INTERNAL REPORT

MOVEMENT OF BLACK BREAM, *ACANTHOPAGRUS BUTCHERI*, IN RELATION TO WATER QUALITY, HABITAT AND LIFE HISTORY CHARACTERISTICS

R. Sakabe and J.M. Lyle

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Tasmanian Aquaculture and Fisheries Institute

Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Private Bag 49, Hobart, Tasmania 7001. E-mail: Jeremy.Lyle@utas.edu.au

Ph. (03) 6227 7277 Fax (03) 6227 8035

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Executive Summary

The general biology of black bream, *Acanthopagrus butcheri* is quite well known; movement patterns on the other hand are poorly understood. In this study, movement patterns of black bream in the Little Swanport Estuary (east coast of Tasmania) were investigated using acoustic telemetry. Thirty-five adult fish were surgically implanted with acoustic tags and their movements tracked using VR2 acoustic receivers (VEMCO) over a period of six months. The acoustic receiver placement had been specifically designed to track small scale movements of the species.

Over 150,000 detections were obtained from 34 individuals over periods of up to 187 days, demonstrating upstream migration during the spawning season. They also showed extensive movement within the estuary linked to tidal cycles, occurring small-scale upstream movements during the flood and downstream movements during the ebb. Generally, fish spent more time in the upper than in the downstream regions except in January when the fish moved more widely throughout the estuary. Freshwater inflows significantly influenced the distribution and movement patterns within the estuary. There was, however, no evidence to indicate that tagged fish left the estuary, even during heavy flood events.

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1. INTRODUCTION

Observing the natural behaviour and movement patterns of marine fish is very difficult. Traditional tagging methods involving mark-release-recapture using external anchor or dart tags (e.g., Pollock, 1982; Moran *et al*., 2003) have been used to describe fish movements. Such external tags are cheap and easy to apply and large numbers of fish can be tagged. However, this method depends upon recaptures and provides only a crude indication of movement patterns, since there is no information about movement between the points of capture and recapture of tagged fish.

In recent years, there have been significant advances in tagging and tagging methodologies through the development of acoustic tags. Acoustic tags allow tracking of fish movements at a range of spatial and temporal scales and can provide details of fish movement over long periods (Ehrenberg & Steig, 2003). By recording long-term movement patterns and associated environmental conditions, we can gain valuable information about how fish utilize their environment and which factors strongly influence movement and distribution.

Biotic and abiotic factors, such as water quality and habitats, as well as behavioural and life history characteristics influence fish movement and distribution (Gubala, 2002). Estuarine environments are structured by vertical and horizontal gradients of salinity, temperature, dissolved oxygen, turbidity and other water quality variables. Estuaries are also subjected to rapid changes and wide variation in physical factors, particularly salinity and water temperature, as a consequence of freshwater inflows and tidal influences. Environmental factors can strongly influence fish movement and distribution as individuals seek out favorable conditions (Gubala, 2002). Habitat utilization also varies at a range of temporal scales (Lucas & Baras, 2000; Miller & Skilleter, 2006), including diurnal and tidal (Morrison *et al*., 2002), and within and between seasons (Young & Potter, 2003). Characterizing fish movement and habitat utilization patterns can provide insights into the ecology of fish and guide conservation strategies (Humston, *et al*., 2005; Semmens *et al*., 2007) and help predict stock responses to changes in their environment (Ault *et al*., 2003; Meynecke, *et al*., in press).

Black bream, *Acanthopagrus butcheri*, is a resident estuarine species distributed around southern Australian, including Tasmania. It is an important commercial, as well as recreational, species in some States, though in Tasmania black bream is a prescribed recreational species, ranking among the top five most frequently caught finfish by recreational fishers (Lyle 2005).

There have been several previous tagging studies on black bream in southern Australia. An early study by Butcher & Ling (1962) used traditional tagging methods to examine movement in East Gippsland, Victoria. The resultant tag recoveries suggested that migratory movement of black bream was very localized, and there was no indication that individuals moved out of the Gippsland Lakes. Weng (1971) also attempted tagging black bream in South Australia using three different kinds of external tags. This study also showed that movements were localized with little evidence of dispersal out of the river and/or estuary in which individuals were tagged. Lenanton *et al*. (1999) used external tags to investigate whether stock enhancement improved black bream catch rates for recreational fishers; in that study assessing movement patterns was not a priority. More recently, Hindell (2007) used acoustic telemetry to assess patterns of habitat utilization by black bream, examining regions with and without re-introduced large woody debris in two rivers of the Gippsland Lakes.

Black bream exhibit two major types of movement, namely spawning and habitat preference movements (Weng, 1971). Spawning seasons vary considerably between estuaries, commencing from early August and extending to late February (Stewart & Grieve, 1993). Although it is generally known that black bream migrate upstream to spawn, the timing and frequency of these spawning migrations and the time that individuals remain on the spawning grounds is poorly understood. Habitat preference movements relate to life cycle distributional patterns; for instance juvenile black bream (0^+ and 1^+ age groups) tend to inhabit the upper estuary whereas adults utilize a wider range of habitats within an estuary (Sakabe, unpubl. data). Habitat preference movements also include those related to feeding activity and environmental factors, such as salinity and temperature, whereby individuals actively seek areas with favorable environmental conditions.

In this study, movement patterns and habitat utilization by black bream over a period encompassing the spawning season was examined using acoustic telemetry. The timing and duration of upstream migrations related to spawning, the influence of tidal cycles and freshwater inflows on the movement and distribution of black bream were examined in a small temperate estuarine system located on the east coast of Tasmania.

2. MATERIALS AND METHODS

2.1. Study area

Black bream movement was studied in the Little Swanport Estuary, which occupies an area of approximately 6.5 km^2, and is located on the western side of Great Oyster Bay, between 42^o 18'S and 42^o 20'S and 147^o 59'E and 147^o 56'E (Fig. 1). The estuary is relatively shallow, ranging from approximately 1 to 9 m in depth at high tide. The deepest waters (>7 m) are located in the middle estuary. The estuary has a very narrow entrance, approximately 30 m wide and 5 m deep, and a long channel with numerous shoals and irregular shape. In the middle to lower estuary, there is an extensive band of seagrass, *Heterozostera tasmanica* and *Zostera muelleri*, on soft muddy and sandy bottoms. The former dominates and forms very dense beds in the middle estuary. Another seagrass species, *Ruppia megacarpa*, is very dense in the shallow water (<1 m), as well as being present in small quantities in the upper estuary. The Little Swanport River, which is the largest river that discharges into the Little Swanport Estuary, originates on Inglewood Hill, at an elevation of approximately 600 m above sea level and has a total length of approximately 61 km and a catchment area of approximately 610 km^2.

2.2. Equipment

VEMCO Model VR-2 acoustic receivers and VEMCO V8SC-2H-R04K coded acoustic transmitter pinger tags operating on 69 kHz frequency with 147 dB power output were used to monitor individual black bream movements over periods of up to six months. Acoustic tags were 30 mm long, 9 mm in diameter and weighed 3.1 g in water, with approximately one year battery life. The pinging sequence is repeated after a random delay of between 60 and 180 seconds; the random delay is to minimize the chance of signal collision if several tagged fish transmit simultaneously to the same receiver. Eight acoustic receivers were deployed in the Little Swanport Estuary and two in the Little Swanport River (Fig. 1) on 27th July 2005 and retrieved on 2nd February 2006. These receivers continuously monitor for the presence of unique, digitally coded transmitter signals emitted by the tags and then record the date, time and identity of tagged fish within the detection range of the unit. Each receiver was shackled to a mooring and buoyed with a subsurface float to ensure that the receiver remained vertical in the water column.

2.3. Detection range testing

The detection ranges of the VR2 receivers were tested by recording signals from a test transmitter at the surface and approximately 30 cm above the bottom. The test transmitter was deployed from a boat at approximately 100 m intervals from the receiver for the first 300 m and at 50 m intervals between 300 m and 600 m from the receiver. The location of the boat was checked by global positioning system (GPS). To match the time of detection of the test transmitter at the receiver, the watch used during this study was synchronized with the receiver's initial clock. Range testing was undertaken within two hours of low tide.

