- develop maps of past (original?) areas of mangroves, using aerial photographs, etc.;
- re-assess extent of mangrove areas in regions of greatest change;
- monitor success of previous restoration projects - improve future projects;
- methods to restore exposed mangrove areas in the tropics;
- detailed characterisation of mangrove topography and intertidal profiles - links to mean sea level (MSL) and astronomical high tide (AHT);
- growth history of mangrove trees - possible silviculture and use with aquaculture;
- role and function of mangroves in nutrient uptake - use in sewage & effluent treatment.

1.4.4 Seagrasses

Description of Seagrass habitats

Seagrasses are intertidal and subtidal flowering plants found mainly in shallow waters of protected estuaries, bays and larger coral reefs. They can complete their life cycle whilst completely submerged and have an anchoring rhizome system that withstands wave, current and tidal movements, and consolidates sediments and nutrients in some cases. An excellent review of the Australian seagrass flora is given by Larkum *et al*. (eds) (1989).

In the southern temperate regions of Australia they often form dense beds, but in the north tropics they may also be found at low densities, widely scattered in near-shore areas (eg King *et al.* 1991, Kirkman and Kuo 1990, Poiner *et al*. 1989).

Australia has the largest number of seagrass species and some of the largest and most diverse beds in the world. The area of seagrasses in Australia is much more than >51,217 km^2, since those in the Northern Territory and north-west WA have not been surveyed, and there are much larger areas of unsurveyed seagrass in deeper waters of north Queensland, and possibly elsewhere.

The estimated area (km^2) of seagrass habitat in Australian States from Hamdorf and Kirkman (1995) is:

	NSW	VIC	TAS	SA	WA	NT	QLD	Total
Seagrass	153	364	500	5,000	22,000	unknown	23,200	>51,217

Seagrasses stabilise sediment, act as filters to overlying waters, and interact with other habitats. Seagrasses are also nursery areas for many commercial and recreational fisheries, as well as being critical habitat for turtles and dugongs.

Seagrass biodiversity and distribution

Australia has the highest diversity of seagrass species in the world, with 31 species -- 14 species having temperate ranges, 14 having tropical ranges, and 4 others with restricted ranges along western and eastern coastlines (Table 1.4.4.1). This is in marked contrast with mangrove species that are all essentially tropical in distribution. However, like mangroves, the regional distributions of seagrass species are primarily influenced by water temperature and latitude.

Seagrass species are grouped in four plant families and 11 genera -- although one other genus, *Ruppia*, is occasionally associated with seagrass meadows, as well as occurring in coastal freshwater wetlands, but has not been included in this section since it is not commonly called a seagrass. Seagrass distribution is influenced at a local-scale by environmental conditions of: tidal exposure; swift currents; turbidity; substratum erosion and accretion; and grazing by dugongs and turtles (Bridges *et al.* 1982).

Structural diversity of seagrass beds

The functional morphology of seagrasses determines their importance as a fisheries habitat, their vulnerability to disturbance, and their potential for recovery and restoration. Seedbanks are of profound importance in the colonising ability of some genera and there is a great need in Australia to consider the dynamics of seagrass around the country in the correct context of their biology and ecology (eg. Lanyon and Marsh 1995). The regionally appropriate R&D needs will follow accordingly. We have summarised these features, and other traits, in Table 1.4.4.2.

In general, seagrass beds in the northern tropics are less dense than those in the south - as illustrated in Table 1.4.4.2 by the respective low and high biomass and "Leaf Area Index" (LAI). This pattern prevails despite seasonal fluctuations in above-ground biomass, and losses from grazing. It is also evident that low density species, like *Halophila* spp, are also the better colonisers and that whilst they will become established first in disturbed areas, they will be replaced within 5-10 years by more dense species, such as *Cymodocea* (Birch and Birch 1984). We also note that the less dense species grow in areas subject to disturbance, notably the intertidal zone, but also in fringe areas of less suitable substrata (see Poiner *et al.* 1987).

Table 1.4.4.1. Seagrass distributions in 5 regions and 12 sub-regions in Australia. Species ordered by distributional range in northern and southern regions.

Legend:
• = common presence
-- = likely or uncommon presence
S = predominant southern range
N = predominant northern range
W = restricted western range
E = restricted eastern range.

Primary sources: SoE (1996), Poiner & Peterken (1995), Kirkman (1994), Larkum *et al.* (eds) (1989).
Specific references: TAS & SA = Shepherd and Robertson (1989); NSW = West (1983), West, Larkum and King (1989); WA = Kendrick (1993), Kirkman and Walker (1989), Walker (1989), Walker and Prince (1987); NT = Poiner, Walker and Coles (1989); QLD = Coles, Poiner and Kirkman (1989), Poiner, Staples and Kenyon (1987), Lee Long, Mellors and Coles (1993).

Seagrass Species		SEast Aust		South Aust			West Aust		North Aust			NE Aust	
		NSW	VIC	TAS	VIC	SA	WA		NT	QLD		QLD	
			E	+BS	W		Sth	Nth		Gulf	TS	NE	SE
Halophila tricostata	N									•	•	•	
Halodule pinifolia	N									•	•	•	
Cymodocea rotundata	N								•	•	•	•	
Cymodocea serrulata	N								•	•	•	•	•
Halophila ovata	N							•	•	•	•	•	--
Enhalus acoroides	N							•	•	•	•	•	--
Thalassia hemprichii	N							•	•	•	•	•	--
Thalassodendron ciliatum	N							•	•	•	•	•	--
Halodule uninervis	N						•	•	•	•	•	•	•
Halophila spinulosa	N						•	•	•	•	•	•	•
Syringodium isoetifolium	N						•	•	•	•	•	•	•
Halophila ovalis	N	•					•	•	•	•	•	•	•
Halophila decipiens	N	•				•	•	•	•	•	•	•	--
Zostera capricorni	E	•	--									•	•
Heterozostera tasmanica	S	•	•	•	•	•	•						
Posidonia australis	S	•	•	•	•	•	•	--					
Halophila australis	S	•	•	•	•	•	•						
Zostera muelleri	S		•	•	•								

Seagrass Species		SEast Aust		South Aust			West Aust		North Aust			NE Aust	
		NSW	VIC	TAS	VIC	SA	WA		NT	QLD		QLD	
			E	+BS	W		Sth	Nth		Gulf	TS	NE	SE
Amphibolis antarctica	S			•	•	•	•	--					
Posidonia antarctica	S				•	•							
Amphibolis griffithii	S					•	•						
Posidonia sinuosa	S					•	•						
Posidonia denhartogii	S					•	•						
Posidonia coriacea	S					•	•						
Posidonia angustifolia	S					•	•						
Posidonia robertsoniae	S					•	•						
Posidonia ostenfeldii	S					•	•						
Posidonia kirkmanii	S					•	•						
Thalassodendron pachyrhizum	W						•	--					
Zostera mucronata	W						•	--					
Cymodocea angustata	W						--	•					
Sub-regions (& States)		8	6	5	8	17	23	16	12	11	12	14	11
Regions		8		14			26		13			14	

Notes:
- no species with broad ranges across both N and S coastlines of Australia
- species mostly distinguished as either temperate or tropical
- diversity highest in WA

Table 1.4.4.2. Summary of structure, morphology and phenology of seagrass in Australia.

Sources: Larkum *et al.* (eds) (1989), Hamdorf and Kirkman (1995), McComb *et al.* (1981b), Finlayson and von Oertzen (1993), Hillman *et al.* (1995b), plus others

Seagrass Species		Tidal Posn	Dispersal of Fruit/seed	Fruiting Season	Rhizome	Leaves	Colonising Ability and Tolerance to disturbance	Standing Crop (g dry wt.m^{-2})/ Leaf Area Index (LAI)
Amphibolis antarctica	S		Slow spread	All year	Slow spread. Creeping.	Short (frond-like), broad tasselate leaves on the ends of long slender stems.	Sometime coloniser. Seedlings hold well. Some veg. propagation.	LAI=4.3
Amphibolis griffithii	S		Slow spread	All year	Slow spread. Creeping.	Broad tasselate leaves on the ends of long slender stems.	Sometime coloniser. Seedlings hold well. Some veg. propagation.	220 (-stems) 780 (+stems) LAI=3.3
Cymodocea angustata	W							
Cymodocea rotundata	N							
Cymodocea serrulata	N	Sub-tidal						44-60 Dense
Halodule pinifolia	N							
Halodule uninervis	N	Inter-tidal			Slender creeping. Shallow rooted.	Short, narrow (mm), flat leaves coming more or less directly from the rhizome. Leaf tips with 3 spines.	Sometime coloniser.	
Syringodium isoetifolium	N	Sub-tidal	Low num. Fast spread.		Fast spread. Slender creeping.	Short, narrow (mm), rounded leaves. Leaf tips pointed.	Reasonable coloniser. Seedlings hold poorly No veg. propagation	
Thalassodendron ciliatum	N							
Thalassodendron pachyrhizum	S	Reefs	Slow spread	All year	Some spread.		Poor coloniser. Seedlings hold well. No veg. propagation.	
Enhalus acoroides	N	Sub-tidal					Low resistance to disturbance, although able to withstand partial covering by sediments.	LAI=2.3
Halophila australis	S							
Halophila decipiens	N		In sediment. High num. Fast spread.	All year	Fast spread. Delicate creeping, white and translucent.	Paired oval, 1-5cm & 5-20mm wide. Includes fine hairs	Good coloniser. Seedlings hold very poorly. No veg. propagation.	

Seagrass Species		Tidal Posn	Dispersal of Fruit/seed	Fruiting Season	Rhizome	Leaves	Colonising Ability and Tolerance to disturbance	Standing Crop (g dry wt.m^{-2})/ Leaf Area Index (LAI)
Halophila ovalis	N	Inter-tidal. Reef flats.	In sediment. High num. Fast spread.	All year	Fast spread. Delicate creeping, white and translucent. Shallow rooted.	Paired oval blades, 1-5cm & 5-20mm wide, on short slender stems.	Good coloniser. Seedlings hold very poorly. No veg. propagation. Tolerates disturbance.	49
Halophila ovata	N	Inter-tidal					Good coloniser. Tolerates disturbance.	
Halophila spinulosa	N		In sediment. High num. Fast spread.	All year	Fast spread.	Frondlike blades on short slender stems.	Good coloniser. Seedlings hold very poorly. No veg. propagation.	
Halophila tricostata	N							
Thalassia hemprichii	N	Inter-tidal						70 LAI=5.1
Posidonia angustifolia	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Poor coloniser. Seedlings do hold. No veg. propagation.	
Posidonia australis	S	Sub-tidal	Med. num. Slow spread. Buoyant.	Annual Dec-Jan	Slow spread. Strong 2cm creeping.	30-60cm long & 6-14 mm wide	Poor coloniser. Seedlings do hold. No veg. propagation.	90-440 LAI=4.9
Posidonia antarctica	S							
Posidonia coriacea	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Sometime coloniser. Seedlings hold well. No veg. propagation.	
Posidonia denhartogii	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Sometime coloniser. Seedlings hold well. No veg. propagation.	
Posidonia kirkmanii	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Sometime coloniser. Seedlings hold well. No veg. propagation.	
Posidonia ostenfeldii	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Sometime coloniser. Seedlings hold well. No veg. propagation	
Posidonia robertsoniae	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Sometime coloniser. Seedlings hold well. No veg. propagation.	

Seagrass Species		Tidal Posn	Dispersal of Fruit/seed	Fruiting Season	Rhizome	Leaves	Colonising Ability and Tolerance to disturbance	Standing Crop (g dry wt.m^{-2})/ Leaf Area Index (LAI)
Posidonia sinuosa	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Poor coloniser. Seedlings do hold. No veg. propagation.	360-660 LAI=4.6-6.5
*Ruppia maritima**	W							
*Ruppia megacarpa**	E					Slender, upright, often tangled stems up to 2m long, with numerous branches and linear leaves <20mm wide.		403
Heterozostera tasmanica	S		In sediment. High num. Fast spread.	Annual Jan-Feb	Fast spread.	1-50 cm long, 1-5 mm wide and flat. Upright vegetative stems.	Good coloniser. Seedlings hold poorly. Some veg. propagation.	
Zostera capricorni	E	Inter-tidal	Upright reproductive stems		Slender.	1-50 cm long, 1-5 mm wide and flat.		26-55
Zostera mucronata	S							10
Zostera muelleri	S	Inter-tidal	Upright reproductive stems		Slender.	1-50 cm long, 1-5 mm wide and flat. Notched tip.		

NOTE: * *Ruppia* spp are not considered to be seagrasses by most authors in Australia.

Seagrass processes and connectivity

Like other aquatic plants, photosynthesis by seagrasses is physiologically limited by sufficient light, nutrients, and diffusion of inorganic carbon sources. Other factors such as temperature, salinity, and water motion also play a role, as seagrasses vary greatly in their physiological tolerances to these factors, and they determine to what extent these plants fix carbon that fuel grazing and detrital food chains.

Perhaps more than marsh grasses and mangroves, the growth and productivity of seagrasses is greatly influenced by water movement, particularly in relation to surface boundary layers. Many such plants living in water quickly experience growth limitation because of nutrient and gas depletion at the boundary layer. Movement of water is necessary to replenish these pools and to remove metabolites in order to sustain growth.

Thus the food chains that rely on seagrasses for shelter and food also rely on seagrass connections to adjacent coastal waters and sediment movements. Currents enhance rates of seagrass primary productivity by mixing and distributing nutrients and gases, and removing wastes, but measurements of seagrass production in relation to hydrodynamics are scarce, and unknown for Australian seagrass systems -- despite their importance for coastal fisheries. It is necessary even from a fisheries perspective to understand what limits seagrass growth and productivity upon which so many commercially important organisms depend (eg. Moriarty *et al*. 1985,1990).

Such studies are urgently needed given the dieback of seagrass throughout Australia. In northern waters, loss of seagrass meadows has occurred, despite lack of urban development and low human population, because of tropical cyclones and floods. Just as individual plants rely on hydrodynamic processes, seagrass communities can be severely affected by adverse climatic changes and storms.

A long-term study of seagrasses in the Gulf of Carpentaria (Poiner and Peterken 1996) showed that up to 70% of seagrass cover was either scoured or smothered by sediments shifting as a result of cyclones. Recovery has been slow, impeded by disturbance caused by succeeding cyclones. In other areas of Australia, losses have been significant and attributable to anthropogenic activities such as coastal developments and nutrient enrichment. Whether natural or anthropogenic, most seagrass losses are directly attributable to reduced light intensity due to turbidity (increased sedimentation) and increased epiphytism, or both. Poor management of catchment areas, sediment instability and dredging interact to make the process of dieback much more complex (see section 3.2).

