuaries for a number of important fishery species, such as dusky kob, is undisputed (Whitfield 1998, Lamberth and Turpie 2003). However, from a fisheries perspective, nursery habitats are only effective if juveniles reach adulthood and contribute to a viable population. Griffiths (1997) showed that the collapse of the dusky kob stock was attributed to recruitment over-fishing and that the spawner biomass-per-recruits (SB/R) ratios were 1.0 to 4.5% of the pristine value.

The recapture of 28% of the fish tagged during the study provides further evidence of their vulnerability. Two tagged fish (codes 81 and 99) were captured prior to the start of the monitoring period and an additional three fish (codes 75, 83 and 84) were caught during the study period. Furthermore, two of the tagged fish (codes 86 and 89) that were still alive at the end of the study period (September 2004) were subsequently captured (prior to adulthood) on 21 January 2006 and 5 March 2005, respectively. Clearly, improved fisheries management within estuaries is required to increase the survival of juvenile dusky kob. This can be achieved by way of size limits, bag limits or area restrictions. Recent amendments to fishery regulations (Marine Living Resources Act; Act 18 of 1998) applicable to dusky kob are as follows: (i) daily bag limit reduced from 10 to 1 fish per person per day, and (ii) minimum size limits increased from 40 to 60 cm. However, Potts *et al.* (2005) showed that anglers had little consideration for minimum size limit restrictions and that a large proportion (55%) of the retained dusky kob catch from the Great Fish Estuary was below the minimum legal size limit of 400 mm TL. If the lack of compliance persists following recent amendments to the fishery regulations (minimum size limit now = 600 mm TL), the proportion of retained undersized fish would be as high as 90%. Furthermore, the reduction in the daily bag limit (from five to one fish per person) will only result in a 50% reduction in the retained catch of this species (Potts *et al.* 2005). Clearly, traditional fishery control measures offer little effective conservation for juvenile dusky kob in the Great Fish Estuary, unless there is improved law enforcement and/or better compliance by the anglers. Over-exploitation of dusky kob within their nursery habitats can therefore only be abated if alternative management measures, such as closed areas, are implemented.

Despite evidence of exchange between estuarine nursery areas and adjacent marine environments by juvenile dusky kob (this study, Griffiths 1996), the extent of exchange between different estuaries is worthy of further research attention. A lack of exchange between estuaries infers that as juveniles, dusky kob exist as a number of small stock units and consequently should be treated as such for fisheries management purposes. Limited exchange between small stock units associated with different estuaries has been observed in other estuary associated fishery species (Pollock 1982, Childs 2005). The recognition of estuarine protected areas in South Africa as a fisheries management objective to assist with the rebuilding of depleted stocks (such as the dusky kob) must be prioritised. Furthermore, estuaries are especially vulnerable to habitat degradation and destruction (Whitfield and Elliot 2002), and the need for improved conservation of estuarine habitats must not be ignored.

5 References

Allanson, B.R. and Read, F.H.L. 1987. The response of estuaries along the south eastern coast of southern Africa to marked variation in freshwater inflow. Institute for Freshwater Studies Special Report No. 2/87. Rhodes University, Grahamstown, South Africa.

Almeida, P.R. 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.

Bernatzeder, A. In prep. Salinity induced physiological responses in dusky kob, *Argyrosomus japonicus*. MSc student project. Rhodes University, Grahamstown, South Africa.

Brouwer, S.L., Mann, B.Q., Lamberth, S.J., Sauer, W.H.H. and Erasmus, C. 1997. A survey of the South African shore-angling fishery. South African Journal of Marine Science 18: 165-178.

Brown, J.L. and Orians, G.H. 1970. Spacing patterns in mobile animals. Annual Reviews in Ecology and Systems 1970.1: 239-262.

Cardona, L. 2000. Effects of salinity on the habitat selection and growth performance of Mediterranean flathead mullet *Mugil cephalus* (Osteichthyes, Mugilidae). Estuarine, Coastal and Shelf Science 50: 727-737.

Childs, A-R. 2005. Movement patterns of spotted grunter, *Pomadasys commersonnii* (Haemulidae), in a highly turbid South African estuary. MSc thesis, Rhodes University, South Africa. 152 pp.

Childs, A-R., Cowley, P.D., Næsje, T.F., Potts, W.M., Thorstad, E.B. and Økland, F. In prep. Home range and space use characteristics of spotted grunter (*Pomadasys commersonnii*) in the Great Fish Estuary, South Africa.

Cowley, P.D., Wood, A.D., Corroyer, B., Nsubuga, Y. and Chalmers, R. 2004. A survey of fishery resource utalization on four Eastern Cape estuaries (Great Fish, West Kleinemonde, East Kleinemonde and Kowie). In: Eastern Cape Estuaries Management Research Programme. Water Research Commission Report No. 1246/1/04 Volume III, Supplementary Report C5, pp. 129 – 165.

Erickson, D.L., North, J.A., Hightower, J.E., Weber, J. and Lauck, L. 2002. Movement and habitat use of green sturgeon *Acipenser medirostris* in the Rogue River, Oregon, USA. Journal of Applied Ichthyology 18: 565-569.

