CHAPTER 6

Fish on Australian saltmarshes

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Introduction

Saltmarshes provide important habitat for fish on all inhabited continents. Fish are a very important aspect of the biodiversity of marsh systems, and the role of saltmarsh in the provision of fish habitat is one of the main reasons why humans value saltmarsh at all. Fish living on marshes or visiting the inundated habitat at high tide are abundant and diverse. Swimming crustaceans such as shrimp and prawns (which together with fish are collectively known as nekton) also occur on saltmarsh, and are included in this Chapter because of the similarities in aspects of their behaviour.

This Chapter focuses on Australian saltmarshes as fish habitat, but our early understanding of fish use of saltmarsh came from studies done elsewhere. A review of all saltmarsh nekton research prior to 2000 (Connolly 1999) found the literature to be overwhelmingly North American (90% of the 113 studies), with surprisingly few papers from Europe (7%) given the large number of botanical studies undertaken there (Adam 1990). Only 3% of papers were from southern hemisphere marshes, all from Australia (see Table 6.1).

Patterns in the use of saltmarsh by nekton are thus best described for North American marshes (Kneib 1997a). Large numbers of certain small species such as killifish (*Fundulus* spp.) and grass shrimp (*Palaemonetes* spp.) are resident on marshes. Numerous other fish and crustacean species visit the inundated marsh as transients (Kneib 1997a). Species using the marsh flat are mainly resident on or near the saltmarsh for their entire lifecycle, while fish congregating around the edge of the saltmarsh are juveniles of species that spawn elsewhere in the estuary or in oceanic waters (Peterson and Turner 1994). A review of the value of saltmarsh as nursery habitat, taking into consideration abundances, growth rates and survival, found that nursery value was greatest for vegetated marsh, particularly at the marsh edge, and lower for unvegetated marsh (Minello *et al.* 2003).

Encroaching human development is resulting in the fragmentation of saltmarshes in many parts of the world (Adam 2002). Where saltmarsh supports major fisheries, the consequences of habitat fragmentation are likely to be large. The marshes of the Gulf coast of the USA, for example, are considered critical nursery habitat for brown shrimp, *Penaeus aztecus*. A combination of empirical data and numerical modelling of survival rates demonstrates that, initially, brown shrimp productivity increases as saltmarshes decline in extent and fragment into smaller units (Browder *et al.* 1989; Haas *et al.* 2004). For a time, these smaller units increase the length of the interface between marsh and water, increasing the linear extent of the marsh edge, the habitat preferred by prawns. However, modelling shows that, ultimately, the amount

Table 6.1 Summary of the geographic effort into research on saltmarsh nekton to year 2000, showing the paucity of Australian studies relative to the area of saltmarsh on this continent (from Connolly 1999). States within USA are ordered by number of studies. Several Australian studies have been published since the review, along with a larger number of recent studies from North America and Europe.

Location	Number	% of total
Georgia	14	12
Louisiana	13	12
North Carolina	12	11
Virginia	12	11
Texas	8	7
New Jersey	8	7
Florida	8	7
South Carolina	7	6
Other USA states	15	13
Total USA	*97*	*86*
Canada	5	4
Total North America	*102*	*90*
Europe	8	7
Australia	3	3
Total	113	100

of marsh relative to open water will decrease to the point where shrimp productivity begins to decline again (Browder *et al.* 1989).

The tidal hydrology of marshes implies strong linkages between marsh and adjacent habitats for mobile animals such as fish and swimming crustaceans (Odum 1995, Rozas 1995). For many species, therefore, saltmarsh is just one of multiple habitats that might be used by individuals over short (one tidal cycle) or long (different parts of the lifecycle) timeframes. The link that nekton provide among habitats has become central to the debate around the outwelling concept. Outwelling describes the transfer of organic matter produced in high intertidal habitats such as saltmarsh to adjacent, deeper-water habitats, where it supports high rates of secondary production (Odum 1968). Outwelling was originally conceived as transfer of particulate or dissolved organic matter (Teal 1962). The emphasis more recently has been on the numerous predator/prey interactions that potentially result in a net transfer of organic matter from intertidal to subtidal habitats, in a process known as trophic relay (Kneib 1997a).

Australian saltmarshes typically occur landward of mangrove forests, high in the intertidal zone, and have shorter and less frequent periods of inundation than marshes on the Atlantic and Gulf coasts of the USA, which generally lack mangroves and extend down to the mid-intertidal zone (Adam 1990). The vegetation of Australian saltmarshes is dominated by succulent herbs and grasses that are considerably shorter than the stands of cordgrass (*Spartina* spp.) dominating northern hemisphere saltmarshes (Adam 1990). These important physical differences mean that ecological patterns and processes for fish occurring on North American marshes might not apply in Australia (Connolly 1999).

