

Table 1.2.3.1. Descriptions for IMCRA regions . *** indicates additional description required

| Code | Map ref. | Region Name | Full Description |
|------|----------|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SC | 1 | Shoalwater Coast | Inshore coastal region comprising large bays with very large tidal range, large coastal islands, mostly sandy substrates, little terrestrial input due to relatively low rainfall. Less extensive and complex mangrove forests, less diverse littoral fauna than regions to the north. |
| PS | 2 | Pompey-Swains | Offshore region comprised mostly of very complex and extensive planar and lagoonal reef systems, sandy sediments of carbonate origin. Fauna otherwise poorly known. A few isolated sand cays. |
| MC | 3 | Mackay-Capricorn | Offshore region comprising the central portion of the very broad continental shelf, characterised by mostly mud and sandy-mud substrates associated with an extensive drowned river valley, fauna very poorly known deep water forms, few reefs or islands except Capricorn-Bunker group in the south, extensive submerged reefs and shoals. |
| LMC | 4 | Lucinda-Mackay Coast | Inshore coastal region including complex high-island groups (Whitsundays and Cumberlands), sandy-mud substrates, less complex and diverse mangrove communities and lower littoral faunal diversity than regions to the north. large tidal range, especially in the south. |
| CR | 5 | Central Reef | Offshore region including the mid- and outer- continental shelf characterised by mostly sandy sediments of carbonate origin with some mud content in midshelf areas. Reefs in earlier stages of development, poorly developed at the shelf margin. |
| WTC | 6 | Wet Tropic Coast | Inshore coastal region dominated by very complex and extensive mangrove forests and very high littoral faunal diversity. Sediments very muddy, of terrestrial origin, from very high but seasonal rainfall. Poorly developed inner shelf reefs. |
| RBN | 7 | Ribbons | Offshore region extending to the edge of the continental shelf, eastern margin comprised of ribbon reefs and detached reef complexes, with small, poorly developed reefs behind. Sandy sediments of carbonate origin. |
| ECY | 8 | East Cape York | Relatively dry inshore coastal region characterised by lower littoral faunal diversity than adjacent regions, muddy-sand substrates and extensive shoals, planar and lagoonal reefs, low wooded cays. |
| TS | 9 | Torres Strait | A complex shallow region with extensive shoals, banks and reefs, extensive seagrass beds. Biology poorly known except commercial fisheries. A mixing zone for waters from the coral sea and Indonesia; major sediment and nutrient inputs from Papua New Guinea rivers. Extremely strong currents and complex tidal regime. Low cyclone incidence. |
| WCY | 10 | West Cape York | Inshore coastal region characterised by significant freshwater input from coastal wetlands, dual tidal cycle and distinctive mangrove and salt marsh assemblages and fauna. Generally sandy substrates subtidally, except at river mouths. Low cyclone incidence. |
| WK | 11 | Wellesley-Karumba | Inshore-coastal region characterised by relatively low diversity mangrove forests, extensive salt pans (seasonally inundated), a single tidal cycle and sandy substrates in subtidal areas. Major coral assemblages. Monsoonal influence. |
| CAR | 12 | Carpentaria | Extensive fairly shallow (<70m) offshore region of the Gulf of Carpentaria. Generally poorly known except from the point of view of commercial fisheries. Mostly muddy substrate, less so towards the east. High cyclone incidence. |
| PEL | 13 | Pellew (was S-W Gulf of Carpentaria) | Coastline of alluvial plains, composed of clays and muds in varying proportions. On these shores mangroves can be regarded as continuous, extending up to 1 km inshore in parts. Coral reefs entirely absent. Tidal range increases to a maximum of 3m. |

| Code | Map ref. | Region Name | Full Description |
|------|----------|--------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| GRO | 14 | Groote (was N-W Gulf of Carpentaria) | Rocky dominated shoreline. Coastline mainly of large parabolic dune systems formed by predominant south-easterly winds. Mangroves restricted to narrow strips along creeks and lagoons, apart from Blue Mud Bay which is sheltered and supports extensive mangroves and mudflats. Coral reefs absent except for parts of Groote Eylandt, particularly north-western region. Tidal range microtidal with a maximum range of 2m. |
| AW | 15 | Arnhem - Wessel | Complex coastline encompassing a variety of bays, inlets, rivers and islands. Tidal range generally increases eastwards from 3m to 5m at Arnhem Bay. Coasts with northerly or easterly exposures generally consist of bare rock or sand barriers and mangrove is absent or restricted between and behind sand ridges. Deeper bays are sufficiently sheltered for greater mangrove development. Alluvial and estuarine plains present, some supporting sparse saltmarsh. Coral reefs generally absent except for fringing reefs off the Wessel and English Company Islands. |
| TI | 16 | Tiwi (was Tiwi - Coburg) | Northern coasts consisting of numerous, deeply indented bays and inlets. Extensive areas of mangrove in sheltered inlets and creeks. Intermittent fringing reefs occur off prominent headlands. |
| BVD | 17 | Beagle - Van Diemen | A complicated region comprising the majority of the Beagle Gulf and Van Diemen Gulf. Coastline can be broadly categorised into four types: 1) drowned river valley systems in the southwest near Darwin; 2) low, flat, alluvial, deltaic estuarine floodplains, particularly southeast; 3) intermittent smooth, beach ridge shores blended with narrow strips of mangroves (such as the southern coasts of Melville and Bathurst Islands), and 4) intermittent fringing reefs behind which are usually well developed mangroves. Surrounding waters always turbid due to large (4- 6m) tidal range and sediments debouched from large tidally-influenced rivers. |
| ANB | 18 | Anson-Beagle (was SE Bonaparte) | Exposed, north-west facing coastline consisting of numerous beach-lined coves and bays flanked by prominent headlands. Sand ridges, in the form of chenier dunes, dominate the backshore landscape intermittently throughout the coastline. From Pearce Point to Cape Ford the coast can be described as moderately hilly or cliffed lacking mangroves. Mangroves are concentrated mainly north of Cape Ford as thin strips along Anson Bay and Fog Bay where sediments are debouched from the Daly and Finniss Rivers respectively. |
| BON | 19 | Bonaparte Gulf | *** |
| ARA | 20 | Arafura | *** |
| CAB | 21 | Cambridge - Bonaparte | Comprises the headwaters of Joseph Bonaparte Gulf, a broad, open marine gulf straddling the WA/NT border. At its head are two major seasonal estuarine systems - Cambridge Gulf (Ord, Pentecost and Durack Rivers) on the WA side, and a complex of three estuaries (Keep, Victoria and Fitzmaurice Rivers) on the NT side. They are separated by a stretch of low-profile shore backed by saline flats. |
| KIM | 22 | Kimberley | This is a remote and little-studied section of the coast, characterised by rocky shore, mud flat, mangal and land-locked marine and estuarine habitats. A broad area of the inner shelf is included within the WA Territorial Sea because the base line is located seaward of the many nearshore islands. Buccaneer Archipelago is included in this region. |
| KS | 23 | King Sound | *** This wide, open gulf encompasses the Fitzroy Estuary and Stokes Bay. |
| CAN | 24 | Canning | *** The northern part of the Canning Basin shore. (Southern part comprises Eighty Mile Beach) |
| EMB | 25 | Eighty Mile Beach | *** |