While seagrasses are directly influenced by hydrodynamic processes, seagrasses can in turn affect local water motion, nutrient exchange, and trophic processes in overlying waters. Water advection and turbulent mixing are reduced among the plants, but significantly increased above the seagrass canopy. The extent to which the presence of seagrasses affects local water hydrology depends not only upon local hydrodynamics but also on shoot densities and areal extent of the meadow. Small, discrete beds show little or no alteration of water flow above the canopy -- turbulent mixing does not appear to be affected by seagrass beds, regardless of size. This implies, for instance, that a subtle decline in area of a given seagrass bed can greatly affect water motion and planktonic communities beyond the meadow. The cascading effects of "blowouts" in altering the ratio of sediment accretion and erosion are illustrated by Clarke (1987) at the scale of an entire bay and its beaches, and at the smaller scale of boat moorings by Hastings *et al.* (in press).

Recent studies of germination, storage and viability of tropical seagrass seeds show that seedbanks and their dynamics are profoundly important, but not sufficiently understood, factors in the survival and spread of some species (Conacher *et al*. 1994, Thorogood and Poiner 1990).

Trophic connectivity of seagrass meadows to adjacent coastal habitats is of immense importance and -- at least for macro-organisms -- much more conspicuous than for most other coastal habitats. For instance, stomach content analyses indicate that dugongs feed extensively on tropical seagrasses. In Indonesian *Halodule uninervis* meadows, dugongs can remove as much as 75% of the root-rhizome biomass, preferring to feed on meadows with sparse above-ground, but rich below-ground, biomass. Selectivity has been documented for dugong populations in Australia, but estimates of the percentage of total plant biomass consumed are not available. More qualitative information exists for sea turtles. Annual migrations of such macro-herbivores can drain nutrients from seagrass beds to other coastal systems. Such transfers of energy and nutrients have never been quantified.

On average, only a small fraction (about 10%) of living seagrass tissue is consumed directly. Important luderick (*Girella tricuspidata*) and leatherjacket species (see Table

1.4.5.1) are known to directly consume seagrass as well as their epifauna (Bell *et al.* 1978b,1980). Benthic epifauna prefer either epiphytes or periphyton -- epifaunal amphipods, shrimps, gastropods, isopods, nematodes, and copepods readily graze down complexes of periphyton consisting of diatoms, chlorophytes, encrusting algae, fungi, protozoa, bacteria and sedimentary material lying on leaf blades and colonising understorey surfaces and surface sediments (see Jernakoff *et al.* 1996 for review).

In turn, a variety of predators feed on these benthic grazers and may themselves feed, to a considerable extent, on the same foods. Most grazers prefer to eat algae rather than detritus or living plant tissue. However, the recent seagrass trophic studies by Edgar and Shaw (1995a,b,c) in southern Australia indicate that trophic connections between invertebrates and fish in these seagrass meadows are no different than those in closely adjacent unvegetated habitats.

This series of papers culminates in the first paradigm regarding regional fisheries production in any Australian coastal habitat type. Based on samples taken from 14 locations across southern Australia, fish production (of taxa <1 gram in weight) was equivalent among habitats. They attributed these findings to high crustacean production and migration and interdependence of fish and invertebrates across habitats. Fish production was found to be correlated with crustacean production and seagrass biomass, and was negatively correlated with wave exposure. They further noted that , while transfer of biomass between fish and invertebrate groups was conservative, the structure of fish communities among seagrass and unvegetated habitats appeared to differ greatly.

These important studies are scrutinised much more closely in section 1.4.4.1, and we stress the point here that comparisons between vegetated and unvegetated sites must be carefully constructed to avoid the confounding effect of detrital pools and other influence of seagrass beds or estuaries on nearby sandy substrata. We are not sure from Edgar and Shaw (1995c) about how far the influence of seagrass extends into bare substrata within bays and along sandy coasts. Outside estuaries there may be a 1000 : 1 ratio in food amounts between vegetated and bare sand, but in estuaries there is very little difference in the same comparison because of the richness of sediments (p.c.#1260 G. Edgar).

The exchange of particulate material from seagrass meadows is small, on average, with available data suggesting some net export. The absolute (0.01 to 1.3 g dry weight m^{-2} d^{-1}) and relative (1-100% of net seagrass production) amounts of exported material differ greatly among locations. The proportion of organic material exported is highly variable but the data suggest net autotrophy.

There is some evidence of enhanced export from more exposed sites. A good example is the *Zostera* meadows in the Beaufort estuary in North Carolina, USA, where rates of export are greater from the exposed than the sheltered beds. In relative terms, a greater percentage of net plant production is lost from exposed beds. The extent of export losses may be genus or species-specific. Some genera such as *Syringodium* and *Posidonia* lose a greater proportion of total net production than *Zostera*. It is not clear why this is so, although species do vary in leaf buoyancy. For instance, species with leaves with large lacunal spaces (eg. *Syringodium isoetifolium*) are highly buoyant.

It is likely that the transport of such relatively buoyant material is affected by climate and tidal range. Wet tropical habitats, dominated by large tides would likely export considerably more material than, for instance, *Zostera* meadows within a microtidal, sheltered lagoon receiving little freshwater input. Thus, differences in physical setting would undoubtedly affect connectivity of seagrass meadows and their associated biota to other coastal habitats.

The export of particulate material from seagrass beds may be small, but several studies report that the trophic impact of this material is disproportionate to the actual amount exported. Many ecological links do not show up in mass balance calculations. For instance, off Tasmania, seagrass detritus rather than phytoplankton, is the main carbon source for pelagic food webs. Storms transport buoyant rafts of seagrass detritus offshore where microbes break down the material which in turn serves as a food source for larvae of the region's major finfish predator, the blue grenadier *Macruronus novaezelandiae* (Thresher *et al.* 1992).

Such detrital material may be exported frequently, and be common and important, if not highly variable, for coastal fisheries off Tasmania. Such a scenario may be true for similar coastal planktonic ecosystems off the southern coast of Australia, although they remain undiscovered.

Finally, seagrass blades and fruits contribute very significantly to the beach-wrack of many bays in southern and south-western Australia. This aggregation and decay of this wrack supports fisheries food chains (see Lenanton *et al.* 1982, Robertson and Lenanton 1984).

In the upper gulfs of South Australia the drifting blades of *Heterozostera* and *Posidonia* also accumulate amongst *Avicennia* mangrove pneumatophores and may both enhance shelter and food for fisheries and cause problems with mangrove respiration, but neither aspect has been studied.

1.4.4.1 Fishery-habitat links

Seagrasses directly provide food, shelter and recruitment sites for major Australian fisheries. They are the most threatened habitat type in estuaries, the intertidal and shallow bays and have severely declined in area in some regions (see section 2.2.2). Pollard (1984) and Bell and Pollard (1989) provided the first reviews of Australian studies of the fishery-habitat links in seagrass beds, and there have subsequently been a relatively large number of studies addressing and testing experimentally some of the key hypotheses concerning what "features" of the habitat govern their value to fishes and crustaceans (see Appendix 4).

The importance of seagrass are best known for:

1) supporting sub-tropical and temperate fisheries inside or adjacent to seagrass beds - There are major bay fisheries in *Posidonia* beds in Victoria, SA, Tasmania, Jervis Bay and WA for species such as sea garfish, calamari squid, King George whiting and yellowfin or sand whiting (*Sillago schomburgkii* and *S. ciliata*). Incidental but important catches of odacids (weedy or rock "whiting"), monacanthids (leatherjackets), rock flathead (*Leviprora laevis*), snook (*Australuzza novaehollandiae*), flounders (*Rhombosolea tapirina*) and arripids (Australian "herring" and "salmon") are also made in the same hauling net and angling fisheries (see Table 1.3.2.1).

Studies of isotopic signatures identified seagrass at the base of food chains for garfish and rock flathead (see Klumpp and Nichols 1983a,b,c, Nichols *et al.* 1985, 1986).
In NSW estuaries and south-east Qld bays there are hauling net and tunnel-net fisheries for luderick, sea mullet, flat-tail mullet (*Liza argentea*), yellowfin bream, sand whiting , dusky flathead and golden-lined whiting (*Sillago analis*) in beds of *Zostera* and *Heterozostera*. Luderick are one of the few species known to directly consume seagrass blades.

2) providing critical tiger prawn nurseries -
Post-larval (PL) tiger prawns appear to actively choose amongst intertidal seagrass beds as settlement sites. CSIRO research has shown high recruitment of 1mm carapace length

PLs to a range of seagrass types, but numbers had shifted by the time the PL had reached a carapace length of 2 mm. A key uncertainty concerns the reason for the shift -- predation or emigration?. Predation rates in *Halodule* and *Syringodium* are similar, and *Cymodocea* provides much better cover. A series of papers has explored the location, type, seasonality and "carrying capacity" of important tiger prawn nurseries (eg. Haywood *et al.* 1995, Loneragan *et al.* 1994, O'Brien 1994b, Vance *et al.* 1994, 1996b; and see Appendix 4).

There has been a concerted effort to survey, sample and protect from trawling the prawn nurseries in Qld seagrass beds; on the east coast (see series of papers by Coles *et al.* 1987a,b, 1990, 1992 and Derbyshire *et al.* 1995); Torres Straits (Long *et al.* 1994 a,b,c); and the Gulf of Carpentaria (Poiner *et al.* 1987, 1989).

3) providing recruitment sites for juveniles of estuarine and bay fishes in NSW -

A large number of NSW studies in estuaries and bays have established that economically important sparids (eg. tarwhine, yellowfin bream), luderick and blue groper wrasse (*Achoerodus viridis*) recruit mainly into aquatic vegetation (eg. see Table 1.4.5.1 and Ferrell and Bell 1991, Ferrell *et al.* 1993, Worthington *et al.* 1992b).

An extension northward of NSWFRI research interest has produced a series of recent papers documenting the use of different estuarine habitats by commercial species (eg. West and King 1996, Gray *et al.* 1996). Some of the complexities in life-histories associated with estuarine seagrass are outlined in Box 1.4.4.1. and Box 1.4.5.1.

4) providing recruitment sites for juveniles of bay fishes in southern and south-western Australia -

King George whiting life-histories have been closely tied to seagrass and other intertidal vegetation in SA and Victoria (see Box 1.3.2.4), and a growing number of studies are documenting the use of *Posidonia* as nursery and juvenile habitat for this, and other, species in Cockburn Sound (see Table 1.3.4.1 and Hyndes *et al.* 1996, Jonker 1993, vanderKlift 1994, vanderKlift *et al.* 1995).

5) providing nursery habitats and food supplies for western rock lobster -

See Edgar (1989, 1990c,d,e), Fitzpatrick *et al.* 1989, Jernakoff *et al.* (1993, 1994), Howard (1987, 1988, 1989a,b) for reviews. See also summaries in Appendix 5.

A special issue of the journal "Aquatic Botany" (see Pollard and den Hartog 1984) led to a decade of experimental and correlative research on the processes of shelter provision and secondary production in seagrasses in Australia that has not been matched in any other vegetated habitat here. Reviews of the results of this focus have been given in Larkum *et al.* (eds) (1989), for example, on trophodynamics (*Klumpp et al*. 1989). Much of the work on fisheries links has been supported by FRDC investment (eg. see Edgar and Shaw 1995c, Jenkins *et al.* 1997 for reviews).

This research interest is due in part to the accessibility of the seagrass beds to sampling by researchers, the development of artificial seagrass units and the ease of manipulation and measurement of major features of the habitat. Research has focussed on fish communities in the temperate and sub-tropical zones and almost exclusively on prawns in the tropics. There are consequently major gaps in knowledge of the importance of tropical seagrasses to finfish.

BOX 1.4.4.1 INFERENCES FROM "BARE" VS "SEAGRASS" COMPARISONS - A NSW EXAMPLE

The spatially and temporally consistent difference between seagrass and bare sand habitats in Gray *et al.* (1996) resulted from the finding that several species were common to only one habitat : *Arenigobius bifrenatus, A. frenatus, Centropogon australis,* luderick, *Petroscirtes lupus* and *Philypnondon grandiceps* were only caught in *Zostera capricorni* , whereas sand mullet *Myxus elongatus* and sand whiting *Sillago ciliata* were caught predominantly on sand.

The seagrass assemblages were dominated by small, resident species such as gobies and the transient juveniles (newly settled, <20 mm) of larger species such as sparids and luderick. The bare sand assemblage comprised mainly larger, schooling species such as mullets and whitings, but most of the sand whiting were also juvenile in the 0+ age class. Species that used both habitats included *Ambassis jacksoniensis* and the flat-tail mullet *Liza argentea* which were considered to use seagrass as shelter and move out over bare sand to forage.

The pattern of association of particular species with either seagrass or sand observed by Gray *et al.* (1996) was virtually the same to that determined from studies in estuaries of southern NSW (Bell *et al.* 1988, Ferrell and Bell, 1991). The luderick, silver biddy (*G. subfasciatus*) and striped trumpeter (*Pelates sexlineatus*) were caught predominantly in seagrass in both studies, whereas sand whiting, sand mullet and the goby *Favonigobius lateralis* were predominantly caught on sand. However, the yellowfin bream and tarwhine displayed different trends in distribution between studies, with greater abundance over seagrass in Gray *et al.* (1996) -- and greater abundance on bare sand immediately adjacent to *Zostera* in Ferrell and Bell (1991) when sampling was carried out in March after the recruitment pulse. These species are known to move to unvegetated habitats after initial settlement in seagrass and *Vallisneria* (Middleton *et al.* 1984, West and King 1996).

In agreement with other authors, Gray *et al.* (1996) proposed that the greater diversity and abundance of fish in seagrass was due to shelter and protection from predators, and increased food resources in comparison with bare sand, but large numbers of fish were found at some bare-sand locations, and discrepancies observed may have been due to the proximity of nearby seagrass beds. Ferrell and Bell (1991) found large abundances of fish on sand immediately adjacent to seagrass, and the distance separating vegetated and bare sand sampling sites are important factors to consider when designing and comparing studies that attempt to draw contrast between the two habitat types.

Some of the major findings of manipulative seagrass research have been:

- location of seagrass beds in relation to hydrodynamic features is a major determinant of recruitment rates in them - eg. Bell *et al.* (1988), Hair *et al.* (1994), McNeill *et al.* (1992), Jenkins and Black (1994);
- leaf length, blade width and blade density are important factors in governing use of different seagrass beds (eg. *Posidonia* vs *Zostera*) -- eg. see Table 1.4.5.1 and Bell and Westoby (1986a,b,c), Bell *et al.* (1987), Middleton *et al.* (1984), Worthington *et al.* (1992);
- epiphytic algal loads can alter the function of seagrass beds as nurseries - eg Bell and Westoby (1987), Worthington *et al.* (1991);
- bed depth is an important factor in determining community structure -- eg. Bell *et al.* (1992).

We have summarised several comparisons of finfish communities in vegetated and unvegetated habitats in bays and estuaries in Table 1.4.5.1. Some key features to note are:

- the regional differences in occurrence of commercially and recreationally important species in seagrass beds - generally highest in NSW estuaries and bays;
- the predominance of "unimportant", small glassy perchlets, gobies and pipefishes in samples - patterns in their distribution explain most of the variation tested for in statistical comparisons between "bare" and "vegetated"; important species are often rarely caught in the studies from which important generalisations are made;
- the evidence of enormous "gear selectivity" and the very small sampling scales of seines generally used - in contrast SA power-haulers sweep more than 39,000 m^2 in single shots with 600 m seines in the search for schooling commercial species in *Posidonia* beds (p.c. P.Ffrench, Whyalla);
- the infrequency of sampling, compared to the quick ontogenetic shifts in habitat use by juveniles reported by Jenkins *et al.* (1993 b,c) and West and King (1996).