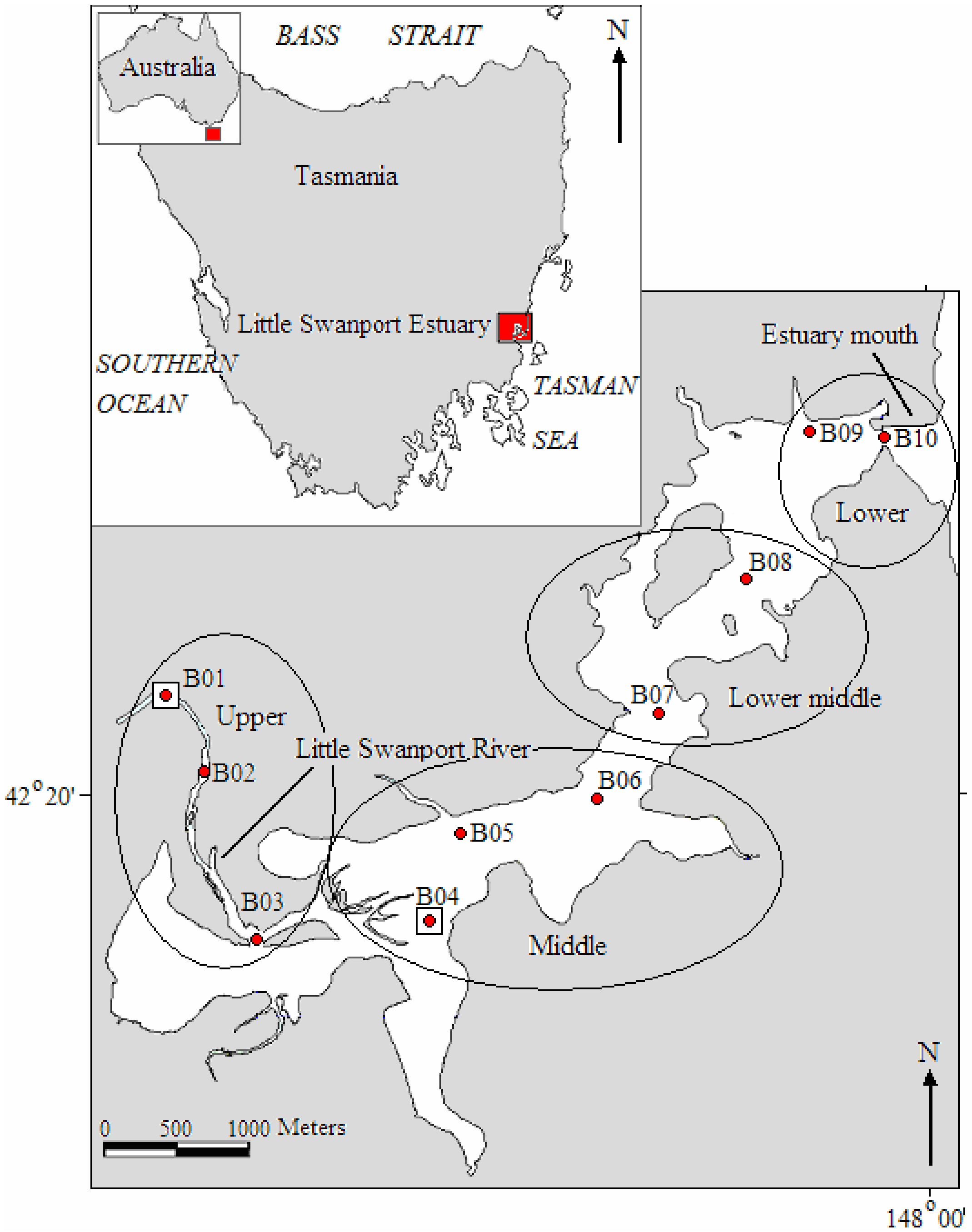

Fig. 1 Map of the study area with individual VR-2 hydrophone receiver locations indicated by circles and numbers (B01-B10). Squares indicate the sites where tagged fish were captured and released. For reporting and analysis the system has been divided into the Upper estuary (including the Little Swanport River, receivers B01-B03), Middle estuary, (receivers B04-B06), Lower middle estuary, (receivers B07 & B08), and Lower estuary (receivers B09 & B10).

2.4. Capture and surgical procedure of fish

Acoustic tags were surgically implanted into the peritoneal cavity of black bream. The fish were captured by gill net (three 10 m panels of mesh size 64, 89 and 105 mm) or by line fishing with bait. The gill net was set for no more than 30 minutes to minimize capture injures and stress. All captured black bream were immediately placed in a tub of clean seawater (approximately 40 L) and transported to a shore-based 300 L fish holding tank. Fish were then removed from the holding tank, anesthetised in a solution of 0.05 $ml.L^{-1}$ of Aqui-S in seawater and reached anesthesia stage 3 (MacFarland & Klontz, 1969) after 2-5 minutes. Fish were measured for fork length (± 1 mm) and then placed ventral-side up on a V-shape surgical table. During surgery, normal seawater was supplied over the gills using a squirt bottle. The surgical table was sprayed with Vidalife, which contained a scavenger of heavy metals, and polyvinylpyrrolidone to protect exterior body surfaces from loss of natural coating. A 15-20 mm long incision was made on the ventral midline between the pelvic fins and the acoustic tag was inserted vertically and gently pushed forward to be 20-30 mm anterior of the incision. The incision was then closed with two stitches, using synthetic absorbable suture, and oxytetracycline was injected near the pectoral fin at a dosage of 50 $mg.kg^{-1}$ fish weight (Summerfelt & Smith, 1990). All fish were further identified with an external T-bar anchor tag (Hallprint Fish Tag) inserted below the dorsal fin. Following surgery, fish were allowed to recover in a 70 L holding tank until they started to swim normally, and were then released near B01 or B04 receiver stations (Fig. 1).

Thirty-five black bream were tagged and released with acoustic pinger tags in the estuary between late-July and early September, before the start of spawning in October, to reduce possible negative effects on gonad development and spawning behaviour.

2.5. Tag retention and survival

Tag retention and survival were tested on wild black bream prior to commencing the field experiment. Black bream were captured by line-fishing in the Little Swanport Estuary and transported to the Tasmanian Aquaculture & Fisheries Institute. Fish were acclimatized in an outdoor 5000 L circular tank for a week prior to the experimentation. Dummy tags that were the same in size and weight as the acoustic tags were implanted using the surgical procedure described above. The tagged fish were stocked with five untagged individuals and supplied with a continuous flow of seawater for seven weeks. Fish were fed either prawns, crabs, horse mussels or gastropods every two days. The tank was checked daily for fish survival, and fish were removed from the tank and checked weekly for tag retention and healing process. Tag retention was checked by searching for lost tags on the bottom of the tank. The incision was considered to be healed when the epidermis had closed up over the whole length of the incision.

No additional damage to the skin and fins of both control and surgical groups was noted subsequent to tagging. The tagged fish returned to normal feeding about 24 hours after implantation. There were no mortalities in either control or surgical groups during the seven week holding period and no tags were expelled. Seven days after tagging all tagged fish had red or swollen incisions and new fibrous tissue had started to grow on the incisions. The site of the incision had effectively healed after 28-49 days.

2.6. Data analyses

Data were downloaded from the receivers at the completion of the study period using VEMCO's system hardware and software interface, and then transferred to Microsoft Access and Excel databases. Data from the first 24 hours following release of tagged fish were not used because of potentially atypical behaviour immediately following tagging.

Movement patterns were inferred by the number and duration of visit events to individual receivers. A visit event was defined as a continuous string of detections at a receiver where there was no more than 30 min break between consecutive observations (Stark *et al*., 2005). Consequently, a visit event could comprise either one hit or a large number of continuous hits at one receiver. If an acoustic hit was registered on another receiver, this signaled the start of a new visit event at that receiver. Visit event duration was the time between the first and last detection of a visit event plus one minute, ensuring a minimum visit duration of one minute for a single hit. In situations where fish were detected by a receiver, then recorded just once by an adjacent receiver within one minute, and then immediately redetected by the initial receiver, the data were treated as if the fish had remained continuously within the detection range of the initial receiver. This situation only applied to receivers B05 and B06 and may have been due to partial overlap in detection ranges (refer below).

This study provided information on the number of visit events and visit event duration for each tagged fish in each region of the estuary between August 2005 and January 2006. Data were assessed for normality and homogeneity of variance prior to analyses using box plots and residual plots. Data were $\log_{10}(X+1)$ transformed where necessary to produce acceptable homogeneity of variances and distribution of residuals. Number of visit events per month and duration of visit events per month were analyzed using a three-factor randomized block ANOVA. Month and region were treated as fixed factors, with fish treated as random blocking factor.

Fourier transformation analysis, which decomposes a regular time series into a finite sum of sine and cosine waves of different frequencies, was used to assess temporal periodicity in black bream movement. For each fish, the number of detections per hourly interval was calculated for each receiver. For every hourly interval, whether or not the fish was detected by the array was calculated as presence or absence. All data series were analyzed using the software package XLSTAT (http://www.xlstat.com/en/home/).

3. RESULTS

3.1. Receiver detection range

Detection ranges for all VR2 hydrophones during low tide are shown in Fig. 2. Detection ranges were highly dependent on the study site conditions, with maximum detection distances ranging from 200 to 600 m. There was no overlap between the detection ranges of the VR2 receivers during low tide. However, based on the occurrence of more or less simultaneous hits on receivers B05 and B06 in a small number of instances, it was likely that under certain conditions the detection ranges for these receivers overlapped periodically. Overall there were thirty-six visit events (0.4% of total visit events and <0.001% of total detections) that appeared to have been affected by this phenomenon. The detection ranges of B04, B09 and B10 were relatively narrow due to the proximity of shallow banks, while B05 and B07 appeared to effectively detect the vast majority of tagged fish present in these areas. For instance, during the six month field experiment, 96.5% of all upstream and downstream movements involving tagged fish moving between B03 and/or B04 and B06 and/or B07 were also detected by receiver B05. Similarly, all fish that were detected to have moved between the middle estuary (B04-B06) and lower middle and lower estuary (B08-B10) were also detected by receiver B07.

Unfortunately, the two upstream receivers (B01 & B02) flooded part way through the deployment, resulting in no movement information being available for the Little Swanport River. However, as B03 was positioned where the Little Swanport River entered the estuary, a width of approximately 10 m, it is highly probable that any fish moving further upstream into the river would have been detected at this point, though not all fish detected at B03 can necessarily be assumed to have moved further upstream. At the estuary mouth the detection range of B10 covered the deep entrance channel but did not extend to the adjacent shallow sand banks (<1 m) and thus it is possible that fish moving about on the shallow banks may not have been detected by this receiver.

3.2. Tracking of black bream

Individual data on fish size, location and date of release, location and date of last contact, and total period tracked (days since tagged) are provided in Table 1. Sex of individual fish was unknown, however, based on known size at maturity, all tagged fish would have been mature. The VR2 hydrophone receivers recorded a total of 158,181 hits from 34 of the 35 tagged fish, representing 8,215 discrete visit events. Thirty-one fish were tracked for over 120 days and 25 of the tagged fish were last detected within a week of the receivers being removed, indicating that tags remained functional throughout the study period and that survival was very high. Fish No. 5 was not detected at any VR2 receivers despite being released within the detection range of receiver B04, implying that the tag may have malfunctioned. Fish No. 31, which was released at B04, was captured by a recreational angler on 11th November 2005 in the Little Swanport River (near B02) after more than two months at liberty. The fish was reported to have been in very good condition and the wound site had fully healed.