Although Australian work remains under-represented in the literature relative to the cover of marsh (about the same extent as in the USA), there have been several local studies since Connolly's (1999) review, and there are now enough data to form useful conclusions about fish on Australian marshes. This Chapter first reports on fish assemblages of Australian saltmarshes in general, followed by specific sections detailing fish distributions in different marsh microhabitats, their feeding behaviour, how fish can be sampled, and directions for future research.

Species and abundances on Australian saltmarshes

Beginning in 1986, patterns in fish abundances associated with Australian saltmarshes have been described in a total of 11 papers, mostly in temperate and subtropical waters rather than tropical waters (see Table 6.2).

Early work in Australia sampled water in creeks draining marshes rather than the inundated marsh flats themselves (see Table 6.2). Fish assemblages in tidal creeks in saltmarsh systems include virtually all of the species now known to occur on the marsh flats themselves, but occasionally also include additional, larger species common elsewhere in estuaries (Gibbs 1986; Morton *et al.* 1987; Davis 1988).

The development of the pop net technique for quantitatively sampling nekton from vegetated saltmarsh in the mid-1990s (Connolly *et al.* 1997) paved the way for several subsequent studies that increased the geographic spread and total amount of information about abundances of fish on saltmarsh. Fish assemblages on inundated Australian marshes are dominated by adults of one or two small species (60–90% of total abundance). These species are usually from the families Ambassidae (subtropical and temperate), Atherinidae (temperate) and Gobiidae (all waters). Very high densities of commercially important species such as banana

Table 6.2 Summary of published research on fish assemblages on Australian saltmarshes. Habitats are: inundated flats (flats), intertidal creeks (creeks), and semi-permanent pools (pools). Densities shown only for quantitative sampling of inundated marsh flats, all using pop nets except Crinall and Hindell 2004.

Region	State	Habitat	Method	Density (fish.100m^{-2})	Reference
Temperate	SA	Flats/creek[a]	Pop/fyke	4	Connolly *et al.* 1997
		Flats	Pop	1–10	Bloomfield and Gillanders 2005
	Vic	Flats	Seine	25	Crinall and Hindell 2004
	NSW	Creek	Dip		Gibbs 1986
		Flats	Pop	56	Mazumder *et al.* 2005a
		Flats[b]	Fyke		Mazumder *et al.* 2006b
Subtropical	Qld	Creek	Fyke		Morton *et al.* 1987
		Pools	Dip		Morton *et al.* 1988
		Flats	Pop	2–45	Thomas and Connolly 2001
		Flats	Pop	31–64	Connolly 2005
Tropical	NT	Creek	Fyke		Davis 1988

a. Density for flats only, not creek
b. Fish collected from retreating tidal waters, no density available

prawns, *Fenneropenaeus merguiensis,* have occasionally been recorded (Connolly 2005). The remainder of the fauna comprises small numbers of up to about 20 other fish species, including juveniles of many economically important species (see Table 6.3).

Because Australian saltmarshes drain fully on the ebb tide they have no equivalent to marsh residents such as the killifish of USA marshes. However, toadfish (family Tetraodontidae) are a particularly conspicuous and common component of the fish fauna on marshes around Australia, yet are rare on North American marshes. Toadfish move onto the marsh early on the incoming tide, pushing far onto the marsh in very shallow water. This strategy has the effect of increasing the likelihood of finding major prey items such as snails and crabs (Hughes 1984). The abundances of this family on Australian marshes relative to those on North American marshes might result from the different hydroperiods. The short, infrequent inundation periods on Australian marshes that prevent residency for small fish may create an opportunity for the toadfish to obtain prey relatively easily as they enter the marsh upon inundation.

The total density of fish (all species combined) on saltmarsh inundated at high tide differs among studies and among locations (see Table 6.2), ranging from 1–64 individuals per 100 m^2 of marsh flat. Fish species diversity on inundated marsh is higher in subtropical waters (23 species, Thomas and Connolly 2001) than in temperate waters (2–10 species at sites along the southern Australian coastline, Connolly *et al.* 1997; Crinall and Hindell 2004; Bloomfield and Gillanders 2005; and 14–16 species at sites around Sydney, Mazumder *et al.* 2005a, 2006b).

Overall, densities of fish on saltmarsh are lower than in other vegetated estuarine habitats in Australian estuaries. Comparisons among habitats are difficult where different sampling methods are used, but a fair comparison can be made by considering studies using pop nets. Fish densities on saltmarsh are typically less than half that in mangroves in similar estuaries (74–187 individuals 100 m^2 in south-east Queensland; Moussalli and Connolly 1998), and relatively lower again compared with densities in intertidal seagrass (600 individuals 100 m^2 in South Australia; Connolly 1994b).

