



SEAGRASS IN AUSTRALIA

STRATEGIC REVIEW AND DEVELOPMENT OF AN R&D PLAN

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6. LINKS BETWEEN SEAGRASS DYNAMICS AND FISHERIES SUSTAINABILITY.

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6.1 INTRODUCTION

6.1.1 Background

Seagrass meadows are fabled worldwide as rich and productive nursery areas for juveniles of economically important fish and crustacean species. Australian scientists have rightly been leaders in research into seagrass as habitat for fisheries species. Australia has a large area of seagrass in all states, and a large number of species (see Chapter 5). With a relatively narrow shelf around most of Australia's coastline, and an absence of major upwelling currents, much of the value of Australian fisheries comes from species harvested in shallow coastal waters. This chapter examines the evidence for links between seagrass and fisheries resources. It especially focuses on the reliability of that evidence, and in particular on:

- The importance of seagrass meadows in fisheries production
- The influence of seagrass status (extent of cover, type, or density) on fisheries sustainability.

The aim is to review links between seagrass dynamics and fisheries production to provide clear guidelines for future research directions. The review provides a detailed examination of Australian work, but includes studies from elsewhere where the information helps to highlight what research is needed in Australia.

6.1.2 Description of approach taken in this paper

Information about links between seagrass and fisheries production was gathered from primary literature and by discussing recent work and work in progress with fisheries scientists from around Australia. This capitalised on a previous, more general review of fisheries habitat (Cappo *et al.* 1998) by focusing solely on seagrass studies except where lessons from other habitats were considered relevant. Results and ideas from all papers and researchers were summarised by geographic location and fishery type. Information relating directly to situations where changes in seagrass status can be linked with fisheries data are shown in Table 6.1. Where relevant, information from outside Australia was also included. This chapter provides a synthesis of that work. Sections 2 & 3 describe what is known (or suspected) about links between fisheries and seagrass dynamics. Section 2 focusses on comparisons between

seagrasses and other habitats such as bare sand, mangroves and algae, while Section 3 concentrates on comparisons between seagrasses of different types. Section 4 lists gaps in our understanding and future research needs. Throughout this chapter, we pursue a clear rationale for future research, and end by summarising our recommendations for future research in Section 5.

Processes linking seagrass with invertebrate production are described in Chapter 5. Literature on fisheries resources and the functionality of restored seagrass meadows is covered in Chapter 7.

The fish and crustacean species discussed in this chapter form the basis of commercial, recreational and indigenous fisheries. Examples of species mainly taken commercially are – most penaeid prawn species; recreationally – whiting, yellowfin bream, flathead (although these species are also taken commercially); indigenous (dugongs, green turtles). Dugongs and green turtles are harvested in small numbers only, and are mentioned here because of their known dependency on seagrasses for food.

6.2. IMPORTANCE OF SEAGRASS MEADOWS IN FISHERIES PRODUCTION?

6.2.1 Comparison of seagrass with other estuarine/nearshore habitats

Assemblages of fish

Seagrass/unvegetated habitat

A paradigm in seagrass research is that, with few exceptions, diversity and abundance of fishes in seagrass is higher than in unvegetated habitats (Bell and Pollard 1989). Research in southeastern Australia shows that while this generalisation appears to be true for fish diversity, the results for abundance (or biomass/production) are equivocal. Diversity of fish in *Zostera* in NSW was higher than over adjacent (<10m) and distant (>100m) unvegetated sand; number of individuals in *Zostera* was also higher than on distant sand, but was similar to adjacent sand (Ferrell and Bell 1991). Fish diversity in Corner Inlet and Port Phillip Bay seagrass beds was higher than adjacent unvegetated habitats, but abundance and biomass was only higher in subtidal *Heterozostera*, intertidal *Zostera* had similar abundance and biomass of fish to adjacent unvegetated habitat (Jenkins *et al.* 1997b). Edgar and Shaw (1995b) found that fish diversity and production was higher in seagrass compared with unvegetated habitat in Westernport, however, when a number of sites across southern Australia were sampled, the production of small (< 1g wet weight) fish did not differ between the two habitats (Edgar and Shaw 1995c).

In South Australia, three comparisons of fish assemblages from seagrass and unvegetated habitat have been made. In Barker Inlet, a marine-dominated estuary almost surrounded by the city of Adelaide, the study included only intertidal areas, and showed a markedly higher richness and abundance in seagrass (*Zostera muelleri*) than unvegetated patches, over all seasons (Connolly 1994a). The unvegetated patches were from 5 to 20 metres distance from seagrass. Sampling in Spencer Gulf also showed a higher fish diversity and abundance in

seagrass (shallow *Posidonia/Amphibolis/Zostera*) than unvegetated areas (Seddon 1997). In contrast, a comparison of *Posidonia*, *Heterozostera* and unvegetated habitats at six sites on the Yorke Peninsula (unvegetated patches up to 30m from seagrass) showed higher species richness in *Posidonia* compared to unvegetated substrates. However, there was no consistent pattern in the total numbers of fish amongst any of the habitats (Jenkins *et al.* 1996a).

A greater diversity and abundance of small fish were found in *Zostera capricorni* patches than over bare sand (with bare sites ranging up to 200 metres from seagrass) in the Clarence River estuary (West and King 1996) and eight estuaries in northern NSW (Gray *et al.* 1996). In Western Australia, the total numbers and density of fish caught in *Ruppia* beds varied between dense and patchy beds and bare substratum (Humphries *et al.* 1992a). The diversity of the fish fauna was lowest, but the total numbers were highest, in dense *Ruppia*.

The physical environment of estuaries is a major controlling factor for both the habitats found within them and the fish and decapods that can colonise these habitats. In south-western, eastern and tropical Australia, marine species dominate the fish fauna of lower estuaries. They become less dominant with increasing distance away from the estuary mouth, where species capable of completing their life-cycle within the estuary become more important (e.g. Loneragan *et al.* 1986; 1989; Bell *et al.* 1988; Blaber *et al.* 1989, Loneragan & Potter 1990). The distribution of seagrasses is also limited in these systems. For example, in the Swan Estuary, seagrass does not extend beyond the middle reaches of the estuary. In making comparisons between the seagrass fish and decapod fauna in estuaries, it is therefore important to take into account where the sampling was carried out.

Seagrass/algal habitat

Comparisons of seagrass with habitats other than unvegetated sand/mud are less common. In nearshore waters of Port Phillip Bay, fish diversity was highest in seagrass, intermediate in reef with algae, and lowest on unvegetated sand (Jenkins and Wheatley 1998). Abundance of fishes was typically higher in seagrass than in unvegetated sand, but not significantly different between seagrass and reef/algae (Jenkins and Wheatley 1998). While the species composition of fish assemblages in seagrass is typically quite different to unvegetated sand (Bell and Pollard 1989; Ferrell and Bell 1991; Jenkins and Wheatley 1998), a number of species previously thought to be strongly associated with seagrass were also common on reef/algae (Jenkins and Wheatley 1998). Sampling on the Yorke Peninsula, South Australia, showed that fish diversity was higher in seagrass (*Posidonia*, *Heterozostera*, *Zostera*) than in intertidal algae (*Hormosira*), but abundances showed no consistent differences between habitats (Jenkins *et al.* 1996a). A similar result was found for shallow seagrass (*Posidonia*), reef/algae and unvegetated sand in Jervis Bay: with highest diversity in seagrass, intermediate in reef/algae, and lowest in sand; no clear patterns emerged for comparison of abundance amongst habitats (Jenkins *et al.* 1996a).

Both seagrass and algae (*Caulerpa* spp.) provide settlement and nursery habitat for the postlarvae and juveniles of grooved tiger prawns (*Penaeus semisulcatus*) in northern Australia (Haywood *et al.* 1995). However, the algal beds provide habitat in only the pre-wet season. During the summer wet season, the algal leaves in upstream algal beds disappear with the onset of summer rainfall and the decline in salinities.

Seagrass/mangroves

Comparisons amongst habitats in subtropical waters more often include mangroves, which usually form a forest higher in the intertidal zone, separated from seagrass beds by unvegetated mudflats. Comparisons either within a single study (Laegdsgaard & Johnson 1995 in Moreton Bay; Small 1997 in Gladstone Harbour) or over several studies done in adjacent waters (e.g. Blaber & Blaber 1980, Morton 1990 in Moreton Bay; Halliday and Young 1996 and Halliday & Connolly submitted in Tin Can Bay) sometimes show a higher species richness in mangroves than in seagrass, but always seem to show a higher proportion of economically important species in mangroves than in seagrass. Laegdsgaard & Johnson (1995) concluded that mangroves form a more important habitat as nursery for economically important fish than seagrass (with unvegetated mudflat intermediate in status). However, it is important to note that all the above comparisons, between the fish faunas of mangroves and seagrass are confounded because of 1) differences in sampling techniques and mesh size and/or 2) differences in water depths. Sampling is often undertaken at slack high tide, at which time even intertidal seagrass is invariably covered by considerably deeper water than mangroves.

Tropical studies

Less is known of the use of seagrass by fish in tropical waters than other regions of Australia. Studies have sampled fish in seagrass (e.g. Coles *et al.* 1990, 1993) and focused on the predation of prawns by fish (e.g. Salini *et al.* 1990, Haywood *et al.* 1998). Relatively few studies have compared the fish fauna in seagrass with different habitats and those that have done so (Robertson & Duke 1987, Blaber *et al.* 1989), have suffered from the problems of confounding outlined above. Whilst no generalisations can be made, one study of fish in different habitats of Groote Eylandt found that in water deeper than 2 m, diversity was higher in the tall, dense seagrass than on bare substrate (Blaber *et al.* 1992). In addition, most species were more abundant on the tall, dense seagrass than the bare habitat.