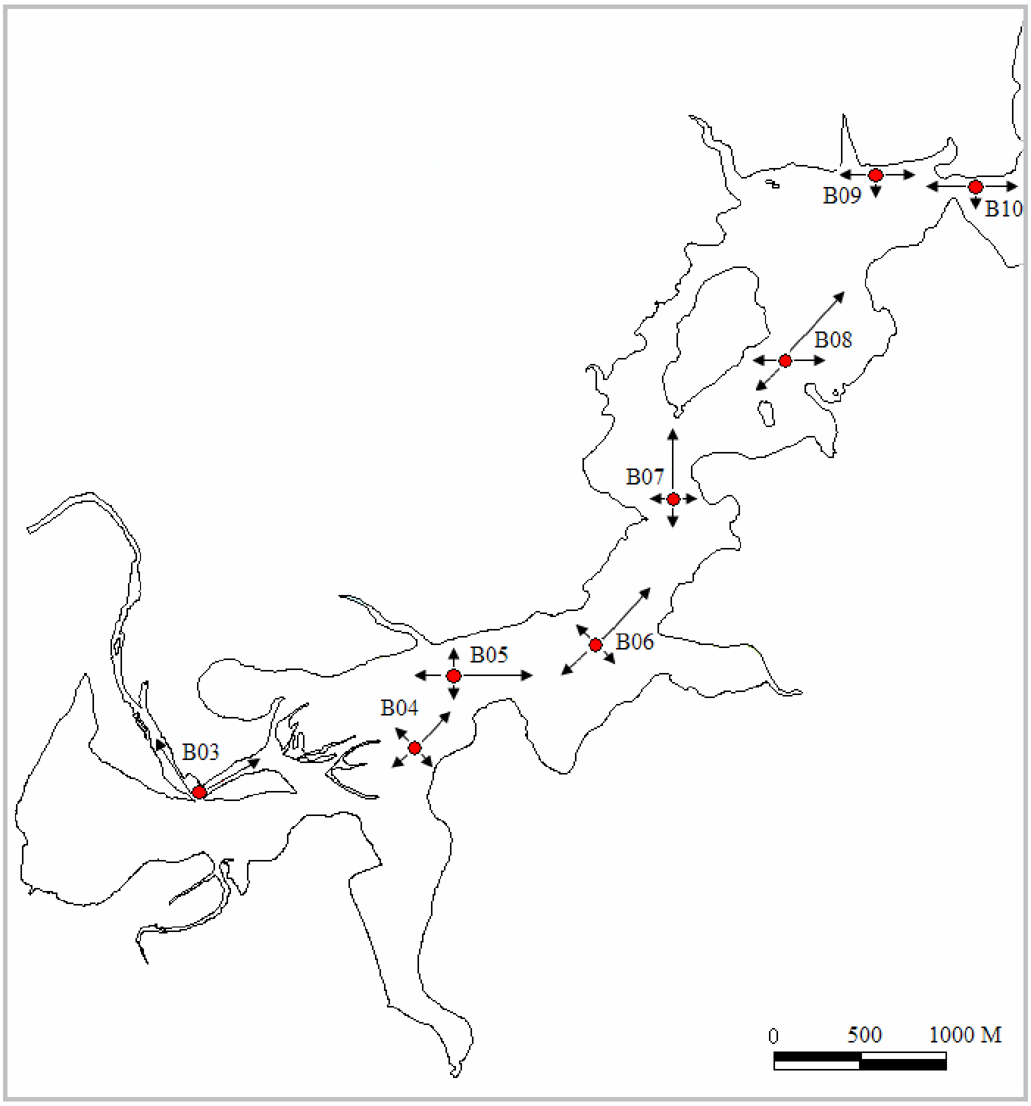

Fig. 2 Detection ranges for receivers B03-B10. Circles indicate receiver positions and arrows represent maximum detection ranges during low tide.

3.3. Movement patterns and habitat usage

All of the successfully tagged fish were detected at least once by each of the receivers placed in the upper and middle reaches of the estuary (i.e. B03-B06), while 28 and 21 individuals visited the lower middle estuary receivers B07 and B08, respectively (Fig. 3). All visit events at B09 and B10 were made by just eight and six individuals, respectively. Positioned at the entrance of the Little Swanport River, B03 recorded the greatest number of detections (92,278 hits) and accounted for 34% of the total visit events. Around 40% of all visit events occurred at the middle estuary receivers, B05 and B06, with a further 14% of visit events from B04. By contrast, B10 positioned at the entrance of the estuary recorded the lowest number of detections (47 hits) accounting for just 0.2% of the total number of visit events (Fig. 4).

Table 1: Summary of tracking data for 35 acoustically tagged black bream.

Fish ID	Fork Length (mm)	Date tagged and released	Release position/Last detection	Last date detected	Total days in tracking
1	330	30/07/2005	B04/B08	04/01/2006	159
2	330	30/07/2005	B04/B05	01/02/2006	187
3	280	30/07/2005	B04/B07	31/01/2006	186
4	320	30/07/2005	B04/B05	31/01/2006	186
5	430	30/07/2005	B04		0
6	325	30/07/2005	B04/B5	01/02/2006	187
7	311	30/07/2005	B04/B06	31/01/2006	186
8	284	30/07/2005	B04/B05	01/02/2006	187
9	318	30/07/2005	B04/B03	01/02/2006	187
10	327	04/08/2005	B04/B04	01/02/2006	183
11	420	11/08/2005	B01/B03	16/01/2006	159
12	325	17/08/2005	B04/B04	01/02/2006	170
13	318	23/08/2005	B01/B08	28/12/2005	128
14	293	23/08/2005	B01/B04	01/02/2006	163
15	294	23/08/2005	B01/B06	01/02/2006	163
16	330	23/08/2005	B01/B03	03/01/2006	134
17	420	23/08/2005	B01/B03	29/01/2006	160
18	338	23/08/2005	B01/B05	01/02/2006	163
19	285	23/08/2005	B01/B03	01/02/2006	163
20	352	23/08/2005	B01/B04	31/01/2006	162
21	337	23/08/2005	B01/B08	23/11/2005	93
22	356	02/09/2005	B04/B05	01/02/2006	153
23	272	02/09/2005	B04/B06	25/01/2006	146
24	340	02/09/2005	B04/B05	25/01/2006	146
25	311	02/09/2005	B04/B03	01/02/2006	153
26	280	02/09/2005	B04/B09	31/01/2006	152
27	292	02/09/2005	B04/B03	01/02/2006	153
28	297	02/09/2005	B04/B10	14/01/2006	135
29	268	02/09/2005	B04/B04	01/02/2006	153
30	278	05/09/2005	B04/B08	31/01/2006	149
31	327	05/09/2005	B04/B03	07/11/2005	64
32	295	05/09/2005	B04/B05	04/01/2006	122
33	330	05/09/2005	B04/B07	17/11/2005	74
34	342	05/09/2005	B04/B09	01/02/2006	150
35	296	05/09/2005	B04/B10	26/01/2006	144

As a general trend, the number of visit events decreased between the uppermost receiver (B03) to the lowermost receiver (B10), with a sharp fall occurring at B07, indicating that most of the localized movements occurred within the upper and middle regions of the estuary (B03-B06) (Fig. 4). The few tagged fish detected at the estuary entrance (B10) were typically redetected within a short period further up into the estuary. There were two exceptions (Fish Nos 28 & 35) which were last detected at B10 shortly before the receivers were retrieved. As such it was uncertain as to whether they had left the estuary or moved further upstream at a later date. The proportion of the combined visit event duration by receiver showed a similar trend to that for visit events, although the average time detected was clearly greater at B03 than at the other receivers as indicated by the proportionally higher (>60%) importance of this receiver.

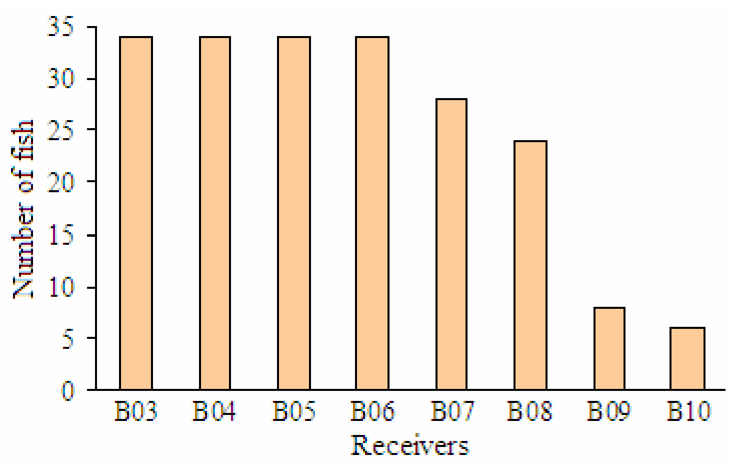

Fig. 3 Numbers of individual tagged fish detected by receiver during the experimental period.

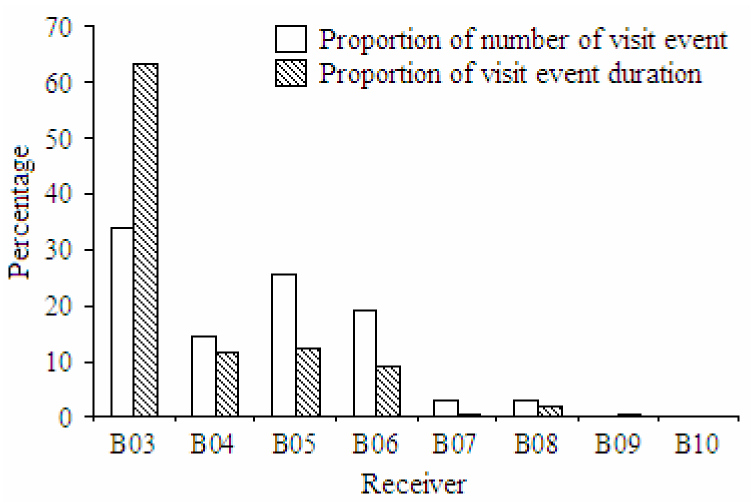

Fig. 4 Percentage of total visit events and total visit event duration for all tagged black bream recorded by each VR2 receiver during the experimental period.