Different sampling methods make comparisons with densities on saltmarshes on other continents even more difficult, but the methods most similar to pop nets are drop nets and flume weirs in the USA. The density of fish on Australian saltmarshes is lower than comparable studies in the USA (e.g. 54–114 in Georgia, 100–200 individuals 100 m^2 in Texas, Kneib and Wagner 1994; Rozas and Zimmerman 2000, respectively). In fact, nekton densities on USA marshes are similar to densities in Australian mangroves. Given that mangroves in Australia occur at the same height in the intertidal zone as saltmarsh in the USA, this raises the question of whether fish densities are influenced by habitat or merely by elevation.

The issue of whether elevation or habitat type is important has been partly addressed using pop net sampling of both saltmarsh and mangrove habitat at the same time in a subtropical estuary (see Figure 6.1). As expected, at high tide, when mangroves have deeper water than saltmarsh, the average number of species in mangroves is higher than in saltmarsh. The important finding, however, is that this difference remains evident when mangroves are sampled before or after the high tide at times when water depth is the same as over saltmarsh at high tide (see Figure 6.1). The conclusion is, therefore, that although elevation is probably important, the habitat type does appear to have some influence, an important finding given the intimate spatial juxtaposition of saltmarsh and mangroves along much of the Australian coastline (see Figure 6.2).

Distributions on inundated marshes

One of the main findings from northern hemisphere studies is that nekton are more abundant in vegetated than unvegetated marsh areas. There is no evidence of this in Australia, however,

Table 6.3 Occurrence of species and families of fish reported from inundated marsh flats in Australia. C = common, P = present in small numbers. From: subtropical Qld (Thomas and Connolly 2001; Connolly 2005), Temperate NSW (Mazumder *et al*. 2005a, 2006b), Temperate Vic/SA (Crinall and Hindell 2004; Bloomfield and Gillanders 2005).

Family	Species	Subtropical QLD	Temperate NSW	Temperate Vic/SA
Ambassidae	Ambassis jacksoniensis	C	C	
	Ambassis marianus	C		
Atherinidae	*Atherinomorus ogilbyi*	C		
	Atherinosoma microstoma			C
	Kestratherina esox			P
	Lepatherina presbyteroides			P
	Pseudomugil signifer	P	C	
Belonidae	*Tylosurus gavialoides*	P		
Clinidae	*Heteroclinus adelaide*			P
Clupeidae	*Herklotsichthys castelnaui*	P		
Galaxiidae	*Galaxia maculatus*			P
Gerridae	*Gerres subfasciatus*	C	C	
Gobiidae	*Arenigobius frenatus*	P		
	Calamiana species nova	C		
	Favonigobius lateralis			C
	Gobiopterus semivestitus	C	C	C
	Mugilogobius stigmaticus	C	P	
	Mugilogobius paludis		P	
	Pseudogobius olorum	C	C	
Hemiramphidae	*Arrhamphus sclerolepis*	C		
Mugilidae	*Aldrichetta forsteri*			C
	Liza argentea	P	P	
	Mugil cephalus		P	
	Myxus elongatus		P	
	Valamugil georgii	C		
Platycephalidae	*Platycephalus fuscus*		P	
Pleuronectidae	*Rhombosolea tapirina*			P
Poeciliidae	*Gambusia holbrooki*		P	
Sillaginidae	*Sillaginodes punctata*			P
	Sillago ciliata		P	
	Sillago maculata	P		
Sparidae	*Acanthopagrus australis*	C	C	
Tetraodontidae	*Tetractenos glaba*			P
	Tetractenos hamiltoni	C	P	
	Torquigener pleurosticta	C		

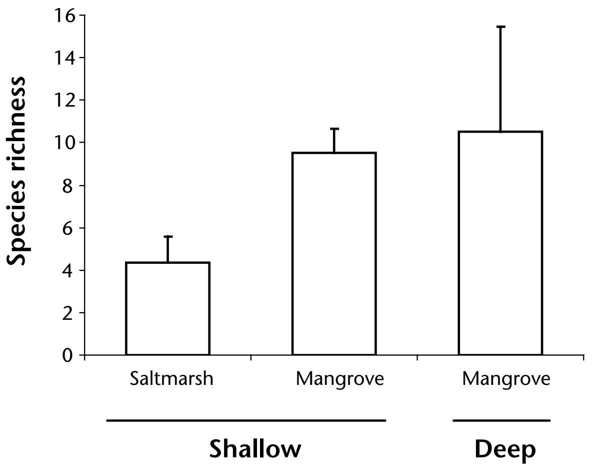

Figure 6.1 Fish species richness over subtropical saltmarsh is lower than in adjacent mangroves both at high tide (deeper water in mangroves) and on ebbing tides (mangrove water depth same as saltmarsh). Values from Moussalli and Connolly (1998) in south-east Queensland (means, SE, over three consecutive months).

since no differences in species assemblages or densities were detected between vegetated marsh and unvegetated pans in a major sampling program over winter and summer in two estuaries (Thomas and Connolly 2001). It has been suggested that the inundation period on Australian marshes is too short to allow fish to move around according to habitat preferences (Thomas and Connolly 2001). Fish densities over the very extensive unvegetated pans on tropical Australian saltmarshes have not yet been reported, a major gap in our understanding given the potential link with adjacent prawn production and evidence from subtropical studies that banana prawns utilise marsh as juveniles (Connolly 2005).

