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Fine-scale movements, site fidelity and habitat use of an estuarine dependent sparid

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Abstract Space use and movement patterns are largely influenced by an animal's size, habitat connectivity, reproductive mode, and foraging behaviours; and are important in defining the broader population biology and ecology of an organism. Acoustic telemetry was used to investigate the home range, habitat use and relative movement patterns of an estuarine dependant sparid (*Acanthopagrus australis*, Günther). Ten fish were internally tagged with acoustic transmitters and manually tracked in a riverine estuary for four, 3-day periods. Positional data was converted into a relative index of fish movement (Minimum Activity Index, *MAI*), and also used to estimate kernel density distributions which approximated areas of core and total space use for each fish. Space use for *A. australis* was not related to fish size; although movement of each fish (*MAI*) increased with fish length and a reduction in water conductivity. The distance between tagged fish and mangrove habitat was correlated with time-of-day and tide level with yellowfin bream moving closer to mangroves during the daytime and on high tides. Fish movements, residency and site fidelity revealed the nature of decision-making for fish, and the conservation value of small patches of estuarine habitats.

Keywords Fish ecology · Movements · Foraging · Site fidelity · Estuary · Mangrove · Acoustic telemetry

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Introduction

Estuaries are a dynamic, transitional environment between fresh and salt water characterised by variability in oxygen, temperature, salinity, and sediment load. Such variability can occur at low-magnitude with regular frequency (such as tidal exchange, Geyer and Farmer 1989), or less frequently at high levels (such as floods, e.g., Eyre and Twigg 1997). The effects of this natural variability are compounded by exposure to varying degrees of anthropogenic modification, such that estuaries often persist in a perpetually stressed state (Elliott and Quintino 2007). Despite this variability, estuarine fish communities have evolved to persist in such environments by adapting their physiology and/or their movements (Childs et al. 2008; Schulte 2014).

The extent to which environmental factors influence estuarine fish is largely governed by estuary morphology and connectivity with marine environments. For example, the impact of tide, temperature and salinity on fish communities within drowned river valley estuaries is likely to be greater than that of an intermittently open coastal lagoon (Roy et al. 2001; Saintilan 2004; Whitfield et al. 2008). Over varying temporal and spatial scales, tide, salinity, temperature, and turbidity can interact with the availability of preferred habitat types to synergistically influence the movement patterns and distribution of fishes (Taylor et al. 2013). Although widely studied in freshwater systems, these relationships are not well known in estuarine systems (Childs et al. 2008). Further understanding the interactions between abiotic variability and the behaviour and distribution of fishes requires high-resolution monitoring of movement and space use of fish in their natural environment. Due to the often rapid anthropogenic changes to estuarine environments and the dependence on estuaries for many fish (Lotze et al. 2006; Elliott et al. 2007), a clear understanding of fish habitat use and movement patterns is important for management and conservation of estuarine species.

Acanthopagrus australis (Sparidae; Günther; hereafter referred to as Yellowfin bream) are an estuarine-dependent predator endemic to Australia's east coast between Townsville in Northern Queensland and Gippsland Lakes in Victoria (Kailola et al. 1992). Yellowfin bream are heavily exploited by commercial fisheries (Momtaz and Gladstone 2008; Rowling et al. 2010), and are amongst the most popular species targeted by anglers due to their ubiquitous distribution in estuaries and relative ease of capture (Broadhurst et al. 2007). The wider population of Yellowfin bream throughout New South Wales has been confirmed as panmictic (Roberts and Ayre 2010); however, fine-scale movement and space use within estuaries is only recently being realised (Payne et al. 2013; Taylor et al. 2013). Of particular interest for this species is the degree of site residency, and how even small sanctuary zones could provide some scientific basis for management options.