Considering the average number of visit events per fish (N_F), average total visit duration per fish (ED_F), and number of fish detected in each region by month, it was evident that black bream showed temporal and spatial variability in their utilization of the estuary, with a strong preference for the upper and middle regions of the estuary (Table 2 and Fig. 5). ANOVA detected significant month and region effects on N_F and ED_F, and there were strong two-way interactions between month, region and fish (Table 2). Although the average number of visit events tended to higher in the middle estuary in most months, the average time spent in the upper estuary tended to be greater (Fig. 5). Between September and December the average number of visit events to the upper estuary remained relatively constant whereas in the middle estuary there was a marked increase in the visit events in September and October (Fig. 5). While the average duration that fish were detected in the upper and middle regions of the estuary was roughly equivalent in September and October there was a strong shift to longer periods of time being spent in the upper reaches in November and December. By January there was an increase in events and time spent in the middle and lower regions of the estuary. In fact the only visit events recorded in the lower estuary occurred in August and January.

Throughout the study period the proportion of tagged fish detected in the lower middle and lower estuary was consistently lower compared with upper and middle regions (Fig. 5c). Over 90% of the successfully tagged fish were detected in the upper and middle estuary in all months apart from August and January. The proportion of the tagged fish detected in the lower middle estuary declined steadily from around 80% to less than 20% between August and December before increasing slightly in January. Comparatively few individuals were detected by receivers in the lower estuary, most detections occurring in January.

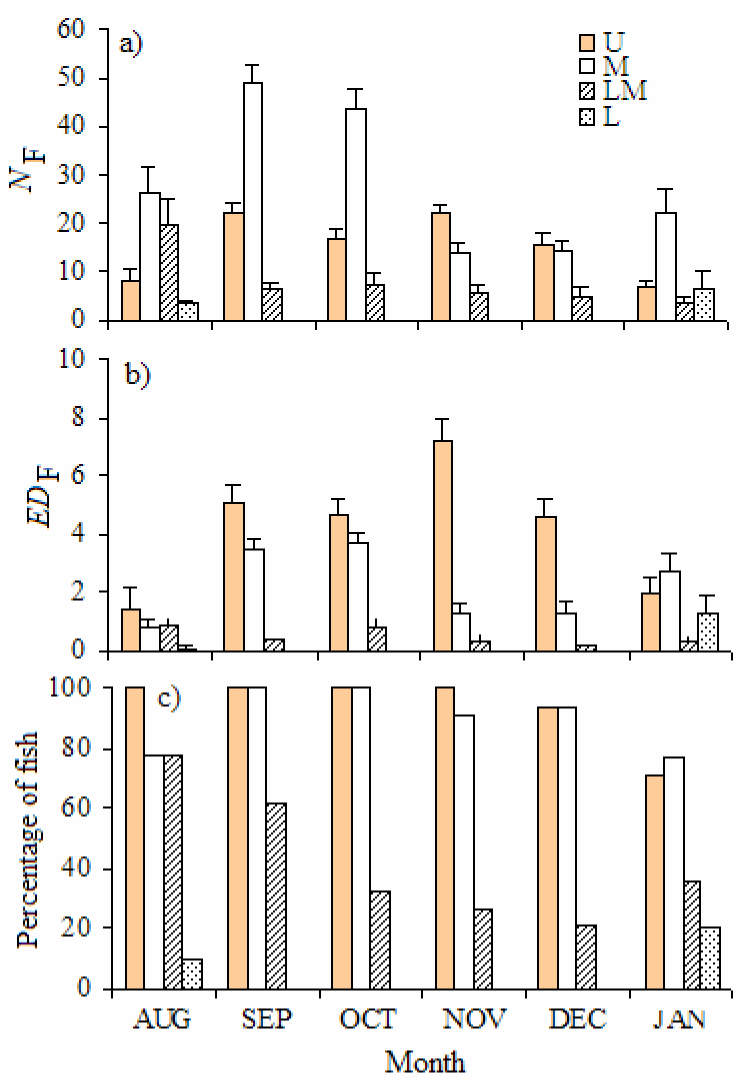

Fig. 5 (a) Average number of visit events per fish (N_F), (b) average total visit duration per fish (ED_F) (days) and (c) percentage of successfully tagged fish observed in each region by month. U: upper estuary (B03); M: middle estuary (B04-B06); LM: lower middle estuary (B07 & B08); L: Lower estuary (B09 & B10). Note: percentage of successfully tagged fish was calculated by total number of fish observed in each region divided by total number of successfully tagged in the estuary. The numbers of successfully tagged fish were 9 for August, 34 between September and November and, following the reported capture of one fish during November, 33 for December and January. Error bars are one standard error.

Table 2: Summary of the analyses of three-factor randomized blocks ANOVA to test difference in the mean number of visit events (N_F) and total visit event duration per fish (ED_F) by month, region and fish (blocking factor).

	N_F			ED_F		
Source	**d.f.**	***MS***	***P***	**d.f.**	***MS***	***P***
Month (M)	5	3.92	<0.001	5	1.63	<0.001
Region (R)	3	46.176	<0.001	3	37.32	<0.001
Fish (F)	33	0.32	0.787	33	0.16	0.992
M×R	15	2.22	<0.001	15	1.36	<0.001
M×F	151	0.17	<0.001	151	0.11	<0.001
R×F	99	0.29	<0.001	99	0.30	<0.001

3.4. Diurnal activity patterns

Detections recorded by receivers B03 and B05 were grouped into hourly bins by month to examine periodicity in black bream activity at these sites. In most months there was a clear pattern in detections at B03, with detections increasing progressively during the afternoon to a peak within a few hours of sunset, and then falling sharply around sunrise and remaining at low levels until around midday (Fig. 6). During January, however, there was no clear pattern, presumably influenced by the limited data available for the month. Assuming that increased detections reflect limited movement, this does not discount small-scale movements within receiver detection ranges, these data suggest that black bream were more active during daylight hours and less active during the night. The diurnal pattern of detections observed at B05 was less pronounced than that at B03, though there tended to be fewer detections during daylight hours in most months apart from September (Fig. 7). In September, there was a clear increase of detections during daylight hours, a trend mainly influenced by detections recorded between 12th and 20th September when the estuary was under the influence of a major flood event (refer below). This apparently anomalous activity pattern may have occurred in response to the flood, with no clear pattern was observed outside of the flood period.

For most fish, the Fourier analysis revealed two main patterns based on the presence/absence data; a diurnal movement pattern (median 23.8 h) was the most obvious, but a tidal movement pattern (median 12.1 h) was also observed, though less frequently (Table 3). There was substantial individual variation in the relative magnitude the diurnal and tidal behaviour activity peaks (Table 3; Fig. 8).

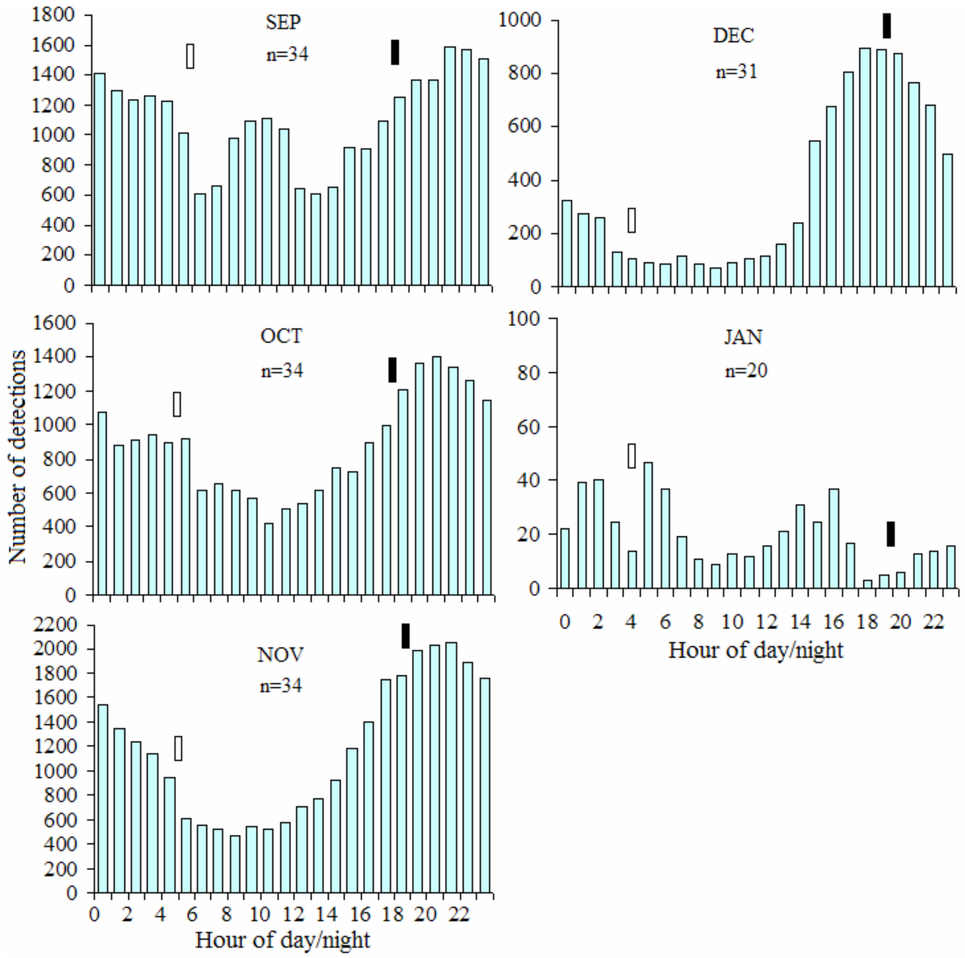

Fig. 6 Number of detections at B03 deployed at the entrance of the Little Swanport River sorted into hourly categories. n: total number of tagged fish detected in each month. Note different scale for y-axes. Sunrise and sunset are indicated by white and black squares, respectively.