Edgar and Shaw (1995c) interpreted the emerging paradigm about fisheries-seagrass links as a prediction that seagrass beds support a greater abundance, and number of species, of juveniles of commercially important species than unvegetated habitats in their vicinity. However, this paradigm has not been able to produce definitive prediction about the fate of fisheries when seagrass beds are partially or completely lost - key uncertainties remain:

- will important species utilise alternative habitats?
- what are the comparative fisheries functions of "stands", "fringes" and "mosaics" of seagrass - eg those caused by blowouts?

- does the density in, and use of, remaining beds rise in the face of adjacent seagrass loss? -- eg. Tasmanian studies have documented "crowding" of fish in seagrass in winter, perhaps into remaining seagrass due to dieback in same bay? (p.c.#1280 A. Jordan)
- how long do detrital pools and other influence on benthic habitats remain after dieback? -- eg. rhizomes, stalks, detritus remain still from a large SA dieback event and blue crabs (*Portunus pelagicus*) aggregate there in summer to feed (p.c.#1530 S. Seddon)
- can artificial reefs replace some fisheries function as nurseries for lost *Posidonia* beds in WA?

In attempting to address some of these questions in Westernport Bay, Edgar and Shaw (1995a) found that :

- seagrass beds were not significantly more important nurseries for commercial species than unvegetated habitats (but see below);
- seagrass beds supported over twice the production of small fishes as unvegetated habitat ;
- a loss of 178km^2 of seagrass translates to a decline in small fish production of about 630 tonnes ash-free dry weight per year (mostly not economically important species with the exception of six-spined leatherjackets and rock "whiting");
- omnivorous yellow-eye mullet accounted for most of the variation in small-mesh gillnet catches between seagrass and unvegetated sites - there was no difference amongst the piscivores higher in the food chain.

This was followed by a study of trophic relationships in the same seagrass and unvegetated comparisons (Edgar and Shaw 1995b). Major findings were:

- the major trophic linkage in all habitats was from benthic microalgae and detritus through epifaunal crustaceans to small fish;
- fish diets were not specialised and crustaceans predominated in the majority of species - polychaetes and molluscs were less important, but with variation amongst locations;
- yellow-eye mullet and some leatherjacket species consumed large amounts of epifaunal algae, but only the sea garfish ingested seagrass in any quantity;
- there were ontogenetic shifts in the types of crustaceans consumed at fish weights of about 0.1 grams (copepods to peracarids) and then again at 100 grams (peracarids to crabs and shrimps);
- prey length generally averaged 7.5% of fish body length;

- there was food-limitation evident, with declines in both crustacean production and fish condition occurring in one season - competition for high quality prey is likely;
- the production of one size class of crustaceans was almost entirely consumed by fishes, whereas only a small proportion of the production of non-crustacean benthos was consumed by fish predators.

The consistency of these relationships were determined by Edgar and Shaw (1995c) in a comparison of habitats at 14 locations in regions from Rottnest Island (WA), SA, Victoria and Tasmania to Jervis Bay (NSW) - a spread of 3000 km. The patterns found in Westernport Bay were confirmed, with the exception that small fish (<1 gram) production was not consistently greater in seagrass in than unvegetated habitats. There were additional relationships discovered:

- abundant large fish generally consumed smaller prey than rare large fish species at the same body size;
- fish production was highly correlated with crustacean production and seagrass biomass, and was negatively correlated with wave exposure (measured as fetch) across the range of sites;
- the production of crustaceans was highly correlated with the biomass of seagrass material and also with the proportion in the sediments of particles < 63 microns in diameter;
- 3 parameterisations were presented to allow for testing of the relationships at unexamined sites - most predictions were with 50%-200% of the measurements of production made at Westernport sites.

Of all these conclusions we urge caution in the use of the generalisation that marine seagrass was not more important as a nursery for commercial species than unvegetated habitats. It should be qualified by species, by ontogenetic stage and most of all by the numbers and variances in samples. Edgar and Shaw (1995c) qualify their conclusion in terms of the low numbers and high heterogeneity of variances associated with most of the commercial taxa in their surveys - like many such studies we suspect that some important juveniles may have been rare and therefore outside the bounds of statistical comparisons (see Table 1.4.5.1). The list of species and numbers caught are not presented in Edgar and Shaw (1995c), but we note that only 53 King George whiting and 18 sea garfish were caught in the small-mesh seining done in Westernport Bay in Edgar and Shaw (1995a).

Finer-scale studies of life-histories and ontogenetic shifts are needed to better assess whether seagrasses are critical to the survival of commercial species in euryhaline estuaries and whether or not they can survive (and support productive fisheries) without seagrasses (eg. Jenkins *et al.* 1993b,c). This level of dependence has yet to be investigated in Australia.

For example:

- the influence of seagrass on fisheries in WA is made less comparable to SA or Victoria due to the major contribution of drifting macrophytes (beach wrack) to food chains in unvegetated habitats in the State. In WA King George whiting are now known to recruit into unvegetated habitats, but only in sheltered waters with higher benthic productivity (see section 1.4.6)
- despite their fishery value, their consumption of epiphytes, and their production of large adhesive eggs, there has been no work on the habitat requirements of sea garfish associated with seagrass and there may be regional differences (a related NZ species *Hyporhamphus ehi* lays eggs on seagrass and some kinds of algae).

We conclude that there must be vary careful qualifications of the findings of such studies in determining the importance of seagrass to finfish, in the context of:

- region, and location (distance from the mouth and local hydrodynamic features) within an estuary (euryhaline) or bay (marine);
- aspect and exposure to waves and tidal energy;
- influence of drifting macrophytes and other beach wrack;
- depth and type of seagrass (narrow- vs broad-bladed, dense vs sparse);
- season, month and time of day and tide;
- specific life-history stages and species (pre-settlement, new recruit, juvenile).

1.4.5 Sheltered coasts and estuaries

By virtue of poleward flowing, oligotrophic, boundary currents on both sides of the continent Australia has low ocean productivity and important fisheries and mariculture have developed in bays and estuaries. These are more productive because of inputs of terrigenous material and detritus produced by aquatic vegetation.

The estuary is difficult to define namely because no one definition can encompass all of the diverse geomorphological settings and water movements that make up Australia's coastlines. The most applicable definition recognises the various biological, physical, chemical and geological forces that come into play where land and coastal ocean meet. An estuary is a coastal indentation that has a restricted connection to the open sea and remains open intermittently. The estuary can be subdivided into three zones:

- the tidal river zone (a fluvial zone characterised by lack of ocean salinity but subject to tidal rise and fall of sea level;
- the mixing zone, characterised by water mass mixing and the existence of strong gradients of physical, chemical and biotic quantities reaching from the tidal river zone to the seaward location of the river mouth or ebb-tidal delta; and
- the nearshore turbid zone in the open ocean between the mixing zone and the seaward edge of the tidal plume at full ebb tide (Kjerfve 1989).

From this definition it is not surprising that estuarine pelagic and benthic food chains are ultimately driven and structured by solar heating, water circulation (tidal, gravitational, and wind-driven) geomorphology, and changes in water chemistry from freshwater to the open sea. These factors have been used to classify shallow coastal habitats:

- river deltas are runoff-driven
- coastal plane estuaries are tidally-driven
- tidal lagoons are driven by tides and waves
- bays are driven mostly by tides with little influence of waves and river-flow
- coastal lagoons are driven mainly by wave action.

Nearly 800 estuarine systems exist around the Australian coastline, most of which (~415) occur in the tropics. Needless to say, with the exception of those in close proximity to major cities, the vast majority of these systems remain unstudied (Saenger 1996). In an analysis of the health of Australia's estuaries, Saenger (1996) points out that data is insufficient to assess the water quality of more than one-half of them, but the majority of estuaries are classified in good to excellent condition. In general, Australian estuaries are "moderately undisturbed", especially in northern Australia where they have been largely unaffected by humans. Estuaries in eastern and southern Australia have generally lower water quality and greater catchment clearance, and most of them face real threats from human encroachment. It is estimated that of the nation's estuaries ~20% possess high conservation value and 15% possess high fishery value , despite our ignorance of their biotic, biogeochemical and general catchment characteristics.

It is somewhat ironic that the characteristics which make estuaries so biologically rich are the least measured. These include:

- nutrient concentrations and cycling
- water physico-chemistry
- freshwater and groundwater inputs and transport,
- phytoplankton and bacterioplankton production
- pelagic respiration, and denitrification.

Estuaries are highly productive because they:

- are very dependent upon new nutrients supplied in freshwater and sediments coming in from their river catchments
- have generally long residence times of water
- are shallow -- which permits benthic and pelagic primary producers to thrive
- have protection from oceanic energy.

All of these factors combine to foster development of extensive intertidal and subtidal plant communities and sediment accumulation. For these same reasons, estuaries are also vulnerable to degradation -- they are traps for nutrients, sediments and pollutants which may concentrate in food webs, including fish and crustaceans. Many of these organisms live at or close to the limits of their tolerances to environmental factors , (such as temperature, salinity and oxygen), so even minor changes or interruptions to freshwater or sediment supply can have major impacts on estuarine communities. Estuarine biota and productivity are therefore closely entwined with terrestrial, marine and atmospheric exchanges.

The combinations of solar heating and evaporation, intermittent closure of entrances to the sea and cycles in primary production can make some shallow estuaries extremely harsh environments - but with very high fish yields in favourable periods (see Pollard 1994). For example, there are about 50 estuaries between Perth and Esperance that are intermittently open, either once every few months or once every few years (Hodgkin and Lenanton 1981). Cycles of *Ruppia* dieback fuel estuary-scale sediment anoxia - the oxic layer is often only 1-2 mm deep in the water column of some south coast estuaries that are only 50-70 cm deep. Fish kills have occurred as a result of this anoxia (p.c.#1360 R. Lenanton).

One problem in linking fisheries production to estuarine productivity is the difficulty in distinguishing trophic links against a background of large inter-annual variability. For instance, tropical estuaries in Australia have a wet season and a dry season. For most of the year, evaporation exceeds precipitation in most systems. However, in the summer wet season, the estuaries flood from excessive runoff, transporting freshwater and dissolved and particulate materials to the coastal zone.

Such extreme land-estuary-sea variations and connections have rarely been examined, but the life cycle of many estuarine dependent organisms, such as penaeid prawns, are cued to climatic changes (eg. Vance *et al.* 1996a,b). Prawn yields are greatest just before and during the wet season, but correlations with environmental cues (eg. rainfall, temperature) are not simple (see section 1.4.5.1 and Staples *et al.* 1995 for review).

The interplay of atmospheric, land and oceanic forces has important management consequences as pollution in land drainage basins often translate into problems in the adjacent coastal zone, especially estuaries and sheltered coastlines where contaminants often accumulate. Thus, nearly all of the major causes of estuarine degradation are actually problems originating on land or in the atmosphere:

- alterations to land management practices in catchments
- river regulation
- direct habitat loss
- urbanisation
- over-harvesting and
- exotic species.

Unfortunately, most information-to-date with regard to Australian estuaries is descriptive, dealing mostly with one or a few study sites within an estuary. Moreover, no information is extant on land-estuary-atmosphere connections in Australia.

The problems with the Peel-Harvey estuary in south-western Western Australia illustrate why such process-functional studies can be successful for management of our coastal waterways and fisheries. By the mid 1970's, large accumulations of nuisance macroalgae in both arms of the estuary gave evidence of eutrophication. The Department of Conservation and Land Management (CALM) coordinated a multi-disciplinary study of the estuary to define the cause of the problem and to identify means to prevent its occurrence in future. These studies (Lord 1994) identified:

- high fertiliser (phosphorus) inputs into the catchments of the Serpentine, Murray and Harvey Rivers
- transport of this material into the estuarine waters of the Peel-Harvey
- long water residence times in the estuary was a key process in determining whether or not the estuary was in net autotrophy or net heterotrophy.

This information was used to control fertiliser inputs in proportion to natural nutrient transport from the catchments into the estuarine zone, and to construct the Dawesville channel from the estuary to the open sea to improve flushing. Initial findings point to improved water quality and commercial and recreational fisheries in the Peel-Harvey estuary (see section 3.2). Other Australian estuaries similarly affected by harmful algal blooms may benefit from interdisciplinary approaches to the problem.

1.4.5.1 Fishery-habitat links

The concept of estuarine dependence has been discussed in section 1.3.5. Here we give some of the major themes of the research summarised in Appendix 4 that are known to govern links between fisheries and sheltered bay and estuarine habitats.

Regional variation - the role of longshore currents and spawning areas

A number of important species are now known to move northward on the NSW and southern Qld coast. These include dusky flathead, yellowfin bream, luderick and sand whiting, which are suspected to spawn in large parts of their range, and sea mullet and tailor which are known to spawn mainly on Fraser Island beaches. There may be some "self-recruitment" of estuaries by species that spawn at sandbars at the estuary mouths such as yellowfin bream, and possibly dusky flathead and whiting, but there is probably also an important dispersal of larvae southward and between estuaries by the EAC (Miskiewicz 1986, 1987).

The EAC is probably of particular importance in distributing the neustonic post-larvae of tailor throughout their east coast range, with indications of a similar role for the Leeuwin Current in the life-history of WA populations. Movements northward on the WA coast amongst bays and estuaries are poorly known due to a lack of tagging studies on species found in estuaries there (but see Chubb *et al.* 1981).

The proximity to spawning locations may explain some of the wide variation in timing and strength of recruitment found amongst regions (eg. Pollard 1992). Research underway at the time of writing also showed striking differences in adult age structure amongst NSW estuaries (p.c.#460 C. Gray), and in growth of daily otolith increments of whiting juveniles (<4 mths old) due to regional variation in temperature (p.c.#580 K. Smith).

In Barker Inlet, SA, SARDI has conducted fishery-independent recruitment surveys since 1980 (see Jones *et al.* 1996) and there are two groups of commercially important species with differing temporal patterns of recruitment:

- for King George whiting, yellow-eye mullet and sea garfish year class strength does not vary much amongst years and is consistently high in Barker Inlet (around 5-6 on Log_n scale)
- for Australian "salmon" and "herring", and yellowfin whiting, recruitment fluctuates greatly amongst years with no signs of covariation between species.

The wide variability in recruitment in the second group is due to the distance from spawning grounds off Albany and the vagaries of eastward transport by the Leeuwin current and westerly winds, or - in the case of yellowfin whiting - the fact that the species is living on the edge of its range in a relict, sub-tropical fauna at the top of St Vincent Gulf.