Past studies on broad-scale movements of this species suggest adults embark on annual winter spawning migrations to coastal surf habitats along the coast, whereas juveniles and an undefined proportion of the adult population typically remain in estuarine and coastal rivers (Pollock 1982a; Pollock et al. 1983). Yellowfin bream can tolerate substantial variability in water quality, yet activity patterns at fine temporal scales are influenced by freshwater inundation (Gillson et al. 2009; Payne et al. 2013) and tidal variation (Taylor et al. 2013). To improve our understanding of these relationships, these recent studies on temporal trends need to be complemented by an improved understanding of spatial use in the species.

Acoustic telemetry is an increasingly popular and progressively diverse method for assessing activity, physiology and space use in aquatic organisms (Cooke et al. 2004; Payne et al. 2014). Such studies, when carried out in conjunction with monitoring environmental conditions, allow interactions between fish and environmental factors to be determined. We used active tracking in combination with habitat and hydrological data to identify factors influencing patterns in small-scale movements, habitat use and space use of Yellowfin bream within a riverine estuary.

Materials and methods

Study site

The Georges River estuary is a permanently open tidal-dominated drowned river valley (34.008°S, 151.119°E). The Georges River is 96 km long and fed by a primarily mixed urbanised and forested catchment of 931 km^2 area. The flow of the Georges River is partially restricted by the Liverpool Weir situated 45 km upstream of the mouth, which also forms the upper limit of the estuary. The system drains into a large, heavily urbanised coastal embayment (Port Botany). The Georges River estuary is classed as extensively modified with much of its catchment land area used for industrial and urban residential purposes. Major habitats identified throughout the Georges River estuary are saltmarsh, mangroves and seagrass (Roy et al. 2001).

Fish capture and tagging

This study was carried out in accordance with recommendations in Barker et al. (2009). The protocol was approved by the Animal Care and Ethics Committee of the University of NSW (Permit number 10/15B). All surgery was performed under anaesthesia, and all efforts were made to minimize suffering.

Yellowfin bream were caught with hook and line in the Georges River estuary approximately 15 km upstream from Botany Bay in May 2011 (area shown in Fig. 1). Once captured each fish was placed in a 60 mg L^{-1} Aqui-S/seawater solution (Aqui-S, Lower Hutt, New Zealand) until sedated. Sonotronics IBT 96-1 continuous transmitters (Sonotronics, Tuscon, Arizona, USA) were surgically inserted, via an approximately 1 cm incision into the peritoneal cavity of each fish. After tag insertion, the incision was closed with 1–2 3/0 Ethicon™ vicaryl dissolving suture (Johnson and Johnson, New Brunswick, New Jersey, USA). Although the effectiveness of antibiotic use for fish surgical procedures is unclear (Cooke et al. 2011), it is common practice for many previous studies (eg. Taylor et al. 2006; Walsh et al. 2013) and all fish tagged in this study were intraperitoneally injected with 100 mg L^{-1} Engemycin (Intervet, Kempton Park, South Africa).