Commercial Species

Fish

In southeastern Australia the association of commercial species with seagrass relative to other estuarine/nearshore habitats varies with locality. In Victorian embayments and estuaries commercial species thought to be linked to seagrass at some stage in their life-cycle include: King George whiting, *Sillaginodes punctata*, rock flathead, *Platycephalus laevigatus*, black bream, *Acanthopagrus butcheri*, blue rock whiting, *Haletta semifasciata*, garfish, *Hyporhamphus melanochir* and six-spine leatherjacket, *Meuschenia freycineti*. Other species which may have links but about which little is known include squid (*Sepioteuthis australis*) and school (*Galeorhinus galeus*) and gummy sharks (*Mustelus antarcticus*).

Two of these species, six-spine leatherjacket and blue rock whiting, are associated with seagrass from settlement to adulthood (Edgar and Shaw 1995b; Jenkins *et al.* 1997b). In south western Australia, adult blue rock whiting are found in offshore beds of seagrass (*Posidonia sinuosa*) (MacArthur 1997). It should be noted that juvenile and adult six-spine leatherjackets are also found on reef-algal habitats (Jenkins *et al.* 1996a; Jenkins and Wheatley 1998). Rock flathead are strongly associated with seagrass as older juveniles and adults, but young juveniles

are mainly found on unvegetated habitat (Jenkins *et al.* 1993c; Edgar and Shaw 1995b; Jenkins *et al.* 1997b). Juvenile black bream are collected over seagrass in Gippsland lakes (Ramm 1986) although they can also be collected over other habitats (S. Walker, MAFRI, unpublished data). In the estuaries of south-western Australia, black bream are found in the middle and upper reaches where seagrasses are either sparse or absent (Holt 1978, Kanandjembo 1998).

Adult garfish appear to have a dietary link with seagrass, as evidenced by gut contents and stable isotope analysis (Klumpp and Nichols 1983a; Robertson and Klumpp 1983; Edgar and Shaw 1995a). Gummy and school sharks are thought to pup in bays and inlets of Victoria. Habitat usage by juveniles in bays and inlets is unclear. Edgar (1995b) found juvenile gummy sharks widely distributed amongst seagrass, unvegetated and channel habitats in Western Port. Juvenile gummy sharks had a high proportion of seagrass associated crabs (*Nectocarcinus*) in the diet, while the small number of juvenile school shark collected in the study mainly ate pelagic fish (Edgar, 1995a, pers. comm.)

King George whiting have a complex association with seagrass habitat. In Victoria, most sampling has shown that young juvenile King George whiting have a strong preference for seagrass or reef-algal habitat immediately after settlement, but show a shift in habitat to unvegetated sand three to four months after settlement (Robertson 1977; Jenkins and Wheatley 1998). However, in one location, Swan Bay, juveniles are associated with unvegetated sediment patches from the time of settlement (Jenkins *et al.* 1997b). Change to unvegetated habitat in older juveniles is associated with a dietary shift from epifaunal harpacticoid copepods and amphipods to infaunal decapods and polychaetes (Robertson 1977). Within Barker Inlet in South Australia, juveniles were found predominantly over seagrass rather than unvegetated habitat at all stages from 20 to 100 mm in length (Connolly 1994a). Sampling by Jackson and Jones (SARDI, unpublished data), in the same estuary detected reasonable numbers of juveniles at some inner-estuary locations devoid of seagrass. These locations support dense beds of loose macroalgae (*Ulva australis*) at times, and whiting may have been associated with this vegetation. Small whiting can commonly be seen feeding very close to *Ulva* plants in this estuary (Rod Connolly, Griffith University, unpublished data).

In contrast to the Victorian studies and those in Barker Inlet, in south-western Australia, King George whiting settle in nearshore sand regions, not in adjacent seagrass (Hyndes *et al.* 1996, 1998). One of the reasons for this difference between regions may be that in south-western Australia, the adjacent seagrass is *Posidonia*, not *Heterozostera*. The dense structure of the *Posidonia* canopy may inhibit settlement and the movement of juveniles. An alternative hypothesis is that King George whiting settle into very sheltered regions, whether or not these regions contain vegetation. This is supported by the higher densities in very sheltered than in exposed areas in south-western Australia (Hyndes *et al.* 1996, 1998).

A number of species of commercial fish in Victoria have juveniles associated with unvegetated sand habitats. Examples are greenback flounder, *Rhombosolea tapirina*, and long-snout flounder, *Ammotretis rostratus* (Jenkins *et al.* 1997b). Juveniles of some commercial species, such as yellow-eye mullet, *Aldrichetta forsteri*, and Australian salmon, *Arripis* spp., can be found on a range of habitats from sheltered seagrass to moderately exposed sandy beaches (Robertson 1978; Jessop 1988; Jenkins *et al.* 1996a; Jenkins *et al.* 1997b). The major habitat requirement of these juveniles seems to relate to water depth, they prefer to be near the waters edge moving in and out with the tide, irrespective of substrate type.

In southern New South Wales, juveniles of four commercial species, sand whiting, *Sillago ciliata*, bream, *Acanthopagrus australis*, tarwhine, *Rhabdosargus sarba*, and sprat, *Hyperlophus translucidus*, were predominantly collected on sand adjacent to seagrass (<10m) (Ferrell and Bell 1991). This is also the case for all species of whiting in western Australia (Hyndes *et al.* 1996, 1998, Rod Lenanton, Fisheries WA, pers. comm.). In NSW, one commercial species, luderick, *Girella tricuspidata*, was predominantly collected in seagrass (*Zostera*), while no commercial species was predominant on sand distant (>100m) from seagrass (Ferrell and Bell 1991). Previous studies had suggested that *Zostera* was an important nursery area for luderick, tarwhine and bream (Middleton *et al.* 1984). However, only luderick showed a strong affinity to seagrass in the study by Ferrell and Bell (1991); the other species apparently utilise a habitat mosaic of seagrass and adjacent sand habitat.

In Tasmania, a recent study has compared utilisation of seagrass and unvegetated habitat by commercial species (Alan Jordan, DPI Fisheries, Tasmania, unpublished data). Only older juveniles and adults of sand flathead, *Platycephalus bassensis*, were found in significant abundances in seagrass, although they were also common on sand. Conversely, juveniles of four commercial species: yellow-eye mullet, *Aldrichetta forsteri*, Australian salmon, *Arripis trutta*, greenback flounder, *Rhombosolea tapirina* and long-snout flounder, *Ammotretis rostratus*; were mainly found over bare sand. Relatively few commercial species are found in seagrass beds of south-western Australia (Glenn Hyndes, Murdoch University, pers. comm.). The paucity of commercial species found in the seagrass beds of Tasmania and south-western Australia contrasts with higher numbers of commercial species on seagrass beds in New South Wales, Victoria and South Australia.

Sampling at two sites within Moreton Bay, Laegdsgaard & Johnson (1995) found that a higher number of economically important species were caught as juveniles in mangrove forest than adjacent seagrass beds (*Zostera*), and that those juveniles were also smaller. They concluded that early recruits predominantly utilise mangroves, slightly older juveniles are found over bare mudflats, while juveniles found in seagrass are older still. Notwithstanding the possibility of a confounding influence of differing sampling techniques among habitats, this scenario provides an interesting parallel with the idea that *Zostera* meadows harbour smaller juveniles than adjacent *Posidonia* meadows (Middleton *et al.* 1984) [see description in Section 3.1.1]. Both patterns can possibly be explained by smaller juveniles being in great abundance in shallower water (mangroves compared to *Zostera*, at high tide; *Zostera* compared to *Posidonia*). Much lower densities of fish (4 to 10 times lower) were found in seagrass than mangrove lined creeks in the Townsville region (Robertson & Duke 1987, Robertson & Blaber 1992). In these cases, the habitat comparisons were confounded with distance from the ocean: the seagrass beds were located at the mouths of creeks and the mangroves were further upstream.

The comparisons of mangroves and seagrass habitats by Laegdsgaard and Johnson (1995) are likely to have overestimated the importance of mangroves given that sampling was only done at high tide. Mangroves are only inundated on the high tide, and cannot be used by most fish species, including all economically important species, at other times of the tidal cycle (over half of the time). Some smaller species, notably gobies, can remain in the mangroves between tides. To properly determine the relative importance to juvenile fish of different habitats in close proximity, we need work which combines sampling at different stages of the tidal cycle, in the same general vicinity over the same period.

Small (1997) compared the same habitats as Laegdsgaard & Johnson (1995) in Gladstone Harbour in one of the few recent subtropical studies aiming to collect data on habitat use by

adult and subadult fish. In this case, fish sampling techniques were quantitative in seagrass and mudflats but not in mangroves, so quantitative comparisons could not be made between the three habitats. Only the proportion of breeding individuals of economically important species could be compared, and this was found to be considerably higher in mangroves. This suggests that mangroves may be a more important site for spawning or recruitment than mudflats or seagrass. However, the data are far too scant to make any firm conclusions.

Decapods

The distribution of early juveniles (postlarvae) of commercially important prawns in Moreton Bay has been thoroughly surveyed (Young & Carpenter 1977, Young 1978) The four main species examined (Brown tiger prawns *Penaeus esculentus*, Eastern King prawns *Penaeus plebejus*, Greasyback prawns *Metapenaeus bennettiae* and School prawns *Metapenaeus macleayi*), were all more common in seagrass than adjacent unvegetated sites. The pattern was equivocal for *P. plebejus*, which was more common at unvegetated sites in some locations. Three species of prawns (*P. esculentus*, *Penaeus semisulcatus* and *Metapenaeus endeavouri*) were more abundant on seagrass than adjacent bare substrate in the Cairns harbour (Coles *et al.* 1993). Whilst there is an association between seagrass and juveniles for these species, an even more striking result in Moreton Bay was the lack of prawns in water deeper than about 2m, whether vegetated or not. There was also a strong pattern of differing abundances at different positions within the bay.