Variation in fisheries-habitat associations – amongst habitat types within estuaries and bays

Australian studies have generally shown that emergent and submerged vegetation generally supports a greater diversity, abundance and production of fish than bare sandy substrata in shallow waters, especially in clearer waters where the need for shelter is greater than for turbid waters. This vegetation ranges from freshwater and brackish-water macrophytes (*Egeria, Vallisneria;* West and King 1996, *Ruppia*; Humphries *et al.* 1992) to seagrass (see section 1.4.4), algae (*Caulerpa*; Haywood *et al.* 1995), beach-wrack (Ayvazian and Hyndes 1995) and mangroves. Nuisance macroalgae such as *Ulva* and *Cladophora* also serve a similar role at some levels of abundance (eg. Potter *et al.* 1983b).

However, channel depth, aspect to tidal currents, sediment type, turbidity and proximity to the mouth are also important factors. Several studies have concluded that spatial variability in assemblages and abundances amongst sampling sites within estuaries were at least as great as differences among estuaries, even though the sampling sites were relatively close and mostly in the lower reaches of the estuaries (eg. Robertson and Duke 1990a, Gray *et al.* 1996). An example from NSW is given in Box 14.5.1.

A wide variety of studies in the temperate (Loneragan and Potter 1990, Loneragan *et al.* 1986), sub-tropical (West 1993, Pollard and Hannan 1994) and tropical (Blaber *et al.* 1989) estuaries of Australia have shown a consistent decrease in species diversity with increasing distance upstream from the estuary mouth. These patterns are particularly marked in the estuaries of south-western WA where rainfall is very seasonally restricted -- so much so that Loneragan and Potter (1990) found that location within the estuary was a greater influence than season or year on the faunal composition.

Salinity regimes and position of the halocline is a major factor governing fish distributions and has received much research attention, especially in southern WA (see Loneragan and Potter 1990, Loneragan *et al.* 1987,1989).

In general terms, and using the terminology of Lenanton and Potter (1987), the penetration of "marine-stragglers" (eg. snapper) and "estuarine-opportunist" species into middle reaches of estuaries is presumably related to the continual presence of high salinities in these regions during dry seasons (summer-autumn in WA and winter in NSW, Qld).

"Estuarine" species, such as black bream, and freshwater species are frequently caught in the upper estuary reaches. The euryhaline sea mullet (*Mugil cephalus*) penetrates all regions, and there are seasonal migrations of the few Australian anadromous species such as Perth herring *Nematalosa vlaminghi* and *Amniataba caudavittatus*.

BOX 1.4.5.1 STUDY OF VARIATION AMONGST HABITAT TYPE WITHIN ESTUARIES - A NSW EXAMPLE

West and King (1996) sampled juvenile fish amongst vegetated and bare substrata in shallows along the entire salinity gradient within the Clarence River estuary. Over 80% of the fish caught were <= 50 mm TL and a single species dominated the analysis -- the glassy perchlet *Ambassis jacksoniensis* comprised 28% of catch by number.

The nursery role of submerged vegetation was found to depend strongly on the species of fish and the location of habitats along the estuarine salinity gradient. There were significant interactions amongst sampling month, salinity regime and habitat type for a number of economically important species in terms of both species diversity and abundance. However, the mean numbers and diversity of species over bare substrata never exceeded those in the vegetated habitats.

New recruits of yellowfin bream (*Acanthopagrus australis*) were found almost exclusively in *Zostera capricornii* beds in July and September, but by November and January ontogenetic movement out of the seagrass yielded small samples without significant differences between bare and vegetated habitats. Juvenile yellowfin bream were also abundant in the brackish-water reaches, mostly in *Vallisneria* beds, and extended into freshwater *Egeria* beds in small numbers. Tarwhine (*Rhabdosargus sarba*) and Luderick (*Girella tricuspidata*) showed a similar pattern to yellowfin bream, with greatest abundance of new recruits in *Zostera* near the mouth of the Clarence River, but smaller numbers in brackish-water.

Sea Mullet (*Mugil cephalus*) were caught almost exclusively in *Zostera* at the river mouth sites, but were most abundant upstream and showed highly variable distribution amongst bare and vegetated sites there, probably because they recruited primarily to vegetated habitats in September, but moved out of them within months.

The study emphasised that *Zostera* beds near the entrance of the Clarence River were habitats of particular importance as recruitment sites and temporary nurseries for young yellowfin bream, luderick, tarwhine and sea mullet, but also showed that previously neglected beds of brackish-water and freshwater vegetation were also very important for these species. The glassy perchlets (*Ambassis jacksoniensis*) were caught as juveniles after recruitment in spring/summer and the main "permanent" residents of the vegetated substrata were various gobies and gudgeons (see Table 1.4.5.1).

It is notable that juveniles of other economically important species were encountered in very low numbers in the shallow waters, and they were not necessarily new recruits: only 43 sand whiting (*Sillago ciliata*); 9 dusky flathead (*Platycephalus fuscus*); 2 Australian bass (*Macquaria novemaculeata*); and only 4 tailor (*Pomatomus saltatrix*). However, this scarcity of commercial species is a feature of many community studies -- the study by Blaber and Blaber (1980) did not catch any whiting or flathead and Lenanton (1982) caught no black bream.

The deeper, subtidal habitats in the same rivers were studied by complementary sampling with low-opening (1m) prawn trawls and high-opening (3m) fish trawls, which covered the entire salinity range and 30-50% of the traditional "shots" employed by commercial prawn trawlers. This enabled inferences to be made about the interactions between such trawling and the local fin-fisheries, as well as defining longitudinal patterns in fish community structure.

Again, small glassy perchlets and southern herring (*Herklotsichthys castelnaui*), and the tropical catfish *Arius graeffii*, dominated catches and comprised about 63% numerically. The majority of luderick and Australian bass were adults, but over 85% of all other economically important species were juveniles or immature, based on comparisons of their length with the NSW minimum legal size limits.

The major patterns were due to the longitudinal position of trawl sites in the river, and the individual sites could be separated and placed in order of their relative longitudinal location to each other on the basis of their fish communities alone. There were three main groupings from cluster analysis that were named "tidal", "gradient" and "freshwater" after Rochford (1951).. The numerous glassy perchlets had no part in determining the grouping of sites, but the southern herring did.

There were also significant temporal patterns in the distribution of fish classified on the basis of their life-histories, after Lenanton and Potter (1987). The "marine stragglers" snapper (*Pagrus auratus*) and tarwhine were found in the "tidal" parts in December only, the "estuarine opportunists" (southern herring, yellowfin bream, silver biddies, flat-tail mullet, mulloway, tailor, sand whiting) were found in "tidal" and "gradient" parts, and "estuarine" species showed little or no preference. Australian Bass were found only in the freshwater.

The consistency of these spatial and temporal patterns within the estuaries allowed West (1993) to list several areas that may require special attention and protection from activities detrimental to juvenile fishes -- such as prawn trawling (see section 4.2.3).

Recruitment "hotspots" and larval advection by tides through estuary entrances

The importance of location of seagrass beds in relation to hydrodynamic features has been discussed in section 1.4.4.1, and reviewed for wider regional and bay scales by Edgar and Shaw (1995c).

Larval movement upstream in estuaries is governed almost solely by tidal movement and flushing for pre- and post-flexion stages. Movement of pre-settlement fish through constricted entrances where tidal flows are often very strong is probably achieved by vertical and horizontal migration in concert with tidal changes (p.c. #560 A. Miskiewicz). For example, the behaviour of post-larval eastern king prawns has been found to "ratchet" them up into the east coast estuaries (Rothlisberg *et al.* 1995), but there is a need for more research on these transport mechanisms in Australia.

Most of the fish larvae in NSW estuaries were found in the epibenthic layer, which may be very important for tidal "ratchetting" of larvae into the estuaries, yet sampling methods are not designed for the epibenthic layer and it remains largely unknown. An epibenthic "sled net" has been used in NSW to capture these larvae (Suthers and Rissik 1992).

Western Australian studies have used traditional surface tows to sample fish larvae in estuaries, and have found very strong structuring of larval assemblages by distance from the mouth and tidal penetration. For example, Neira *et al.* (1992b,c) found poor penetration of marine fish larvae past the first 12.5 km of the Swan estuary - presumably reflecting the weak tidal effect in the wide basins of the middle estuary and saline regions of the tributary rivers. The larvae of 13 species that typically spawn within the estuary accounted for 93.8% of the total numbers of larvae (gobies comprised 88% overall).

Flushing regimes and intermittent closure greatly affect larval advection. The low occurrence of marine-spawned larvae in Wilson Inlet was concluded by Neira and Potter (1992b) to reflect the fact that tidal water movement within the basin of the system is so small that it is unable to facilitate the transport and dispersion of larvae. The ichthyoplankton of Wilson Inlet resembles that of other poorly-flushed estuaries in that it is low in species richness and dominated by estuarine-spawned larvae. Only 59 species were found in flood tide samples, and 8 of the 9 species also found on ebb tides were spawned in the estuary (eg. anchovies *Engraulis australis*). Snapper and tarwhine entered the estuary as post-flexion larvae during flood tides.

In the permanently open Nornalup-Walpole estuary Neira and Potter (1994) found that the larvae of most marine species were at the preflexion stage and that all but 3 of these 26 species had never been previously recorded as juveniles or adults. This led to the conclusion that they were passively transported from outside the estuary. Marine larvae were common in the entrance channel but not the basin and the absence of larvae of the marine teleosts that are common in the estuary basins parallels the situation in nearby, and seasonally closed, Wilson Inlet.

Thus for common commercially important Australian "herring" (*Arripis georgianus*), King George whiting and snapper, which are abundant in Wilson Inlet and Nornalup-Walpole estuaries, recruitment occurs as juveniles and or adults. The larval habitat for these species is till largely unknown.

The entry of other older, pre-settlement stages has not been investigated in WA, but the development of "light-traps" (eg. Doherty 1987a), "channel-nets", "crest-nets" and "epibenthic sled nets" on the east coast could allow study of these stages. The attractive research opportunities afforded by narrow tidal entrances to some NSW estuaries have received surprisingly little attention since Miskiewicz (1986).

The role of freshwater flows in structuring communities in bay and estuarine fisheries

The most widely cited example of effects of the environment on fisheries production concern significant correlations between rainfall, salinity and river discharge for banana prawns (*Penaeus merguiensis*). Decreased salinities make estuarine habitat temporarily unsuitable for survival of post-larval and juvenile banana prawns, so there is also a correlation between adult catch and the amount of juvenile habitat. There is also a direct correlation between production and area of mangroves (see Staples *et al.* (1985,1995) for review.

However, this relationship can be positive in one location and negative in another:

- rainfall is positively correlated with banana prawn catch in the southern Gulf of Carpentaria - due to the amount of emigration of juveniles (more prawns of all size classes migrate in wetter years; only large juveniles migrate in drier years)
- there is no such correlation with catch in the northern Gulf - due probably to 2 major differences in climate and topography ; rainfall in the southern Gulf is more than twice as variable as rainfall in the north-east; the southern catchments are about 20 times the area of catchments feeding freshwater in to the north-eastern region. This greatly dampens effects of rainfall on salinity regimes in nurseries.
- there is a negative correlation with catch in the Gulf of Papua.

There is also a positive influence of freshwater on production of NSW school prawns (*Metapenaeus macleayi*) that has not been refined since reports by Ruello (1973) and

Glaister (1978a,b). Bycatch in estuarine prawn fisheries is largely driven by episodic freshwater flow events as fish encounter gear as they move quickly downstream to seek saltier waters - see section 4.2.3.

There is lack of detailed study of the relationship between freshwater flow and the spawning and subsequent recruitment needs of major coastal finfish. For example, Hall (1984) noted that peak Murray River discharge generally coincides with or just precedes the spawning season of black bream, mulloway and yellow-eye mullet, and he assessed this relationship by correlating flows with later catches, lagged by time to recruitment.

Both positive and negative correlations were evident, which depend on the place and timing of spawning and the early life-history of the species. There were no direct correlations between flow and subsequent yellow-eye mullet and black bream catches, however all lag correlation coefficients were negative for black bream, indicating that year class strength is inversely related to flow.

Mulloway showed highly positive correlation when lags of 15 and 27 months were applied, which equate to age at recruitment to the gillnet fishery. A similar relationship was found with greenback flounder (*Rhombosolea tapirina*). Hall (1984) interpreted these data as supporting the hypothesis that freshwater flows promoted larval and juvenile recruitment of these two species, but possibly flushed bream eggs and larvae out to sea from (suspected) channel mouth spawning sites.

However, uncertainties about spawning location of some of these taxa limit the use of the relationships. For example, Hall (1984) proposes spawning sites at the Murray mouth channel for mulloway, but B. Pierce (SARDI p.c. #1510) favours the idea of offshore spawning sites with attraction of relatively large juveniles (>= 150 mm) into the freshwater interface at the Murray Mouth. Potter *et al.* (1993) stress that gonad ripeness alone is not a good indicator of estuarine spawning, as the gonads can be elaborated and then resorbed.

In the Gippsland Lakes and elsewhere in Victoria there is extreme variation in recruitment of black bream and relationships with freshwater outflow will be investigating using hindcasting of recruitment from age structures of catches (FRDC#96/102).

In the Northern Territory, the main source of variation in barramundi production models can be attributed to amount of rainfall before. Habitat quality and timing of access and departure are affected by rainfall -- early rain catches and distributes the contribution of both early and late spawners (p.c. #1670 R. Griffin). Similar relationships are being explored for both barramundi and spanish mackerel in north Queensland -- there are positive correlations between catches and rainfall in the wet season 5 years previous to recruitment to fisheries (p.c. #90 R. Garrett *et al.*).

There are also interactions between freshwater input to estuaries and the amount and type of benthic habitat. Surveys of epibenthic larvae in nine estuaries along the NSW coast showed significantly greater diversity in estuaries without freshwater inflow -- due to a "seagrass effect" in open, clear, oligotrophic waters where seagrass grow (p.c. #580 I. Suthers).

Seasonal salinity shifts have been shown in many studies to alter the patterns of distribution, abundance and emigration from estuaries. For example, Potter *et al.* (1983a) found shifts in distribution of blue swimmer crabs (*Portunus pelagicus*) in their search for preferred salinities of 30-40 ppt. Salinity changes are also known to be cues for emigration of western king prawns and upstream migration of western school prawns.

The role of turbidity in structuring communities in bay and estuarine fisheries

Blaber and Blaber (1980) concluded that the juvenile fish fauna of Moreton Bay could be divided into "clear water", "turbid water" and "turbidity indifferent" species with the only common denominator being a preference by juveniles for shallow water. They suggested that it may not be estuaries *per se* that are attractive to juvenile fish, but shallow, turbid waters.

The "estuarisation of the shelf" in the tropics (*sensu* Longhurst and Pauly 1987) means that there are large coastal areas that are shallow and turbid, and even larger areas become "estuarine" when freshwaters and heavy silt loads are transported seaward and long-shelf during wet seasons and flood events. There are obviously many more areas suitable as nursery areas compared to the high energy coasts of the temperate zones in Australia.