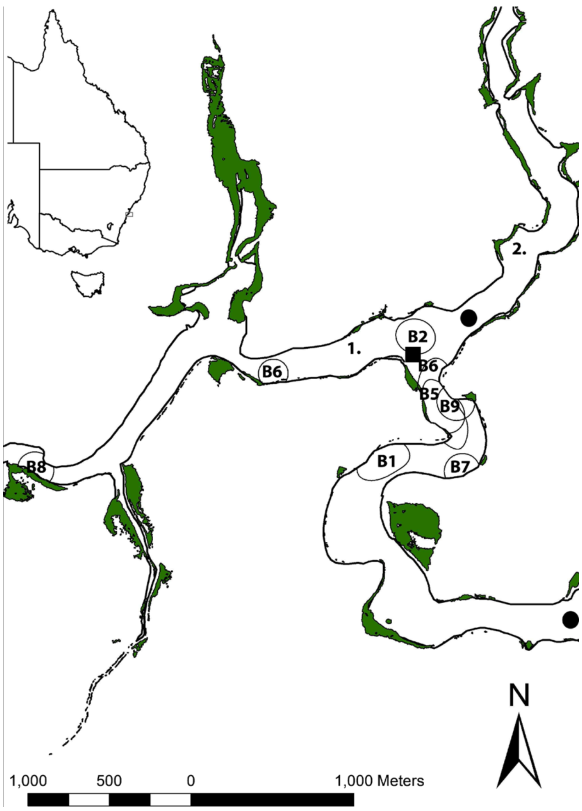

Fig. 1 Study area within the Georges River NSW Australia, showing placement of passive SUR receivers (*filled circles*), subsurface hydrological logger (*filled square*) and core areas of space use for *Acanthopagrus australis* derived from active tracking data (*unfilled*) for each fish (Table 1). Mangrove habitats are shaded. The main river channel (*1.*) and Salt Pan Creek (*2.*) are indicated

Following surgery, fish were placed in a boat-based 200 L recovery tank until they fully recovered from anaesthesia or for a minimum period of 1 h. Following recovery, fish were gently released back into the water directly over the site of capture.

Fish tracking

Tracking of fish was undertaken using a combination of both passive tracking (using Sonotronics submersible underwater receivers; SUR) and manual tracking. SUR units were deployed at strategic locations within the tracking area to identify the passage of fish out of the tracking area, and also evaluate associations with a shallow mangrove-lined tributary in the vicinity of the main tagging sites (Salt Pan Creek, Fig. 1, note that this area could not be safely navigated by boat for manual tracking).

Monitoring of fish movements commenced 2 weeks after surgical tagging of the last fish; thus ensuring sufficient time for each fish to recover from the surgical procedure. Tracking of fish was partitioned across four, 72 h periods during June and July 2011, and tracking effort was standardised throughout the study site, with recurrent unidirectional sweeps of tracking area at a constant speed (~1.8 m s^{-1}) from an upstream to downstream direction. Sonotronics IBT-1 tags transmit their codes as a series of discrete acoustic pulses in a unique sequence, which allows auditory deciphering of the up-modulated signal to identify individual fish. Tagged fish were located and listened to using a Vemco VH110 directional hydrophone and VR100 acoustic receiver mounted on the side of an open hull aluminium boat. When a fish was detected, the signal was interpreted to identify the individual detected on the basis of their code, and a waypoint marked using a Garmin handheld GPS (waypoints were also logged on the internal memory of the VR100).

Environmental variables

Hydrological variables (temperature [°C], conductivity [µS cm^{-1}]) were recorded by a subsurface logger operated by the Botany Bay Water Quality Improvement Program at Picnic Point, which was located directly in the centre of the tracking area (identified in Fig. 1). Lunar phase data (calculated daily on a scale of 0=new, 1=full) was obtained from Geoscience Australia (http://www.ga.gov.au/) and tidal heights (m) were collected from the Picnic Point tidal gauge (33.982°S, 151.

000°E) operated by the Manly Hydraulics Laboratory (www.mhl.nsw.gov.au).

Analysis

Movement and abiotic data were synthesised in Microsoft Excel, and imported into ArcGIS v. 10 for visualisation and spatial analysis. Core (50 %) and total (90 %) space use contours were estimated from weighted kernel density distributions for each fish in ArcGIS v.10 (using a search radius of 150 m, Silverman 1986). The relationship between space use and fish size was evaluated using Ordinary Least Squares Regression. Distances between successive data points were calculated in ArcGIS v.10, and accounted for the curvature of the river where necessary. To further explore the potential use of shallow sediment habitats near mangroves (as proposed in Taylor et al. 2013), proximity analysis (ArcGIS v.10) on tracking data and existing habitat maps (updated from those published in Creese et al. 2009) was used to calculate the proximity (m) of each point data to adjacent mangrove habitats (creating variable "*Distance-to-habitat*"), which was expressed as an arcsin transformed proportional distance between 0 and 100 m (any distances >100 m were recorded as 100 m). A coarse measure of relative fish activity (Minimum Activity Index, *MAI*, m h^{-1}) was calculated by dividing the distance between successive positions of individual fish by the elapsed time between detections (Taylor et al. 2006; Taylor and Ko 2011). Factors contributing to relative fish activity were evaluated using a generalised least squares fit of data (in the Linear and Nonlinear Mixed-effects Models package, Pinheiro et al. 2012) to the model:

$$MAI = \beta_0 + \beta_1 \dot{} Moon + \beta_2 \dot{} Temp \dot{} + \beta_3 \dot{} Cond + \beta_4 \dot{} Size + \varepsilon$$

where independent variables represented lunar phase (described above), temperature (°C), conductivity (µS cm^{-1}, $\log_{10}$ transformed), and fish size (FL). The model included a first-order autoregressive term to account for serial correlation in our dataset arising from multiple data points being recorded from single individuals. Factors contributing to the *Distance-to-habitat* were evaluated using the model:

$$\begin{aligned} Distance\text{–}to\text{–}habitat &= \beta_0 + \beta_1 \dot{} Tide + \beta_2 \dot{} Moon + \beta_3 \dot{} Diel + \beta_4 \dot{} Temp \ldots \\ &\ldots + \beta_5 \dot{} Cond + \beta_6 \dot{} Size + \beta_7 \dot{} Tide \dot{} Diel + \varepsilon \end{aligned}$$

where independent variables were as listed above, *Tide* reflected water height, and diel period was a binary variable reflecting day or night (*Diel*). All variables were standardised to a scale of −1 to +1. The best combination of explanatory variables was determined on the basis of Bayesian Information Criteria using an adaptation of the stepAIC routine (Venables and Ripley 2002). Dependent variables were transformed using $\log_{10}$ (for *MAI*) or arcsin (for *Distance-to-habitat*). All analyses were performed using R v. 2.12.1 (R-Core Development Team).

Results

General observations

Movement and spatial use data was recorded through manual tracking for seven of the 10 individuals tagged during this study (Table 1). Three tagged individuals not detected by manual tracking were recorded on SUR receivers at the down-river boundary of the tracking area during the 2 week period following tagging, suggesting they had departed the tracking area. Consequently, no detections for these individuals were made during manual tracking.

Space use

Patterns in space use of Yellowfin bream indicated that all tracked fish except one occupied a single core area; B6 occupied two core areas (Table 1). Overall mean (± SE) total and core use contour areas for all manually tracked fish were 146000±28000 m^2 and 49000± 10000 m^2 respectively. There was no correlation between spatial use and fish length for either total (F=0.000, P=0.99), or core (F=0.117, P=0.75) areas. The core:total area ratio was calculated to evaluate the

Table 1 Summary of manual tracking data for individual fish tagged in the Georges River showing fork length (FL), identification and detection data. Space use information is also summarised

Fish ID	FL (cm)	# Detections	50 % contour (m^2)	90 % contour (m^2)	# core areas	50:90 (%) ratio
B1	28.2	65	47100	123500	1	38
B2	29.0	35	40100	126300	1	32
B3	36.0	0*	–	–	–	–
B4	31.5	0*	–	–	–	–
B5	29.0	43	54000	194300	1	28
B6	27.0	60	106500	275800	2	39
B7	26.8	57	46100	155600	1	30
B8	27.1	45	22400	43800	1	51
B9	27.5	43	27600	101100	1	27
B10	40.3	0*	–	–	–	–

* Left tracking area

residency of Yellowfin bream to core areas within their overall distribution (Table 1), and ranged between 27 and 51 %, with a mean of 35 %.

Relative movement patterns

Relative movement patterns were evaluated for comparison with previous studies that monitored activity over fine temporal scales. Minimum Activity Index (*MAI*) appeared elevated during the dawn and daytime periods and lower during the night and dusk (Fig. 2). Modelling indicated that relative fish movement was related to fish size (Table 2), with larger fish displaying a greater average *MAI* (Fig. 3). *MAI* was negatively related to conductivity, indicating that relative fish movement was elevated under low conductivity conditions (Table 2).