Megalopae of blue swimmer crab (*Portunus pelagicus*) settled in shallow, intertidal seagrass in Morton Bay (Greg Skilleter, University of Queensland, unpublished data). This was also the case for juvenile blue crabs *Callinectes sapidus* in north America which were found in much higher densities on seagrass and in saltmarsh until the 3rd to 5th juvenile instar (Pile *et al.* 1996). Experiments with seagrass and artificial seagrass in the laboratory, and with seagrass in the field have shown that the postlarvae and juveniles of tiger prawns prefer seagrass to bare sand (Kenyon *et al.* 1995, 1997, Liu & Loneragan 1997). In fact, tiger prawn postlarvae were found in bare trays covered with monofilament mesh to exclude predators, which suggests that they respond strongly to structure when settling, not necessarily to seagrass *per se*. Small juvenile blue swimmer crabs were found in much higher numbers on artificial seagrass units than bare units (i.e. controls, Loneragan *et al.* 1996, Kenyon *et al.* in press).

Some of the most complete evidence for the use of seagrass by juvenile stages comes from studies of tiger prawns (*Penaeus esculentus*, *P. semisulcatus*) in northern Australia. These species contribute to major fisheries along the east coast of Queensland, the Torres Straits, across northern Australia and in Exmouth Gulf and Shark Bay of Western Australia (Table 6.1). They are found on intertidal and shallow subtidal (< 2.5 m deep) beds of seagrass (Coles & Lee Long 1985, Staples *et al.* 1985, Turnbull & Mellors 1990, Coles *et al.* 1993, Loneragan *et al.* 1994, in press) and algae (Haywood *et al.* 1995). In the Torres Straits, the main nursery grounds for tiger prawns are seagrass on the reef tops of the Warrior Reefs (Turnbull & Mellors 1990). Endeavour prawns are also important commercial species in the same regions as tiger prawns. While the juveniles of blue endeavour prawns *Metapenaeus endeavouri* are found on similar habitats to tiger prawns (Staples *et al.* 1985, Coles *et al.* 1993), those of the red endeavour *M. ensis* are more widely distributed and are found on seagrass, algae and mangrove-lined mudbanks (Staples *et al.* 1985). In contrast to tiger and endeavour prawns, western king prawns *Penaeus latisulcatus* are found in greater numbers on sandy substrates (Potter *et al.* 1991).

The fishery for western rock lobster *Panulirus cygnus* is the most valuable single species fishery in Australia. The newly settled or post-juvenile stages are usually found in small cracks and crevices within limestone substrate (reefs and pavement). In all cases, the only potential shelters that are occupied are covered by seagrass and/or algae (Jernakoff 1990). As the juveniles become older and larger they move to the caves and ledges of limestone reefs and continue to forage amongst seagrass (Jernakoff 1987). Near Geraldton, the densities of a key prey species were higher in *Halophila* than *Amphibolis* or turf algae (Edgar 1990).

6.2.2 Knowledge of *in situ* seagrass fisheries

The commercial species most commonly targeted in seagrass habitats of Victoria are King George whiting and rock flathead, with incidental catches of blue rock whiting and leatherjackets. Other species targeted in areas with seagrass, but not specifically over seagrass habitat, include black bream, flounder, garfish, yellow-eye mullet and Australian salmon.

One way to 'test' for links between seagrass and fisheries is to examine the fate of fisheries where seagrass has been lost. The major loss of seagrass in Western Port, Victoria, over a 15 year period (75%) led to major changes in the characteristics of associated fisheries (MacDonald 1992) (Table 6.1). A parallel decline occurred in catches of King George whiting, rock flathead, blue rock whiting and leatherjackets, while other species such as yellow-eye mullet, Australian salmon and southern sea garfish either showed no change or increased (MacDonald 1992). It seems unlikely that these changes were a result of fishing pressure because some of the species that declined were only caught incidentally and were of low commercial value (blue rock whiting and leatherjackets), and catches of King George whiting returned to historically high levels in nearby Port Phillip Bay where fishing pressure was higher, but not in Westernport (MacDonald 1992). It is important to note that the species which declined have the strongest association with seagrass in terms of habitat use and diet, while species that did not change or increased had only an incidental association with seagrass (Jenkins *et al.* 1993a; Edgar and Shaw 1995b; Jenkins *et al.* 1997b). Catches of rock flathead have also declined markedly after seagrass loss in Port Phillip Bay and Corner Inlet (Table 6.1).

Large changes in the extent of seagrass and associated estuarine fisheries have also been recorded in the Peel-Harvey estuary of south-western Australia. Seagrasses in this system were greatly reduced in the 1970s because of massive increases in the biomass of macroalgae (*Cladophora* and *Chaetomorpha*) caused by increased nitrogen in the system (McComb & Lukatelich 1995). Following the loss of seagrass and increase in macroalgae, the commercial catches of sea mullet *Mugil cephalus*, yellow-eye mullet *Aldrichetta forsteri* and cobbler *Cnidoglanis macrocephalus*, increased by about 100%. Catches in the Swan estuary, where a similar fishery operates and no such increase in macroalgae was recorded, did not increase to the same extent (Lenanton *et al.* 1984, Steckis *et al.* 1995). Catches in the Peel-Harvey estuary of western king prawns *Penaeus latisulcatus*, a species whose juveniles use sandy substrates, declined over the same period. In the 1980s, increases in phosphorus led to blooms of cyanobacteria in the spring and summer (McComb & Lukatelich 1995) and this led to the construction of a new entrance channel in the system. It will be interesting to note whether seagrasses have recolonised in the system and whether there has been another marked change in the fish and decapod fauna. Current research at Murdoch University is investigating changes in the fish fauna of the Peel-Harvey estuary associated with the new channel (Glen Young, PhD student at Murdoch University).

A similar comparison between vegetation loss and fishery catch has been made for Gippsland Lakes, Victoria. From approximately 1920 to 1960 there was apparently a large loss of seagrass from lakes Victoria and King. One hundred years of catch data shows an extended gap in the catch histories of black bream and luderick over the same period (Table 6.1). Commercial fishing for these species occurs in a number of habitats other than seagrass, however both species are thought to have a strong association with seagrass in the juvenile stage, although the data is more convincing for luderick than it is for black bream (Ramm 1986; Ferrell and Bell 1991; Jenkins *et al.* 1997b).

A large-scale die-off of seagrass (*Amphibolis antarctica*) at the lower margin of the intertidal shelf in Spencer Gulf in South Australia provided an opportunity to examine differences between assemblages of small fish from healthy seagrass, die-off zones and habitat unvegetated prior to die-off (Seddon 1997). No data had been collected prior to or during the die-off event in March 1993, but a rigorous sampling program over 12 months, beginning two years after die-off, showed that fish assemblages differed markedly among the three habitat types. Die-off patches had low diversity (similar to bare sand) but fairly high abundance (although not as high as seagrass). Certain species, including the commercially important blue-swimmer crab (*Portunus pelagicus*) were most abundant in die-off areas. It seems that die-off areas will eventually either remain unvegetated with a nekton fauna like that of bare sand, or be recolonised by seagrass (albeit a different species at this stage, namely *Zostera*) and a seagrass fauna will return (Seddon 1997, University of Adelaide unpublished data).

In northern Australia, two major events have resulted in the loss of seagrass: cyclone 'Sandy' in the Gulf of Carpentaria in March 1984, and major runoff from Papua New Guinea into the Torres Strait in 1992/93 (Table 6.1). Following Cyclone Sandy, twenty percent of the seagrasses in the Gulf of Carpentaria were lost (Poiner *et al.* 1989). This led to a marked change in the composition of the juvenile prawn communities in shallow water seagrasses, with tiger prawns being replaced by western king prawns (*Penaeus latisulcatus*) and non-commercial metapenaeid prawns (Poiner *et al.* 1993). Commercial catches in the southern Gulf of Carpentaria declined, but only by 2 to 5% (Poiner *et al.* 1993). The seagrasses took about 12 years to return to their original extent and juvenile prawn communities have also returned to their original composition.

Seagrasses affected by the major runoff from Papua New Guinea in 1992/93 were in deeper water and the effect on tiger prawns has not been investigated in detail. However, the loss of seagrasses probably had an effect on painted crayfish (*Panulirus ornatus*) in the region (Pitcher *et al.* 1994, Darrin Dennis, CSIRO Marine Research, pers. comm.), as no juvenile crayfish were found in the area where seagrass was lost. It is thought that, prior to loss, seagrasses stabilised the sediments around the juvenile crayfish burrows. After the seagrass was lost, sediment filled the burrows, and juvenile crayfish were not able to colonise the area. Once the seagrass recolonised, juvenile crayfish were again found in burrows in the region.

There are very good descriptions of a massive die-off of seagrasses (over 24% of the area of all known seagrass beds in Queensland) in Hervey Bay (Preen *et al.* 1995) and Great Sandy Strait (Thorogood & Horrocks 1994). Although this event reportedly led to mass reductions in dugong numbers in Hervey Bay (this coincided with an increase in dugong numbers in Moreton Bay, presumably being animals that migrated south), we can find no attempt to link the die-off with changes in fisheries catch data. During the same event, die-off of an entire bed of *Zostera capricorni* in Tin Can Bay in 1991 had a strong effect on juvenile fish and prawns, when

compared to the same site prior to die-off and with another site within the bay where seagrass did not die-off (Halliday & Connolly submitted). Abundances and biomass of trumpeter whiting (*Sillago maculata*), silverbiddies (*Gerres oyeana*) and eastern king prawns (*Penaeus plebejus*) increased significantly after seagrass loss. No commercial species declined significantly in abundance or biomass, although several cryptic non-commercial species did (e.g. hairy pipefish, *Urocampus carinirostris*). Only juvenile fish and prawns were sampled, so we can only infer what effects loss of seagrass might have had on stocks of adult fish. Longer term effects of seagrass loss were not measured; these could be much more detrimental to densities of important fish and crustacean species.

