

The habitat-related distribution of small fish in tropical estuaries.

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Abstract

We examined the habitat-related distribution of the small (< 100 mm length) benthic-associated fish assemblage at two spatial scales in Australian tropical estuaries. At broad spatial scales fish demonstrated a strong preference (82.1% of individuals) for channel banks rather than mid-stream sites (17.9% of individuals). The distribution of fish on those banks was influenced by depth, with higher abundance of most species at depths less than 0.775 metres. Depth was the most influential of the small-scale habitats examined. Most individuals (95.3%) were found at depths less than 0.375 metres. Bank architecture influenced distributions when depths were less than 0.275 metres, with highest abundances in drain habitats. The lack of small fish in deeper water at any stage of the tide suggests the fish are migrating up and down banks as the tide floods and ebbs. The strong association between the small benthic-associated fish assemblage, channel banks and shallow (< 0.775 m) water suggests that availability of shallow sub- and inter-tidal habitat may be crucial for the survival of small fish.

Key words: distribution, estuary, fish, habitat, migration

Introduction

There are two ways of addressing the problem of rebuilding native fish populations in estuaries. One approach is to initiate stocking programs. However because estuaries are open systems the stocking of fish may produce undesirable outcomes, e.g. the introduction of potentially inferior genes into native populations (Martinez et al., 2001). Furthermore, if conditions in the stocked estuary are not suitable, the stocked fish may leave the estuary or may not survive. A second and more ecologically sound approach is to allow natural recruitment processes to rebuild population numbers. However we do not know enough about the biological functioning of Australian estuaries to determine the likelihood of success, or problems associated with either approach. The lack of knowledge is of major concern because Australian estuaries are important nursery areas (Robertson and Duke, 1990a,b). Moreover, less than one percent of juvenile fish survive to reproductive maturity (Blinov, 1977), consequently knowledge about the specific requirements of juvenile fishes is crucial to the maintenance, or re-building, of adult populations.

The successful rebuilding of populations, can only occur in an estuary if sufficient appropriate habitats are present. A necessary first step towards successfully rebuilding fish populations is to identify the habitats that are important, particularly to the juvenile fish. To

address this we examined the habitat-related distributions of small (< 100 mm fork length [FL]) benthic-associated fishes at two spatial scales, small-scale (metres), and meso-scale (tens to hundreds of metres).

Methods

The study was conducted between April 2000 and December 2002 in three estuaries on the tropical north-eastern coast of Australia (Fig. 1). **Insert Fig. 1 here** All systems are mangrove-lined throughout most of the lower reaches (0-7 km), where sampling was conducted, and have a semi-diurnal tidal regime with a maximum range around 3.8 metres. Flood tides entered the lowest mangrove fringes at around one metre but the majority of forest was not accessible to fish until tidal height exceeded two metres. Faunal samples were collected during spring tides immediately preceding the new moon. Sampling commenced once the ebb tide had receded from mangrove forests and concluded before the flood tide re-entered the forest.

Development of protocols and extensive validation of cast nets as a sampling tool were undertaken because conventional fish sampling approaches were not appropriate for collecting the discrete samples at the small spatial scales required for this study. Cast nets provided samples of the small fish assemblage that were at least as representative of a habitat as those collected with beach seine and Danish seine nets across a variety of habitat types (Johnston et al., in preparation). Changes in the patterns of distribution of the fish assemblage (differences between locations, trips and sites) that were detected by beach seine and Danish seine nets, were also detected in the cast net samples, and estimates of rank abundance and density differed minimally between net types (Johnston et al., in preparation).

The meso-scale distribution of fish was examined across channel profiles, from low angled depositional banks, through the mid-stream to the opposing steep angled erosional banks in two estuaries, Stuart Creek and Deluge Inlet (Fig. 1). Cast nets 4.58 metres in diameter (18 mm mono-filament mesh) were used to collect fish. At each of 32 sites four net samples were collected from each of the habitats, depositional bank, mid-stream, and erosional bank. Results (below) of this study suggested that most small fish were strongly associated with channel edges so the distribution of fish was further examined in small-scale habitats along channel edges at depths less than 2.0 metres. Data were collected every second month for twelve months from Deluge Inlet and Victoria Creek (Fig. 1). The habitat categories, and habitat types within those categories, investigated were: bank architecture, depth, bank slope, hydrodynamic features and current velocity (Table 1). Cast nets (3.07 metre diameter, 6 mm multi-filament mesh) were used to sample small-scale habitats. A smaller mesh net was used for this study to provide a better representation of the smaller juveniles (new recruits and early post-settlement fish). All cast netting for the meso- and small-scale studies was conducted from a small boat powered by an electric motor to minimise disturbance. Fauna were euthanased in an ice-water slurry before transport to the laboratory where they were identified to species level, counted, weighed and measured.