Cyrus (1992) recognised three types of turbidity gradient in both the tropical Embley River estuary in the Gulf of Carpentaria and the South African estuaries. In the Embley River there were;

- Wet Season -- distinct longitudinal gradient (low turbidity at mouth, increasing upstream)
- Early Dry Season -- decrease in river flow, low level, reversed turbidity gradient with lowest values in the upper reaches
- Late Dry Season -- negligible river flow and no longitudinal gradient present in turbidity levels.

Cyrus (1992) classified catch by turbidity range and also found distinct trends in catch-per-unit-sampling-effort using gillnets. A variety of ariid catfish, mullet species, barramundi and threadfin salmon had increasing CPUE with increasing turbidity. However, we believe this could be partly explained by the hypothesis that gillnet efficiency increases with turbidity -- fish are better able to detect and avoid gillnets in clearer water. This was not considered by Cyrus (1992).

The role of bar opening and closure regimes in structuring communities in estuarine fisheries

Breaching of bars at the entrances are followed by marked declines in salinity, but also the emigration of a considerable number of those marine teleosts that have overwintered in that system. Since many species spawn in spring their offspring are able to move into estuaries as soon as salinities and temperatures begin to rise and freshwater discharge begins to decline (Potter *et al.* 1983a).

Potter *et al*. (1993) suggested that evolutionary pressures must have been strong in seasonally closed estuaries for species to develop the capacity to spawn in such land-locked environments. They found this ability even for the long-lived catfish (“cobbler”) *Cnidoglanis macrocephalus* and the flathead *Platycephalus speculator* -- which presumably could have delayed spawning in the marine environment until re-opening of estuaries.

The extent of seasonal changes with breaching of bars has been found to depend on the tidal regime in the estuary. Neira and Potter (1992a) detected only slight changes in the spatial distribution, time of occurrence and abundance of larvae in Wilson Inlet during “open” and “closed” periods, because of the rarity of marine fish larvae penetrating what was essentially a fauna dominated by estuarine-spawning species. They suggest this low occurrence of marine larvae was due to the lack of tidal movement being unable to transport and disperse larvae.

Potter *et al.* (1993) proposed that depth of the entrance channel and its width are important factors in structuring fish communities within. For example, the relatively shallow, narrow entrance of the Wilson Inlet means that there is little exchange of water and essentially no means for tidally transporting the larvae of marine teleosts into the main body of this system. The very strong tidal currents at some narrow mouths (eg. Lake Macquarie) may also act as hydrodynamic barriers to entry of some species of larvae.

Presence of a permanently open entrance channel in the Nornalup/Walpole Estuary results in the recruitment of a wider range and greater number of species into the deeper waters, than nearby seasonally closed Wilson Inlet (Neira and Potter 1994). The presence of high bottom salinities for many months in the permanently open estuaries is considered important in encouraging marine species, including sharks and rays, to remain for extended periods. However, the upstream shallows are dominated by estuarine species - reflecting poor recruitment of marine species from outside and successes of the estuarine spawners (see also Neira *et al*. 1992c).

Gibbs (1997) has collated knowledge of timing of fish recruitment to estuaries for economically important finfish in NSW that shows a complex and variable relationship between timing of lagoon opening and the recruitment of fished species. The data show a spread in timing caused by latitude and seasonal differences in sea temperature and patterns of prevailing surface currents.

Pollard (1994a) compared the fish populations of one permanently open lagoon with that from two intermittently opening lagoons on the NSW south coast and found that the permanently open lagoon had a much “richer” fish population than did the intermittently opening lagoons (approximately 100 species versus approximately 40 species). The fauna from the intermittently opening lagoons was simply a subset of that found in the permanently open lagoon - there were no species unique to the intermittently opening lagoons, with the exception of the introduced Mosquito Fish (*Gambusia holbrooki*) (see Table 1.3.2.2).

Despite the reduced diversity of fish species, Pollard (1994a) found that the intermittently opening lagoons were more productive from a commercial fisheries perspective, producing a greater weight of fin-fish and prawns per unit area per year at least for the first 18 to 24 months following closure. These waters also developed particularly valuable fisheries for a few species such as black bream, sea mullet and prawns (*Metapenaeus*) which grew to a large size in the enclosed waters.

This difference was also reported by Lugg (1996) and Gibbs (1997) for Coila and Tuross Lakes, which lie adjacent to one another on the NSW south coast. Coila Lake opens intermittently and Tuross Lake is permanently open. Analysis of ten years of commercial fish production figures from these lakes on the basis of their surface area demonstrated some trends that Lugg (1996) considered may apply more widely. Coila Lake opened on ten occasions and while commercial fish production from Tuross Lake over the period was relatively constant in terms of both weight and dollar value, that from Coila Lake was highly variable. However, Coila Lake (59.9 $kgHa^{-1}yr^{-1}$; \$388 $kgHa^{-1}yr^{-1}$) was slightly more productive and much more lucrative than Tuross Lake (47.0 $kgHa^{-1}yr^{-1}$; \$111 $kgHa^{-1}yr^{-1}$). The main reason for the higher value of the catch from Coila Lake was the periodic abundance of prawns.

Other important sources of variation in structuring communities in bay and estuarine fisheries

There has been widespread study of temporal variation in fish community structure at a variety of scales. For example, significant diel differences occurred amongst habitats in Gray *et al.*'s (1996) study. Within each habitat some species were caught in greater numbers ta night. This may have been due to:

- foraging movements out of deeper channels by dusky flathead and silver biddy at night to feed in shallow waters
- movement out of seagrass onto bare sand at night by glassy perchlets
- vertical migration up out of seagrass shoots to forage in the water column at night by *Centropogon australis*
- net avoidance by some species during the day, and increased vulnerability of fish to trawling at night.

Recruitment events and ontogenetic shifts in habitat use are a feature of the few studies that have compared seasons and years. For example, in NSW, yellowfin bream are found along the coast in ichthyoplankton at 10-30 mm TL (Miskiewicz 1986), they settle in vegetated intertidal habitats in about September at a mean length of 17 mm LCF, then move to deeper subtidal habitats at 38-59 mm LCF (West 1993).

Gear selection and the need for standardisation and innovation

The greatest leverage in analysis of the diversity and abundance patterns in datasets of many of the community studies in Appendix 4 is provided by small, resident species that may be particularly vulnerable to the sampling gear being employed. The glassy perchlets (Ambassidae), for example, dominate the catches in numbers and biomass of nearly all estuarine and mangrove studies on the east coast of Australia (see Table 1.4.5.1). They are particularly vulnerable to capture by a wide range of gears and mesh sizes because they are thigmotropic, they school tightly in motionless aggregations, and they have deep dorso-ventrally elevated bodies with high spines.

Studies of adult fish in estuaries and bays are often conducted at scales too small, or with gear that is too restricted or selective, to make inferences at larger areas. The studies in Table 1.4.5.1 show the range of gear types usually employed for juveniles and adult stages.

The results of community studies must be carefully reported in the context of the types of gear used, otherwise misleading inferences can be made about the fisheries value of particular habitat types and locations. The rarity or absence of economically important taxa in studies may reflect only their mobility and ability to evade sampling gear. For example, the absence of finfish species in seagrass reported by Coles *et al.* (1987a) has sometimes been cited in north Queensland environmental impact statements for coastal developments as evidence of the unimportance of seagrass beds as nurseries - but that study was focussed entirely on prawn juveniles and employed a very small beam trawl.

Attempts to overcome this have included use of the commercial fleet or their gear types to take samples and also use of more comprehensive and innovative gear types (eg. Blaber *et al.* 1989, 1994c). For example, QDPI compared the use of professional tunnel-netters (1500 metre wings) and research block-netting to sample older commercial taxa in south-east Qld. On a logarithmic scale the tunnel-netter's catches were within the confidence limits of research sampling in terms of both numbers and weight -- at the bottom end of researcher's range in terms of fish density, but at the upper end in terms of biomass per unit area sampled (p.c. # 220 I. Halliday).

The value of careful gear choice in community studies is exemplified by West (1993) who used both commercial prawn trawl and Bollinger fish trawls in the Clarence and Richmond rivers to sample subtidal habitats. Flathead were caught in a ratio of prawn trawls : fish trawls of 5.7 : 1 and snapper 24 : 1. There did not appear to be significant differences for mulloway in the ratio 0.85 : 1, tailor in the ratio 1.02 : 1. The opposite trend was true for southern herring at 1 : 15.6 and flat-tail mullet 1 : 3.72.

These results are in clear contrast to Gray *et al.* (1996) who did not catch a single mulloway, and only one tailor, with the suite of gear they employed to catch juveniles in the Clarence River.

We found a surprising lack of calibration of gear types to assess their accuracy or precision (but see Connolly 1994b, Edgar and Shaw 1995b, Loneragan *et al.* 1995, Vance and Staples 1992, Vance *et al.* 1994, vanderKlift *et al.* 1995), and even major overseas reviews do not always cover the range of gears needed in some habitats (eg. Rozas and Minello 1997).

Table 1.4.5.1. Examples of fish community studies in temperate, sub-tropical and tropical bays and estuaries at different spatial and temporal scales, and with different gear types. Species are listed in decreasing order of abundance in surveys. Numbers in brackets refer to the highest and lowest numbers of taxa captured in the studies.

Location	habitats	gear	temporal spread	N spp	6 major taxa	6 major comm/rec species	reference
Port River delta (35-41 ppt)	Section Bank	beach seine (120m long ; 2@30m wings of 30mm mesh ; 60m bunt section with 10mm mesh)	Jan 1986-May1987	27	* *Hyporhamphus melanochir, Atherinosoma microstoma, Platycephalus bassensis, Sillago bassensis, Arripis georgianus, Sillaginodes punctata*	*H. melanochir, S. punctata, A. forsteri, A. georgianus, A. truttaceus*	Jones *et al.* (1996) *recalculations from density data
Port River delta	Torrens Island Beaches	as above	monthly 1981-1987	29	* *A. microstoma, S. punctata, Aldrichetta forsteri, Pelates octolineatus, H. melanochir, Nesogobius sp.*	*A. forsteri, S. punctata, H. melanochir, A. georgianus, A. truttaceus*	Jones *et al.* (1996) *recalculations from density data
Port River delta	Eastern passage	as above	monthly 1981-1987	21	* *A. forsteri, A. microstoma, P. octolineatus, Nesogobius, Arenogobius bifrenatus, Spratelloides robustus*	*A. forsteri, H. melanochir, S. punctata, Hyporhamphus regularis, Arripis truttaceus, A. georgianus*	Jones *et al.* (1996) *recalculations from density data
Westernport Bay,	seagrass, intertidal, unvegetated flats	15 m seine, with 3m drop and 1mm square mesh	1989-90; 3 monthly intervals, some day vs night	75	*Stigmatopora nigra (5454), Arenigobius frenatus, Heteroclinus perspicillatus, Vanacampus phillipi, Favonigobius tamarensis, Urocampus carinirostris (718)*	*Haletta semifasciata (58), Sillaginodes punctatus (53), Engraulis australis (53), Platycephalus bassensis (45), Sardinops neopilchardus (36), Hyporhamphus melanochir (18), P. laevigatus (34), Aldrichetta forsteri (20),*	Edgar and Shaw (1995a)
Westernport Bay	seagrass, unvegetated, channel habitats	50 m monofilament gillnets, with 3m drop; 2 panels @ 64mm and 108mm mesh	day/night as above	38	*Aldrichetta forsteri (1300), Arripis trutta, Callorhinchus milii, Pseudocaranx dentex, Arripis truttacea, Mustelus antarcticus (109)*	*Aldrichetta forsteri (1300), Arripis trutta (402), Callorhinchus milii (244), Pseudocaranx dentex (153), Arripis truttacea (135), Mustelus antarcticus (109)*	Edgar and Shaw (1995a)
Wilson Inlet (seasonally closed)	shallow basin margins	beach seines (46 m x 1.5m x wings 25mm and 9.5 mm mesh pocket)	bimonthly Sept1987-Aug 1988	20	*Leptatherina wallacei, Atherinosoma elongata, Leptatherina presbyteroides, Favonigobius lateralis, Pseudogobius olorum, Afurcagobius suppositus*	*A. forsteri (48), Engraulis australis, M.cephalus, Hyporhamphus melanochir, Platycephalus speculator, Sillaginodes punctata (6)*	Potter, Hyndes, Baronie (1993)

Location	habitats	gear	temporal spread	N spp	6 major taxa	6 major comm/rec species	reference
Wilson Inlet (seasonally closed)	deeper waters away from margin/Hay river	gillnets (180 m long x 6 panels x 30m each; panels = 38-102 mm mesh)		27	*C. macrocephalus, Platycephalus speculator, Engraulis australis, Sillaginodes punctata, Arripis georgianus, M.cephalus*	*C. macrocephalus (1517), Platycephalus speculator, Engraulis australis, Sillaginodes punctata, Arripis georgianus, M.cephalus (81)*	Potter, Hyndes, Baronie (1993)
Wilson Inlet (seasonally closed)	demersal fauna; basin	otter trawls (5m long x 51 mm mesh x 25mm bunt ; mouth width of 2.6 m and height 0.5 m)		>=3	*C. macrocephalus, Pseudogobius olorum, Afurcagobius suppositus*	*C. macrocephalus (126)*	Potter, Hyndes, Baronie (1993)
Nornalup/Walpole (permanently open)	shallow basin margins	beach seines (41.5 m x 1.5m x wings 51mm and 9.5 mm mesh pocket)	Oct 1989- Aug. 1990; bimonthly	14	*L. presbyteroides, F. lateralis, L. wallacei, Atherinosoma elongata, Acanthopagrus butcheri, S. punctata*	*A. butcheri (52), S. punctata, A. forsteri, Arripis truttaceus, Rhabdosargus sarba, Ammotretis rostratus (2)*	Potter and Hyndes (1994)
Nornalup/Walpole (permanently open)	deeper waters away from margin	gillnets (180 m long x 6 panels x 30m each; panels = 38-102 mm mesh)	Oct 1989- Aug. 1990; bimonthly	23	*Arripis georgianus, A. butcheri, M. cephalus, P. speculator, A. forsteri*	*Arripis georgianus* (277), *A. butcheri, M. cephalus, P. speculator, A. forsteri* (92)	Potter and Hyndes (1994)
Botany Bay	*Zostera* North (Airport)	Wall net and rotenone (10mm mesh = 100 sq m.); Beam trawl (3mm mesh = 1600 sq. m.; Gillnets (5 mesh panels of 38-102mm @ 300m long)	day/night, summer/winter	78	*Favonigobius lateralis, Stigmatopora nigra, Pelates sexlineatus, Centropogon australis, Velambassis jacksoniensis*	*Meuschenia trachylepis* (152), *Platycephalus fuscus, M. freycineti, Pomatomus saltatrix, L. argentea, Girella tricuspidata* (56)	Middleton *et al.* (1984)
Botany Bay	*Zostera* West	as above		60	*Stigmatopora nigra, Favonigobius lateralis, Centropogon australis, Urocampus carinirostris, Herklotsichthys castelnaui*	*Herklotsichthys castelnaui* (257), *M. trachylepis, Sillago ciliata, M. freycineti, Gerres ovatus, Girella tricuspidata* (44)	Middleton *et al.* (1984)
Botany Bay	*Posidonia australis*	as above		67	*Velambassis jacksoniensis, Bathygobius kreffti, Centropogon australis, Pranesus ogilbyi, Monacanthus chinensis*	*M. freycineti* (118), *M. chinensis, M. trachylepis, G. tricuspidata, Myxus elongatus, Liza argentea* (68)	Middleton *et al.* (1984)
Swan River estuary	lower (>14 ppt)	seine (133m x 2m x 25.4 mm mesh wings and 15.9mm in pocket)	fortnightly-bimonthly for 5yrs		Main indicator species = *Torquigener pluerogramma, Leptatherina presbyteroides, Favonigobius lateralis*		Loneragan and Potter (1990)