Habitat use

Modelling the contribution of various independent variables to the *Distance-to-habitat* revealed that both diel period and tide were key drivers of a fish's proximity to mangrove habitat; however, there was no interactive effect (Table 2). These terms indicated that fish were closer to mangrove habitat during the daytime, and at high tide, and at a greater distance away from habitat during the evening and during low tide (Fig. 4). Whilst these results do not indicate that fish are using mangrove habitats per se, they likely reflect foraging of Yellowfin bream in shallow, productive intertidal waters adjacent to mangrove habitats. These results were supported by passive tracking data logged on an SUR receiver positioned in the shallow benthic habitat at the entrance of Salt Pan Creek, a major shallow mangrove lined

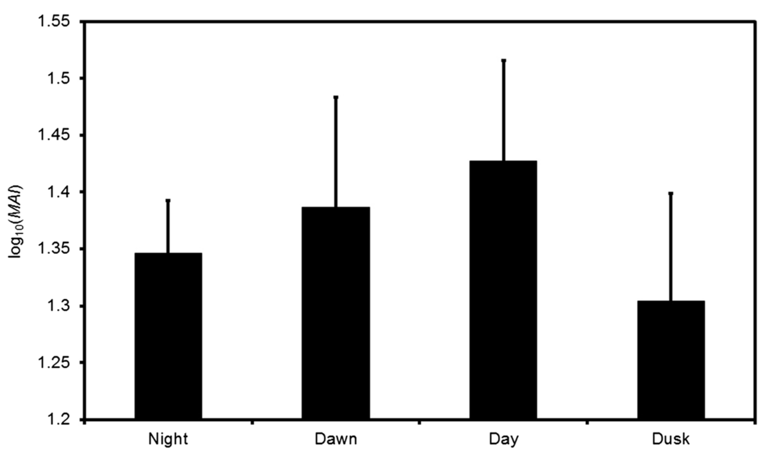

Fig. 2 *Acanthopagrus australis* Mean MAI measurements for 24 h tracking of fish throughout entire study by photoperiod (night, 18:00 to 05:59 h; dawn, 06:00 to 09:59 h; day, 10:00 to 15:59 h; and dusk, 16:00 to 17:59)

Table 2 Independent variables retained from the best autoregressive model and their respective β-values, and P-values ('+' β denotes a positive correlation and a '–' β denotes a negative correlation), for both Minimum Activity Index (*MAI*) and *Distance-to-habitat*. ρ is the first-order autoregressive parameter

Variable	β	S.E.	*t*-value	p-value
MAI				
Log₁₀(Cond)	−0.235	0.058	−4.034	<<0.001
Size	0.297	0.054	5.445	<<0.001
ρ	0.27			
Distance-to-habitat				
Diel	0.146	0.035	4.159	<<0.001
Tide	−0.152	0.053	−2.841	0.005
ρ	0.50			

tributary which entered the Georges River in the centre of the tracking area. A coarse "detection index" was derived from logged data which reflected the proportion of days monitored during which tagged fish were present within the range of the receiver during each combination of diel and tidal period (Fig. 5). On the basis of this index, fish presence was greatest during the daytime high tide, compared to low tide or at night.