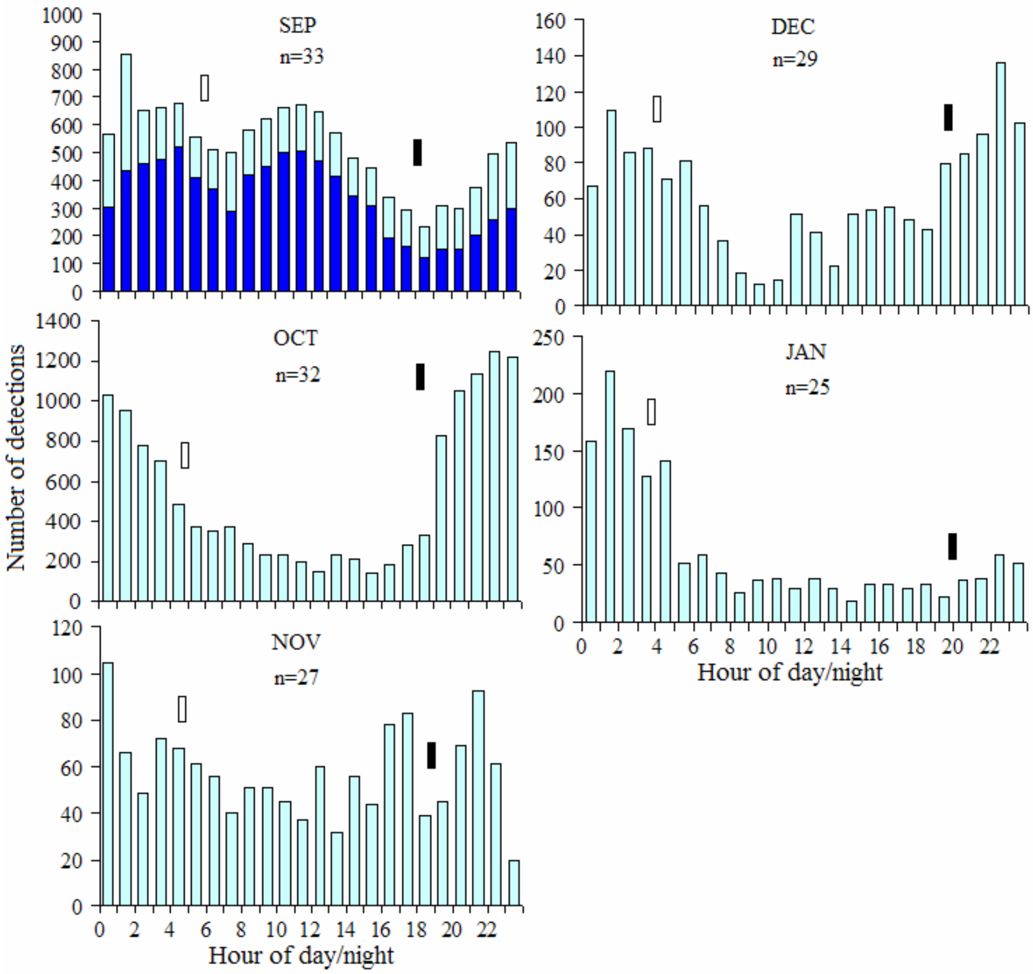

Fig. 7 Number of detections at B05 deployed in the middle estuary sorted into hourly categories. n: total number of tagged fish detected in each month. Note different scale for y-axes. Sunrise and sunset are indicated by white and black squares, respectively. In September, number of detections during the heavy flood event (12–20 September 2005) are shown as dark bars.

Table 3: Periodicity of black bream activity based on Fourier analysis.

The dashes indicate no peak detectable.

Fish ID	Presence/absence First peak (h)	Presence/absence Second peak (h)	Fish ID	Presence/absence First peak (h)	Presence/absence Second peak (h)
1	-	13.9	**19**	22.6	12.5
2	24.8	12.1	**20**	23.9	12.1
3	-	-	**21**	23.7	12.1
4	23.7	-	**22**	-	12.4
6	23.7	-	**23**	23.6	11.9
7	23.7	12.1	**24**	23.8	11.9
8	23.1	12.2	**25**	23.8	9.8
9	23.7	-	**26**	23.6	-
10	23.8	-	**27**	23.8	11.9
11	23.6	11.5	**28**	-	16.3
12	23.1	11.4	**29**	23.6	11.8
13	26.6	-	**30**	-	-
14	22.7	-	**31**	27.5	6.2
15	25.4	-	**32**	23.8	11.4
16	23.8	-	**33**	20.4	10.8
17	23.9	-	**34**	24.2	12.9
18	23.9	12.4	**35**	24.3	-
			Median	23.8	12.1

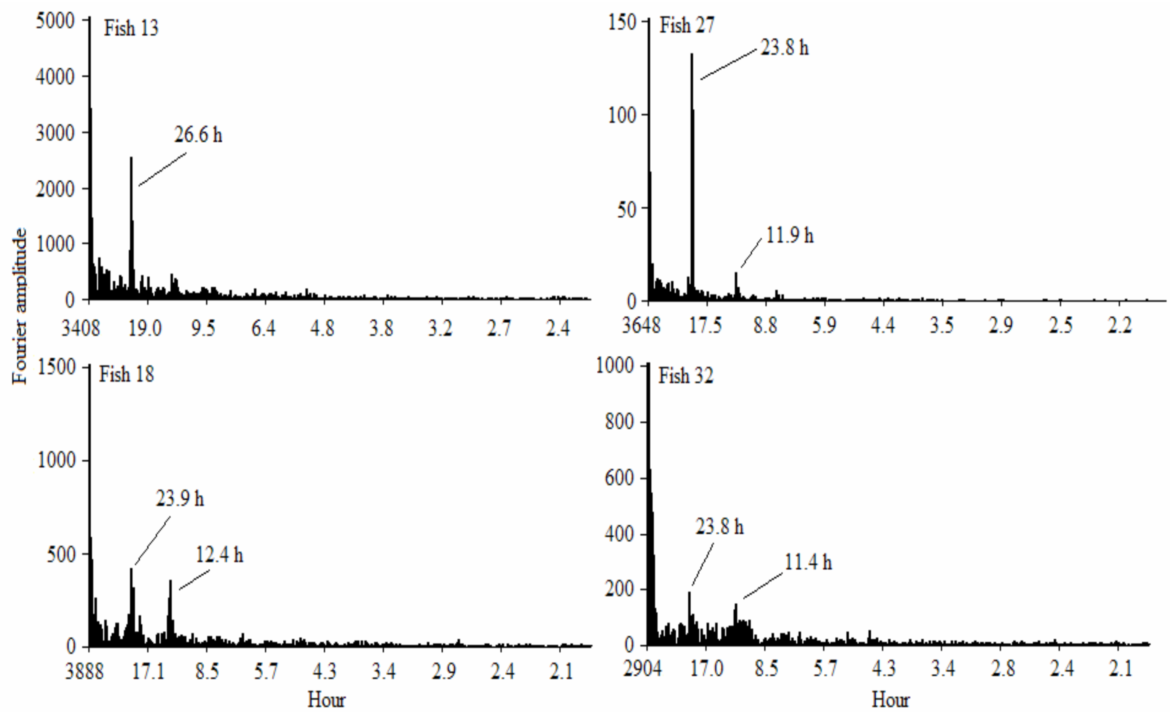

Fig. 8 Examples of Fourier analysis of presence/absence every hour for four tagged black bream.

3.5. Tidal influences on movement

To examine relationships between tidal cycle and movement, tidal influenced movement was assumed to have occurred if a fish was detected by more than one receiver during a given flood (incoming) or ebb (out-going) tidal phase, with detections that occurred 30 minutes either side of the predicted high or low tide excluded from this analysis. Whether net movement had occurred and its direction (upstream or downstream) was determined by reference to the receivers at which the initial and final detections within the given tidal phase had occurred. For example if initial detection occurred at B05 and final detection occurred at B03, an upstream movement of two receivers was recorded.

A summary of tide-related movement patterns is shown in Fig. 9. Overall, 82% of all tidal influenced movement (as defined above) during flood tide was upstream, with the most common displacement being one receiver (46%), followed by two receivers upstream (28%) though there were a small number of instances involving upstream movements of up to 6 receivers. In a small proportion of instances (8%), tagged fish exhibited downstream movement during the flood tide, the balance (9%) resulted in no net displacement. Conversely, during the ebb tide, around 73% of the tidal influenced movements were downstream, most (37%) by one receiver, followed by two receives (28%), with small proportion moving downstream by three or more receivers (Fig. 9). Upstream movement was rare during the ebb tide (7%) while the proportion of instances resulting in no net movement (20%) was minor but slightly higher than during the flood tide.

Examples of tidal related movement patterns for individual fish are shown in Fig. 10. Fish No. 3 was detected initially by B03, approximately 7 km upstream from the estuary mouth at the beginning of the ebb tide. As the tide fell, it moved downstream as far as B08 and then returned upstream to B06 by the following flood tide. This pattern of movement was then repeated during the following days, in one instance with the individual traveling as far as the estuary mouth (B10) on the out-going tide. Generally similar tide-related movements were observed in Fish No. 7, but there were some differences. This individual occasionally detected more or less continuously by a single receiver for extended periods of time, and thus apparently not always moving in relation to the tidal cycle. This was clearly evident between midnight of 7th and midnight of 8th August when the fish was detected more or less continuously at B08 during both ebb and flood cycles.

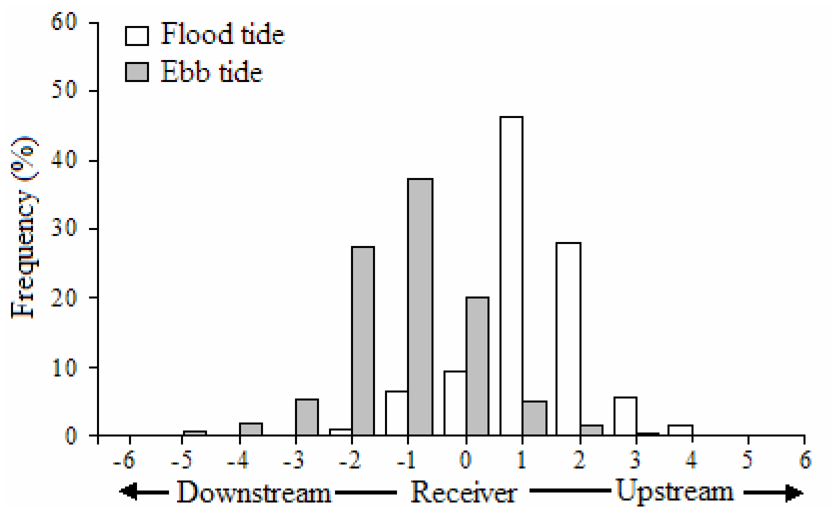

Fig. 9 Summary of flood tide and ebb tide related movement for black bream in the Little Swanport Estuary. The x-axis represents the number of receivers fish moved to from the position of the first detection upstream (positive numbers) and downstream (negative numbers). 0 indicates no net movement during the tidal phase.