Location	habitats	gear	temporal spread	N spp	6 major taxa	6 major comm/rec species	reference
Swan River estuary	middle (2.2 to 35.5 ppt)				Main indicator species = *Leptatherina wallacei, Gerres subfasciatus, Nematalosa vlaminghi, Craterocephalus mugiloides*		Loneragan and Potter (1990)
Swan River estuary	upper (2.6 to 27.3ppt)				Main indicator species = *Papillogobius punctatus, Nematalosa vlaminghi, Engraulis australis, Acanthopagrus butcheri*		Loneragan and Potter (1990)
Peel-Harvey estuary (permanently open)	shallow water	beach seines (102.5 m x 1.83m x wings 25.4 mm-15.9mm and 9.5 mm mesh pocket)(1600 sq. m. sampled)	"wet" (June-Nov.) vs "dry" (Dec-May)	43	*Pelates sexlineatus, Apogon rueppelli, Gerres subfasciatus, Hyperlophus vittatus, Aldrichetta forsteri, Favonigobius lateralis*	*Hyperlophus vittatus (4532), Aldrichetta forsteri, Sillago bassensis, S. schomburgkii, N. vlaminghi, Mugil cephalus (569)*	Potter, Loneragan, Lenanton, Chrystal, Grant (1983b)
Peel-Harvey estuary (permanently open)	deeper waters away from bank/rivers	gillnets (220m long x 11 panels x 20m each; panels = 38-102 mm mesh)		27	*Mugil cephalus, A. forsteri, Nematalosa vlaminghi, Gerres subfasciatus, Cnidoglanis macrocephalus, P. sexlineatus*	*Mugil cephalus (6066), A. forsteri, Nematalosa vlaminghi, C. macrocephalus, Pomatomus saltatrix, Sillago schomburgkii, Argyrosomus hololepidotus (192)*	Potter, Loneragan, Lenanton, Chrystal, Grant (1983b)
Peel-Harvey estuary (permanently open)	demersal fauna; deep water	otter trawls (5m long x 51 mm mesh x 25mm bunt ; mouth width of 2.6 m and height 0.5 m)		29	*A. rueppelli, G. subfasciatus, C. macrocephalus, Amniataba caudavittatus, Pseudorhombus jenynsi, Gymnapistes marmoratus*	*C. macrocephalus (95), Pseudorhombus jenynsi, Sillago bassensis, S. schomburgkii, A. forsteri, M.cephalus (3)*	Potter, Loneragan, Lenanton, Chrystal, Grant (1983b)
Jervis Bay	semi-exposed sandy beaches	"Small seine" (25m x 3m x 6mm mesh)	years (1988-91); quarters (spring, summer, autumn, winter); day/night	93	*Hyperlophus vittatus, Sardinops neopilchardus, Engraulis australis, Atherinason hepsetoides, Atherinosoma presbyteroides, Myxus elongatus*	*Myxus elongatus* (9734), *Sillago ciliata, Hyporhamphus australis, Trachurus novaezelandiae, Trachinotus copperingi, Pomatomus saltator* (6)	Jervis Bay Baseline Studies CSIRO (1994)
Jervis Bay	semi-exposed sandy beaches	"Large seine" (40m x 2m x 30mm mesh)	as above	64	*Sillago ciliata, Myxus elongatus, Hyperlophus vittatus, Trachurus novaezelandiae, Rhabdosargus sarba, Tetractenos hamiltoni*	*Sillago ciliata* (3152), *Myxus elongatus, Trachurus novaezelandiae, Rhabdosargus sarba, Aldrichetta forsteri, Acanthopagrus australis* (186)	Jervis Bay Baseline Studies CSIRO (1994)

Location	habitats	gear	temporal spread	N spp	6 major taxa	6 major comm/rec species	reference
Jervis Bay	semi-exposed sandy beaches	Beam Trawl (1m x 0.5 m x 2m long net x 6mm mesh)	as above	53	*Atherinason hepsetoides, Sillago bassensis, Hyperlophus vittatus, Platycephalus caeruleopunctatus, Engraulis australis, Crapatalus arenarius*	*Sillago bassensis (164), Platycephalus caeruleopunctatus, Sillago ciliata, Paraplagusia unicolor, Ammotretis rostratus (15)*	Jervis Bay Baseline Studies CSIRO (1994)
Tweed, Cudgera, Brunswick, Richmond, Evans, Clarence, Sandon, Wooli Wooli, Corindi rivers	shallow seagrass (*Zostera capricorni*)	seine (10m by 2m by 6mm mesh) 25 sq.m sampled	Sept-Nov, 1994, day vs night	49	*Ambassis jacksoniensis, Redigobius macrostoma, Mugil cephalus, Pelates sexlineatus, Rhabdosargus sarba, Acanthopagrus australis*	*M. cephalus, R. sarba, A. australis, Girella tricuspidata, Trachurus sp.*	Gray *et al.* (1996)
As above	bare sand		Sept-Nov, 1994, day vs night	29	*M. cephalus, S. ciliata, A. jacksoniensis, Favonigobius exquisites, F. lateralis, Myxus elongatus*	*M. cephalus, S. ciliata, Myxus elongatus, A.australis, Gerres subfasciatus, Platycephalus fuscus*	Gray *et al.* (1996)
as above	deeper channels	otter trawl (8m footrope by 25mm mesh)	Sept-Nov, 1994, day vs night	35	*G. subfasciatus, Marilyna pleurosticta, Plotosus lineatus, S. ciliata, Pseudorhombus jenynsi, Cnidoglanis macrocephala*	*G.subfasciatus, S. ciliata, P.jenynsii, P. arsius, P.fuscus, A. australis, R. sarba*	Gray *et al.* (1996)
Clarence - Grafton	freshwater, *Egeria densa* vs fluvial sediments	seine (30 m by 2m by 6 mm mesh) 25 sq.m sampled	Sept 1989- July 1990, day, every second month	25	*Hypseleotris compressus, M. cephalus, Gobiomorphus australis, P. grandiceps, Priopodichthys marianus, Favonigobius tamarensis*	*M. cephalus (801), A. australis, Liza argentea*	West (1993)
Clarence-Maclean	<= 15 ppt, *Vallisneria* vs sand/mud and gravel	seine (30 m by 2m by 6 mm mesh)	Sept 1989- July 1990, day, every second month	34	*A.jacksoniensis, A.australis, Redigobius macrostomus, G. australis, F. tamarensis, H. compressus*	*A. australis (1828), M. cephalus, Gerres ovatus, G. tricuspidata, L. argentea, R. sarba*	West (1993)
Clarence-Yamba	<= 35 ppt, *Zostera* vs marine sand	seine (30 m by 2m by 6 mm mesh)	Sept 1989- July 1990, day, every second month	39	*A. jacksoniensis, R. macrostomus, Ac. australis, Pelates quadrilineatus, Gobiopterus semivestita, M. cephalus*	*A. australis (1152), M. cephalus, L. argentea, R. sarba, G. tricuspidata, G. ovatus*	West (1993)

Location	habitats	gear	temporal spread	N spp	6 major taxa	6 major comm/rec species	reference
Richmond and Clarence	subtidal	otter trawls (twin-rigged prawn trawl 10m headline by 40mm mesh)(Bollinger fish trawl 22m headline by 3m by 229mm wings-152mm-57mm-38mm codend)	Sept 1989- July 1990, day, every third month	88	*A. jacksoniensis, Herklotsichthys castelnaui, Arius graeffii, Ac. australis, Ambassis marianus, Gerres subfasciatus*	*H. castelnaui (111,884), A. australis, G. subfasciatus, M. cephalus, L. argentea, Argyrosomus hololepidotus, Pomatomus saltatrix (4063)*	West (1993)
Embley River	open-water channels <5m	gillnets (66m x 50-150mm mesh)	day/night; pre-wet; wet; dry	127	*Scomberoides commersonianus, Arius proximus, Lates calcarifer, Nematalosa erebi, Polydactylus sheridani, Carcharhinus cautus*	*Scomberoides commersonianus, Lates calcarifer, Polydactylus sheridani, Carcharhinus cautus, C. limbatus, Pomadasys kakaan*	* Blaber, Brewer and Salini (1989); * = all data expressed in terms of biomass (grams liveweight) not numbers
Embley River	inter-tidal sandy-mud beaches	seine (60m x 2m x 25mm)		72	*Acanthopagrus berda, Arrhamphus sclerolepis, Himantura uarnak, Lates calcarifer, S. commersonianus*	*Lates calcarifer, S. commersonianus*	* Blaber, Brewer and Salini (1989)
Embley River	seagrass (*Enhalus*)	beam trawl (2m x 1m x 28mm mesh)		53	most small <10cm; *Epinephelus coioides, Pelates quadrilineatus, Siganus canaliculatus, Apogon ruppelli, Lutjanus russelli, Monacanthus chinensis*		* Blaber, Brewer and Salini (1989)
Embley River	intertidal mudflats adj. to mangrove	stake net (240m x 2m x 50mm mesh)		39	*Dasyatis sephen, Himantura uarnak, Drepane punctata, Arius proximus, Gerres abbreviatus*		* Blaber, Brewer and Salini (1989)
Embley River	small mangrove creeks and inlets	Block net and rotenone (2mm mesh)		66	*Tetraodon erythrotaenia, Liza subviridis, Anodontostoma chacunda, Toxotes chatareus*		* Blaber, Brewer and Salini (1989);
Albatross Bay	prawn trawl grounds 7-43 m	Frank and Bryce Trawl, Demersal Otter Trawl (26m footrope, 50mm mesh)		91	91 common to both; mainly *Leiognathus splendens, L. equulus, Anodontostoma chacunda, Secutor insidiator, S. ruconius, Gerres filamentosus*		* Blaber, Brewer and Salini (1989);

1.4.6 Open coasts - sandy shores

Roughly one-half of Australia's coastlines consist of open, sandy shores (Fairweather and Quinn 1996). Given this impressive figure it is very surprising that so little ecological work has been done in these habitats, especially with respect to the community composition and structure, and energetics of pelagic and benthic food chains. Indeed, extensive studies on sandy beaches and adjacent surf-zones off southern Africa have shown that these shoal water ecosystems are rich fishery grounds and are important nursery sites of fish prey (Brown and McLachlan 1990). It is highly likely that such a scenario is true for vast expanses of the Australian coastline with similar geomorphology.

Because of their physical settings, sandy shores are among the most physically dynamic environments in the sea, and their food chains are directly dependent upon food inputs from land and offshore, and are immediately responsive to changes in weather and physico-chemical conditions (McLachlan and Hesp 1984). Tides, storms and wind-induced waves play key roles in regulating sandy shore food chains and the interstitial environment, including organic matter content, sediment grain size, pH, redox and porewater chemistry. Pelagic and benthic organisms are continually mixed by these physical processes in such shallow waters, and the exchange of suspended matter and organisms between tidal flats/ beaches and overlying and offshore waters is often very rapid. Open shore ecosystems that are "closed" in terms of trophic and energy flow undoubtedly "open" when, for instance, storms break down surf cells. Although most of such systems have autochthonous sources of fixed carbon, most rely on some inputs of particulate organic carbon from offshore reefs, seagrass beds, salt marshes, kelp beds, mangrove forests, and, conversely, from terrestrial plants such as dune grasses and trees. Most open sandy shores vary over time as to whether or not they import or export organic matter.

Sandy beaches and tidal flats lack much of the spatial complexity of other coastal environments such as salt marshes, mangroves, rocky shores, and kelp beds, and their foods chain and pathways of energy flow were thought to be correspondingly simple and dependent upon the unidirectional flow of matter and energy from the sea. However, the South African work has shown that sandy beach food webs are subtle and complex, physically and ecologically coupled with the adjacent shallow surf zones, forming semi-closed ecosystems with respect to food chain dynamics. The sandy systems have wide, dissipative subtidal surf zones where extensive diatom blooms occur that are retained within the beach/surf zone area by the maintenance of rip currents and surf-cell circulation patterns.

When waves approach the beach perpendicular to the shore, water flowing back off the beach tends to flow into areas of low wave height, giving rise to rip currents. These currents ebb in strength with distance from the beach as they are met by incoming waves of higher energy, change direction as water motion slows, to form a cell circulation pattern. Where tidal range is very large, tidal motion may play an important role in determining cell circulation patterns. Several reasons have been advanced to explain this phenomenon, including beach hydrography and morphology, wind, nutrient supply, and rainfall (McLachlan and Hesp 1984).

Energy and carbon flow within these ecosystems are dominated by high rates of diatom production that drive highly productive pelagic and benthic food chains. On the southeast coast of Africa in Algoa Bay, high diatom productivity drives microbial food chains in surf waters and sediments and macro-consumers such as benthos, zooplankton, fishes and seabirds. Nearly 40% of this material is shunted through microbial food chains, 20% is consumed by the interstitial fauna, and 5% is consumed by macrofauna -- the remainder is presumably exported further offshore.

The macrofaunal food web is most dynamic in the surf zone, where longshore currents concentrate diatoms exploited by zooplankton. These zooplankton assemblages are composed of copepods, ostracods, cladocerans, chaetognaths, siphonophores and medusae, but mysid shrimps and small penaeid prawns make up 90% of this fauna. Mysids attract many pelagic species of juvenile, predatory fish. Benthic filter-feeding bivalves attract many consumers including crabs, fishes, sharks and rays, birds and mammals. Mullet that are the main invertebrate feeders are, in turn, a source of food for larger, predatory fish.

The recent South African study by Clark (1997) illustrates the extent to which fish communities on open sandy shores are directly influenced by physical processes. At beach sites across a gradient of wave-exposure, Clark (1997) found both high fish densities (> 25,000 individuals) and species richness (24 species). The dominant species were the teleosts, *Atherina breviceps* (hardiheads), *Liza richardsonii* (mullet) *and Psammogobius knysnaensis* (gobies), and the elasmobranchs, *Rhinobatos annulatus* (shovelnose ray), *Mustelus mustelus* (gummy shark), and *Myliobatis aquila* (eagle ray).

Of particular interest was that teleost abundance increased with decreasing wave action and highest species richness and diversity were found at sites with intermediate levels of exposure -- elasmobranchs showed no clear patterns. However, some fish species of both taxa displayed a positive relationship with increasing wave exposure. These patterns were attributed to spatial and temporal trends in food resources in relation to wave action, and to species-specific responses to physical disturbance from waves breaking on the shore.