| Code | Map ref. | Region Name | Full Description |
|------|----------|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PIN | 26 | Pilbara (nearshore) | *** Inside the 10 m bathymetric contour. |
| PIO | 27 | Pilbara (offshore) | Beyond the 10 m bathymetric contour in the West Pilbara; the ocean water is less turbid than that of the inshore area and there are significant differences in marine ecosystems. |
| NWS | 28 | North West Shelf | The outer part of the North West Shelf comprises an oceanic province (sometimes divided into the Sahul Shelf and Rowley Shelf). There is a series of coral atolls along the shelf-edge (Seringapatam, Scott, Mermaid, Clerke, Imperieuse) and a number of outer-shelf islands and platform reefs (Hibernia, Ashmore, Cartier, Browse, Adele, Lynher). Some of these atolls and islands are within State waters. |
| NIN | 29 | Ningaloo | *** |
| ZUY | 30 | Zuytdorp | (1) mainland coast north of Carnarvon, (2) western sides of the outer Shark Bay islands and Edel Land Peninsula, and (3) Kalbarri cliffs. |
| SB | 31 | Shark Bay | *** |
| ABR | 32 | Abrolhos | This is an off-shore, shelf-edge unit comprising a series of three dissected limestone platforms and islands. |
| CWC | 33 | Central West Coast | *** |
| LN | 34 | Leeuwin-Naturaliste | *** |
| DO | 35 | Donnelly | *** |
| WSC | 36 | WA South Coast | *** |
| EUC | 37 | Eucla | Shallow offshore gradient. Microtidal ~ 0.8 to 1.2 metre range. Open, moderate energy, west facing coastline. Nullarbor tertiary limestone cliffs, Pleistocene dune rock headlands and reefs, Holocene beaches and dune barriers. Warm temperate water. Leeuwin current. |
| MUR | 38 | Murat | Shallow offshore gradient. Moderate to low energy coastline. Microtidal ~ 0.8 to 1.2 metre range. Crenulate bays due to Precambrian crystalline rock headlands usually with a dune rock capping. Pleistocene dune rock cliffs, reefs and headlands. Holocene beaches, dunes and estuarine deposits including intertidal and supratidal flats. Offshore islands and seamounts. Warm temperate waters. Leeuwin current. |
| EYR | 39 | Eyre | Shallow to moderate offshore gradients. Moderate to high energy coastline. Pleistocene dune rock cliffs, headlands and shore platforms. Microtidal ~ 0.8 to 1.2 metre range. Holocene dune barriers, beaches and lagoon deposits. Precambrian metasediment cliffs. Cainozoic colluvial and fluvial sediments. Warm temperate water subject to nutrient rich upwellings. |
| NSG | 40 | North Spencer Gulf | Confined, inverse estuary with minimal land water input. Shallow offshore gradients. Low energy shorelines. Micro to mesotidal ~ 1.8 to 3.6 metre range. Precambrian metasediment shore platforms. Holocene sandflats, beach ridges, recurved spits, and extensive intertidal and supratidal flats. Warm temperate waters with a subtropical biotic element. |
| SG | 41 | Spencer Gulf | Semi confined. Shallow offshore gradients. Low to moderate energy shorelines. Microtidal ~ 1.8 metre range. Precambrian crystalline rock headlands forming embayments. Cainozoic outwash sediments forming low cliffs. Holocene beaches, dunes and estuarine deposits. Cool temperate waters. |

| Code | Map ref. | Region Name | Full Description |
|------|----------|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SVG | 42 | St Vincent Gulf | Confine inverse estuary. Shallow offshore gradients. Low to moderate energy coastline. Micro to mesotidal ~ 1.2 to 3.3 metre range. Precambrian metasediment and Tertiary cliffs. Holocene beaches, sandflats, dunes, beach ridges, estuarine deposits, extensive intertidal and supratidal flats. Cool temperate waters. |
| COR | 43 | Coorong | Offshore gradient decreases from steep to flat resulting in a gradational coastline change from high to low energy. Microtidal ~ 0.8 to 1.2 metre range. Precambrian crystalline rock and metasediment headlands and cliffs. Pleistocene dune rock cliffs, headlands, shore platforms and reefs. Holocene pocket beaches and an extensive beach-dune barrier lagoon complex. Cool temperate waters. |
| OTW | 44 | Otway | (SA) Steeply sloping offshore gradient. High energy coastline. Microtidal ~ 0.8 to 1.2 metre range. Pliocene - Pleistocene volcanic outcrops forming headlands. Pleistocene dune rock cliffs, shore platforms and reefs. Holocene beaches and dunes. Cold temperate waters subject to nutrient rich upwellings. (VIC) (1) SA border to Cape Otway. Steeply sloping offshore gradients, dominated by Quaternary dunes and associated sandy shorelines. Dominantly southwest facing coastline. Currents generally slow. Sea-surface temperatures representative of Bass Strait waters. High wave energy (2) Cape Otway transition zone Very steep offshore gradients, dominated by cliffed shorelines Mean annual sea-surface temperature is representative of Bass Strait waters. High wave energy. |
| BGS | 45 | Boags | Sheltered open coastline with long sandy beaches broken by rocky headlands that extend under sand in relatively shallow depths (normally < 20m). High tidal range \approx 3m. |
| DAV | 46 | Davey | Very exposed coastline with extensive rocky headlands separated by short sandy beaches. Low tidal range \approx 1m. Biotically depauperate. Cold water. |
| BRU | 47 | Bruny | Highly-dissected coastline with extensive embayments protected from submaximal swell by islands and peninsulas. Low tidal range \approx 1m. Endemic plants and animals. |
| FRT | 48 | Freycinet | Submaximally exposed coastline with approximately equal areas of rocky headlands and sandy beaches, and numerous coastal lagoons. Moderate tidal range \approx 1.5m. Cool water, sub-tropical convergence. |
| FLI | 49 | Flinders | (Wilson's Promontory Transition Zone) Rapid changes in offshore gradient. Granitic coastline exposed to submaximal swells on east-facing shores of Flinders Island and moderate to low swells elsewhere. Sandy beaches of moderate length with seagrass beds prevalent in shallow water. High tidal range \approx 3m and strong tidal currents. Sea-surface temperature is representative of Bass Strait waters. Waves highly variable. |
| CV | 50 | Central Victoria | Very steep to steep offshore gradients dominated by cliffed shorelines. Sea-surface temperature is representative of Bass Strait waters. Moderate wave energy. |
| CBS | 51 | Central Bass Strait | The region is about 60,000 sq. km in size and lies in the central area of Bass Strait. The sea floor is shaped like an irregular saucer with water depth varying from about 80m at its centre to 50m around the margins. The substrate of central area is mainly mud. Tidal velocities vary from $<0.05 \text{ ms}^{-1}$ in the central area to as high as 0.5 ms^{-1} at the margins where the islands and promontories form the western and eastern entrances to Bass Strait. Water mass characteristics are complex and vary seasonally representing the mixing of the different water masses present on western and eastern side of the Strait. |