Data were analysed using multivariate classification and regression trees (mC&RTs) (De'Ath, 2002). Explanatory variables used for analyses were location, trip, and the habitat categories. Abundances of the nine most frequently occurring species, fourth root transformed to limit the influence of a few nets with very high abundance, were entered as response variables. Models produced by mC&RTs are presented as frequency distribution

and figures for ease of interpretation. In analysing data mC&RTs partition combinations of variables such that combinations with a low density of data are separated from high density combinations. As a consequence of the differences in data density, most emphasis is placed on high density combinations (high abundance when data are abundances) because there is little information, and substantial random variability, contained in the low density groups. Depths were recorded from the centre of the area enclosed by the net, but because there was usually some slope associated with the stream bed, depth would be shallower than the measured (centre) depth at one edge of the net and deeper on the other. Consequently, depth measurements used in analyses represented average depths.

Results

The primary split in the mC&RT model of cross channel distribution of the fish assemblage separated the high abundance from the low abundance location/trip combinations. This indicated that differences in location and time accounted for more of the explained variance than any of the habitat variables.

Within high abundance location-trip combinations the small benthic-associated fish assemblage demonstrated a strong preference for edges, 82.1% of individuals on depositional or erosional banks and just 17.9% in mid-stream areas (Fig. 2a). **Insert Fig. 2 here** As well as large differences in abundance, the assemblage composition in the mid-stream habitat differed substantially from that on the banks. *Pomadasys kakaan* and *Yongeichthys nebulosus* were not recorded from mid-stream sites, whereas *Sillago sihama* and *Liza subviridis* were found in similar numbers in both mid-stream and bank sites. Abundance of the remaining five species was substantially lower in mid-stream sites than on depositional and erosional banks. In turn the distribution of small fish on the depositional and erosional banks was strongly influenced by depth, with 60.8% of individuals found at depths between 0.475 and 0.775 metres, 27.8% at depths greater than 0.775 metres and 11.4% at depths less than 0.475 metres (Fig. 2b). Two species, *Acanthopagrus berda* and *Y. nebulosis* did not occur at depths greater than 0.775 metres, and highest abundance for each of the other species occurred in water between 0.475 and 0.775 metres deep.

During low abundance location-trip combinations most small fish (75.5%) were recorded from low angle depositional banks, with relatively few (24.5%) on steep erosional banks or in mid-stream sites.

Location and trip also produced the primary split in the mC&RT model of the small-scale distribution of the benthic-associated fish assemblage. During the high abundance location-trip combinations depth had the strongest influence on the composition of the assemblage, with 4.7% of individuals at depths greater than 0.375 metres, 42.2% at depths less than 0.275 metres, and the remaining 53.1% found between those two depths (Fig. 3a). **Insert Fig. 3 here** Four species, *P. kakaan*, *Leiognathus splendens*, *Butis butis*, and *L. decorus* were not recorded from at least one depth range, although it is reasonable to expect *B. butis* to occur in the missing depth range given the observed depth distribution. *Leiognathus equulus* in particular was strongly associated with the two shallowest depth ranges, and *P. kakaan*, *L. splendens*, and *L. decorus* were not encountered at depths greater than 0.375 metres. Although *Acanthopagrus berda* was one of the nine most frequently encountered species, they were not encountered in the high abundance location-trip combinations, and *L. splendens* did not occur at depths less than 0.275 metres. At depths less than 0.275 metres

(42.2% of individuals) bank architecture was important, with higher abundance of most species, and a high proportion of individuals (70.6%) in drain habitats (Fig. 3b). *Pomadasys kakaan* was the only species not recorded from drain habitats, and the abundance of *Marilyna pleurosticta*, *L. decorus* and *Glossobobius circumspectus* differed little between drain and non-drain habitats.

In contrast to high abundance location-trip combinations, when abundances were low the differed in response to current velocity. Only 27.4% of individuals were found in sites where there was no current flow. In sites with current flow, depth again became important, and reflected the important split from the high abundance samples with 60.1% of individuals at depths less than 0.375 metres and 39.9% at deeper depths. The remaining small-scale habitat variables, hydrodynamic features and bank slope, apparently had little or no influence on the distribution of the small fish assemblage.