Discussion

Space use and fish size-related movements

Tracking Yellowfin bream movements revealed novel patterns in space and habitat use, and also revealed a surprising degree of site fidelity in the species. Contour size for Yellowfin bream varied between 43,800-275,800 m^2 (total), and 22,400–106,500 m^2 (core), and tagged fish spent 50 % of their time within an average core area of only 35 % of their home range, indicating fidelity to a relatively discrete division of their home range when compared with other species. In comparison, mulloway (*Argyrosomus japonicus*), tagged in the same estuary, spent 50 % of their time in an average core area size of 53 % of their home range (Taylor et al. 2006). The lack of correlation between home range size and fish length in this study may have been due to the limited size range of Yellowfin bream tracked (26.8 – 40.3 cm). Larger fish were tagged at the beginning of this study but they were not detected by manual tracking; however, receivers strategically placed at the downstream limit of the tracking area detected these larger fish most likely on a down-estuary migration. Adult Yellowfin bream have been shown to emigrate from estuarine habitats between May and August to near-shore marine areas such as surf zones for the purpose of spawning (Pollock 1982a, 1984), and it is possible that the three largest tagged fish left the estuary for coastal areas to join the spawning population. Pollock (1982a), however, noted that a substantial portion of the adult Yellowfin bream population does not join the spawning egression from estuaries to coastal habitats. Yellowfin bream are reported to mature at 20.5 cm (Pollock 1982a) and considering the smallest fish tagged in this study was 26.8 cm it is reasonable to assume all individuals were sexually mature. The timing of this study within the winter spawning season for Yellowfin bream (May–August, Pollock 1982a; Pollock 1982b), suggests that the majority of our tracked

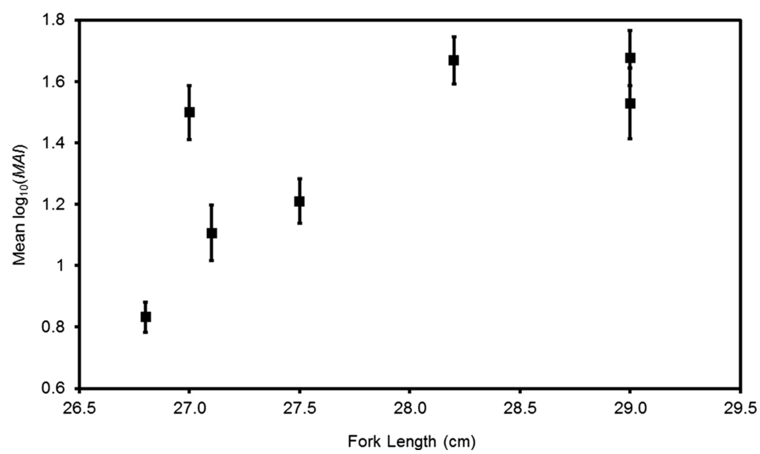

Fig. 3 Relationship between average Minimum Activity Index (*MAI*) and fish size, showing a trend for increasing relative activity with fish fork length

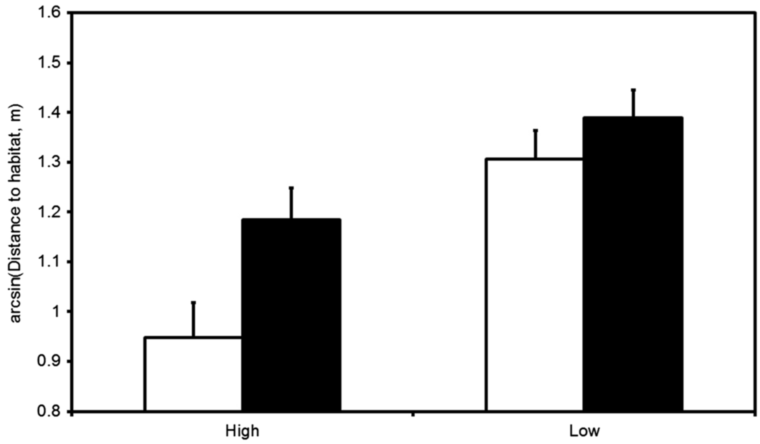

Fig. 4 *Distance-to-habitat* across tidal period and diel period (day, unfilled bars; night filled bars), reflecting the relative distance to mangrove habitat during each combination of these conditions

individuals either did not form part of the Yellowfin bream spawning population or they may have been resting within the estuary pre- or post-spawning during the monitoring periods.