| Code | Map ref. | Region Name | Full Description |
|------|----------|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| TWO | 52 | Twofold Shelf | Submaximally exposed coastline with long sandy beaches broken by rocky headlands, and numerous coastal lagoons. Moderate tidal range \approx 2m. Mean annual sea-surface temperature reflects the influence of warmer waters brought into Bass Strait by the East Australian Current. Variable wave energy. |
| BAT | 53 | Batemans Bay Shelf | Southern NSW invertebrate assemblage. Oceanographic 2. |
| HAW | 54 | Hawkesbury Shelf | Oceanographic 2. Southern NSW fish and algal assemblage. South of the Tasmanian front. Mid south coast invertebrate assemblage. |
| MAN | 55 | Manning Shelf | Distinctive algal assemblage. Only 21 species of hard corals. Bass Point southern boundary. |
| TM | 56 | Tweed-Moreton | Inshore coastal region comprising narrow continental shelf. Characterised by extensive sandy beaches interspersed with rocky headlands. Sediments of terrestrial origin, also extensive estuaries formed behind sand islands. Occasional sandstone outcrops form substrates for reefal faunas. Southern limit of hard corals and distinctive algal species assemblage. Significant difference in occurrence of seagrass between Qld and NSW southern boundary (Coffs Harbour). Offshore sand barrier islands. Offshore benthic fauna not well known. |
| FRA | 57 | Franklin | Extremely exposed open coastline with long sandy beaches broken by rocky headlands. Moderate tidal range \approx 1.5m. |
| COB | 58 | Cobourg | Coast of numerous bays and inlets lined by sandy beaches. Lack of rivers with small tidal range (2-3m) infers minimal sediment debouchment and relatively low turbidity throughout the region. Mangroves restricted to narrow strips along bays and creek inlets. Numerous fringing reefs throughout entire region. |

Table 1.2.3.2. Examples of the detailed attribute data for IMCRA regions.

| Region Code | Attribute | Data |
|-------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ABR | 32 | <i>Abrolhos Islands</i> |
| | Climate: | Temperate with a moderate winter rainfall. |
| | Geology & geomorphology: | The three carbonate platforms are composed of Pleistocene coralline limestone with Holocene sand sheets and prolific contemporary coral growth in back-reef and lagoonal situations. Coral growth has been intermittent through the Quaternary. The reef platforms are separated by 40 m deep channels. Located close to the shelf edge, there is a steep outward slope off their seaward sides. The leeward, eastern sides shelve onto the wide mid-shelf platform between the islands and the mainland. Each of the reef platforms has a complex of reef-front, lagoonal, back-reef and channel habitats. There are many emergent rock platforms forming low limestone islands and, in the Wallabi Group, three larger islands with eolianite and Holocene dune mantles, rising to heights up to 50 m. |
| | Oceanography: | The water is clear and oceanic. Of paramount importance is the warm south-flowing Leeuwin Current in late summer and winter which is believed to introduce propagules of tropical animals from more northerly locations. |
| | Sediments: | The seabed surrounding the reef platforms bears deposits of carbonate sands. |
| | Tidal range: | Diurnal with a maximum range of 1 metre. |
| | Wave energy: | High on the seaward reefs, moderate on the leeward sides, low in the lagoons. |
| | Biology: | <p>The Abrolhos coral reefs are the most southerly in the Indian Ocean. They have a remarkably high species diversity with 184 species recorded, belonging to 42 genera. The associated fish and invertebrate fauna, however, is a blend of temperate, tropical and West Coast endemic species, making these reef communities of great scientific interest. In the contemporary phase of reef growth, corals are dominant in the lagoonal and back-reef areas while the high-energy seaward side of the reefs are dominated by macro-algae. In this respect also the Abrolhos reefs are unusual.</p> <p>One species of mangrove (<i>Avicennia marina</i>) is present in some sheltered areas but forms only very small mangals. There are well developed seagrass meadows on the northern side of West Wallabi Island.</p> <p>Many of the islands are important nesting sites for seabirds and, for this reason alone, have high conservation value. The eastern Indian Ocean subspecies of the Lesser Noddy Tern (<i>Anous tenuirostris melanops</i>) nests only at the Abrolhos. The high islands of the Wallabi Group support relict populations of terrestrial flora and fauna, including the Tammar Wallaby and a threatened eucalypt (<i>Eucalyptus oraria</i>).</p> |

| Region Code | Attribute | Data |
|-------------|------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| OTW | 44 | Otway |
| | (SA) | |
| | Climate: | Cool temperate, meso-thermal climate with cool, wet winters and warm, dry summers. |
| | Oceanography: | Coastline typically high energy, with a high deepwater wave energy, attenuated by a steep offshore-nearshore gradient and offshore reefs which provide for moderate to low energy conditions. Waters are cold temperate and typified by regular, seasonal, cold, nutrient-rich coastal upwellings. |
| | Mean sea surface temperatures: | Vary from 14°C in winter to 18° C in summer (decreasing to 11-12° C under the influence of the upwellings). |
| | Tidal range: | Microtidal ~ 0.8 to 1.2 metres range. |
| | Coastal Geomorphology & Landforms: | Small barrier coast dominated by a steeply sloping offshore gradient and few coastal embayments. Coastal geology comprises headlands of Pliocene - Pleistocene volcanic outcrops, and also Pleistocene dune rock cliffs, shore platforms and offshore reefs, which provide coastal protection. Coastal embayments (ie. Rivoli Bay, Guichen Bay) characterised by Holocene beaches and dunes. |
| | Biology: | Marine flora and fauna typically cold temperate (ie. Maugean element of the Flindersian Province). Intertidal and sublittoral fringe dominated by the bull kelp, <i>Durvillea potatorum</i> . Rocky subtidal macro-algal communities are dominated by <i>Macrocystus angustifolia</i> , <i>Phyllospora comosa</i> and other large brown furoid algae. For many macro-algal communities, this region forms the westward limit of a number of key species. Extensive areas of seagrass occur in the limited sheltered embayments (generally <i>P.ostenfeldii</i> group), with smaller areas in the lee of reefs (<i>P.australis</i>). Subtidal seagrass meadows dominated by <i>Posidonia australis</i> in shallow areas, <i>P.sinuosa</i> , <i>P.angustifolia</i> and <i>Amphibolus antarctica</i> in deeper waters. |
| | (VIC) | There are 2 major components comprising this region: |
| | (I) SA border to Cape Otway | |
| | Bathymetry: | Offshore gradient increases rapidly from 1:600 near the SA border to 1:100 just to the west of Cape Bridgewater; very steep (1:50) around the Cape. Portland Bay is locally steep (1:100) to the 20 m contour but generally flatter to the 50 m contour (1:500). From Portland Bay to Cape Otway offshore gradient is very steep to the 20 m contour and steep to the 50 m contour (1:100) |
| | Geology/ geomorphology: | Dominated by Quaternary dunes and dune sediments, and associated sandy shorelines. Quaternary dunes and dune sediments also feature as cliff top dunes on some cliffed shorelines. Dominantly southwest facing coastline. |
| | Tides, sea-levels and currents: | Amplitudes and phases tend to remain constant and diurnal constituents tend to dominate over semi-diurnal constituents. Currents generally slow - <0.05 ms-l. |
| | Sea-surface temperature: | Mean annual sea-surface temperature is approximately 15.5° C, representative of Bass Strait waters. |
| | Waves: | High wave energy (46 kW/m). |