Another finding from northern hemisphere studies is that fish densities on inundated marsh are high near the marsh edge and decline with increasing distance from subtidal water (Kneib and Wagner 1994). In Australia, this has been studied most thoroughly in subtropical

Figure 6.2 Subtropical Australian saltmarsh (marsh grass, *Sporobolus virginicus*) with distinct transition to mangroves, *Avicennia marina*. Photo: M. Guest.

waters, where pop nets were released at different distances up to 400 m from subtidal water (Thomas and Connolly 2001). No relationship was detected between distance from subtidal water and either fish density or fish species composition. Different species occurred at different distances and many species were found far onto the marshes, with several species caught at the limit of sampling, over 400 m from subtidal water (see Figure 6.3).

The factors influencing fish densities on Australian saltmarshes are different to those in the USA. In Australia, the two main influences are water depth and the distance from mangrove-lined feeder creeks. Higher fish densities are found with increasing water depth in pop net samples taken at high tide (see Figure 6.4). Higher densities have also been found alongside (within 20 m) rather than further from (100 m) mangrove-lined feeder creeks linking marshes with subtidal water (Connolly 2005). The importance of intertidal creeks within the marsh system is becoming increasingly clear. Kneib (2003) has shown on the *Spartina* marshes of Georgia, USA, that fish productivity is much higher at sites having greater than about 2000 m of linear creek edge within a radius of 200 m of the site (see Figure 6.5).

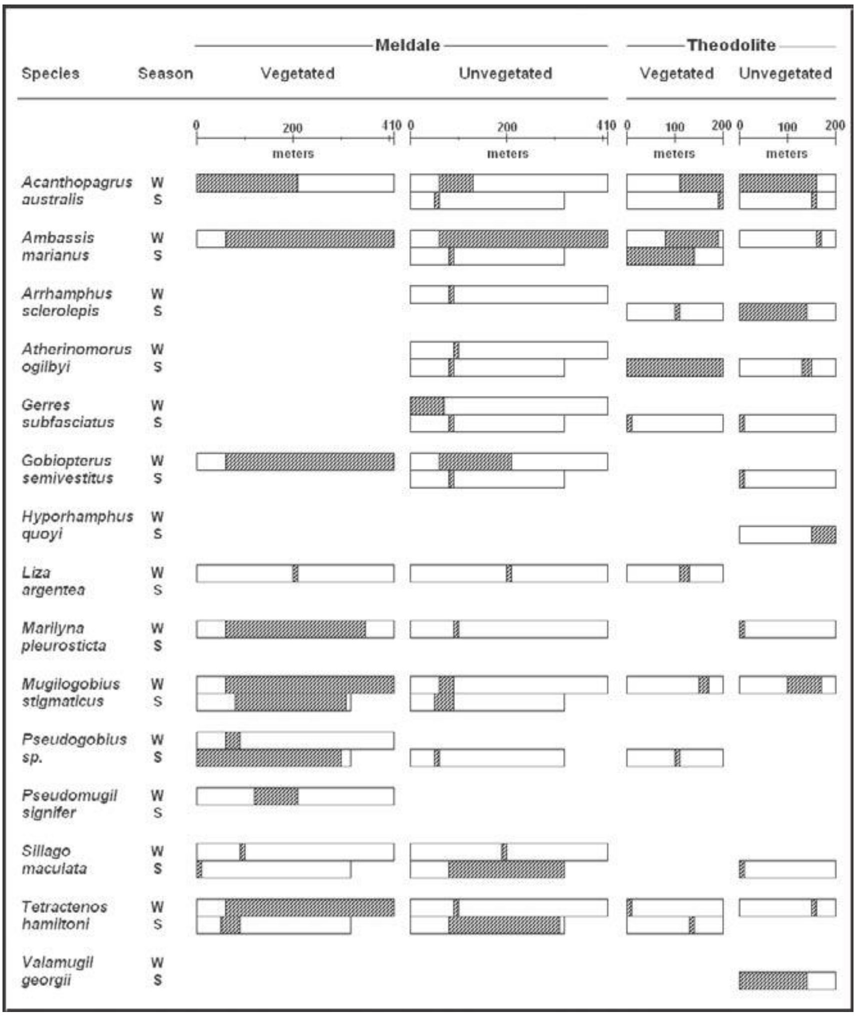

Figure 6.3. Distances fish were caught onto subtropical marsh at two locations (Meldale and Theodolite Creek) in south-east Queensland (Thomas and Connolly 2001).