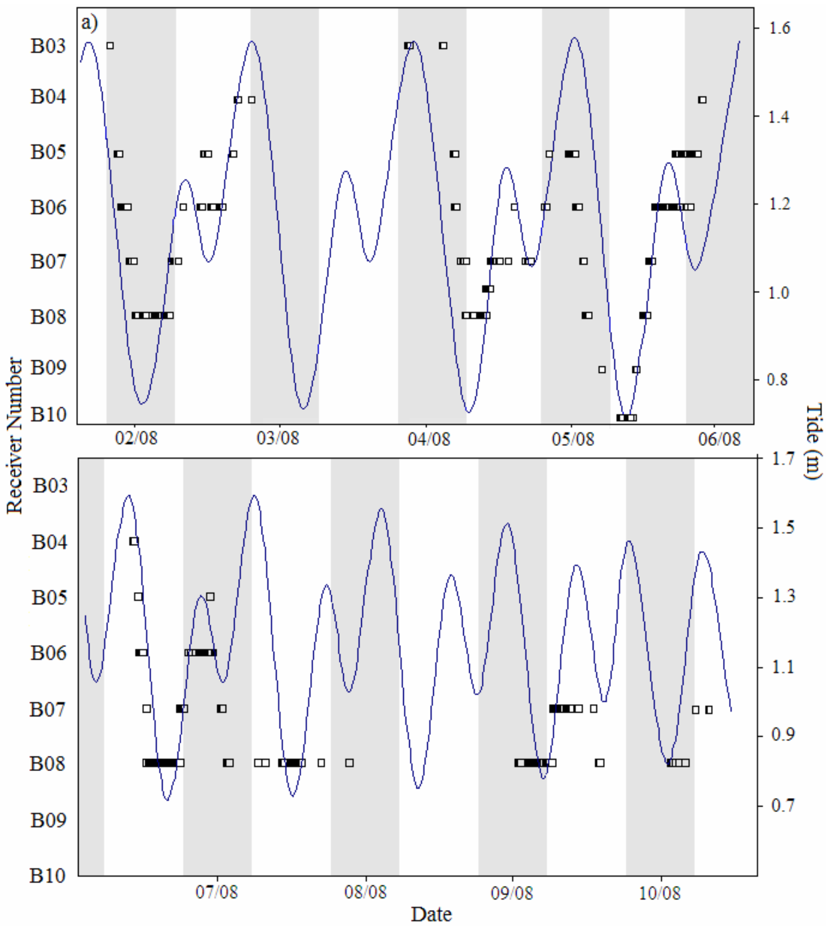

Fig. 10 Tidal influence on upstream and downstream movements for a) Fish No. 3 and b) Fish No. 7. Open square symbols indicate tag transmission detected at individual VR-2 receivers. Cyclical variation in tide height is indicated as continuous line and gray bars indicate night time.

3.6. Upstream migration

Due to the malfunction of receivers B01 and B02 in the Little Swanport River, we were unable to obtain information about upstream movements onto the spawning grounds. However, if it is assumed that fish which were detected and then redetected at B03, without detection at another receiver during the intervening period, had moved upstream, then some inferences can be made about the potential utilization of the Little Swanport River. When downstream redetections occurred, 95% fell within 3 days of the last detection at B03. It was assumed, therefore that there was a high probability that fish that were redetected at B03 after intervals of more than 3 days had moved further upstream during the intervening period. In fact, Fish No. 31, which was recaptured by a recreational angler on 11th November near the position of B02 had been last detected on 7th November at B03, presumably as it moved upstream into the Little Swanport River.

Furthermore, since tagged fish often exhibited movements linked to tidal cycles, it was also assumed that individuals detected at B03 and then redetected within 12 hours at the same receiver, without detection at another receiver, had effectively remained within the general vicinity of B03 during the period. Based on this assumption, Fig. 11 represents periods during which individual fish were detected continuously at B03, or with breaks of less than 12 hours between visits without detections at other receivers. In addition, inferred periods (≥3 days) that individuals may have been further upstream in the Little Swanport River are represented (white bars). These data suggest that there were up to 107 events involving upstream migration. The number of such migration events increased gradually from August to November, to a peak of 24 events in November. There was considerable variability between individuals that were inferred to be on upstream migration in terms of frequency and duration (Fig. 11). Some fish, for example Fish Nos. 6, 8 & 9, were detected more or less continuously at B03 throughout this study, whereas Fish Nos. 3, 10 & 12 were detected much less frequently. Throughout the study period it was evident that at various times relatively large numbers of tagged fish were detected concurrently at B03 (Fig. 11).

A total of 1075 visit events (continuous detection periods at B03 with interval of less than 12 hours between visits) were recorded at B03 during the experimental period. ANOVA detected significant difference in the average number of visit events between months (ANOVA, $F_{5,160}$=6.287, P<0.0001). The average number of visit events per fish was the lowest in August but increased sharply in September and peaked in November, with 293 visit events recorded and then fell steadily, to return to August levels in January (Fig. 12a). Average monthly visit duration at B03 followed essentially the same trend (Fig. 12a) with significant difference between months (ANOVA, $F_{5,160}$=10.093, P<0.0001).

The average number of inferred upstream visits did not differ significantly between months (ANOVA, $F_{5,52}$=1.574, P=0.184), whereas there was a significant difference between months in the average duration of the inferred upstream residency (ANOVA, $F_{5,52}$=6.043, P<0.0001). The average number of inferred visits per fish ranged between about 1.0-1.4, being slightly higher in October-December, with the number of individuals involved with the inferred upstream visits being much higher between September and December than in August and January (Fig. 12b). The overall average visit duration per fish was 9.2 days, the highest value being in August, influenced by inferred periods of 30 days for just two individuals. Discounting August, visit duration rose steadily from September to peak in November/December at around 10 days, and then declined slightly in January (Fig. 12b).

When rainfall was considered in relation to detections at B03, or inferred upstream migrations, an interesting pattern emerged (Fig. 11 & 13). Generally the numbers of fish detected at B03 fell sharply after periods of relatively high rainfall, such as days when precipitation levels of over about 20 mm were recorded (e.g. daily rainfall of 77.6 mm on 12th Sep, 28.2 mm on 9th Oct, 24 mm on 23rd Oct and 20.4 mm on 4th Dec 2005). Most of the tagged fish moved further downstream and were detected at receivers in the middle or lower middle estuary. Fish were typically not redetected at B03 for several days following these rain periods.

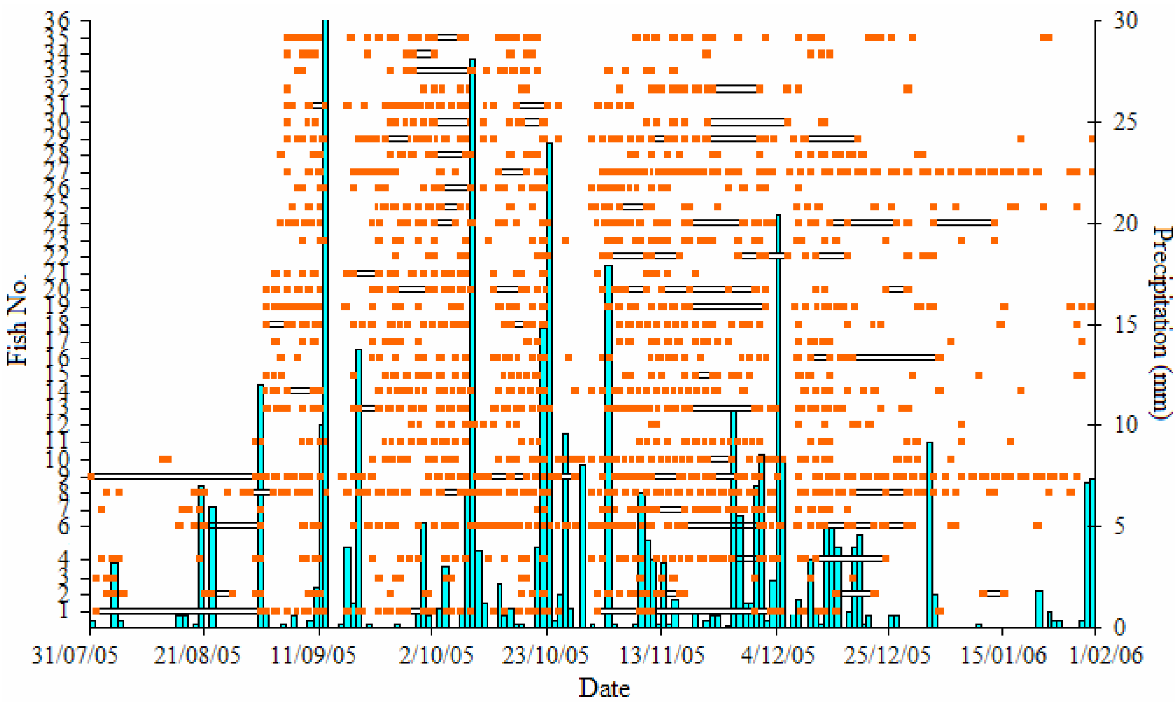

Fig. 11 Periodicity and timing of inferred upstream spawning migration of individual tagged black bream in the Little Swanport Estuary. Horizontal grey bars represent continuous detection periods at B03 with interval of less than 12 hours between visits without detection at other receivers, and white bars represent the periods between detection and redetection at B03, without detection at other receivers. Vertical bars represent daily rainfall (mm). Note: on 12th September, daily rainfall of 77 mm was recorded, but the bar has been truncated for clarity.