Although the space use contour size was not influenced by fish length, the relative movement of tagged fish was influenced by fish length with larger fish exhibiting greater mean *MAI* (Fig. 3). It is important to note, however, that *MAI* is a coarse measure of relative movement, and does not usually reflect fine-scale rhythms which can be detected using novel biotelemetry tags (e.g., activity tags, Payne et al. 2013; Taylor et al. 2013; Payne et al. 2014). Such size-related differences in fish movement may be brought about by several factors including changes to fish morphology, increased swimming speed and changes in foraging behaviour or prey type, or increases in boldness as fish grow (Bainbridge 1958; Drucker 1996; Mittelbach 1981). Energetic requirements of animals also increase in accordance with body size due to greater gross metabolic cost (Glencross and Felsing 2006). When considering the fish movements within this study, it is likely the increased relative movement of larger fish is due to intensified foraging to satisfy greater food requirements (Watanabe et al. 2011).

Habitat use

Previous studies have shown Yellowfin bream to be generally most active within shallow habitats during daylight periods (Meynecke et al. 2008; Payne et al. 2013; Taylor et al. 2013). Activity rhythms derived from biotelemetry (acceleration/activity) tags were modulated by diel and tidal rhythms, with much greater fish activity

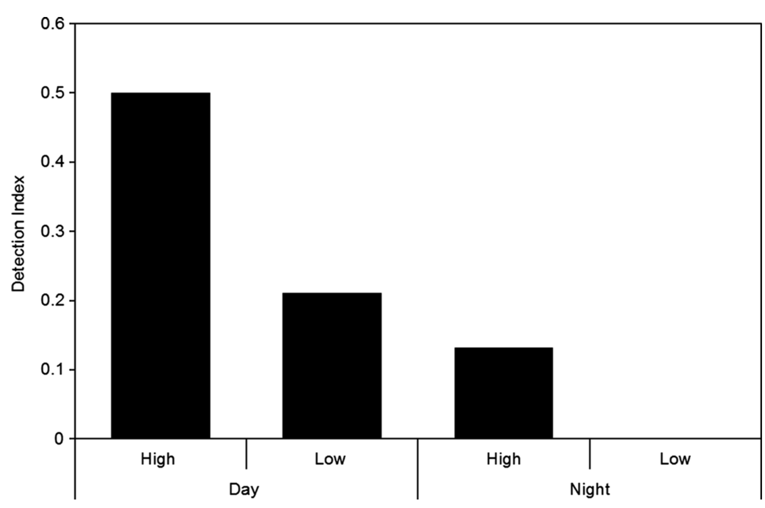

Fig. 5 Detection index derived from fish detections on a fixed-position receiver at mouth of Salt Pan Creek (Fig. 1) during periods of differing water level and photo period (Day 06:00 – 18:00; Night 18:00 – 06:00 h)

during the daytime high tide than at other times (Taylor et al. 2013). Furthermore, auxiliary pressure sensor data from these biotelemetry tags indicated that activity rates were greater when fish were at shallower depths, although the specific location of these fish during these suspected foraging bouts was unknown. Spatial data collected in the current study indicated that Yellowfin bream were closer to intertidal mangrove habitat during daytime high tides (which also corresponded with periods of elevated *MAI*). In addition, during these periods a greater proportion of detections from tagged fish were logged on a submersible receiver positioned at the mouth of Salt Pan Creek, a shallow tributary in the centre of the tracking area which supports large stands of fringing mangroves (Fig. 1) and shallow soft sediment habitat. These receiver detections of tagged fish must be interpreted with caution, however, as detection rate differences in some instances may be due to signal attenuation through obstruction by natural barriers such as sand and rock bars during low water level periods or through increased background noise from nocturnal invertebrates during night time periods (Heupel et al. 2006; Payne et al. 2010). Building on previous studies, active tracking and automated receiver data recorded in this study provide multiple lines of evidence for a foraging strategy of Yellowfin bream within a temperate estuarine system, whereby foraging is conducted during the day time high tide in the vicinity of mangrove habitats, when shallow soft sediments are inundated, and when predation risk is lower (Taylor et al. 2013).