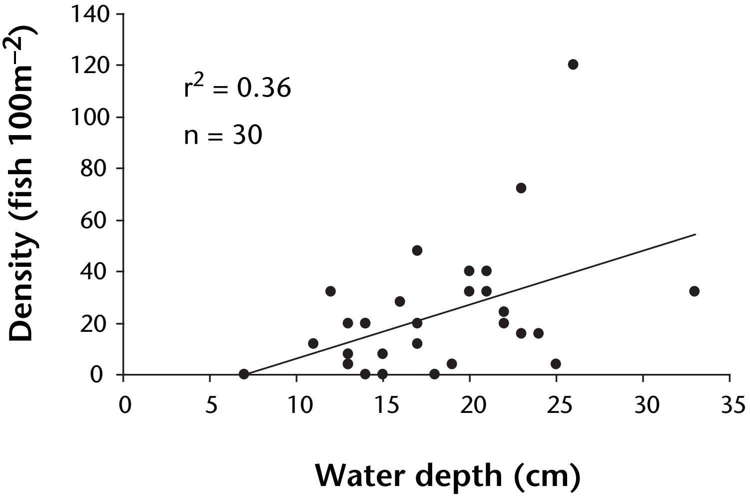

Figure 6.4 Fish densities increase with water depth of sites sampled at high tide using pop nets. Redrawn from Thomas and Connolly (2001).

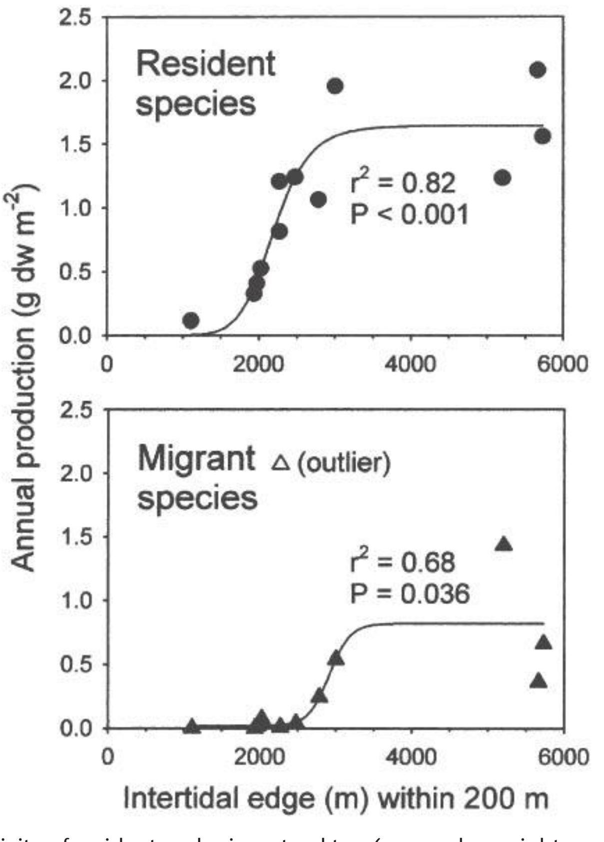

Figure 6.5 Productivity of resident and migrant nekton (grams dry weight per m^2) is much higher at sites having greater than about 2000 m of intertidal creek edge within 200 m radius. Data from Sapelo Island marshes, by Kneib (2003).

Fish feeding on saltmarsh

Knowing what fish go where on saltmarshes is obviously a useful first step in understanding saltmarsh nekton ecology. Unfortunately, in Australia the lack of knowledge of basic distributional patterns even until recent times has meant that few researchers have been able to tackle questions of what use fish make of their time on the marsh. We know little, for example, of predator-prey or interspecific competition relationships in saltmarsh systems in Australia. One aspect that is beginning to be better understood, however, is the role of saltmarsh in fish feeding.

Early descriptions of fish diets using stomach contents were done on fish caught in creeks draining saltmarsh rather than on the marsh flats themselves. Morton et al. (1987) described the feeding behaviour of fish caught in a small creek draining one of these marshes in south-east Queensland. The marine component of the diet of the six species examined was dominated by benthic invertebrates, predominantly adult shore crabs, although some species also ate planktonic invertebrates (crab larvae and amphipods). The diets also included a range of terrestrial invertebrates, especially a striking diversity of adult insects from eight different orders. It cannot be assumed, however, that the diets described by Morton *et al.* (1987) are the result of feeding behaviour on the marsh itself, since it has been shown elsewhere that fish can remain in marsh creeks and feed without entering the inundated marsh (Szedlmayer and Able 1993; Le Quesne 2000).