Discussion

The edges of channels, depositional and erosional banks, were clearly preferred over mid-stream sites by small benthic-associated fishes (Fig. 2a). On those banks depth had an important influence on distributions (Fig. 2b), with most fish (60.8% of individuals in the assemblage) in depths between 0.475 and 0.775 metres. When distributions related to small-scale habitat types was examined depth again had an important influence with 95.3% of individuals at depths less than 0.375 metres (Fig.3a). When depth was less than 0.475 metres bank architecture (high abundance in drains) also influenced the distribution of fish (Fig. 3b). The use of intertidal and shallow estuarine habitats by small fish has been widely reported, however, few authors have defined shallow water to specific depths, and frequently shallow water has been defined as intertidal (e.g. Shenker and Dean, 1979; Moreton et al., 1987; Patterson and Whitfield, 1996), an approach that is ambiguous because the depth in any part of the intertidal depends on the state of the tide. Moreover, few studies directly compared shallow with deeper water habitats (Sheaves, 2001). It is frequently suggested that the extensive use of shallow estuarine habitats by small fish is because the shallow water physically excludes large piscivores (Cain and Dean, 1976; Reis and Dean, 1981; Moreton et al., 1987; Patterson and Whitfield, 2000). In contrast, Sheaves (2001) suggested that it had not been demonstrated that there are in fact few piscivores in shallow water and presented support for the alternative idea that predator-mediated mortality of small fish may be substantial in shallow water.

A temperate estuary study (McIvor and Odum, 1988) found distribution patterns similar to the present study. McIvor and Odum (1988) suggested the significantly higher fish abundance on depositional (accreting) banks in their study could have resulted from three factors, reduced predator pressure due to shallow water, to energetic advantages through reduced current speeds on low angle banks (see also Gaudin & Sempeski, 2001), or to a longer period of access to intertidal areas. We found that during low abundance periods most fish were on depositional banks and that current velocity may be influential during these times. However, when abundances were high, fish discriminated less between bank types (Fig. 3a), responded strongly to depth (Figs. 3b,4a) and were not influenced by current velocity.

As well as shallow water, drains have also been reported to hold high abundances of small fish (Rozas et al., 1988; Blaber et al., 1989). Drains may act as conduits into intertidal areas (Rozas et al., 1988), and in that role may facilitate access to intertidal areas for longer periods

of time than alternative habitats. Alternatively, drains may just provide another shallow habitat and the principle explanation for the high abundances of fish may be a response to depth rather than an intertidal access point. Drains may also provide greater opportunity to feed than other habitats. It is possible that drains accumulate and concentrate nutrient from intertidal areas and thus promote the abundance of benthic prey organisms.

The consistently low abundances of fish in mid-stream, and in deeper waters on the banks through a range of tidal heights, and the strong preference for waters less than 0.775 metres in depth suggests that the fish may follow the shallow water up and down the bank as tides ebb and flood. Tidally-driven migrations have been reported for fish (Gibson, 2003; Krumme et al., 2004), and extensions to the present study indicate that the small fish in tropical estuaries do undertake tidal migrations and remain within the shallow water (Johnston et al., in prep). The distribution and migration patterns observed in the present study are logical responses to the driving factors discussed above, predator avoidance, energetic advantage, and access to intertidal areas, but it is likely that an important explanation for the patterns is food availability. Again, we lack definitive information about distribution of the prey species targeted by benthic fish, however juvenile prawns which are an important component of diet for many benthivores also show a preference for similar shallow edge habitats (Staples et al., 1985; Vance et al., 1990) and apparently move into intertidal areas on flood tides (Vance et al., 1996).

At the spatial scales examined, our data indicated that the shallow edges of estuary channels (banks/shorelines < 0.775 m deep) and intertidal banks are particularly important and possibly obligate habitats for the small, benthic-associated, fish assemblage. Those same habitats are the most modified habitats in estuaries and continue to be focus areas for future development. We suggest that development that reduces the extent of shallow water (sub-tidal and inter-tidal) habitats in estuaries could reduce their viability as nursery areas. The restoration of fish populations is dependent on the successful functioning of nursery habitats. Ultimately, effective and predictable management strategies for estuarine nurseries will only become a reality if we develop a better biological understanding of those systems.

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