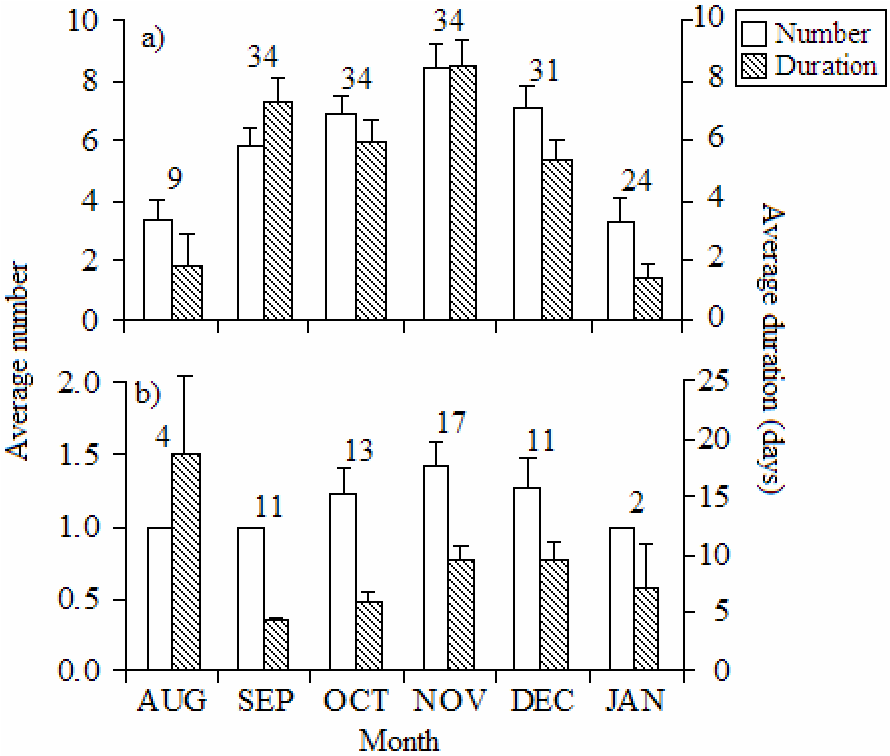

Fig. 12 a) Average number and duration of visit events at B03 and b) average number and duration of inferred upstream visits. Error bars represent one standard error and numbers represent number of tagged fish detected.

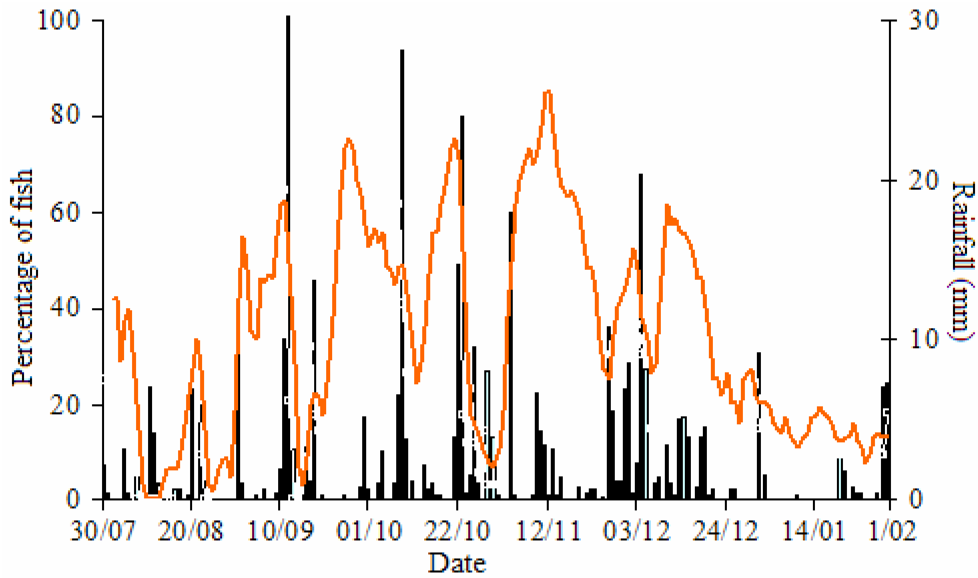

Fig. 13 Proportion of tagged fish detected by B03 (a running three point average is represented to smooth the trend line). Vertical bars represent daily rainfall (mm). Note: on 12th September, daily rainfall of 77 mm was recorded, but the bar has been truncated for clarity.

3.7. Movement during a major flood event

Heavy rainfall on 12th September 2005 caused the largest flood event in the Little Swanport Estuary during this study. Water levels in the upper estuary increased by approximately 3-4 m (Appendix 1). The waters of the upper estuary (around B03) became fresh while brackish water (> 20‰) persisted in the deeper areas of the middle estuary region (around B05) (Fig. 14). It took about a week before the bottom salinity at B03 exceeded 5‰. Visit events over the period prior to, during, and following the flood (4-27 September) were grouped into upper (B03), middle (B04-B06), lower middle (B07 & B08) and lower (B09 & B10) estuary and are shown in Fig. 15. Prior to the flood most of the visit events occurred in the upper and middle estuary. However, during the flood the proportion of events in the upper estuary declined dramatically, as fish moved downstream into the middle and lower middle estuary. Most of the visit events during 12-20 September occurred in the middle estuary. Ten days after the flood started, there was a sharp increase in the proportion of visit events to the upper estuary, indicating a general movement of fish back upstream. During the flood event there was no evidence of any tagged individuals having moved out of the estuary. The relative duration of time spent within each region over the period exhibited the same trend as for visit events (Fig 15).

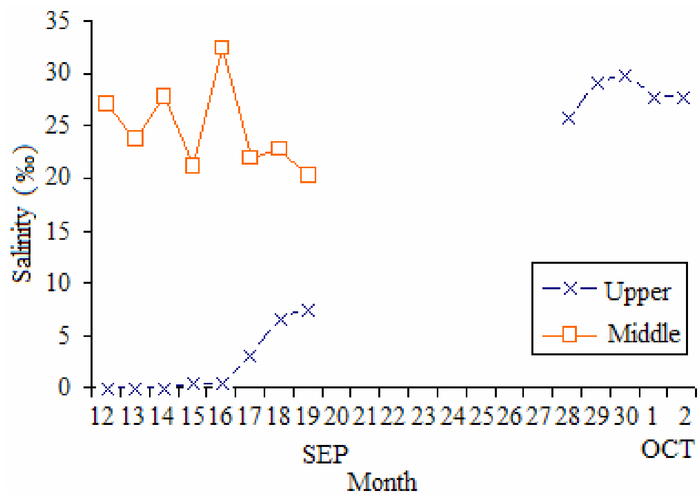

Fig. 14 Bottom salinities recorded in the upper (near B03) and middle (near B05) estuary between 12th September and 2nd October 2005. No data were available for 20-27 September.

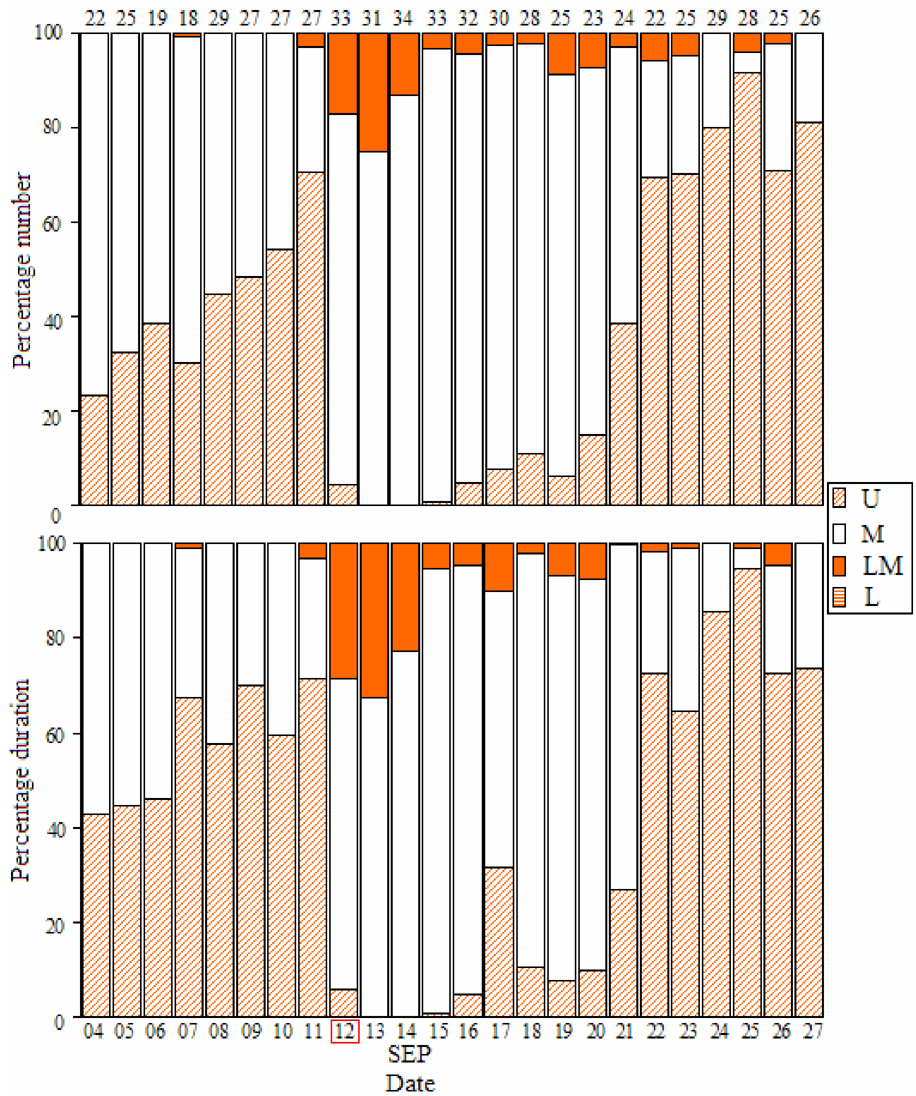

Fig. 15 Percentage of visit events (above) and visit event duration (below) by day between 4th and 27th September 2005. Visit events by receiver were pooled as Upper (B03), Middle (B04-B06), Lower Middle (B07&B08) and Lower estuary (B09 &B10). Square on the date indicates the highest daily rainfall recorded during the study period. Number of tagged fish detected by the receiver array on each day is shown.