The only similar food chain work done in Australia was by the CSIRO Marine Laboratory located at Marmion near Perth (Robertson 1995). Microtidal, reflective beaches of low energy on the south-western coast receive large subsidies of seagrass and seaweed detritus that deposits as beach wrack along extensive lengths of coastline. Storms and heavy swell detach and transport this material from limestone reefs and seagrass meadows lying further offshore. The major components of this material are the kelp, *Ecklonia radiata* , dead seagrasses, and several species of small red algae. Up to 20 kg dry weight of this material accumulate per metre of coastline.

Studies conducted on these exposed sandy beaches have shown that they are important nursery grounds for fish originally thought to be estuarine-dependent. Moreover, this work signifies the importance of detached macrophyte material in food chain energetics. In daytime, more species of fish live in patches of macrophyte beach wrack than open sandy beach, but at night there are equal numbers of fish species between the two habitats, because fish migrate from under macrophyte protection to feed. Accumulations of beach wrack support high production of the amphipod *Allorchestes compressa*, which is an important prey item for fish and birds (Robertson and Lucas 1983).

A food chain model of these Western Australian beach ecosystems shows that the main pathway of this material is via colonising microbes and large populations of *A. compressa*. An average of 72 kg carbon of macrophyte debris deposits each year on each metre of coast and is broken down on the beach and in the surf zone by wave action, sand abrasion, and microbial decay. These wrack banks behave like compost piles -- the standing mass of this detritus turns over 12-14 times per year.

Recent work in WA by CSIRO and Murdoch University has focussed on the interaction between fish life-histories and vegetated and unvegetated habitats on low-energy beaches of varying aspect and levels of exposure (p.c.#1420 G.Hyndes, p.c. # 1460 M. vanderKlift).

These locations are open to inundation during winter and early spring with detached macrophytes. The source of material varies with beach aspect and region, and amongst months, with *Posidonia* in winter and *Ecklonia*, *Sargassum* and red algae in spring.

Early, unpublished results show that in a classification/ordination of the whole fish community the detached macrophytes provide an overlap between seagrass and sand habitats, and that this overlap occurs in sheltered sand areas. Sheltered sand areas are distinguished separately from exposed beaches in this analysis, and it is presumed there is more primary production in the finer sediments found in sheltered areas. This is supported by Edgar and Shaw (1995c).

Amphipods and bacteria play a large role in other Australian sandy beaches where plant detritus accumulates. On the north Queensland coast, macerated mangrove litter deposits as beach wrack on many sheltered sandy shores. These litter piles shelter large populations of microbes and invertebrates, but predators such as fish are unknown. However, given the similarity between the Western Australia and Queensland sandy shores with debris, it is likely that the Queensland sandy beach/ surf-zones also enhance fish and crustacean productivity. Unfortunately, no such studies exist for Queensland sandy shores and those of other States.

1.4.6.1 Fishery-habitat links

The sub-tropical and temperate surf-zone fisheries in Australia have similar components to those studied in South Africa, but their magnitude does not reflect their importance as fisheries habitats because:

- several species use surf-zones as a focus for spawning migrations from estuarine or sheltered habitats elsewhere - eg the very large landings of sea mullet and Australian salmon are taken in “gauntlet” beach seine fisheries during spawning runs;
- some species use surf-zones as shelter sites in between feeding bouts offshore -- eg. western salmon *Arripis truttaceus* feed offshore on pilchards and return to “lie-up” in large schools (up to hundreds of tonnes) in the surf zone (see Hoedt and Dimmlich 1994).

However, given the limited knowledge of diet for many species, there are probably very important links between teleosts (eg. mulloway, bream, sand whiting) and elasmobranchs (eg. gummy sharks) and food chains of Australian surf-zones.

Temperate

There is a low diversity of fish and sharks exploited in commercial and recreational fisheries along temperate sandy shores. These include Australian salmon and herring (*Arripis* spp), mulloway, yellow-eye mullet, flathead, silver trevally (*Pseudocaranx dentex*, *P. wrighti*), bronze and dusky whaler, gummy and school sharks. Snapper and tailor are also caught in some areas. The catches of *Arripis* spp are very large in relation to most coastal and embayment fisheries with annual catches around 7000 t not uncommon for the genus across its range.

Donacid bivalves (pipis and Goolwa cockles) and surf crabs *Ovalipes australis* are abundant and form the basis of some fisheries as well as being consumed by teleosts and elasmobranchs.

sub-Tropical

The movements out of estuaries to spawn, by dusky flathead, yellowfin bream, sand whiting and luderick, and spawning migrations northward, by sea mullet and tailor, make these species the subject of important “ocean beach” fisheries on the east coast for both commercial and angling sectors.

In 1990/91 for example, West (1993) gave the ratio of estuarine : ocean beach catch as 407 : 152 t for yellowfin bream, 736 : 115 t for luderick, 124 : 39 t for sand whiting and 175 : 2 t for dusky flathead. There does not appear to be a similar relationship on the west coast, where fishing for members of some of these genera is confined to the estuaries.

Spawning-run and juvenile tailor form the basis of major angling fisheries and minor commercial fisheries on the ocean beaches of the east and west coasts. The sea mullet fishery for adults on a spawning migration is the largest sub-tropical beach fishery for which records are kept.

Mulloway are widely sought by anglers throughout their range on the east and west coasts. Swallow-tail dart (*Trachinotus botla*) are also locally important in southern Queensland. Donacid bivalves (pipis), and to a lesser extent onuphid beachworms, are exploited commercially and by anglers, as bait.

Tropical

The aspect of the tropical coasts, their protection by Barrier reefs, the turbid waters and the wide intertidal flats of unstable mud result in commercial and recreational fisheries that are mainly extensions of the estuarine fisheries. Commercial "foreshore" fisheries are based on barramundi, threadfin salmons, lesser mackerels (*Scomberomorus* spp ; particularly grey mackerel *S. semifasciatus*), sea mullet, grunter, black jewfish (*Protonibea diacanthus*) and whaler sharks (Ludescher 1997).

Relatively little is known of shore-based fishing by anglers in the tropics, but club records show sand whiting, golden-lined whiting, dusky flathead, grunter and yellowfin bream to be important as far north as Townsville (p.c. S. Boyle). The sheltered coasts also enable anglers to pursue the commercial "foreshore" species from boats.

Banana prawns, mud crabs and blue swimmer crabs are also caught along these low-energy foreshores.

Surf zones as larval and juvenile habitats

There has been very little study of the early life-history stages present in surf zones in Australia:

- the sampling of some beaches inside and outside Sydney Harbour entrance with a larval seine net by Leis (In Prep.) caught a lot of whiting, sparids (yellowfin bream, tarwhine, some snapper) and clupeoid "baitfish" with striking patterns of temporal variability, including evidence of sequential depletion by sampling
- studies by Shaw (in prep.) inside Port Phillip Bay showed that the sandy bay margins (watermark out to 10m) are a distinct nursery habitat - especially for the yellow-eye mullet, the sandy sprat *Hyperlophus vittatus* (an important baitfish). Other juveniles caught were the flatheads *Platycephalus bassensis* and *P. speculator,* the green-back flounder *Rhombosolea tapirina,* and hardiheads *Atherinosoma presbytoides*
- similar sampling on the very exposed Torquay-Ocean Grove beaches in summer caught an average of 6-7 Australian salmon (50-60 mm juveniles) per haul (p.c. #950 C. Shaw)
- in the sub-tropics, juvenile trawl or redspot whiting occur just inshore, outside sandbars on high energy coastlines -- in May they recruit just north of Point Lookout on Stradbroke Island, and move offshore as they get older (p.c.#160 A. Butcher)
- in the same area, dart juveniles are in the surf zone and wind-blown terrestrial insects are important in their diet (p.c. #920 D. McPhee).

1.4.7 Open coasts - hard substrata

Less than 20% of Australia's coast consists of rocky shores (Fairweather and Quinn 1996), but comparatively more research effort has been put into hard substrata than into sandy or muddy shores (see Appendices 4 and 5 for contrast). Most ecological studies have focused on population and community interactions (competition, predation, zonation, etc.) and community composition, rather than on ecosystem energetics (production, feeding, energy flow, detritus export and import) -- despite the fact that rocky shores represent the pinnacle of marine habitats governed by physical forces. There is little information on vertebrates that use Australian rocky shores, and not much more on the ecology of major rock lobster fisheries there.

Only two studies exist budgeting energy flow on rocky shores (Field 1983, Hawkins *et al.* 1992). Neither of them are from Australia. Nonetheless, they illustrate the importance of physical factors in the functioning of rocky intertidal food webs and potential energy available for fish and other top predators. Field's South African model for an exposed system indicates that phytoplankton, advected from offshore by tides, longshore currents, and waves, contributes greatly with seaweed detritus to the nutrition of filter feeders -- grazers feed mainly on a thin veneer of microalgae and sporelings covering the rock surface. The filter feeders dominate the biota, but the relative amounts of carbon they assimilate from seaweed and phytoplankton, and how much carbon is consumed by predatory fish, are not known.

The Isle of Man model (Hawkins *et al.* 1992) shows that the major flux of carbon from producers to macro-consumers shifts with degree of wave exposure. In sheltered rocky shores, the main route is from fucoids (kelps) to gastropods -- microalgae and phytoplankton contribute little compared with macroalgae. However, from semi-exposed to fully-exposed shores, phytoplankton -- and to a lesser extent, microalgae -- become the major primary producers. How the transfer of carbon to lobsters, fish and other top predators varies across the exposure gradient is unknown.

Extensive kelp beds off the west coast of South Africa exist on subtidal rocky reefs, and have been extensively studied to give us the most complete energy and nutrient budgets available for any macrophyte-dominated system on hard substrata. These budgets have led to considerable insights into the relative importance of phytoplankton, macrophytes, and microbes in nutrient flows in these systems, but there is no information on how much fixed carbon and other organic materials are transferred to higher trophic levels.

The major conclusion from these studies was that phytoplankton and detritus are the major carbon sources for the dominant filter-feeding benthos, because bacteria are insufficient at incorporating carbon from kelp detritus and faeces. As the major flow of carbon is directly from primary producers to benthic macro-consumers, it is likely that there is significant flux of material available to support large populations of top predators, including fish. Much work remains to be done worldwide to estimate the energetics of food chains on hard substrata and the use of these little-studied habitats by finfish and large crustaceans.

1.4.7.1 Fishery-habitat links

Commercial rocky shore and reef fisheries are dominated by very valuable crustacean and mollusc fisheries. Rock Lobsters, abalone, octopus, sea urchins, and calamari squid are taken in these habitats. There are also major recreational fisheries along rocky coasts, and shoreline harvesting is known to have measurable effects on communities (see section 4.2.4). Sub-tidal rocky outcrops on the entire Australian shelf are important features for both demersal and pelagic fishes, ranging from tuna and trevalla (*Hyperoglyphe* spp) fisheries over sea-mounts down to lutjanid and lethrinid aggregations over Pleistocene remnants of coral reefs and the numerous recreational fishing “marks” on isolated “lumps”. These features are poorly mapped and their ecology is largely unknown, although the shallower habitat has been studied in the Torres Strait (eg. Pitcher *et al*. 1994).

The summary of literature in Appendix 5 shows that there has been much attention to the roles of ecological processes in determining community and habitat structure in shallow rocky reef habitats. There has been a substantial body of small-scale, field experimental work and a large contribution from New Zealand for rocky reef fishes, which is included here because of a lack of local studies. Themes of the research include:

- patterns of spatial variation in community structure at scales from within-habitat to amongst region - eg. McCormick (1989b), Andrew and Underwood (1992), Lincoln-Smith *et al.* (1991)
- species interactions and the role of herbivory in structuring macro-algal communities and “urchin barrens” - eg. Andrew and Jones (1990), Andrew (1993b), Carr (1994)
- density-dependence and the roles of food supply in governing individual growth rates - eg. Worthington *et al.* (1995)
- predation - eg. Mower and Shepherd (1988)
- ontogenetic shifts amongst habitats - eg. Dove *et al.* (1996), Jenkins *et al.* (1996)

- larval transport and recruitment at local scales - eg. Shepherd *et al.* (1992)
- recruitment at regional scales, and amongst locations within regions - eg. Caputi *et al.* (1995a,b).
- metapopulation concepts and a role for marine harvest refugia - eg. Shepherd and Brown (1993)

Some brief examples of the sources of variability in valuable invertebrates at various scales are given in Table 1.4.7.1.

Table 1.4.7.1. Some hypotheses invoked to explain variation within the production of invertebrate fisheries of exposed coasts (from Lewis 1986, Caputi et al. 1995a, Shepherd 1990).

variation	taxa	feature observed	observation	hypotheses
amongst habitats	*Jasus novaehollandiae* (SA)	size	decreasing density, increasing size with depth immed. off settlement sites	antagonistic encounters for den space with increase in size
within regions	*Jasus novaehollandiae* (SA)	proportion of reproductive females	5% (Kingston) vs 75% (west of Cape Jaffa)	migration to area influenced by upwelling for spawning
between regions	*Jasus novaehollandiae* (SA)	% undersize rock lobsters	low on West Coast	lack of regular puerulus settlement, faster growth rate
between regions	*Jasus novaehollandiae* (SA)	moult increment	6-8 mm CL (South East) vs 15-20 mm CL (West Coast)	greater stock densities in SE
between regions - over 2 decades	*Panulirus cygnus*	egg production	Abrolhos egg prod. unchanged	coastal egg prod. important contributor to Abrolhos recruitment
between regions - over 2 decades	*Panulirus cygnus*	puerulus settlement	50% reduction in Abrolhos settlement	fishing down of coastal spawning stock
within location - over 2 decades	*Haliotis laevigata*	recruitment and survival	2 oscillations from high to low	density-dependent predation, recruitment variation
within location - over 13 years	*Haliotis laevigata*	recruitment	increase by 2.7 times	closure to fishing

Abalone are very well known because of their accessibility to researchers, their limited larval life and dispersal and the ease with which they can be manipulated in experimental designs. Abalone growth is driven by supply of drift algae, and thus demography varies consistently amongst habitats and regions of different exposure to waves and currents.

There is a well-developed knowledge of the relative effects of habitat type and recruitment on SA abalone stocks (eg. Shepherd and Partington 1995). A review of their ecology and fisheries biology is presented in a special issue of the journal "Marine and Freshwater Research" (1995 Volume 46). The close understanding of their relationships with competitors, spatfall requirements and food supply has allowed a manipulation of ecological relationships by fishing to enhance abalone production in NSW (see Box 4.5.1).

In contrast, western rock lobster (*Panulirus cygnus*) studies are now focussed on application or development of recruitment indices to allow forecasting of catch levels in later years. There was an early emphasis on juvenile biology, which invoked density-dependence and potential effects of rock lobster predation in structuring benthic communities, but this has largely ceased (eg. Jernakoff *et al.* 1994). Key uncertainties still remain about the effects of rock lobster fishing on the benthic communities that support the fisheries (see section 4.5.1).