Seagrasses have also been lost from the western side of the highly populated Moreton Bay in southeast Queensland since 1987 (O'Donohue & Dennison 1996, Udy & Dennison 1997). Unlike the seagrass loss from the Gulf of Carpentaria and Torres Straits, no recovery has been recorded. Changes in the commercial fishery have not been investigated in Moreton Bay.

Overseas, the clearest link between seagrass loss and fisheries decline in the United States was the collapse of the bay scallop, *Argopecten irradians*, fishery in North Carolina and Chesapeake Bay (Virginia, Maryland, Delaware), following the eelgrass wasting disease of 1931-32 when more than 90% of the eelgrass was lost. As eelgrass recovered in North Carolina, the scallops returned, but, in Chesapeake Bay, scallops have not returned even though some seagrass regrowth has occurred (Peter Sheridan, US National Marine Fisheries Service, pers. comm.). In a recent study, the pink shrimp, *Penaeus duorarum*, fishery in southern Florida underwent a severe (50%) decline in the late 1980's - early 1990's, at the same time as a 20% loss of seagrass, *Thalassia*, the purported main nursery. However, pink shrimp stocks have since recovered in spite of continued disruption to the seagrass ecosystem (Peter Sheridan, US National Marine Fisheries Service, pers. comm.).

Penaeid shrimp, crab and finfish fisheries in the Seto Inland Sea in Japan declined rapidly during the 1960s at the same time that *Zostera marina* beds were massively reduced by pollution (Kikuchi 1974). While fisheries information is simple catch data rather than CPUE, the association is impressive. Kikuchi (1974) points out, however, that the pollution that killed the seagrass (increased turbidity, dinoflagellate blooms) might also have had a direct adverse effect on fisheries.

In Barker Inlet, South Australia, an experimental approach was taken to examining the effect of seagrass loss. Patches of *Zostera muelleri* (30 m²) were cleared of above-ground vegetation (Connolly 1994b) to test the explanation by Bell & Westoby (1986a) that higher fish abundances for some species are the result of those fish actively selecting seagrass rather than unvegetated habitat. Fish abundances were only slightly reduced by the removal of seagrass, and were significantly higher than in habitat unvegetated prior to the experiment. Abundances of key species such as King George whiting were not reduced at all. The experiment had the benefits of being properly replicated (at least along the 1 km stretch of coast under study), with interspersed and randomisation of different treatments. The limitations were the relatively small scale of seagrass "loss", and the short term nature of the experiment. Fish were sampled two weeks after seagrass removal, the longest time possible before *Zostera* began to regrow. We note also that Barker Inlet is an exceptionally productive and sheltered region, and results of this experiment would not necessarily be the same if it was repeated in more exposed seagrass beds. At the time of sampling, invertebrate prey were just as common in plots from which seagrass had been removed as they were in healthy seagrass plots (Connolly 1995).

A possible explanation for the lack of effect on fish abundances of seagrass removal is that fish abundances are determined by prey availability. For example, one or two months after settlement, King George whiting show a correlation between abundance on a seagrass bed and fullness of the gut, suggesting an important influence of food availability (Jenkins *et al.* 1996b). Research on the role of food availability in determining habitat preference of King George whiting is continuing in Port Phillip Bay (Greg Jenkins, MAFRI, unpublished data).

Another approach for examining the importance of seagrass to fisheries production is to correlate fisheries catch with seagrass cover. In South Australia, seagrass cover within "Fishing Sectors" has been shown to be positively correlated with garfish catch within the sector (Karen Edyvane, Lynne Scott, Keith Jones, SARDI, unpublished). The work is at an early stage but shows promise in highlighting links between fisheries species and seagrass.

6.2.3 Links between seagrass and fisheries elsewhere

Juveniles occurring in seagrass before departing for other habitats

In NSW, commercial species of fish that occur as juveniles in seagrass before moving to other habitats fall into two categories (Bell and Worthington 1992): 1) species whose adults are common in both estuaries, including seagrass beds, and offshore habitats (e.g. yellow-fin bream, *Acanthopagrus australis*, and luderick, *Girella tricuspidata*), and 2) species whose adults are found only in habitats other than seagrass, usually offshore reefs (e.g. eastern blue groper wrasse *Achoerodus viridus*, tarwhine, *Rhabdosargus sarba*, and leatherjackets, *Meuschenia* spp.) (Gillanders and Kingsford 1992, Bell and Worthington 1992). Species which spend only the juvenile stage in seagrass may be less likely to show correlations between catch and seagrass loss. For example, in NSW, species such as bream and tarwhine spawn offshore from estuaries (or just outside estuaries) and therefore the loss of seagrass from an individual estuary may not have a large impact on the population as a whole. Loss of seagrass across a number of estuaries would, however, be likely to have an impact. The extent to which larvae from coastal spawning are spread amongst estuaries is relatively unknown and deserves further investigation. For many of these species the assumption has been made that most of the adult population is derived from juveniles in seagrass. It has been assumed that coastal populations of blue groper, *Achoerodus viridus*, are derived from juveniles that settled in estuarine habitats including seagrass (Bell and Worthington 1992). However, work using otolith microchemistry suggests that a significant proportion of the adult population may be derived from juveniles that recruited directly to coastal reefs (Gillanders and Kingsford 1992).

Results from stable isotope studies have shown that juvenile prawns found on seagrass in the Embley River estuary assimilate carbon that is derived either directly from seagrass or from seagrass epiphytes (Loneragan *et al.* 1997). Research is currently underway using enriched isotopes to investigate whether seagrass or their epiphytes are the source of carbon assimilated by prawns (Michelle Winning *et al.* Griffith University, unpublished data). Other studies have dismissed seagrass as a direct source of food for brown shrimp (*Penaeus aztecus*, Kitting *et al.* 1984). However, brown tiger prawns (*P. esculentus*) consume seagrass seeds in large quantities when they are available (Wassenberg 1990). Seagrass carbon and nutrients could, therefore, contribute directly to the nutrition of juvenile prawns.

Seagrass production sustaining fisheries elsewhere

It may be misleading to consider that only species physically living in seagrass beds derive benefit from it. Juvenile greenback flounder in Port Phillip Bay, Victoria, for example, are found only in unvegetated habitats. Research has shown, however, that unvegetated areas near seagrass are enriched with detritus that results in increased production of the small crustaceans that are the food of juvenile flounder (Shaw and Jenkins 1992). It was assumed that the detritus was mainly of seagrass origin as this was the dominant macrophyte in the area. Therefore more juvenile flounder were found on unvegetated areas enriched by seagrass detritus, and these flounder had higher feeding and growth rates compared with flounder in other areas (Jenkins *et al.* 1993b). Seagrass detritus may also contribute significantly to the food web of recently settled and juvenile King George whiting in the sandy habitats (adjacent to the seagrass *Posidonia*) they colonise in south-western Australia (Glenn Hyndes, Murdoch University, pers. comm.)

Most fish species in Western Port, including a number of commercial species, were supported by a detritus - epifaunal crustacean food chain (Edgar and Shaw 1995a). This included pelagic species not directly associated with seagrass such as yellow-eye mullet and silver trevally (Edgar and Shaw 1995a). As Edgar (1995b) has pointed out, most studies of habitat utilisation are carried out on a relatively small scale, while most seagrass production is not utilised *in situ*, but is exported from seagrass beds (Whitfield 1988). Thus, the long term effects of a major seagrass loss will be to reduce the detritus in sediments, and therefore reduce the productivity of food for fish in unvegetated habitats. Consequently, commercial species that are common in areas with seagrass but do not physically live in seagrass beds may nevertheless be benefiting from seagrass production through the food chain. Therefore, studies of commercial fish distribution and abundance, feeding rates (including stable isotope analysis) and growth rates should be carried out over a long period and a wide area after an episode of seagrass loss, as the detrital load from seagrass declines.

Simulation studies have been used to estimate the yield and value of three species of prawns (*P. esculentus*, *P. semisulcatus* and *M. endeavouri*) caught in waters offshore from three seagrass beds in the Cairns area (Watson *et al.* 1993). The yield depends on the density of prawns in different beds and the extent of the beds, while the value is also affected by the price of the different species. The highest yield and value were not from the bed with the greatest area. In fact the highest value was derived from the smallest bed (230 ha of seagrass in the western harbour compared with 270 ha in the eastern harbour and 376 ha in Mission Bay). From stable isotope studies, it has so far not been possible to distinguish whether prawns in offshore waters derive their carbon from exported seagrass detritus, or benthic diatoms (Loneragan *et al.* 1997).

Seagrass productivity may also benefit fisheries at large distances from the seagrass habitat. Thresher *et al.* (1992) used stable isotope analysis to show that larval blue grenadier, *Macruonus novaezelandiae* on the west coast of Tasmania, are likely to be supported by a food chain based on the microbial decomposition of seagrass from mainland Australia. Furthermore, the growth rates of larvae were correlated with winter storm events that would lead to export of buoyant seagrass material. In contrast, preliminary results from stable isotope work on food chains leading to demersal trawl fish in eastern Bass Strait has found that seagrass production is only of minor significance (Nick Bax, CSIRO Marine Research, pers. comm.).