| Region Code | Attribute | Data |
|-------------|------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | (2) Cape Otway transition zone | |
| | Bathymetry: | Very steep offshore gradient (1:50) to the 20 m contour but flattens off slightly to the 50 m contour (1:100). |
| | Geology/ Geomorphology: | Dominated by cliffed shorelines in Quaternary and Tertiary sediments. Orientation changes from facing south west to south east. |
| | Tides, sea-levels and currents: | Amplitudes and phases increasing eastward, except for the M ₂ phase which decreases. Relative importance of the semi-diurnal constituents increases rapidly eastwards. Rapid eastward increases in diurnal and semi-diurnal currents, with velocities in the order of 0.1 -0.5 ms ⁻¹ . |
| | Sea-surface temperatures: | Mean annual sea-surface temperature is approximately 15.5° C, representative of Bass Strait waters. |
| | Waves: | High wave energy (46 kW/m), though decreases rapidly in an easterly direction as the coastline changes from facing to parallel with the prevailing swell direction. |
| | (TAS) | |
| | Sea temperature: | Influenced during winter months by a warm-water extension of the Leeuwin Current, making this region warmer than other Tasmanian waters at that time. Summer water temperatures are cooler than elsewhere in the Bassian province. |
| | Biota: | Fish and plant species richness both moderate. This is the only recorded area within Tasmanian waters where several species more typically associated with South Australia occur (eg. the queen morwong <i>Nemadactylus valenciennesi</i>). |
| COR | 43 | Coorong |
| | Climate: | Cool temperate, meso-thermal climate with cool, wet winters and warm, dry summers. |
| | Oceanography: | Offshore gradient decreases from steep to flat resulting in a gradational coastline, from high deepwater wave energies at Cape Jaffa to low energies near the Murray Mouth. Waters are cool temperate. |
| | Mean sea surface temps: | Varying from 14°C in winter to 18°C in summer. |
| | Tidal range: | Microtidal ~ 0.8 to 1.2 metre range. |
| | Coastal Geomorphology & Landforms: | Large barrier coast dominated by a gradational nearshore-offshore gradient. Offshore gradient traversed by the extensive Murray Canyons which extend offshore from the Murray River. |
| | Coastal geology: | Comprises headlands and cliffs of Precambrian crystalline rock and metasediments and also, Pleistocene dune rock cliffs, headlands, shore platforms and reefs, interspersed with Holocene pocket beaches. Southern coast dominated by a large beach-dune barrier lagoon complex comprising the extensive Coorong lagoon. |
| | Biology: | Marine flora and fauna typically cool temperate waters (ie. Flindersian Province). Intertidal and sublittoral fringe dominated by the brown alga, <i>Cystophora intermedia</i> . On rocky limestone shores, subtidal macro-algal communities are dominated by red algae assemblages (particularly <i>Osmundaria</i> and species of <i>Plocamium</i>), species of <i>Caulerpa</i> (particularly <i>C.flexilis</i>) and <i>Cystophora</i> (such as <i>C.subfarcinata</i> , <i>C.moniliformis</i> and <i>C.platylobium</i>) and <i>Ecklonia radiata</i> . Granite boulder coasts are dominated by <i>Scytothalia dorycarpa</i> , <i>Acrocarpia paniculata</i> , <i>Carpoglossum confluens</i> , and <i>Ecklonia radiata</i> on exposed coasts and species of <i>Cystophora</i> in areas of moderate wave energies. Extensive seagrass meadows occur at Kingston (Lacepede Bay). Seagrass meadows dominated by <i>Posidonia australis</i> in shallow areas, <i>P.sinuosa</i> , |

1.3 Fisheries-habitat links

1.3.1 Key issues

A major strategic issue for the FRDC concerns the lack of knowledge of “critical” habitats and habitat links for many fisheries at all scales. This has meant that there is an inability to identify which estuaries, bays, reefs or coasts contribute most to recruitment -- and therefore lost opportunities to be proactive in including them in regional development plans for conservation and rehabilitation. It has also hampered the prediction of effects of habitat change, such as seagrass dieback and coastal infrastructure developments, on fisheries production. Studies of freshwater fisheries have had a longer history of development of approaches to determine key factors (eg. see Koehn 1993), but estuarine and marine problems are sometimes less tractable. For example, the immense sampling benefits of electrofishing are available only in freshwater. Basic life-history information is needed for both marine species and the aquatic vegetation or benthic communities they inhabit to determine approaches for habitat conservation and restoration of fisheries function.

For examples:

- barramundi life-histories are relatively well-known , but there has been no attempt to rank threatened north-eastern coastal nurseries by their importance to the Queensland fishery. This has allowed ongoing destruction of wetland nurseries.
- larval distributions of southern rock lobsters suggest the existence of “sources” and “sinks” that are not reflected in the State-by-State stock assessment and management regimes for the species.
- short-and long-term changes in location and density of tropical seagrass beds have occurred, but the role of accelerated sediment inputs and other anthropogenic disturbance is unclear
- estuarine infilling and creek evolution are both natural and rapid (in geological time frames) processes that are poorly recognised in coastal management.

This situation has arisen at the regional scale because of:

- a widespread emphasis in life-history R&D on factors presumed useful to species-specific stock assessment -- coarse stock delineation, spawning seasonality and age and growth of adult stages - with a lack of study of post-larval, juvenile stages of many major species;

- a lack of regional, fishery-independent inventories of nursery habitats and of major areas of fisheries production;
- widespread collection of intertidal and subtidal habitat data in inventories of the Australian coast (eg. NatMIS, CYPLUS) which are not yet matched to fisheries production figures (due to restricted availability or spatial scale of such data);
- a focus on the determination of “estuarine dependence” of members of fish communities on east and west coasts, with few contrasts and no overviews of factors limiting production in estuaries and bays;
- the inherent difficulties in studying sub-tidal habitats.

Recent advances in pursuing such habitat inventories include the development of methods for classification and assessment (eg. Blackman *et al.* 1992), and use of geographic information systems (GIS) to store information and make interpolations (Johnston and Barston 1993). For example, GIS has been a key platform in mapping trochus, prawn, seagrass, mangrove and holothurian habitat in Torres Strait (see Ahmad and Hill 1994, Derbyshire *et al.* 1995, Long *et al.* 1993, 1995, 1997b, Taranto *et al.* 1997a, 1997b, 1997c, Long and Mcleod 1997, Long and Poiner 1997).

At the local scale there are still persistent gaps in knowledge of fishery-habitat links that may best be overcome with wider use of innovative biomarkers and stable isotopes. These gaps range from a paucity of knowledge of habitat requirements for temperate-reef rock lobster (*Jasus* spp), to a need for further refinement of knowledge of bed depth and position for tiger prawn-seagrass associations.