4. DISCUSSION

4.1. Movement patterns and habitat utilization

This study has successfully used acoustic telemetry to described black bream movement patterns within an estuarine environment. Hindell (2007) also found that black bream responded well to surgical implantation of tags and could be successfully tracked over a relatively long period of time.

In the main, black bream undertook localized movements within the Little Swanport Estuary, exhibiting diurnal and tidally related activity, involving movement at the scale of kilometers within the estuary. This study has clearly indicated that adult black bream have a preference for the upper and middle regions of the estuary, where typical estuarine habitats and environmental conditions occur. In this region, freshwater inflows cause greater variability in water conditions, especially salinity, than in the lower estuary, where more constant marine conditions persist. Thus in the context of the entire estuarine system, black bream primarily utilize a narrow range of available habitats, an observation that is consistent with that reported for the species in the Swan River Estuary, Western Australia (Dibden *et al*., 2000) and the related *Acanthopagrus berda* in mangrove creeks (Sheaves *et al*., 1999). Within this relatively narrow habitat range, black bream showed spatial and temporal variation in habitat utilization. Fish spent more time in the upper estuary between September and December than at other times covered by this study, presumably linked to spawning activities in the upper reaches, including the Little Swanport River. Furthermore, fish were rarely detected in the lower middle and lower estuary during the study period, implying that these regions were relatively unimportant for black bream. Hindell *et al.* (in press) also reported that black bream in the much larger Gippsland Lakes system utilized the upper reaches of the rivers more than the lakes during the spawning season (July-November), and that fish residency time in the downstream lakes areas increased gradually after the spawning season.

Black bream appeared to be more active during daylight hours than at night, with more detections recorded during nighttime at a given receiver, indicating that fish were more likely to remain within the detection range of the receiver at night and thereby implying limited movement. Fewer detections during daytime hours were assumed to reflect movement between habitats, possibly in search of prey. Greater activity during daylight hours was also evident in the feeding periodicity of this species, showing an increase of feeding activity prior to sunset with little evidence of night feeding activities (Sakabe, unpubl. data). However, during September the diurnal pattern in activity was less distinct with increased detections in the morning (8:00-11:00 a.m.) at B03 and consistently higher detections during daylight hours at B05. It is unclear why detections at B03 increased during the morning period, but the pattern observed at B05 may be related to the influence of the major flood event between the 12-20 September. Since this receiver was deployed in a deep channel in the middle estuary where the heavy freshwater inflow presumably had reduced impacts, with brackish conditions persisting, it is possible that the tagged fish remained within the detection range of the receiver throughout long periods of the day to avoid more unfavorable conditions.

This represents the first study to demonstrate the link between tidal cycles and small-scale movements in black bream, as inferred from the Fourier analysis and patterns of movement between receivers. Black bream typically moved with the current during both flood tide and ebb tides, and regularly travelled distances of up to several kilometres during a tidal cycle, although most movements were less than about 2 km (2 receivers). Connections between movement and tidal exchange have been demonstrated in another sparid, *Pagrus auratus*, in a New Zealand estuary (Hartill *et al*., 2003). Tidal movements in that species tended to be more limited, generally in the order of several hundreds of meters upstream and downstream during a given tidal cycle. Another estuarine-dependent species exhibiting tidal movement is the spotted grunter, *Pomadasys commersonnii*, which move extensively between the lower reaches of the Great Fish River (South Africa) during low tide and upstream during high tides (Childs *et al*., 2008). Utilising tidal forces in this manner enables fish to move between habitats with minimum energy cost (Almeida, 1996), such that they can maintain more stable environmental conditions, particularly salinity, and/or accessing foraging habitats. Colton & Alevizon (1983) and Humston *et al.* (2005) reported that bonefish, *Albula vulpes* venture onto tidal flats during periods of high tide and retreat into deep channels during periods of low tides, suggesting that they respond to the dynamics of tide flow to gain access to very shallow waters for foraging. The thin-lipped grey mullet, *Liza ramada*, inhabiting the middle reaches of the Tagus estuary (Portugal), also uses the tidal cycle to access extensive intertidal mud flats which only become available during periods of high tide inundation (Almeida *et al*., 1993; Almeida, 2003). Black bream may use the same strategy since there are extensive intertidal mud flats within the Little Swanport Estuary and these areas support many benthic invertebrates, including the gastropod *Zeacumantus diemenensis*, which is a preferred prey of black bream (Sakabe, unpubl. data).

Salinity also emerged as an important factor influencing black bream movements and distribution and has been recognised as one of the most important factors influencing the utilization of fauna within estuarine environments (Marshall & Elliot, 1998). Although black bream are able to tolerate a wide range of salinities, ranging from 0-60‰ (Hoeksema *et al*., 2006), they have a preference for brackish water (10-25‰), typically found in the upper and middle reaches of estuaries. This suggestion is supported by Hindell *et al.* (in press) who found that the movement of black bream into the river systems of the Gippsland Lakes was associated with salt-wedge formation in the regions where haloclines of 17 and 20‰ occur. In the Little Swanport Estuary when salinities fell outside of this range as a result of freshwater inflows, fish generally moved further downstream, presumably seeking more favourable water conditions. Following particularly heavy floods, most fish actively moved, or were possibly swept away, from the upper estuary but tended to remain in the middle and lower middle region of the estuary for periods of up to two weeks. When water conditions, especially salinities in the upper estuary returned to around 10‰, the fish moved back upstream. Although Lenanton *et al.* (1999) suggested that black bream may be flushed out of estuaries when subjected to heavy flood events, the present study provided no evidence to support this phenomenon for the Little Swanport Estuary.

There was in fact no clear indication that black bream left the Little Swanport Estuary during the present study, though movement out to sea by at least some individuals can not be discounted. With the exception of two individuals that were last detected by the receiver located at the mouth of estuary shortly before the receivers were removed, all other individuals detected in the lower estuary were subsequently re-detected further upstream. A tagging experiment in the Gippsland Lakes (Gorman, 1965) indicated that the majority of the tagged black bream were recaptured within the lakes, very few fish moved out of the lakes into the sea. Thus, although migration between adjacent estuaries is possible, it is unlikely that local estuarine populations are replenished by immigrants (Burridge &

Versace, 2007). A related species, *Pagrus auratus*, also exhibits localized movement patterns, with home ranges of within 20 km (Gilbert & McKenzie, 1999; Sumpton *et al.*, 2003) but despite their ability to move outside of their home estuary, this species also tends to remain within the system.

4.2. Spawning related movement

Spawning occurred in the upper reaches of the Little Swanport Estuary, in the Little Swanport River, as evidenced by the aggregations of individuals with fully developed gonads near the interface between fresh and brackish waters (at the positions of B01 & B02), and the presence of large numbers of post-settlement fish in that region (Sakabe, unpubl. data). Previous studies have also indicated that spawning of black bream occurs in the upper estuary (Neira & Potter, 1992, 1994; Newton, 1996; Walker & Neira, 2001). Thus it is likely that some of the movement to B03, and further upstream, during the spawning season was related to spawning behaviour. According to the present study, the average number of visit events per fish in the upper estuary was relatively high between September and December, with average visit duration peaking during November. During the spawning period, individual fish spent up to a month in the upper estuary, frequently moving back and forth between that region and the middle estuary. It is feasible that in the absence of significant freshwater discharges during the spawning period, as occurred during the 2004/05 spawning season, fish may spend longer periods in the upper estuary and the frequency of movement into and out of the region would have been less. By the end of spawning season in January, there was a sharp fall in the number and duration of visit events to the upper estuary, as fish moved further downstream, in particular to the middle estuary.

Back-calculated birth dates of newly recruited fish spawned during the 2005/06 spawning season suggested that the earliest birth dates were during December, spawned when salinities on the spawning ground was above approximately 15‰ (Sakabe, unpubl. data). By contrast, successful spawning occurred as early as mid-October during the 2004/05 spawning season. This is a strong indication that spawning activity was negatively influenced by low salinities, a suggestion supported by Haddy & Pankhurst (2000), who found that fertilization of black bream eggs was significantly reduced at low salinities (<10‰) due to a reduction of sperm activity, even though fertilized eggs were able to develop over a wide range of salinities (10 to 35‰). The heavy freshwater discharges that occurred between September and November 2005 may also have influenced spawning success by suppressing spawning behaviour and/or by flushing eggs and larvae out of the system.

While heavy freshwater discharge has a negative impact on the spawning activity of black bream, a reduction of freshwater inflows may also be deleterious. Since freshwater inflows are important for water exchange processes in estuarine ecosystems, providing additional nutrients (Drinkwater & Frank, 1994a), a reduction in freshwater flows may result in marked changes in water temperature and reduction in dissolved oxygen levels, factors which are often the cause of fish die-off (Phan-Van *et al.*, in press), degraded estuarine habitats (Gillanders & Kingsford, 2002), and changes in general community composition such as phytoplankton, crustaceans and fish (Jassby *et al.*, 1995; Loneragan & Bunn, 1999; Pierson *et al.*, 2002). For some commercially important estuarine species a reduction of large flow events has been found to impact negatively on catch levels (Meynecke *et al.*, 2006).

4.3. Conclusion

The present study has advanced our understanding of how black bream utilize estuarine systems. The tagging techniques used in this study were applied successfully, with high survival rates and relatively long-term tracking times. Movement patterns are very localised within an estuary, with no strong evidence of large-scale movement out of the estuary. This study has also provided an important understanding of the spatial and temporal utilization of estuarine habitats by black bream, including the influence of tidal cycles. Finally, this study has revealed that freshwater discharge into the estuarine environment has a significant influence on the movement and spawning activities in black bream.

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APPENDIX 1

Photograph showing typical water conditions near the position of B02. Water was clear with less than 1 m in depth.

Photograph of extreme flood conditions encountered on 12th September 2005 at the same location as above. Water level was approximately 3 m higher than normal condition.