Yellowfin bream are known to be a visual predator (Ochwada et al. 2009), which prey on primarily suprabenthic organisms such as polychaetes, gastropods, bivalves and penaeid shrimp (Pease et al. 1981), all of which are strongly associated with estuarine soft sediments. Mangrove jack (*Lutjanus argentimaculatus*) exhibited similar behaviour to Yellowfin bream, with greater activity levels detected within inundated mangrove forests during high tides (Zagars et al. 2012), which reflected increased foraging in areas where food supply was greatest. Penaeid prawns have similarly been shown to be active and abundant on soft sediments surrounding mangrove habitats at high tide (Robertson 1988; Skilleter et al. 2005). Finally, the soft sediments surrounding mangrove stands in south-eastern Australia support the other favoured prey items for Yellowfin bream, including crustaceans and polychaetes (Pease et al. 1981; Warren and Underwood 1986; Dittmann 2001). These shallow habitats may also offer a refuge area not frequented by large piscivorous predators such as mulloway (Taylor et al. 2006). Mangroves are accepted to be important habitats for juvenile fish (e.g., Laegdsgaard and Johnson 2001; Meynecke et al. 2008); our study adds to the growing literature that supports the potential role of mangroves and surrounding environments as key habitats for adult fishes (Zagars et al. 2012; Honda et al. 2013). Whilst we could not directly track fish within mangrove habitats, it is possible that Yellowfin bream were directly interacting with mangrove habitats during periods of inundation. This needs to be verified, however, using alternate methods such as remote video surveys directly in the mangrove habitats.

Other factors influencing movement

Conductivity was also found to be an important factor contributing to movement of *A. australis*, whereby a higher *MAI* coincided with lower conductivity. Most of the variation observed in the study period was due to intermittent freshwater inflow from heavy rainfall. Payne et al. (2013) investigated Yellowfin bream activity outside and during periods of freshwater influx in the Georges River, and demonstrated a behavioural change immediately following heavy rainfall events. Payne et al. (2013) suggested that intensified foraging may occur due to reduced predation success, whereby a visual predator may experience less successful foraging in the turbid conditions associated with increased freshwater flow to estuaries (Benfield and Minello 1996; Eyre 1998). Alternatively, increased movement may reflect increases in foraging behaviour to compensate for the energetic and metabolic cost of osmoregulation. Although the influence of variation in salinity on Yellowfin bream metabolic rates is unknown, a sudden reduction in salinity has been shown to increase the rate of respiration in other fish species (e.g., Hettler 1976). It is possible that several factors not directly observed in this study may have contributed to increased activity at low conductivities, which may in combination influence the physiology, behaviour and ecology of Yellowfin bream. Considering the difficulties in separating the effect of environmental factors from estuarine field based studies, further experimental studies may be required to gain a full understanding of the influence of singular environmental variables on Yellowfin bream behaviour.

Conclusion

Fine-scale movements of Yellowfin bream were largely influenced by fish size and conductivity whereas habitat use was affected by both diel and tidal cycles. Yellowfin bream showed substantial site fidelity in the Georges River estuary, with core areas less than 500 m long (sometimes substantially less). Management of fishes, especially in an urban context where sanctuary zones are small and often contentious, would find this dimension useful. This study also provides spatial data to support the interpretation of previous findings regarding Yellowfin bream movement patterns, but further work is required to develop a mechanistic understanding of factors driving our observations. Such work should target the relationship between conductivity and activity, and the use of mangrove habitat for foraging. Comprehensive information on biotic and abiotic factors influencing Yellowfin bream movements and habitat use will not only significantly progress our understanding of individual species ecology, but also aid the understanding of other species of similar life histories in estuarine systems.

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