Seagrass beds typically support large numbers of small species with cryptic habits and/or juveniles of larger species (Bell and Pollard 1989). Non-commercial species in these categories

could potentially be an important food source for commercial fish. Some evidence suggests that this is the case. In Corner Inlet, Victoria, seagrass associated fish such as weedfish, *Heteroclinus perspicillatus*, and juvenile leatherjackets, *Acanthaluteres spilomelanurus*, is an important component of the diet of rock flathead (Klumpp and Nichols 1983b). Diets of juvenile Australian salmon also included small, seagrass associated species such as pipefish, *Urocampus carinirostrus*, blue-spot goby, *Arenigobius bifrenatus*, and weedfish, *Heteroclinus perspicillatus* (Robertson 1982). In Western Port, the diet of rock flathead and sand flathead consisted partly of fish, predominantly small seagrass-associated species (Edgar and Shaw 1995a). Three commercial species; eastern and western Australian salmon, and tailor, consumed mainly pelagic baitfish, although demersal, seagrass associated fish were also included in the diet of western Australian salmon, *Arripis truttaceus*. A study presently underway has shown that small seagrass-associated species form an important part of the diet of rock flathead and yank flathead, *Platycephalus speculator*, in Port Phillip Bay seagrass beds (J. Hindle, Melbourne University, unpublished data). A species of shrimp (*Palaemonetes australis*) found throughout beds of *Ruppia* in Wilson Inlet south-western Australia (Humphries et al. 1992), is also the main prey species for *P. speculator* in this estuary (Humphries et al. 1992b)

The question of non-commercial fish and shrimp species in seagrass beds becoming food for commercial species has parallels in the recent call by Kneib (1997) for scientists to stop ignoring small, non-commercial species common on saltmarshes. Kneib stresses the need to examine trophic linkages. The overlapping ranges of different sizes and species of fish offers the possibility that fish resident in saltmarshes high in the intertidal zone are eaten directly by slightly larger fish that venture a little way onto the marshes. These in turn might be eaten when they return to deeper water in marsh creeks by fish that spend time in the creeks but also in deeper parts of the estuary. A similar scenario is possibly being played out among the small but abundant fish of shallow *Zostera* beds (e.g. families Gobiidae, Syngnathidae, Ambassidae) and the larger fish caught in deeper seagrass beds and other parts of the estuary.

6.2.4 Summary

1. Fish and decapod diversity in seagrass is generally higher than in unvegetated habitats but this is often not the case for abundance or biomass.
2. Diversity and abundance of fish and decapods in other structured habitats such as reef/algae and mangroves can be comparable to seagrass.
3. A number of important commercial fish and decapod species show a strong association with seagrass at some stage of their life-cycle although there are other commercial species that are associated with unvegetated habitat. Juvenile tiger prawns are always strongly associated with seagrass.
4. The clearest evidence for links between seagrass and fisheries comes from Western Port, Victoria, where the catch of a number of commercial species declined in parallel with seagrass decline. Catches of some other commercial species, however, remained stable or increased over the same period. Such examples are rare on a world scale. Other studies have shown no detrimental effects of seagrass decline on fisheries.

5. There seems to be geographic variation in the proportion of commercial species utilising and caught in seagrass beds: it is lower in Tasmania than other temperate states.
6. Fish assemblages in seagrass tend to be dominated by small individuals of non-commercial species, but these form part of the diet of some commercial species.
7. A number of commercial species spend their juvenile phase in seagrass but the adults occur partly or wholly elsewhere. For these species the contribution of juveniles from seagrass to future adult populations is unknown, as is the extent of mixing of larvae amongst different bays and estuaries from distant spawning.
8. Although a number of commercial species may be associated with unvegetated habitat, growth and survival may still be enhanced by seagrass detritus increasing benthic productivity.
9. Dietary and stable isotope studies show that direct feeding on seagrass is rare. However, for some species such as garfish and juvenile tiger prawns, carbon from seagrass and/or seagrass epiphytes is assimilated.
10. Sampling methods and protocols (depth, tidal state, time of day etc.) vary widely making broad geographic comparisons difficult.

6.3. INFLUENCE OF SEAGRASS STATUS ON FISHERIES SUSTAINABILITY

6.3.1 Are all seagrass meadows of equal importance to fisheries?

Seagrass beds are not all of equal importance to fisheries, but finding the reasons why is difficult due to confounding factors.

Water depth

In NSW, *Zostera* has been consistently found to support more juvenile fish than *Posidonia* (Middleton *et al.* 1984; Bell and Westoby 1986b). Commercial species may be found in *Posidonia* at an older juvenile stage (Middleton *et al.* 1984). While this difference may relate to morphological characteristics of the seagrass species, it may also simply be a function of water depth. *Zostera* grows in shallow estuarine areas while *Posidonia* is found in deeper marine waters. Depth may be important because pre-settlement larvae of fish have distinct depth preferences which may subsequently be reflected in settlement depth (Bell and Pollard 1989). Depth is certainly a critical factor in defining the settlement and juvenile habitat for juvenile tiger prawns (Young and Carpenter 1977, Loneragan *et al.* 1994).

A similar situation occurs in Victoria with intertidal *Zostera* and subtidal *Heterozostera*. Distinct assemblages of fish and decapods are found in each of these species and the assemblages are more similar to assemblages in adjacent unvegetated areas of the same depth than between seagrass species at different depths (Jenkins *et al.* 1997b). These seagrass species are morphologically very similar and the differences between assemblages most likely relate to

physical differences in the intertidal versus subtidal environments. The commercial species that declined most in Western Port were those most closely associated with *Heterozostera*, the seagrass species that showed the greatest decline (Jenkins *et al.* 1993a).

Even beds of the same seagrass species can support different assemblages of small fish. For example, the abundances of most fish species differed as much between different *Zostera* beds (0.5 to 2 km apart) within an estuary as they did between estuaries (15 – 300 km apart) along the northern NSW coast (Gray *et al.* 1996).

Compared with the nearshore, shallow seagrasses, relatively few studies have examined the fauna of deeper water seagrasses, possibly because of difficulties in this habitat. Bell *et al.* (1992) found that the fauna caught in beam trawls did not differ consistently between shallow (1 to 2 m) and deep seagrasses (6 to 7 m) in Jervis Bay, New South Wales. Current research is investigating the fish fauna of deeper water seagrasses (4 to 9 m deep) in waters offshore from Fremantle, Western Australia (Glenn Hyndes, Murdoch University, pers. comm.).

Seagrass structure

Features of seagrass beds such as leaf density, length and morphology can influence fish assemblages on a local scale. Earlier theory suggested that the main link between seagrass and fish was shelter from predators, leading to the hypothesis that fish numbers would increase with the complexity of seagrass beds up to a threshold when the seagrass bed became too dense for fish to move freely (Heck Jr and Orth 1980). Research has found that fish species respond to structural complexity with seagrass beds, but not necessarily in a way that supports this hypothesis. Bell and Westoby (1986b) manipulated the height of seagrass in *Zostera* and *Posidonia* and found strong responses in abundances of fish and decapods but not all in the expected direction. While some species decreased when seagrass was thinned or shortened, others increased or remained stable. Another study showed a decrease in abundance of fish and decapods when seagrass was thinned, but this happened whether predators were present or not, suggesting behavioural choice was involved (Bell and Westoby 1986a). Worthington and Westoby (1991) measured settlement into artificial seagrass beds of different leaf densities and found a sharp threshold of increasing settlement at low leaf densities and little change in settlement at higher leaf densities. Similar findings have been reported for postlarvae tiger prawns (Kenyon *et al.* in press). Jenkins and Sutherland (1997) compared artificial seagrass beds with low and high complexity and found little difference in species richness but a much higher number of some species, particularly pipefish and juvenile leatherjackets, in high complexity beds. None of these studies, however, included significant numbers of juveniles of commercial fish.

These findings on the early life history stages in beds of different structure contrast with preliminary results from deeper water seagrasses in Western Australia. This study is investigating the fish fauna found in *Posidonia sinuosa* and *Amphibolis griffithii* beds in depths of 4 to 9 m. Major differences are being found in the number of species, total numbers of individuals and the composition of the community between beds of different structural complexity. In addition, the size of individuals of some species differs between beds: smaller fish are being found in beds of *P. sinuosa* than *A. griffithii* (Glenn Hyndes, Murdoch University, pers. comm.).

Studies of the fish fauna and predation rates on prawns in a high biomass (70 g.m⁻²) and a low biomass (7 g.m⁻²) seagrass bed in the Embley River estuary of northern Queensland have shown

that of the smaller species (sampled by beam trawl, beach seine and rotenone), 11 species were more abundant on the high biomass bed and three on the low biomass bed (Haywood *et al.* 1998, CSIRO Division of Marine Research, unpublished data). There were fewer differences for the larger species sampled by gill nets. It should be noted that the differences in both the above studies were confounded by location of the beds and the different habitats were not replicated.

Spatial location of beds and hydrodynamics

Of more interest to managers is whether characteristics of individual beds are important over larger scales. For example, a decision over preservation is more likely to be a choice amongst different seagrass beds rather than parts of an individual bed. A major concern is whether patterns found for individual beds are important over larger spatial scales. Over a broad (estuarine) scale in NSW, *Zostera* height and density varied among beds but were not correlated with abundance of fish and decapods (Bell and Westoby 1986c). Patterns seen at the within-bed scale (Bell and Westoby 1986b) were therefore not reproduced at the larger scale. A similar result was found by Worthington *et al.* (1992) for a number of NSW south coast estuaries, and in this case some commercial species, such as luderick and tarwhine, were included in the analysis. There was a trend, however, for patterns of fish abundance to be related to distance from the mouth of an estuary, suggesting that the supply of larvae from outside the estuary may influence patterns (Bell *et al.* 1988).