Traditional techniques in assessing community composition inside and outside particular habitat types are of limited use in making inference about links and for predicting effects of habitat loss. Key features of these limitations are:

- surveys focus on adult or late juvenile stages, with selective gear types, and “important” species are often relatively rare in samples (see Table 1.4.5.1);
- there has been poor standardisation of gear types in studies done in topographically complex habitats, such as mangroves;
- the temporal patterns of sampling often miss crucial recruitment events and are generally not matched to the quick ontogenetic shifts amongst habitat types that may happen on hourly (tidal), daily (day vs night) and lunar time scales;
- trophodynamic relationships are not discernible from community surveys.

Recent R&D has shown that there are recruitment “hotspots” determined by local hydrodynamic processes in transport of larval stages (eg. Carrick 1997b, Jenkins and Black 1994, Steffe and Westoby 1992). This implies that important recruitment sites can be predicted and mapped in some cases, and also that broad generalisations regarding incremental habitat destruction cannot be weighed simply against indices of remaining habitat availability. There are also obvious opportunities for further R&D to test the utility of such predictions.

1.3.2 Lack of regional overviews of pattern and process in fisheries production

Despite the growing number of coastal studies and the importance of sheltered bays and estuaries to fisheries production there are relatively few thorough attempts to synthesise the information at large regional scales to give overviews of patterns of abundance of economically important species, and why they occur. For most areas and fisheries the research is still in the descriptive phase -- what are the habitats and fisheries resources, what communities live in different habitat types, and how does their composition vary with time and other factors? (Appendix 4, Table 1.4.5.1). Inventories of coastal fisheries and the habitats that support them are underway in most States and are described in Appendix 4:

- Tasmania (eg. Edgar *et al.* in press, and FRDC#94/037);
- Victoria - much focus on Westernport and Port Phillip Bays (eg. Jenkins *et al.* 1993c, 1996);
- South Australian estuaries and Gulfs (eg. Jones *et al.* 1996);
- sub-tropical Western Australia - a very close focus on estuaries and a good understanding of biology and variability of species in sheltered waters (eg. Lenanton 1982, Loneragan and Potter 1990): sampling is now being extended along more exposed coasts (Kendrick 1993, Ayvazian and Hyndes 1995, Hyndes *et al.* in press);
- New South Wales (eg. Gibbs 1997, Gray *et al.* 1996, Pollard 1994a,b, West and King 1996);
- Queensland (eg. Hyland, 1985, 1993a,b, Lupton 1993, Lupton *et al.* 1995, Quinn 1992) - the FRDC#95/167 “CHRIS” project integrates catch and habitat data;
- major focus on the South-eastern Gulf of Carpentaria and Torres Strait (see special issue of AJMFR Vol 45 and series of papers by Long and Taranto in Torres Strait);
- Cairns (eg. Coles *et al.* 1993, Russell *et al.* 1996a,b) and Townsville regions (eg. Robertson and Duke 1990a, Sheaves 1996);
- some studies near Darwin (eg. Davis 1988, Griffin in press) and only one in northern WA (Blaber *et al.* 1985).

Contrasts in latitudinal and longitudinal patterns of fisheries production

With the exception of some within-region comparisons (Gibbs 1997, Pollard 1994a, Potter *et al.* 1990) Australia lacks a definitive collation and interpretation of the latitudinal and longitudinal patterns in major fish and fisheries of sheltered bays and estuaries -- yet there are interesting similarities in the fisheries at similar latitudes on both sides of the continent, and some important differences in harvests that may relate to rainfall, exposure and flushing regimes.

In Table 1.3.2.1 we have identified the major targets of commercial and recreational fisheries in estuaries and along the coast. In Table 1.3.2.2 we have built on and adapted the only available east-west comparisons of rank of fish family in community surveys. There are no available assemblages of comparative biomass or numerical information from such surveys - partly because of the lack of standardisation of gear types and sampling effort. Even amongst habitats within regions (see Table 1.3.2.5) there is poor ability to compare fish densities and production.

Table 1.3.2.1. Similarity in composition of major target families in nearshore fin-fisheries of Australia

| Fishery Target | TAS | VIC | SA | WA | NSW | QLD | QLD tropics | NT tropics | WA tropics |
|------------------------------------------------------|--------------------------------|-------------------------------------------------------------|------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-----------------------|------------------------|
| Mulletts (Mugilidae) | <i>Aldrichetta forsteri</i> | <i>A. forsteri</i> | <i>A. forsteri</i> , <i>L. argentea</i> , <i>M. cephalus</i> | <i>A. forsteri</i> , <i>M. cephalus</i> | <i>M. cephalus</i> , <i>Liza argentea</i> , <i>Myxus elongatus</i> | <i>M. cephalus</i> , <i>L. argentea</i> | <i>M. cephalus</i> , <i>Valamugil cunnesius</i> | mugilids --spp? | ? |
| Luderick (Girellidae) | <i>Girella tricuspidata</i> | <i>G. tricuspidata</i> | | | <i>G. tricuspidata</i> | <i>G. tricuspidata</i> | | | |
| Garfishes (Hemirhamphidae) | <i>Hyporhamphus melanochir</i> | <i>H. melanochir</i> , <i>H. regularis</i> | <i>H. melanochir</i> | <i>H. melanochir</i> , <i>H. regularis</i> | <i>H. australis</i> , <i>H. regularis</i> , <i>Arrhamphus sclerolepis</i> | <i>H. australis</i> , <i>A. sclerolepis</i> | <i>Hemirhamphus far</i> , <i>A. sclerolepis</i> | hemirhamphids --spp? | ? |
| Herrings, sardines, pilchards, anchovies (Clupeoids) | | <i>Sardinops neopilchardus</i> , <i>Engraulis australis</i> | <i>S. neopilchardus</i> | <i>S. neopilchardus</i> , <i>E. australis</i> , <i>Sardinella lemuru</i> , <i>Hyperlophus translucens</i> , <i>H. vittatus</i> , <i>Spratelloides robustus</i> , <i>Nematalosa vlaminghii</i> | <i>Sardinops neopilchardus</i> , <i>Engraulis australis</i> , <i>Herklotsichthys castelnaui</i> | <i>S. neopilchardus</i> , <i>H. castelnaui</i> | <i>Sardinella spp</i> , <i>Amblygaster sim</i> , <i>Herlotsichthys spp</i> , <i>Nematalosa come</i> | ? | ? |
| Snapper and bream (Sparidae) | <i>Acanthopagrus butcheri</i> | <i>A. butcheri</i> , <i>Pagrus auratus</i> | <i>P. auratus</i> , <i>A. butcheri</i> | <i>P. auratus</i> , <i>A. butcheri</i> , <i>A. latus</i> , <i>Rhabdosargus sarba</i> | <i>A. australis</i> , <i>A. butcheri</i> , <i>R. sarba</i> , <i>P. auratus</i> | <i>A. australis</i> , <i>R. sarba</i> , <i>A. berda</i> , <i>P. auratus</i> | | <i>A. berda</i> | |
| Catfishes (Plotosidae and Ariidae) | | | | <i>Cnidoglanis macrocephalus</i> | <i>Arius graeffi</i> | <i>Arius spp</i> | <i>Arius spp</i> | <i>Arius spp</i> | <i>Arius spp</i> |
| Whiting (Sillaginidae) | | <i>Sillaginodes punctata</i> | <i>S. punctata</i> , <i>Sillago schomburgkii</i> , <i>S. bassensis</i> | <i>S. punctata</i> , <i>S. schomburgkii</i> , <i>S. bassensis</i> | <i>S. ciliata</i> | <i>S. ciliata</i> , <i>S. analis</i> , <i>S. maculata</i> | <i>S. analis</i> , <i>S. ciliata</i> , <i>S. maculata</i> | <i>Sillago-- spp?</i> | <i>S. schomburgkii</i> |