In contrast, the feeding activity of fish visiting inundated saltmarsh during high tides has been well studied internationally. Several studies have demonstrated feeding on saltmarsh by comparing stomach fullness and prey composition of fish entering and leaving marsh habitat. Studies in the USA (Rountree and Able 1992; Nemerson and Able 2004; and in brackish marshes, Rozas and LaSalle 1990) and Europe (Lefeuvre *et al.* 1999; Laffaille *et al.* 2001; 2002) have detected higher stomach fullness after fish visit marshes. These studies have recorded a range of prey types, dominated by marine invertebrates (e.g. polychaete worms, amphipods) with occasional terrestrial (insect) invertebrates. One early Australian study took a different approach and sampled fish from the brackish, semi-permanent pools that occur high on some subtropical marshes. The small fish that live in these pools feed predominantly on insect larvae that breed there (Morton *et al.* 1988).

In Australia, stomach content analysis of fish leaving saltmarsh habitat has demonstrated feeding activity on temperate water marshes in Victoria and NSW. Fish moving over the edge of narrow marshes in Victoria feed on amphipods and hemipteran insects (Crinall and Hindell 2004). On a marsh in Sydney, NSW, the diets of different fish species varied. Juvenile yellowfin bream (*Acanthopagrus australis*) ate mainly adult shore crabs, whereas several other species consumed small numbers of crabs and larger numbers of other items including zooplankton and insects. The mangrove goby (*Pseudogobius olorum*) fed on zooplankton and insects as well as plant material. Perhaps most importantly, the extremely abundant Port Jackson glassfish, *Ambassis jacksoniensis*, fed predominantly on shore crab larvae (Mazumder *et al.* 2006).

The Port Jackson glassfish has also been the subject of intensive dietary analysis on a subtropical marsh in south-east Queensland (Hollingsworth and Connolly 2006). The glassfish ate mainly crab larvae, but showed a striking temporal pattern of feeding (see Figure 6.6). In winter, the marsh is inundated only at night and only on spring tides. Glassfish visiting the marsh on the first night of a tidal cycle feed only lightly, eating a small number of a range of prey types. This inundation, however, apparently acts as a cue for shore crabs to release larvae, and on subsequent nights, glassfish eat an average of 100–200 crab larvae per fish (see Figure 6.6). Perhaps most importantly, Hollingsworth and Connolly (2006) made a particularly convincing demonstration of the importance of saltmarsh in glassfish diets using a series of other comparisons. As

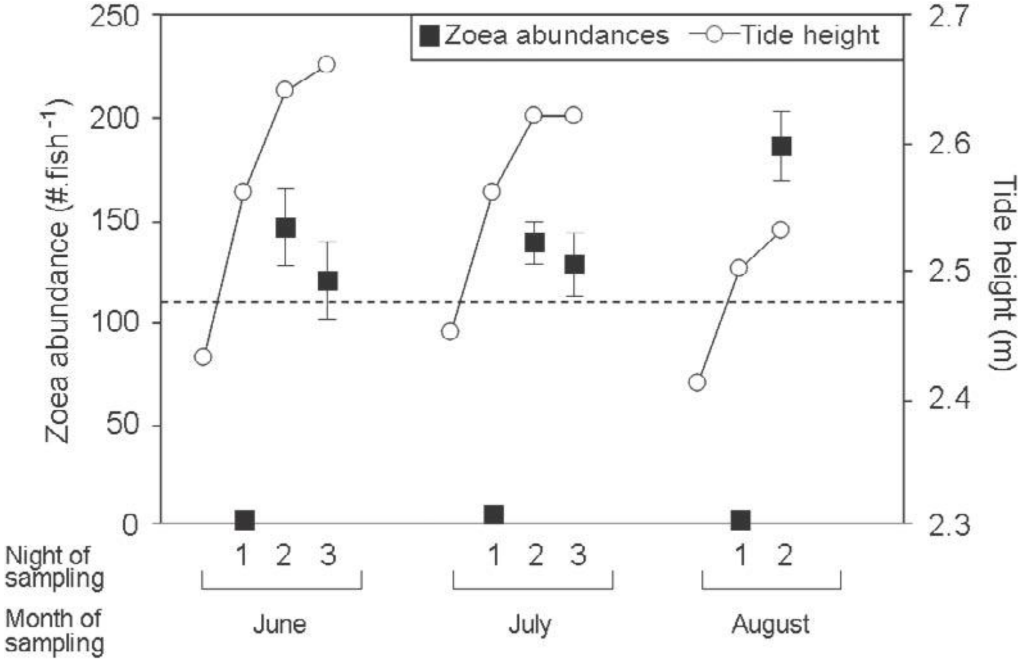

Figure 6.6 Crab zoea abundances in glassfish (*Ambassis jacksoniensis*) stomachs after feeding on subtropical saltmarsh (Hollingsworth and Connolly 2006). In each monthly cycle, fish do not feed on zoea on the first night a marsh is flooded but do so on subsequent nights (values are means, SE, scale on LHS). Tidal height is shown for each night of sampling and the night before sampling. Tidal height at which marsh is inundated (2.48 m) is shown by dotted line.