Position of seagrass bed within estuary

In Victoria, the broad-scale abundance of recently-settled King George whiting has been investigated in Port Phillip Bay. Over approximately 40 km of coastline, abundance of juvenile King George whiting showed no correlation with the structural characteristics of *Heterozostera* beds (Jenkins *et al.* 1996b; Jenkins and Wheatley 1998). When artificial seagrass beds of constant structure (i.e. density and height) were placed near natural *Heterozostera* of varying structure at locations around the coast, juvenile whiting abundance was highly variable amongst sites but almost identical between natural and artificial habitats. A correlation has been found, however, between whiting abundance and distance from the bay entrance (Jenkins *et al.* 1996b), suggesting a strong influence of larval supply, because spawning of this species occurs outside the bay (Jenkins and Black 1994). Hydrodynamic modelling has shown that a large amount of the variation in abundance at sites can be explained by two factors: variation in the currents delivering larvae, and exposure of the site to wave action which either kills or re-transportes larvae (Jenkins *et al.* 1997a). All this suggests that the location of the seagrass bed within the bay is far more important to King George whiting abundance than characteristics of the seagrass.

Other evidence for the importance of position of seagrass beds within an estuary comes from Barker Inlet in South Australia. Over the whole estuary, fish assemblages differed between the outer and inner parts (Gary Jackson & Keith Jones, SARDI, unpublished data). In the outer part of the estuary, the degree of exposure to open water was a major factor influencing fish abundances, overriding even the strong influence of seagrass presence (Connolly 1994a).

In northern NSW estuaries, where there is a strong riverine influence on estuaries in general, fish diversity and abundance can be strongly affected by the distance upstream (i.e., amongst other things, degree of freshwater influence). Seagrass sites just inside the estuary opening are

of particular importance to newly recruited fish (West and King 1996; Gray *et al.* 1996), but the importance of different positions changes through time (see below, within this section).

In Moreton Bay, Queensland, juvenile prawns of several species all showed habitat preferences based on vegetation and strong affinities for shallow water (< 2 m), but there was also a strong influence of position within the bay (Young & Carpenter 1977, Young 1978). Whereas *Penaeus plebejus* occurred all over the bay, *P. esculentus* was found mainly in the middle of the bay, while greasyback (*Metapenaeus bennettiae*) and school prawns (*M. maclaeyi*) were found on the eastern side associated with rivers. The position of seagrass bed is also an important factor in northern Australia where the number of tiger prawn postlarvae passing over seagrass beds was higher in regions where current flow was higher (Vance *et al.* 1996a, Loneragan *et al.* in press).

The 'importance' of a seagrass bed for commercial fish in bays and estuaries may depend on the location of that bed relative to hydrodynamic patterns (McNeill *et al.* 1992; Jenkins *et al.* 1997a). This suggests that an assessment of potential important seagrass beds could be made using hydrodynamic modelling. Generalised hydrodynamic models can be applied to different bays and estuaries with a knowledge of bathymetry, sea-level and wind records (Black *et al.* 1993). Because this approach does not require field work in the first instance, it has potential as a rapid assessment tool for evaluating the significance of different seagrass beds to the larvae of fish and decapods.

Another question of relevance to managers is the temporal consistency in the 'importance' of seagrass beds. Earlier suggestions that spatial variation in settlement to beds is 'stochastic' (Bell and Westoby 1986c) has given way to recognition that certain beds may be of greater importance to juvenile fish depending on their location within a bay or estuary. In NSW, juveniles of commercial fishes tend to occur consistently on certain beds within a season (Worthington *et al.* 1992) and across seasons (McNeill *et al.* 1992). High recruitment at one site in Botany Bay is seasonal and related to the recruitment of commercial species; the hypothesis was forwarded that stable oceanographic processes resulted in a high supply of larvae to this bed (McNeill *et al.* 1992). In the same way, certain seagrass beds have large numbers of newly settled King George whiting in Port Phillip Bay consistently across years, suggesting that current and wave exposure patterns mentioned above are relatively stable across time (Jenkins *et al.* 1997a).

Temporal consistency of the 'importance' of a seagrass bed depends to some extent on whether juveniles continue to stay in the bed they settled in, or whether they migrate to other habitats as they grow. In NSW there is conflicting evidence with regard to migration from the site of settlement. Some studies have argued that there is little redistribution of settlers to other seagrass beds over a full year of growth (Worthington *et al.* 1992). Other studies suggest that juvenile fishes will redistribute to alternative habitats within the first year of life (Middleton *et al.* 1984; Gillanders and Kingsford 1992). McNeill *et al.* (1992) found outstandingly high abundances of juvenile commercial fish at one site during the recruitment season, but no significant difference at other times of year. In Victoria, King George whiting juveniles showed an initial settlement pattern related to hydrodynamic patterns, but a month or two after settlement they had redistributed amongst seagrass beds (Jenkins *et al.* 1996b). At this time a correlation was found between their abundance on seagrass beds and the fullness of the gut, suggesting that juveniles were migrating to areas of high food abundance (Jenkins *et al.* 1996b). Studies of colonisation and turnover of fishes in artificial seagrass in Port Phillip Bay

have shown that colonisation of 'new' habitat by juvenile fish (rather than settlers) is very rapid, and that the turnover of fish in a bed from day to day is high (Jenkins and Sutherland 1997).

In the Clarence River estuary in Northern NSW, *Zostera* sites just inside the mouth of the estuary support high densities of new recruits of several economically important fish species (yellowfin bream, luderick, tarwhine and sea mullet). Older juveniles of these species, however, were common in other habitats and further into the estuary (West and King 1996; and see Box 1.4.5.1 in Cappo *et al.* 1998). For example, juveniles moved up and down the estuary, and between vegetated and unvegetated habitats.

6.3.2 Is there a critical threshold below which seagrasses do not sustain fisheries?

The question of critical thresholds in seagrass cover is a difficult one. Bell (1986b) showed that the response to seagrass thinning was uneven and depended on species. Experiments with artificial seagrass of differing densities showed that the density threshold for fish recruitment was very low and suggested that even a minimal amount of seagrass cover may be important for fish recruitment (Worthington and Westoby 1991). This result was consistent when a subset of commercially important species (yellow-fin bream, tarwhine and luderick) was analysed (Worthington and Westoby 1991). In a study of broad-scale recruitment of King George whiting juveniles in Port Phillip Bay, most of the variation in abundance was attributable to the location of the bed; no effect of seagrass density or biomass was found, but there was a small but significant trend for abundance to be higher on beds with shorter leaves (Jenkins *et al.* 1998).

Low cover seagrass beds are also of great significance to postlarval and juvenile tiger prawns. Studies of these early life history stages in the western Gulf of Carpentaria have shown that numbers of prawns did not differ between seagrass beds ranging in biomass from about 5 to 90 g.m⁻² (Loneragan *et al.* in press). However, numbers were higher in seagrass beds where the biomass of seagrass exceeded 100 g.m⁻². Although these high biomass beds support higher numbers of juvenile prawns, they account for only 6% of the total seagrasses in the Gulf of Carpentaria (Poiner *et al.* 1987, 1989). In field experiments using fine mesh enclosures, juvenile tiger prawns *P. semisulcatus* grew faster on a high biomass bed (70 g.m⁻²) than one with low biomass (7 g.m⁻²), which suggests that more food is available for prawns in seagrass beds with high biomass (Loneragan *et al.* in press).

Both the behaviour of tiger prawns and rates of predation by fish on them are affected by the structure of the seagrass (Laprise & Blaber 1992, Kenyon *et al.* 1995). Small juvenile tiger prawns (5 mm carapace length – about 2 months old) behave similarly in seagrass with different structures. However, this changes as the prawns increase in size, when they prefer larger seagrass (Kenyon *et al.* 1995, 1997). Predation rates in the laboratory are greatly affected by seagrass structure. Predation rates were three times lower in tall, dense seagrass than bare substrate, and twice as low in dense seagrass compared with short, sparse seagrass (Kenyon *et al.* 1995). In the field, however, there was little difference in the numbers of prawns found in guts of fish from dense (*Enhalus acoroides* 70 g m⁻²) and sparse seagrass (*Halophila ovalis*, *Halodule uninervis* 7 g m⁻²) (Haywood *et al.* 1998). Perhaps this is because the densities of postlarvae and small juvenile prawns in seagrass in the field are very low compared with the densities of other crustaceans of a similar size. A two year comparison of

fish and prawns from intertidal *Zostera* beds of differing densities in Tin Can Bay found that faunal abundances were similar, even in beds of strikingly different seagrass densities. However, when seagrass was not present, the abundances of the fauna were much more markedly affected (either increasing or decreasing abundances, depending on species) (Halliday & Connolly submitted). In that study, the sparse *Zostera* site had an above-ground dry biomass of around 5 g.m⁻², 85% lower than the dense site (35 g.m⁻²). This suggests that there is no critical threshold for *Zostera* density in this bay. Seagrass presence is important, while seagrass density is not. It must be borne in mind that the abundance of several commercially important species (*Penaeus plebejus*, *Sillago maculata* and *Gerres oyeana* (a bait fish)) increased markedly after total loss of seagrass (Halliday 1995, Halliday & Connolly submitted). This study took advantage of a seagrass die-off phenomenon during the survey, but even with such a serendipitous event, limitations of sampling (e.g. a single moon phase, inability to replicate beds of different seagrass densities) limit the confidence of the conclusion. We encourage future sampling to be very carefully planned, with full scientific scrutiny of aims and experimental design at funding stage.