Grange, N., Whitfield, A.K., De Villiers, C.J. and Allanson, B.R. 2000. The response of two South African east coast estuaries altered river flow regimes. Aquatic conservation: Marine and Freshwater ecosystems 10: 155-177.

Griffiths, M.H. 1996. Life history of the dusky kob *Argyrosomus japanicus* (Sciaenidae) off the east coast of South Africa. South African Journal of Marine Science 17: 135-154.

Griffiths, M.H. 1997a. 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.

Griffiths, M.H. 1997b. Management of South African dusky kob *Argyrosomus japonicus* (Sciaenidae) based on per-recruit models. South African Journal of Marine Science 18: 213-228.

Hartill, B.W., Morrison, M.A., Smith, M.D., Boubee, J. and Parsons, D.M. 2003. Diurnal and tidal movements of snapper (*Pagrus auratus*, Sparidae) in an estuarine environment. Marine and Freshwater Research. 54: 931-940.

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

Lepage, M., Taverny, C., Piefort, S., Dumont, P., Rochart, E. and Brosse, L. 2005. Juvenile sturgeon (*Acipenser sturio*) habitat utilization in the Gironde estuary as determined by acoustic telemetry. In. Spedicato, M.T., Lembo, G and Marmulla, G. (eds). Aquatic 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.

Mann, B.Q., James, N.C. and Beckley, L.E. 2002. An assessment of the recreational fishery in the St Lucia estuarine system, KwaZulu-Natal, South Africa. South African Journal of Marine Science 24: 262-279.

Marais, J.F.K. 1984. Feeding ecology of major carnivorous fish from for Eastern Cape estuaries. South African Journal of Zoology. 19: 210-223.

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

Marshall, S. and Elliot, M. 1998. Environmental influences on the fish assemblage of the Humber Estuary, UK. Estuarine, Coastal and Shelf Science 46: 175-184.

Næsje, T.F., Childs, A-R., Cowley, P.D., Potts, W.M., Thorstad, E.B. and Økland, F. 2006. Movements of undersized spotted grunter *(Pomadasys commersonnii)* in the Great Fish Estuary, South Africa: implications for fisheries management. Hydrobiologia (in press).

O'Keefe, J.H. and De Moor, F.C. 1988. Changes in the physio-chemistry and benthic invertebrates of the Great Fish River, South Africa, following an interbasin transfer of water. Regulated Rivers: Research and Management 2: 39-55.

Pollock, B.R. 1982. Movements and migrations of yellowfin bream *Acanthopagrus australis*, in Moreton Bay, Queensland as determined by tag recoveries. Journal of Fish Biology 20: 245-252.

Potts, W.M., Cowley, P.D., Corroyer, B. and Næsje, T.F. 2005. Trends in fishery resource utilization on the Great Fish Estuary. NINA Report 50. 34 pp.

Pradervand, P and Baird, D. 2002. Assessment of the recreational linefishery in selected Eastern Cape estuaries: Trends in catches and effort. South African Journal of Marine Science 24: 87-101.

Reddering, J.S.V and Esterhuysen, K. 1982. Fluvial dominated sedimentation in the Great Fish Estuary. ROSIE Report 4. Department of Geology. University of Port Elizabeth, Port Elizabeth, South Africa. 62 pp.

Ter Morshuizen, L.D. 1996. Distribution patterns of fishes in the head region of a turbid Eastern Cape estuary. MSc Thesis. Rhodes University, Grahamstown.

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

Ter Morshuizen, L.D., Whitfield, A.K. and Paterson, A.W. 1997. Distribution patterns of fishes in an Eastern Cape estuary and river with particular emphasis on the ebb and flow region. Transactions of the Royal Society of South Africa 51: 257-280.

Vorwerk, P.D., Whitfield, A.K., Cowley, P.D. and Paterson, A.W. 2003. The influence of selected environmental variables on fish assemblage structure in a range of southeast African estuaries. Environmental Biology of Fishes 66: 237-247.

Wallace, J.H. 1975. The estuarine fishes of the east coast of South Africa. I. Species composition and length distribution in the estuarine and marine environments. II. Seasonal abundance and migrations. Investigational Report Oceanographic Research Institute 40: 1-72.

Whitfield, A.K. 1998. Biology and Ecology of Fishes in Southern African Estuaries. Ichthyology Monographs of the J.L.B. Smith Institute of Ichthyology, No. 2. 44 pp.

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

Whitfield, A.K. and Elliot, M. 2002. Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. Journal of Fish Biology 61: 229-250.

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

Whitfield, A.K., Paterson, A.W. and Ter Morshuizen, L.D. 2003. An investigation into the structure and functioning of the ichthyofauna associated with the REI zone in two Eastern Cape estuaries with differing freshwater inputs. Water Research Commission Report. 756/1/03: 260 – 309.

Wirjoatmodjo, S and Pitcher, T.J. 1984. Flounders follow the tides to feed: Evidence from ultrasonic tracking in an estuary. Estuarine, Coastal and Shelf Science. 19: 231-241.

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