well as comparing stomach contents of glassfish leaving the marsh with those of fish entering the marsh, they also examined fish in two other treatments: 1) fish collected at the same time elsewhere in the estuary that had no opportunity to visit the marsh, and 2) fish collected before and after neap high tides that inundated intertidal mudflats but not saltmarsh. Of all the comparisons, fish that had visited marsh at high tide were the only individuals to have full stomachs; all others had much lower stomach fullness indices and few if any crab larvae.

The glassfish research points to a major contribution of saltmarsh habitat in fish diets not available to fish using other parts of the estuary. This could result from the limited time fish have to feed on saltmarsh in Australia. The fish do not get to dine on saltmarsh often, but when they do it seems to be a meal worth waiting for. There is obvious potential for the feeding by glassfish to result in a net transfer of organic matter from the marsh to deeper waters, assuming that a certain amount of predation on glassfish by larger fish occurs when they retreat to deeper habitats at low tide. Such a system of trophic relay has been conceptualised for Australian marshes (Mazumder *et al.* 2006a; Connolly and Lee 2007), but further work on predation of glassfish is required to demonstrate it.

Future research

Research into saltmarsh nekton in Australia is at an early stage, with much still to be learned. The most obvious knowledge gap is in tropical marshes, where basic distributional patterns remain unknown. Several features of tropical marshes make work there more difficult. The extent of inundation is often vast, the inundation is somewhat dependent on unpredictable

Box 6.1 Sampling saltmarsh fish

Many theories about saltmarsh function can only be tested with quantitative sampling of nekton on marshes. This presents a real problem, however, because of the short inundation time and erect vegetation (Connolly 1999). The most common collection technique is a fyke net deployed in creeks either draining (e.g. Morton *et al.* 1987) or flooding (e.g. Davis 1988) a marsh (see Figure 6.7). Although fyke nets catch large numbers of fish efficiently, they cannot usually quantify nekton densities. Research needing quantitative use of fyke nets requires considerable additional effort. The nets can, for example, be deployed in creeks draining a well-defined area of marsh, measured using computerised geo-referencing tools (Connolly *et al.* 1997). Even in these situations, however, nothing about the distribution of nekton on the inundated marsh itself can be gleaned. Fortunately, with regard to sampling nekton on the inundated marsh flats themselves, necessity has bred invention, and several purpose-specific methods have been developed. Many of the techniques now used to sample fish in estuaries and shallow coastal waters were developed for sampling nekton from the inundated marsh (Rozas and Minello 1997). Each technique has its advantages under different circumstances.

Figure 6.7 Fyke net method of fish collection from large areas of marsh on ebbing tides. Photo: R. Connolly.

Buoyant pop nets with remotely controlled release have become popular, particularly in Australian studies where they are now used more commonly than any other technique (Connolly *et al.* 1997; Thomas and Connolly 2001; Mazumder *et al.* 2005a, 2006b; Bloomfield and Gillanders 2005; Connolly 2005). On saltmarsh, pop nets have been shown to catch a slightly different assemblage of fish to fyke nets, typically missing very uncommon species and therefore catching fewer species overall, because of the overall reduced area sampled (Mazumder *et al.* 2005b). Pop nets are modelled on earlier lift net designs (Rozas 1992), and consist of four mesh walls, buoyant at the top and pegged to the sediment at the bottom (Connolly 1994a). Pop nets can be used to sample small areas accurately (up to 25 m^2), and

Figure 6.8. Pop net method of quantitative fish collection from specific areas of inundated marsh. Photo: R. Connolly.

their mobility allows multiple deployments at randomly selected locations (see Figure 6.8). They are labour intensive, however, and cannot be used in tall marsh grass without disturbing vegetation.

Another technique, the drop sampler, is popular for sampling nekton on the Gulf coast of the USA (e.g. Baltz *et al.* 1993; Rozas and Zimmerman 2000). A drop sampler consists of a fibreglass cylinder (usually 1–2 m in diameter), with a metal skirt that cuts through vegetation and into the sediment when it is deployed by dropping swiftly from a boom on the bow of a small boat (Zimmerman *et al.* 1984). Animals are then removed with small nets and potentially also by pumping the trapped water through fine mesh. Drop samplers can be used in any type of vegetation, but are restricted to marsh edges where a boat can gain access.