| Fishery Target | TAS | VIC | SA | WA | NSW | QLD | QLD tropics | NT tropics | WA tropics |
|---------------------------------------------|-------------------------------------------------------|--------------------------------------------------------------------------------------------|---------------------------------------------|------------------------------------------------------------|----------------------------------------|--------------------------------------------------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------|
| Flounder (Pleuronectidae) | <i>Rhombosolea tapirina</i> | <i>R. tapirina</i> | <i>R. tapirina</i> | <i>Pseudorhombus jenynsi</i> , <i>Ammotretis rostratus</i> | | | | | |
| Flatheads (Platycephalidae) | <i>Platycephalus bassensis</i> , <i>P. speculator</i> | <i>P. bassensis</i> , <i>P. fuscus</i> , <i>Leviprora laevigata</i> , <i>P. speculator</i> | <i>L. laevigata</i> , <i>P. bassensis</i> | <i>P. endrachtensis</i> , <i>P. speculator</i> | <i>P. fuscus</i> , <i>P. arenarius</i> | <i>P. fuscus</i> , <i>P. arenarius</i> | <i>P. fuscus</i> , <i>P. endrachtensis</i> | | |
| Tailor (Pomatomidae) | | <i>Pomatomus saltatrix</i> | | <i>P. saltatrix</i> | <i>P. saltatrix</i> | <i>P. saltatrix</i> | | | |
| Mulloway, black and silver Jew (Sciaenidae) | | <i>Argyrosomus hololepidotus</i> | <i>A. hololepidotus</i> | <i>A. hololepidotus</i> | <i>A. hololepidotus</i> | <i>A. hololepidotus</i> | <i>Protonibea diacanthus</i> , <i>Nibea squamosa/microgene</i> ? | <i>Protonibea diacanthus</i> | <i>Protonibea diacanthus</i> |
| Sea pike (Sphyraenidae) | <i>Sphyraena novaehollandiae</i> | <i>S. novaehollandiae</i> | <i>S. novaehollandiae</i> | <i>S. novaehollandiae</i> | | | <i>S. jello</i> ? | <i>S. jello</i> ? | <i>S. jello</i> ? |
| Aust. "salmon" and "herring" (Aripidae) | <i>Arripis trutta</i> , <i>A. truttaceus</i> | <i>A. truttaceus</i> , <i>A. trutta</i> , <i>A. georgianus</i> | <i>A. truttaceus</i> , <i>A. georgianus</i> | <i>A. georgianus</i> , <i>A. truttaceus</i> | | | | | |
| Barramundi (Centropomidae) | | | | | | | <i>Lates calcarifer</i> | <i>L. calcarifer</i> | <i>L. calcarifer</i> |
| Trevallies (Carangidae) | | <i>Pseudocaranx dentex</i> | | <i>P. wrightii</i> ? | <i>P. dentex</i> | | <i>Scomberoides commersonianus</i> | <i>S. commersonianus</i> , carangids – spp | |
| Sea Perches (Lutjanidae) | | | | | | <i>Lutjanus argentimaculatus</i> | <i>L. argenti-maculatus</i> , <i>L. johnii</i> | <i>L. argenti-maculatus</i> , <i>L. johnii</i> | <i>L. argenti-maculatus</i> , <i>L. johnii</i> |
| Groupers (Serranidae) | | | | | | <i>Epinephelus coioides</i> | <i>E. coioides</i> , <i>E. malabaricus</i> | <i>E. coioides</i> + ? | ? |
| Grunter (Pomadasyidae) | | | | | | | <i>Pomadasy kakaa</i> | <i>Pomadasy kakaa</i> ? | |
| Lesser Mackerels (Scomberomoridae) | | | | | | <i>Scomberomorus munroi</i> , <i>S. queenslandicus</i> | <i>S. semifasciatus</i> , <i>S. munroi</i> , <i>S. queenslandicus</i> | <i>S. semifasciatus</i> , <i>S. munroi</i> , <i>S. queenslandicus</i> | <i>S. semifasciatus</i> , <i>S. munroi</i> , <i>S. queenslandicus</i> |

| Fishery Target | TAS | VIC | SA | WA | NSW | QLD | QLD tropics | NT tropics | WA tropics |
|--------------------------------|------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|----------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| Threadfins (Polynemidae) | | | | | | | <i>Polynemus sheridani</i> , <i>Eleutheronema tetradactylum</i> | <i>P. sheridani</i> , <i>E. tetradactylum</i> | <i>P. sheridani</i> , <i>E. tetradactylum</i> |
| Sharks | <i>Galeorhinus galeus</i> , <i>Mustelus antarcticus</i> | <i>G. galeus</i> , <i>Callorhynchus milii</i> , <i>M. antarcticus</i> , <i>Carcharhinus brachyurus</i> | <i>M. antarcticus</i> , <i>C. brachyurus</i> , <i>C. obscurus</i> | <i>C. obscurus</i> , <i>C. plumbeus</i> , <i>C. brachyurus</i> | <i>C. leucas</i> +? | <i>Carcharhinus</i> spp | <i>Carcharhinus</i> spp | <i>Carcharhinus</i> spp | <i>Carcharhinus</i> spp |
| Swimming crabs (Portunidae) | | <i>Ovalipes australis</i> | <i>Portunus pelagicus</i> , <i>O. australis</i> | <i>P. pelagicus</i> | <i>P. pelagicus</i> , <i>Scylla serrata</i> | <i>P. pelagicus</i> , <i>S. serrata</i> | <i>S. serrata</i> , <i>P. pelagicus</i> , | <i>S. serrata</i> | <i>S. serrata</i> |
| Prawns (Penaeidae) | | <i>Penaeus plebejus</i> , <i>Metapenaeus bennettiae</i> , <i>M. macleayi</i> | <i>P.latisulcatus</i> | <i>P.latisulcatus</i> , <i>M. dalli</i> | <i>Penaeus plebejus</i> , <i>Metapenaeus bennettiae</i> , <i>M. macleayi</i> | <i>Penaeus plebejus</i> , <i>Metapenaeus bennettiae</i> , <i>M. macleayi</i> | <i>P. longistylus</i> , <i>P. esculentus</i> / <i>semisulcatus</i> , <i>M.endeavouri</i> , <i>P.merguiensis</i> , <i>P.latisulcatus</i> | <i>P. esculentus</i> / <i>semisulcatus</i> , <i>P. indicus</i> , <i>P.latisulcatus</i> , <i>M. endeavouri</i> | <i>P. esculentus</i> / <i>semisulcatus</i> , <i>P. indicus</i> , <i>P.latisulcatus</i> , <i>M. endeavouri</i> |
| references | Kailola et al. (1993), Jordan (FRDC#94/037) | Kailola et al. (1993) ,Hall and McDonald (1986) | Kailola et al. (1993), Hall (1984) | Lenanton (1982), Potter et al. (1986) | Kailola et al. (1993), West and King (1996) | Kailola et al. (1993), Williams (1997) | Ludescher (1997), Kailola et al. (1993) | W. Gillespie p.c. (NTDPIF) | R. Lenanton p.c.# 1360 Kailola et al. (1993) |