BOX 1.4.7.1 EFFECTS OF THE ENVIRONMENT ON WESTERN ROCK LOBSTER RECRUITMENT

The effects of fishing on the western rock lobster spawning stock should be detected best on the outliers of recruitment (edges of population distribution) so WAMRL has a spread of sampling sites from Shark Bay in the north to Cape Mentelle in the south

The eggs are driven offshore by Ekmann transport during south-westerly winds and by easterly winds . The planktonic larvae have an oceanic distribution, being swept hundreds of kilometres into the Indian Ocean. The puerulus recruit after about a pelagic phase of about 10 months to shallow inshore reefs and then move offshore to deeper reefs as they grow. Major effects of the environment on this process are:

- there is a strong correlation in interannual variation in puerulus recruitment with an ENSO-related atmospheric pressure signal, and with sea-level changes off Fremantle due both to westerly winds and Leeuwin Current
- this correlation is attributed to changes in onshore advection associated with the strength of the Leeuwin Current - but there could also be a secondary mechanism in current flow, related to enhanced larval growth and survival in warmer water
- the westerly wind has a positive effect on coastal recruitment, but a negative effect on the Abrolhos islands whereby the puerulus are "blown over" the reefs.

(p.c.# 1370 N. Caputi)

1.4.8 Coral reefs

The extent to which coral reefs are biologically and physically connected to other habitats depends upon several factors, most notably their distance from the coastal zone (ie. their proximity to terrigenous materials, groundwater and movements of coastal species), size, geomorphology, and location in proximity to upwelling. For example, outer shelf reefs on the Great Barrier Reef are more closely interconnected with the open ocean than inter-reefal and lagoonal habitats and biota. Conversely, coastal and fringing reefs are more closely interconnected with other coastal biota and habitats, most apparent from the occurrence of mixed terrigenous-carbonate facies in soft sediment areas near and within these reefs.

The external origin of most of the nutrients supporting reef productivity attests to the importance of the connections between coral reefs and their immediate environment, and their proximity to other coastal and oceanic habitats. Seawater impinging upon and moving within reefs ensures that food webs and material flow within the different zones of a coral reef are interlinked -- helping to maintain a balance between production and consumption of energy. Reef geomorphology undoubtedly plays a role in determining the residence time of water and organisms, and thus the flux of energy and material transfer within a coral reef.

Biogeochemical models have provided some estimates of the extent to which nutrient cycles on coral reefs interact and depend upon the surrounding environment. What is most poorly understood are the nutrient-related factors limiting primary production. It is often presumed that nitrogen is most limiting, but more recent evidence suggests that nutrient limitation is not simply related with the low concentrations of nutrients normally found on most coral reefs, but the rate of supply into the reef from outside. If true, this idea has enormous consequences for the productivity of coral reef biota.

Atkinson (1988,1992) has proposed the “mass transfer limitation hypothesis” which predicts that the extent to which phosphorus (and nitrogen) is regulated within a coral reef is independent of concentration but dependent on the rate at which nutrients are transported onto, into and off the reef. For instance, phosphorus would be limited if the rate of uptake by reef organisms exceeds rate of input. Nutrient regulation and reef productivity on coral reefs is therefore dependent upon the rate of water motion into and across a reef. For phosphorus, Atkinson (1992) concluded:

- there is a maximum rate of P uptake under highest water flow conditions, but the residence time of the water over the reef is shortest; and
- the amount of P removed from the water is only ~5% of the amount that passes over the reef.

The idea of coral reefs being limited by mass transfer of nutrients agrees with the strong water-flow dependence observed for growth of many reef organisms. By implication, the abundance of fish and other top consumers is ultimately regulated by the rate of water motion onto and into a reef, suggesting that coral reefs and their food chains are much more reliant on the surrounding environment than previously believed. Although the crux of coral reef food chains is the coral-zooxanthellae relationship, both organisms are dependent upon the rate and availability of dissolved nutrients.

The recent study by Nakamori *et al.* (1992) on the Shiraho and Southern Reefs of the Ryukyu Islands is a good example of how carbon fluxes between reefs are closely linked to water circulation. They were able to show that inorganic and organic carbon fluxes within reef zones on Shiraho Reef were linked to adjacent Southern Reef and contributed to net export of carbon from the system. The driving force behind the export of organic carbon is the strong unidirectional movement of water from the front edge of Shiraho Reef to Southern Reef caused by tidal oscillations and wave action at the reef front.

Mass balance estimates suggest that coral-dominated reefs export little, if any, organic carbon. Considering the variations in rates of gross primary production and respiration within reef zones, the variations associated with the methods used, and the extrapolations to entire reef area, the range of net primary production values (-5 to 170 mg C $m^{-2}d^{-1}$) are exceedingly small and well within the boundaries of probable error. These estimates only apply to healthy reefs, not those disturbed by anthropogenic inputs.

Perhaps the most subtle and often forgotten role that coral reefs play is in the dampening of water motion, permitting the development of a quiescent seascape suitable for the colonisation of mangroves and seagrass beds, and helping to maintain stable shorelines. The organic connection between coral reefs and adjacent coastal ecosystems is often of localised or regional significance. The inorganic connection may be more widespread, given the distribution of reef-derived carbonates on some low latitude continental shelves.

1.4.9 Continental shelves

Continental shelves make up only 0.5% of the volume of the world ocean, but the high productivity of coastal seas equates to nearly 30% of total net oceanic production and at least 90% of the global fish catch.

The continental margin of Australia is somewhat different than those of the other continents in that its total fish catch is only 0.2% of the world's total. This is due to the generally low net plankton productivity in Australia's subtropical and tropical regions -- most primary productivity in lower latitude waters is vested in nano- and pico-planktonic size classes that are recycled within microbial food webs rather than transferred to higher trophic levels.

Shelf productivity is driven by nutrient inputs from rivers and groundwater, upwelling, exchanges at the continental shelf edge, and atmospheric inputs. The lack of large rivers and major upwelling systems are why Australian waters are generally less productive than other continental margins.

Rates of carbon fixation that drive shelf food webs are determined ultimately by the confluence of local- and regional-scale patterns of water circulation, chemistry, and shelf geomorphology. The coastal zone extends across the entire shelf off some of the world's major rivers, but on Australia's continental margin, the estuarine front meanders mainly within the inner shelf.

It is on the shelf proper where oceanic and estuarine boundaries intermingle. Tongues of oceanic water regularly or irregularly intrude onto the outer shelf margins often, but not always, to mid-shelf. Such exchanges are often rapid, promoting conditions favourable for higher fertility on the shelf than in the open ocean. The boundary between oceanic and coastal water is frequently a region of high productivity. For instance, tidal and estuarine plumes and fronts off many of Australia's major rivers are sites of intense nutrient recycling, and primary and secondary productivity. In the wet tropics, these fronts break down leading to estuarisation of the entire shelf.

Three generalisations about shelf ecosystems -- including Australia's -- seem valid:

- outwelling of materials from the continents is usually restricted to the coastal zone by complex physical, chemical, and geological processes, but this material greatly influences inshore food chains and nutrient cycles (eg. the Great Barrier Reef shelf)

- impingement of nutrient-rich, open-ocean water enhances primary and secondary productivity on the outer shelf and shelf edge, including important fisheries (eg. off north-western Western Australia), particularly along boundary currents
- little organic matter is exported from the continental margin.

Whether or not any portion of Australia's continental margin violates any of these generalisations depends upon several factors:

- presence or absence of large rivers
- presence or absence of upwelling
- location of ocean boundaries
- shelf width.

All of these factors are influenced by climate.

In regard to the potential for long-term disturbance by trawling on different regions of the Australian shelf, Long *et al.* (1995) indicated that the relationship between megabenthos abundance and species richness, and geographical location and environmental factors is complex - there may not be a simple link between species richness and latitudinal gradients in the subtidal marine environment. However, the link between substratum type and sessile megabenthos may be a general feature of our shelves, as Long *et al.* (1995) note that:

- sponges, alcyonarians and gorgonians were the dominant sessile megabenthos in the coarse sediments of the North West Shelf, but there was little sessile megabenthos in the pelagic carbonate muds on the nearby Scott Reef -Rowley Shoals platform
- sponges, ascidians, alcyonarians and hydroids were abundant in the coarse sediments of the deeper (50-70m) waters of the northern GBR, but there were few sessile megabenthos in the muddy inshore areas.

What remains unknown for Australia's continental margin are the links between primary producers and secondary producers, especially fish and macro-crustaceans. For instance, much trophic work has been done within the Great Barrier Reef lagoon, but it is not clear how spatial and temporal changes in rates of primary productivity relate to macrobenthic and zooplankton secondary production through to fish and prawn yields -- no shelf-scale models or budgets encompassing entire food webs are yet available for Australian waters.

This is unfortunate as heuristic and predictive models are urgently needed (such as those which exist for the North Sea) to help define the upper and lower limits on fisheries yields for Australia. The greatest hindrance to such models becoming reality is the fact that the biological communities across vast expanses of the continental shelf and slope remain unsurveyed.

1.4.9.1 Fishery-habitat links

Our review is focussed in the shallower, coastal parts of the mainland shelf but four major points must be stressed for the other 90% of the EEZ that lies in deeper waters:

- most of the EEZ and many major fisheries are on the shelf and deeper waters. Nationally this is the main region of active expansion of the fishing industry into previously unfished areas and habitats to exploit new resources
- the deeper regions of the temperate Australia EEZ, and especially areas such as seamounts, have a very high level of endemism, have a very high biodiversity by global standards, and contain apparently unique habitats (see Koslow 1997)
- many (and probably most) species beyond the coastal fringe recruit there directly, and not via coastal systems such as estuaries and seagrass beds. Consequently the habitat requirements of these species are not met solely by habitat R&D and protection in the coastal zone
- there is a very weak information base or inventory of habitats and their importance for areas deeper than the coastal fringe (about 20m depth), and there is extremely little information for areas deeper than 200m. That is, most of the EEZ.

Our literature searches indicate that the best known areas of the entire Australian shelf are the:

- Gulf of Carpentaria and Torres Strait - habitat inventories of seagrass, reefs, sediments and benthos; studies of the effects of current stress, depth, sediment type and trawling on fish, crustacean and megabenthos communities; identification of trophic links to identify major predators of prawns and fate of discards from trawlers (eg. Gladstone and Dight 1994, Pitcher *et al.* 1994, Long *et al.* 1995, 1997b,c, and see Chapter 4)
- North West Shelf -- testing hypotheses about the effects megabenthos destruction and recovery on species shifts (see Chapter 4)
- south-east region off the eastern coast of Tasmania - study of meso-scale events on pelagic production and fisheries; study of food-chains supporting shelf and sea mount demersal fisheries.

The Australian research on shelf resources summarised in Appendix 6 can be also grouped under the following themes:

- surveys of patterns of cross-shelf and along-shelf distribution and abundance of demersal and pelagic communities of fish (and larvae) - eg Okera and Gunn (1986), Pender *et al.* (1993b), Stevens *et al.* (1984), Young *et al.* (1986)
- studies of shelf spawning localities in stock assessments - eg Fletcher *et al.* (1994), Hoedt *et al.* (in press), Jordan *et al.* (1995)
- studies of fish and larval abundance at and outside plumes, fronts, mesoscale eddies and other hydrodynamic features - eg Kingsford (1990, 1993), Gray (1996)
- comprehensive studies of pelagic food-chains supporting pelagic and demersal south-east fisheries - eg Blaber and Bulman (1987), Koslow *et al.* (1994), Young and Blaber (1986)
- studies of bycatch and the effects of fishing (see Chapter 4)
- an attempt to understand and document the patterns of catch and effort and abundance of stocks of south-east fishery species - eg Tilzey (1994), Tilzey and Klaer (1991), Tilzey et al. (1990).

Some of the key findings of these studies are that:

- there are strong cross-shelf patterns in fish community structure that are related to depth and sediment type - eg Blaber *et al.* (1994b) found six groups in terms of overall fish occurrence and biomass in the Gulf of Carpentaria. They also recognised 15 species groups that fall into four broad categories - widespread, regional, reef-associated and "other" that may not be closely related. Five of these groups were found at only a single station of the 107 sampled. Partial correlation analyses were necessary to examine the relationship between 11 abiotic variables (including turbidity, percentage mud, sand and gravel in sediments and bottom temperature) and community structure patterns. These revealed that only depth was significant but sediment type, turbidity and temperature may be worth further investigation. Long *et al*. (1995) proposed that substratum type and quality and quantity of food in the water column govern the abundance of sessile megabenthos in the Gulf , with sponges, zoantharians, alcyonarians and ascidians in an eastern-south-eastern grouping, and only few such megabenthos in muddy central and western Gulf areas. Long *et al*. (1997c) found that seabed current stress was a significant correlate of factors controlling the distribution and abundance of sessile epibenthos in inter-reef areas of Torres Strait, and may provide a powerful surrogate for seabed mapping in the absence of information on sessile benthos

- there may not be strong vertical and horizontal patterns associated with hydrodynamic features - eg. Young *et al.* (1996) found little horizontal and depth-related structuring of the midwater fish community amongst the East Australian Current, Sub-Tropical Convergence and Sub-Antarctic Water . This may be because the lack of strong thermal gradients in the study region and the thinness of the overlying EAC water appear to have reduced the horizontal and vertical scale of mixing -- limiting secondary circulation and the resultant productivity. This gradient was less than half that found in a South African study of front-induced enhancement of productivity where the thermal gradient was 10°C in 1 degree of latitude.
- there are important faunistic boundaries associated with bioregions (see section 1.2.3)
- there may be important influence of "structure" (hard substrata and megabenthos) on the fish community composition of adjacent fishing grounds - eg. Gray and Otway (1994) found consistent longshore differences in trawl fauna between Long Reef and Port Hacking that may have been due to unmeasured differences in substratum and topography. Many more reef-associated fishes, such as snapper, were caught at the Long Reef.
- secondary production of deep-sea orange roughy and oreo dories is driven by capture of sparse, incoming, off-shelf production from the open ocean - eg. Koslow (1997)
- storms and climatic shifts can alter patterns of distribution and producti0on at short and long time scales - eg. Gray (1993), Harris *et al.* (1988, 1992) and see section 1.2.1.
- there are significant diurnal changes in the behaviour of demersal species - eg Blaber *et al.* (1994b) found that night time trawls in were consistently only half as productive in terms of catch rates and biomass per unit area in the Gulf of Carpentaria. There were also big differences in the dominant taxa, with *Pomadasys, Upeneus, Pentaprion,* and *Nemipterus* dominating day trawls and *Lutjanus malabaricus, Saurida, Priacanthus* and *Nemipterus* dominating night trawls. Fish behaviour in the same families is also widely different between the North West Shelf and the Arafura and Timor seas (p.c.#20 D.Ramm).

We have not covered the important international literature on shelf fisheries production (eg. Mann 1993) because our brief was to review Australian knowledge and information.