The largest device used for sampling nekton on marshes is the flume weir (Kneib 1991). A flume weir consists of a series of posts arranged so that when mesh screens are dropped into place on the posts at high tide, the structure forms a polygon sampling 100 m^2 of marsh in a single event. Kneib's (1991) system of carefully constructed walkways to the flume weirs on Sapelo Island, Georgia, USA, allows researchers access without walking on the marsh. The flume weir can be built anywhere on a marsh and, once built and allowed to settle, avoids disturbance of even the tallest marsh grass during deployment. Like the pop net, the flume weir uses the brevity of tidal inundation to advantage. Both techniques rely on fish being caught in a pit on the down-current side as the tide retreats. Although flume weirs are impressively large, they are very labour-intensive to build and cannot, therefore, be deployed easily at multiple locations.

One further technique has proven useful for sampling larval and small juvenile fish and crustaceans. Small saucers embedded in sediment successfully collect these small animals that aggregate in any residual water on the marsh as the tide retreats. These small samplers are known as simulated aquatic microhabitats, or SAMs (Kneib 1997b).

cyclonic events, most sites require vehicular and vessel access from remote settlements, and the waters also support populations of saltwater crocodiles. It is nevertheless essential that data be collected from these tropical regions since, in Australia, human development is predicted to be most rapid there. There could be considerable excitement in determining the contribution by tropical marshes to Australia's Northern Prawn Fishery. The harvesting of tiger and banana prawns in the shallow waters of Gulf of Carpentaria and elsewhere in northern Australia is the country's second most valuable fishery. Juvenile prawns might well be utilising marsh and saltpan habitat, if results from south-east Queensland are indicative (Connolly 2005).

Further descriptions of patterns of use of saltmarsh by fish would also be useful in southern Australian marshes, where more data are required to develop a generalised understanding. The most rigorous surveys have been in south-east Queensland, and these have demonstrated major differences in fish use of marshes among estuaries and between seasons (Thomas and Connolly 2001).

Another aspect of saltmarsh that remains unknown is the degree to which the shallow water of inundated marshes offers small fish protection from predators. Although this idea has long been held for estuarine systems (Baltz *et al.* 1993), comprehensive surveys of predators in estuaries suggest that the degree of protection has been overstated (Sheaves *et al.* 2006). Addressing predation patterns should go hand-in-hand with future work on patterns of movements of fish on and around marshes. Early work by Morton *et al.* (1987) using fin-clipping to show that certain species tend to be recaptured in the same marsh creek over time could now be done with greater replication and efficacy using modern ultrasonic tracking methods.

Our understanding of feeding behaviour of fish on Australian marshes currently relies on data from single estuaries in each of three states (Victoria, New South Wales, Queensland). Additional data from other locations would help to build a broader understanding. The contribution of marsh plants and animals to estuarine food webs will continue to be a major issue in the protection and conservation of marshes. More rigorous data is required on this issue. Chemical tracers such as stable isotopes have helped to distinguish energy (carbon) pathways through food webs in Australian estuaries (e.g. Guest *et al.* 2004, 2006) and have proven useful in determining fisheries food webs associated with other vegetated habitats (Connolly *et al.* 2005; Melville and Connolly 2005). Stable isotopes are likely to be useful, too, in confirming the fate of plant and algal production on saltmarshes in food webs on the marsh itself and in adjacent waters.

Large areas of saltmarsh have been lost along the more urbanised coasts of Australia. This unfortunate loss might have been scientifically informative had researchers been able to correlate the extent of loss with local changes in fisheries catch statistics. Although great care is required to avoid misinterpreting such correlations (Lee 2004; Loneragan *et al.* 2005), the approach has been used for saltmarshes in the USA (Boesch and Turner 1984) and would likely be useful in the Australian context.

Saltmarshes degraded by urbanisation are beginning to be restored. The science underpinning restoration of Australian saltmarsh is relatively poorly developed, and the number of sites earmarked for restoration is small. There is every likelihood that restoration will become more prevalent in the near future, and it will be important to incorporate the requirements of nekton. International as well as local science has highlighted the importance of intertidal feeder creeks in supporting fish abundances on marshes (Kneib 2003; Connolly 2005). The presence and density of such creeks will need to be carefully matched with original habitat demography for restoration to be fully successful. It will be important, too, to determine natural levels of connectivity with other habitats, so that these can be as nearly as possible emulated in restored marshes. Several studies have measured connectivity among habitats such as saltmarsh and seagrass in the USA (Irlandi and Crawford 1997; Nagelkerken and van der Velde 2004), but in Australia data are only now beginning to be compiled (Saintilan *et al.* 2007), and we remain at the stage of formulating likely theories about connectivity among estuarine habitats (Sheaves 2005).

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