Table 1.3.2.2. Comparison of rank occurrence in numerical terms of taxa in studies done in estuarine and marine embayments at similar latitudes in southern Australia. ** chose highest ranking species within family. *Italic* = intermittently open only.

| Family/Location | Swan-Avon 115°E 32°S | Cockburn Sound | Peel-Harvey 115°E 32°S | <i>Blackwood</i> 115°E 34°S | <i>Wilson Inlet</i> 117°E 35°S | Botany Bay 151°E 34°S | Jervis Bay** 150°E 35°S | Lake Conjola** 150°E 35°S | <i>Swan Lake**</i> 150°E 35°S | <i>Lake Wollumboola**</i> 150°E 34°S |
|------------------------------------|--------------------------|--------------------------|---------------------------|--------------------------------|-----------------------------------|--------------------------|----------------------------|------------------------------|----------------------------------|-----------------------------------------|
| Girellidae -- luderick | | | | | | ? | 21 | 22 | | |
| Mugilidae - mullet | 4 | 7 | 3 | 3 | 3 | 8 | 2 | 3 | 3 | 3 |
| Sparidae - bream | 11 | 37 | 15 | 2 | 9 | 1 | 4 | 14 | 2 | 2 |
| Sillaginidae - whiting | 9 | 6 | 9 | 1 | 7 | 5 | 1 | 4 | 12 | 4 |
| Platycephalidae - flathead | 15 | 8 | 24 | 19 | 4 | 18 | | 37 | | 14 |
| Hemirhamphidae - garfish | 21 | 15 | 13 | 8 | 10 | 23 | 17 | 30 | 3 | 5 |
| Carangidae - trevally | 18 | 4 | 16 | 11 | | 7 | 7 | 30 | | |
| Bothidae/Pleuronectidae - flatfish | 23 | 21 | 14 | 15 | | 10 | 15 | 20 | 21 | 9 |
| Monacanthidae -- leatherjackets | 17 | 9 | 22 | 14 | | 12 | | 22 | | 28 |
| Arripidae - "salmon" | 25 | 20 | 20 | 6 | 6 | 39 | 14 | 50 | | 15 |
| Clupeidae - herrings, sprats | 1 | 12 | 1 | 12 | | 13 | 19 | 6 | 7 | 7 |
| Engraulidae - anchovies | 6 | 55 | 18 | 21 | 8 | 22 | 25 | 41 | | 28 |
| Atherinidae - hardiheads | 2 | 3 | 5 | 5 | 1 | 4 | 5 | 2 | 1 | 1 |
| Gerreidae - ponyfish | 10 | 10 | 6 | - | | 6 | 12 | 11 | | |
| Teraponidae - trumpeters | 3 | 11 | 2 | 7 | | 16 | | 41 | | |
| Apogonidae - mouth almighties | 8 | 2 | 4 | - | | 34 | | | | |
| Gobiidae - gobies | 5 | 25 | 7 | 4 | 5 | 2 | | 7 | 6 | 10 |
| Tetraodontidae -- blowfish | 7 | 13 | 8 | 9 | | 9 | 3 | 15 | 14 | 8 |
| Plotosidae - catfish | 13 | 23 | 10 | 13 | 2 | 20 | 31 | | | |
| Callionymidae - stinkfish | 29 | 1 | - | - | | 30 | | | | |
| Ambassidae - glassy perchlets | - | - | - | - | | 3 | 31 | 1 | 10 | |
| Nemipteridae - threadfin bream | | 5 | - | - | | - | | | | |
| SPECIES | 54 | 130 | 55 | 56 | 38 | 229 | 64 | 76 | 22 | 35 |
| FAMILIES | 31 | 66 | 29 | 37 | 24 | 90 | | | | |
| sampling gear | ? | ? | ? | ? | ? | ? | beach seine | beach seine | beach seine | beach seine |
| reference | Potter et al. (1983a) | Potter et al. (1983a) | Potter et al. (1983a) | Potter et al. (1983a) | Potter et al. (1990) | Potter et al. (1983a) | CSIRO (1994) | Pollard (1994a) | Pollard (1994a) | Pollard (1994a) |

This makes it difficult to assign regional significance to different areas and to correlate production with environmental factors, and has not fostered development of useful hypotheses to explain variation observed at smaller scales.

This gap is partly due to the lack of reliable catch and effort data from both commercial and recreational sectors and inaccessibility of existing data to initiatives (eg. IMCRA) or researchers outside of State fisheries authorities. There have been recent advances in overcoming these problems, with painstaking collation and validation of long-term historical information on fisheries production and effort (eg. Pease and Grinberg 1995 , Hall and MacDonald 1986) .

Latitudinal patterns that are obvious from Table 1.3.2.1 and 1.3.2.2 include the prevalence on both sides of the continent of the same, or very similar, members of the families mugilidae (mulletts), sillaginidae (whittings), platycephalidae (flatheads), sparidae (breams, tarwhine, snapper), hemirhamphidae (garfish), sciaenidae (mulloway) and teraponidae (trumpeters) in harvests. Tailor, blue swimmer crabs and sub-adult king and school prawns (eastern or western) are ubiquitous in subtropical latitudes. Notable - but unexplored - differences include the abundance of girellids (luderick), siganids (rabbit-fishes or “black trevally”) and gerreids (silver-biddies) on the east coast and their insignificance on the west coast. The ubiquitous ambassids (glassy perchlets) of the east coast are completely absent from the equivalent habitats on the west coast, while the opposite pattern is true for the apogonids (mouth almighties).

Herbivorous sea mullet, luderick, leatherjackets and “black trevally” are the most important commercial finfish on the sub-tropical east coast estuaries, in terms of biomass - yet herbivores apparently are not so abundant in the western estuaries. Instead it appears that detritivorous clupeids (*Nematalosa*) and omnivorous yellow-eye mullet and tarwhine, and benthic macrocarnivores (breem) dominate the western landings of finfish.

There are further contrasts with the relatively small fin-fisheries in tropical estuaries. Carnivores predominate (barramundi, threadfin “salmons”, queenfish and trevallies), with smaller numbers of benthic macrocarnivores (grunter, lutjanids, serranids). The absence of herbivores is in small part due to markets - the sea mullet catch on the north tropical east coast is growing as markets for mullet roe develop.

The role of consistent freshwater input is visible in the restriction of productive school and greasyback prawn (*Metapenaeus* spp) fisheries to areas of significant freshwater input on both sides of the country (eg. Gippsland Lakes in the south, Clarence River in the north and Swan-Avon in the west), the restriction of catadromous Australian Bass, Eel and Estuary Perch to east coast waters, and the absence of major barramundi stocks in the north-west of the country.