The 'landscape ecology' of seagrasses and its effects on fish and decapods is another relatively new area that needs urgent appraisal. This approach takes into account factors such as size, shape and area of seagrass bed, and position of the bed in relation to other beds. There has been little attention to whether there is a lower limit to the size of a seagrass bed, below which the bed is less important for fisheries production. Patches of artificial seagrass as small as 1 m² placed in unvegetated habitat in Moreton Bay attracted a high number of recruits of commercial species (Hopkins 1996). It remains for links between high numbers of recruits to such small patches and ultimate contribution to fishery stock to be demonstrated.

Research on mangroves and saltmarshes suggests that landscape ecology is an important area for further development in seagrass research. For example, the linear extent of mangroves was a better predictor of mean average catch of banana prawns in the Northern Prawn Fishery than the total area of mangroves (Staples *et al.* 1985). In addition, large fish were found in much higher densities in mangroves near the mangrove/water interface than further into the mangrove forest (i.e. away from the interface) (Vance *et al.* 1996b). Work on saltmarshes, the critical nursery habitat for brown shrimp *Penaeus aztecus*, suggests that as saltmarshes decline in their extent, they break up, or fragment, into smaller units (Browder *et al.* 1989). For a time, these smaller units increase the length of the interface between marsh and water. Empirical modelling of the relationship between the fragmentation of saltmarshes and brown shrimp catches in Louisiana has shown that as marshes decline in their extent, catches of brown shrimp increase for a time as the interface between marsh and water increases, before catches eventually decline (Browder *et al.* 1989). This type of modeling suggests that results from short-term or small-scale experiments might not reflect what would ultimately happen after changes in vegetated habitats.

Recent advances in information technology and remote sensing mean that it is now possible to map seagrasses at a large scale and place confidence limits on these estimates (see Chapter 8). Such information would allow researchers and managers to better assess links between seagrass and the fishery/ies they support, and to assess changes in the extent and quality of seagrass and what impact this is likely to have on fisheries production. In some cases, joint funding for this type of research might be appropriate e.g. between FRDC and agencies such as Environment Australia or state agencies. Application of landscape ecology to fish assemblages in seagrass of Port Phillip Bay is the focus of a PhD study presently underway (T. Anderson, unpubl. data).

6.3.3 Summary

1. Seagrass meadows are not all equal as habitat for fish and decapods. In certain estuaries and bays in Australia, there is some knowledge of the way in which meadows differ.
2. Differences in fish and decapod assemblages and abundances between vegetation types (e.g. *Zostera-Posidonia*; *Zostera-Heterozostera*; mangroves-*Zostera*) are confounded with effects of water depth (shallow versus deeper, in the pairings above).
3. There is very strong evidence that water depth is a major influence on juvenile prawn distribution. Water depth also influences the distributions of juvenile fish in some places, but the importance of water depth remains to be shown in other regions.
4. Small-scale experiments show differing effects of changing seagrass density or height; some fish and decapod species decrease in abundance, others increase, while others are not affected.
5. In general, over whole estuaries/bays or a series of estuary/bays, no correlation has been documented between seagrass density or height and fish and decapod abundance. An important exception is brown tiger prawns in northern Australia, where juvenile numbers are higher on seagrass beds with high biomass.
6. Regardless of the extent, density or type of seagrass cover, the position of a bed within an estuary or bay is very important in explaining abundances of juvenile fish and decapods. This has been shown in many locations around Australia.
7. Certain meadows have high numbers of recruits each year. For some species, these high numbers may not last beyond the recruitment season because of redistribution of juveniles within the estuary/bay.
8. The latest evidence suggests that prey availability is the main factor in determining abundances of some important commercial fish (e.g. King George whiting) once they have redistributed.
9. The important aspects of position of the seagrass bed within the estuary are still to be determined in many places, but seem to be related to currents delivering larvae (i.e. importance of distance to mouth of estuary, or bay opening) and exposure to open water.
10. From studies of inshore, shallow seagrasses, it is the *presence* of seagrass, rather than the type, density, height or cover of seagrass, that seems to be important. However, preliminary results from some areas on deeper water seagrasses, show that seagrass type does influence the community structure of fish populations. There is no known threshold of seagrass density, height, or cover, below which fish and decapod abundance shows a marked decrease.

6.4. GAPS IN OUR UNDERSTANDING AND FUTURE RESEARCH NEEDS

1. Associations between finfish and seagrass in tropical waters are virtually unknown. In view of the proposed developments in the region, we recommend further work.
2. We recommend standardisation of methods, or perhaps more importantly protocols (e.g. stage of tide, water depth, time of day etc.), wherever possible
3. Detailed studies of commercial fish catch trajectories subsequent to episodes of seagrass loss appear to be lacking for many areas. This requires effective monitoring of both seagrass and catch.
4. Changes in juvenile fish and decapods before and after seagrass loss are poorly known; is the seagrass *per se* important, or are certain estuarine/embayment environments beneficial to both seagrass and fish? Baseline studies of sufficient spatial and temporal intensity are needed to quantify natural variability in fish and decapods in seagrass beds so useful comparisons after seagrass loss can be made.
5. The importance of exported seagrass detritus to commercially important fish in unvegetated habitats is poorly understood. What is the long term effect of seagrass loss to these species? Stable isotope studies can determine whether carbon and nitrogen from seagrass beds are being assimilated by species in unvegetated habitats. The population characteristics (growth, survival etc.) for species need to be studied over a significant period and a sufficiently large area after seagrass decline.
6. It is important to study habitat ‘mosaics’, rather than concentrating on preferences for individual habitat types. Do fish, for example, preferentially colonise mixed habitats such as sand patches amongst seagrass?
7. The nature of links with seagrass (feeding, protection from predators, amelioration of physical disturbance) is still poorly known for many species. Understanding these links is important for increasing our capacity to predict the effects of changes in seagrass extent on commercial fish. Small scale manipulative experiments need to be conducted over a large enough spatial scale, so that we make generalisations about the nature of these links.
8. For species in which juveniles are found in seagrass as well as other habitats, the relative contribution of juveniles in seagrass to future adult populations is poorly known; otolith microchemistry shows promise in this area.
9. The older juvenile/subadult life-stage is the most poorly understood in terms of habitat utilisation. A new emphasis on these life stages is needed using new sampling programs and/or advances in tracking technology.
10. The extent of dispersal of larvae from distant spawning locations to different estuaries/bays has implications for whether seagrass loss in an individual bay or estuary will affect populations of commercial fish, such as bream (*Acanthopagrus australis*). Studies using otolith microchemistry and mitochondrial DNA may be useful in this area.

11. The role of small, non-commercial species in food chains for commercial species is only known in localised areas. Further dietary and isotope studies of piscivorous fish are required in many regions.
12. Research has hinted at the importance of many aspects of seagrass meadows relating to landscape ecology. It is critical to determine the importance of features such as size, shape, and spatial arrangement of meadows, proximity to currents, and relations with other habitats (e.g. unvegetated areas, mangroves, deep water, sand bars).
13. Another important aspect of landscape ecology is position within the habitat patch e.g. edge versus interior. Recent work shows that fringing mangroves are utilised more heavily by fish. This suggests that edge effects and habitat fragmentation should be studied in seagrass.
14. The aspect of habitat position in relation to larval supply of commercial fish and crustaceans suggests that an assessment of the importance of beds could be made using hydrodynamic modelling. Generalised hydrodynamic models can be applied to different bays and estuaries with a knowledge of bathymetry, sea-level and wind records. Because this approach does not require field work, in the first instance, it has potential as a rapid assessment tool.
15. When considering whether some seagrass meadows are more important than others, we need to consider not only the direct use by fish, but also the role of beds in nutrient cycling and sediment stabilisation. This point suggests collaborative projects with other organisations, such as EPAs or Environment Australia.
16. What are the important things to monitor in seagrass beds? For some fish and crustaceans, determining the extent of seagrass and the depth of beds is more important than knowing the individual species present. We do not know whether this is the case for all species, particularly those found in deeper water seagrasses.
17. Recent advances in technology (e.g. GPS, GIS) make it possible to map seagrass beds more rapidly, accurately and over much larger areas than previously possible. These advances should be taken into account in any future proposals to map seagrass in relation to fisheries production (see also Chapter 8).

6.5. SUMMARY OF RECOMMENDATIONS FOR FUTURE RESEARCH

Many conclusions reviewed in this chapter are speculative. Hard data on links between seagrass and fishery species are needed urgently. In some situations, seagrass might not be more important for fish and decapods than adjacent habitats (e.g. bare mudflats in sheltered bays) but they are more vulnerable to loss or degradation than some of these other habitats. The current vagueness in links between fisheries and seagrass could result in a weakening of the current conservation status of seagrass, and solid research results are necessary to provide coastal managers with arguments for the protection of seagrass.

1. Correlations of large scale seagrass loss with fisheries data and baseline data on the abundance of juveniles are needed.

2. There is a need to understand processes linking seagrass with fish and decapods far better than we currently do to be able to predict the effects of seagrass changes on fisheries.
3. Studies are needed comparing the ecology (e.g. extent of assimilation of food from seagrass beds) of fishery species that spend all or only part of their life associated with seagrass.
4. For all important fish and decapod species we should be aiming to determine the extent to which early juveniles occurring in seagrass contribute to adult stocks. Studies of dispersal using modern genetic or otolith microchemistry methods will be useful.
5. Stable isotope studies should be done to trace the contribution of material exported from seagrass beds to fishery species elsewhere.
6. Researchers should aim for standardisation of methods and protocols: e.g. stage of tide, water depth, time of day, frequency of sampling in relation to timing of recruitment.
7. The proximity and nature of habitats adjacent to seagrass beds can be important, and should be incorporated in studies of seagrass fish/decapod assemblages.
8. Large scale mapping of seagrasses by recently developed techniques is needed for fisheries where there is a demonstrated link between seagrass and fisheries production. These studies will help establish a sound baseline for later comparison, particularly if there is a large scale loss of seagrass.
9. Associations between finfish and seagrass in tropical waters need to be established.
10. Habitat utilisation by older juvenile/sub-adult life stages should be studied using new sampling programs and/or advances in tracking technology.
11. The extent of dispersal of larvae from distant spawning locations to different estuaries/bays should be studied. Techniques such as otolith microchemistry and mitochondrial DNA will be useful.
12. In many regions, dietary and isotope studies of piscivorous fish are required to determine the role of small, non-commercial species in food chains of commercial species.
13. The landscape ecology of seagrass beds needs to be studied to determine the importance to fish of features such as size and shape of beds, edge effects and proximity to currents and other habitats.
14. Where the bathymetry, sea-level, wind records and larval supply of commercial fish and crustaceans are known for bays and estuaries, hydrodynamic modelling could be used to assess the importance of beds.
15. Collaborative projects with organisations such as EPAs and Environment Australia should be undertaken to study the role of beds in nutrient cycling and sediment stabilisation.
16. In shallow, inshore waters, the extent of seagrass and depth of beds should be determined rather than studying the individual species of seagrass present. Further work is needed to determine if this is true in deeper waters.

6.6. ACKNOWLEDGEMENTS

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Table 6.1. Summary of information about links between changes in seagrass status and fisheries production.

Fishery	Location	Target species	Average catch	Extent of seagrass	Number of seagrass spp	Evidence for link	Impact of loss	References
Temperate								
Bay & Inlet finfish	Western Port, Victoria	King George whiting, <i>Sillaginodes punctata</i>	60 declining to 10 Tonnes	180 km ² declining 75%	4	Recently -settled juveniles associated with seagrass	Major loss of <i>Heterozostera</i> between 1970 to 1984 and concurrent major decline in catch not observed in nearby bays	MacDonald (1992) Robertson (1977) Jenkins <i>et al.</i> (1996, 1997) Jenkins & Wheatley (1998) Connolly (1994)
	“	Rock flathead <i>Leviprora</i> , (<i>Platycephalus laevigatus</i>)	35 declining to 10 Tonnes	“	4	Adults and older juveniles closely associated with seagrass	as above	MacDonald (1992) Jenkins <i>et al.</i> (1997) Edgar and Shaw (1995)
		Rock whiting, <i>Haletta semifasciatus</i>	30 declining to 2 Tonnes	“	4	Juveniles and adults closely associated with seagrass habitat	As above	As above
		Six -spine leatherjacket, <i>Meuschenia freycineti</i>	5 declining to 0.1 Tonnes	“	4	“	As above	As above
	Port Phillip Bay, Victoria	Rock flathead, <i>Platycephalus laevigatus</i>		Dieback of 30 km ² of <i>Heterozostera</i>	1	Adults and older juveniles closely associated with seagrass	Dieback coincided with sharp decline in catch 1982-1990	M. MacDonald Pers. Comm.
	Corner	Rock			1	“	Decline in	M. MacDonald Pers.

	Inlet , Victoria	Flathead, <i>Platycephalus laevigatus</i>					seagrass, mid 70's to mid 80's, concurrent sharp decline in catch	Comm.
	Gippsland Lakes, Victoria	Black bream, <i>Acanthopagrus butcheri</i>	4-500 declining to 20 Tonnes	poorly known	3	Juveniles associated with seagrass habitat	Period of seagrass dieback from 1920 - 1960 coincided with historically low catches	MacDonald (1992) Ramm (1986)
	“	Luderick, <i>Girella tricuspidata</i>	70-80 declining to 1 tonne	“	3	“	“	“
Bay, Inlet & Estuary	Barker Inlet, SA	Whiting (<i>Sillaginodes punctata</i> , <i>Sillago schomburgkii</i>), salmon (<i>Arripis truttacea</i>), tommy rough (<i>Arripis georgiana</i>), yelloweye mullet (<i>Aldrichetta forsteri</i>), garfish (<i>Hyporhamphus melanochir</i>): juvenile through to adults	Total catch for SA of KGW = 600t. (commercial only). Gulf St Vincent small proportion, but big rec catch.	Posidonia/Amp hibolis in deeper waters, Zostera/Heteroz osteria in shallow parts. Seagrass loss suspected but never quantified.	4	Juveniles and adults closely associated with seagrass habitat Conclusion that fish differ between inner & outer sectors of estuary, but this virtually matches presence & absence of seagrass.	No change reported over survey period (10 yrs: 1985-94). Instead, shows high interannual variability for ALL spp., no impt long term trends.	Gary Jackson & Keith Jones (submitted), Connolly 1994a
	“	as above		Zostera muelleri	1	Experimental removal of Zostera (30m ² patches) followed (2 wks later) by fish collections	NONE. Loss of above ground structure did not greatly affect fish abundance (certainly did not reduce it to levels found in bare habitat)	Connolly 1994b

	Spencer Gulf	Assemblages of small fish, including economic species of fish (e.g. <i>Sillaginodes punctata</i> , <i>Arripis georgiana</i> , <i>Aldrichetta forsteri</i> , <i>Hyporhamphus melanochir</i>) & crustaceans (<i>Portunus pelagicus</i>)	For KGW, around half of all commercial tonnage in SA is from Spencer Gulf	Very extensive in Spencer Gulf, large scale dieback.	8 intertidal spp alone (including <i>Ruppia</i> types)	Comparison of die-back areas with healthy <i>Posidonia</i> / <i>Amphibolis</i> / <i>Zostera</i> and bare sand shows fish assemblages of die-back areas more similar to bare sand than healthy seagrass.	Reduced total biomass, although density of some species (e.g. <i>Portunus pelagicus</i>) in <i>Amphibolis</i> die-back zone.	Stephanie Seddon's ASFB talk (Darwin)
Subtropical and Tropical								
Bay & inlet finfish	Tin Can Bay, Qld	small fish assemblages	Region supports 300 commercial fishing operations, landed value \$28.8 million p/a, 2 nd highest recreational catch and effort for any region in Qld	12 300 ha Great Sandy Straits/Tin Can Bay region. This is more seagrass per unit area than in any other estuarine system on the Qld coast.	6, dominated by <i>Z.capricorni</i>	Comparison of fish catch (small beam trawl) in dense & sparse sg site over 2 yrs. In second yr, sparse site lost ALL sg.	Loss of sg matches by increase in whiting (<i>Sillago</i>) and silverbiddies (<i>Gerres oyeana</i>). Non-commercial spp such as pipefish lost completely.	Halliday & Connolly (submitted)
Prawn fishery	Tin Can	<i>Penaeus plebejus</i>	P.pleb. 100	“	“	Comparison of	Marked	Halliday 1995

	Bay	Metap. bennettiae	t/yr			prawn catch in dense & sparse sg site over 2 yrs. This was matched with associated changes in prawn catch in beam trawl.	INCREASE in P.plebejus after seagrass loss, whereas no change where sg remained healthy. Pattern for M.benn. not so clear, possibly same as for P.pleb.	
Northern Prawn Fishery*	Northern Australia – tropical	Brown tigers <i>Penaeus esculentus</i>	3, 000 t (tiger prawns)	Gulf of Carpentaria = 1, 000 km ²	11	1. Seagrass defines extent of fishery	Loss of seagrass in cyclone Sandy (1984) -	Poiner <i>et al.</i> 1993 Loneragan <i>et al.</i> 1994, 1998
		Grooved Tigers <i>Penaeus Semisulcatus</i>				2. a) juveniles found only in shallow beds of seagrass and algae	1. Change in composition of juvenile populations	Vance <i>et al.</i> 1996 Haywood <i>et al.</i> 1995
		Endeavours Metapenaeus <i>Endeavouri</i> <i>M. Ensis</i>	1, 000 t			b) juveniles also found on bare substrates	2. Small reduction in catch	Liu & Loneragan 1997
Torres Straits prawn trawl fishery*	Northern Australia – tropical	Brown tigers P. Esculentus	600 t		5	Juveniles found in reef top seagrasses	Loss of seagrass from large wet 1992/93	Turnbull & Mellors 1990 Derbyshire & Dennis 1990
		Endeavours	900 t			Juveniles found in reef top seagrasses		Turnbull & Watson 1992
		Red-spot kings P. Longistylis	40 t			juveniles on sparse reef top seagrasses		Turnbull pers comm.

Torres Straits Rock Lobster	Torres St	<i>Panulirus ornatus</i>				No juveniles found after loss of seagrass. Seagrass stabilises sediments and prevents burrows being covered.	As above	Pitcher et al. 1994, Dennis pers comm.
Queensland East coast trawl fishery	East coast of Qld – tropical and sub-tropical	Brown & grooved tigers	2, 300 t	5, 000			1. Loss of seagrass in Hervey Bay – large wet	Coles <i>et al.</i> 1993
		Endeavours Metapenaeus <i>Endeavouri</i> <i>M. Ensis</i>	1, 468 t				2. Loss of seagrass in Moreton Bay between 1987 and 1995	
		Eastern king	> 2, 000 t					
*Moreton Bay prawn trawl	Part of east coast	Brown tigers						
		Endeavours						
		Eastern king P. Plebejus						

<i>Overseas</i>								
Inshore finfish	Japan (Seto Inland Sea)	Peneaid shrimp, portunid crabs, estuarine fish			Mostly Z.marina	Decline in Zostera correlated with decline in fisheries catch (total catch, no mention of CPUE)	Markedly reduced fisheries catch	Kikuchi 1974
Scallop fishery	Chesapeake Bay	Scallops			Z.marina			Pete Sheridan (pers. comm.)