Much more difficult to explain are the differences in magnitude in fisheries associated with *Posidonia* in Cockburn Sound (mainly planktivorous pilchards and other “baitfish”) and the SA Gulfs and Victorian Bays (sea garfish, King George Whiting, calamari squid). In that comparison the amount of seagrass cover is not a good predictor of fisheries yield - depth and exposure of the beds are important variables.

Pollard (1994a,b) attempted to collate and contrast the historical data for south coast estuaries of NSW. He found that only rank abundance could be derived from this information for comparative purposes - similar to the approach taken by Potter *et al.* (1983a, 1990). Pollard (1994a) also interrogated the available catch data and found that opening regime may govern fisheries yield of southern NSW lagoons - with intermittently open lagoons having consistently higher fisheries production, obtained from a trapped, relatively depauperate fauna (<40% of the diversity of permanently open lagoons).

There is important influence of coastal currents in determining estuarine faunas. For example, Potter and Hyndes (1994) found that the faunas of shallow and deeper waters of WA south coast estuaries were depauperate compared with equivalent habitats on the lower west coast. This was suggested to reflect the fact that several species do not extend downwards and around the South coast (under the influence of the Leeuwin current), or if they do it is in greatly reduced numbers. The only warm-temperate species in the Nornalup/Walpole estuary was the tarwhine *Rhabdosargus sarba*, and the marine species that were most abundant, such as King George whiting and Australian “herring” *Arripis georgianus*, were temperate endemics.

The only attempt we found to compare production amongst regions were the coarse comparisons made by Gwyther (1990) to place the input of sewage into Port Phillip Bay into the context of regional patterns in primary production as a means of inferring effects of nutrification (Table 1.3.2.3).

| Table 1.3.2.3. Comparison of commercial and recreational catch (t yr^{-1}) and production ($\text{kg Ha}^{-1} \text{ yr}^{-1}$) from Victorian, NSW and WA bays, inlets and estuaries. Adapted from Gwyther (1990). *scallops. | | | | | | | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|-----------------|-----------------|---------------------|------------------|------------------|-----------------|-------------|
| | Area (km^2) | Avg comm. catch | Avg recr. catch | Avg shellfish catch | comm. fish prodn | recr. fish prodn | shellfish prodn | TOTAL prodn |
| Port Phillip Bay | 1950 | 1196 | 1048 | 4680 | 6.1 | 5.4 | 24 | 35.5 |
| Western Port | 680 | 238 | 50 | 2 | 3.5 | <1 | <1 | 4.3 |
| Coroner Inlet | 500 | 348 | 110 | n.a. | 7.0 | 2.2 | n.a. | 9.16 |
| Gippsland Lakes | 400 | 524 | 351 | 2 | 13.0 | 8.8 | <1 | 22 |
| Lake Tyers | 25 | 20 | 15 | 3 | 8 | 6 | 1 | 15 |
| Tamboon Inlet | 7 | 29-48 | n.a. | n.a. | 42-68 | n.a. | n.a. | n.a. |
| Mallacoota Inlet | 25 | 84 | 27 | n.a. | 33 | 10.8 | <1 | 44 |
| Sydney Estuary | 50 | 40-108 | 164 | 38 | 8-21.5 | 33 | 7.5 | 48-62.5 |
| Jervis Bay | 100.5 | 61 | 78 | 400 | 6.1 | 7.8 | 40 | 54 |
| Botany Bay | 42 | 183 | 59 | n.a. | 43.5 | 14 | n.a. | 57.5 |
| Tuggerah Lakes | 79 | n.a. | 67 | n.a. | 34 | 8.4 | n.a. | 42.4 |
| Cockburn Sound | 103 | 344 | 210 | 474 +250* | 76 | 20 | 46-70 | 142-166 |
| Peel Harvey Estuary | 131 | n.a. | n.a. | 66 | 26 | n.a. | 5 | 31 |

This tabulation should not be used without reference to the original description of the sources, assumptions, weighting factors and data selection employed by Gwyther (1990), but it does serve to illustrate how regional comparisons could be drawn from the time series of production data now available. Gwyther (1990) suggested that there were two geographical categories of commercial fish production, to the east and west of Tamboon Inlet, and that the NSW bays were being enriched by intrusions of the East Australian Current.

The best comparisons might be drawn by examining only species for which the best historical data exists -- cultured molluscs and those caught only commercially, such as sea mullet, anchovies and pilchards. Scallop stocks are notoriously variable due to recruitment fluctuations (eg. 0 - 7000 tonnes in Port Phillip Bay and episodic in Jervis Bay (Fuentes 1994). The wider use of CPUE figures is discussed below in section 1.3.4.

It may be that larger scale comparisons amongst these regions will yield key environmental correlations with fisheries production, and will enable the major sources of recruitment to be identified and better preserved.

Some interesting, within-region comparisons can be made between the Clarence and nearby Richmond Rivers in northern NSW. The Clarence River is the largest commercial fin-fishery in NSW and supplies 20% of the total State estuarine catch by weight - 75% of which is sea mullet. About 40% of the total prawn production for estuarine and adjacent coastal waters also comes from the fishery for *Metapenaeus macleayi* in this river system.

| Table 1.3.2.4. Differences in area of habitat and estimated total (commercial + recreational) finfish production (tonnes) from the Clarence and Richmond Rivers. Data adapted from West's (1993) Table 5.2 and Fig 2.3, and West and Gordon (1994) Table 6. * 1986 commercial catch only | | | | | | | | | | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|----------|----------|-----------|-------------|----------------|--------------|----------|----------|--------|-------------|
| km ² | open water | mangrove | seagrass | saltmarsh | Y'fin bream | dusky flathead | sand whiting | luderick | mulloway | tailor | sea mullet* |
| Clarence | 103 | 5.2 | 0.9 | 1.9 | 64-73 | 28-34 | 14-16 | 19-22 | <3-5 | <2-3 | 402 |
| Richmond | 14 | 4.9 | 0.9 | 0.1 | 13-20 | 7-12 | 4-7 | 13-16 | <3-3 | <2-6 | 107 |
| difference | 7.46 | 1.06 | 1 | 1.9 | 4.9-3.6 | 4-2.8 | 3.5-2.3 | 1.5-1.4 | 1-1.7 | 1-0.5 | 3.7 |

To compare the two rivers in Table 1.3.2.4 we used estimates of area of habitat cover, commercial finfish catch and lower and upper estimates of recreational catch in West (1993) and West and Gordon (1994). Although the Clarence is nearly 7.5 times the size of the Richmond and has roughly equivalent areas of seagrass and mangroves, the ratios of Clarence : Richmond catch are only different, on average, by about a factor of 4 for bream, flathead, whiting, luderick and mullet.

These and other observations would be worth studying to make further inferences. For example:

- West (1993) noted that more bream, sand whiting, tailor and mulloway were caught in the northern NSW rivers than in previous studies done in the Hawkesbury and Botany Bay with the same gear;
- mulloway juveniles are in outstanding abundance in relatively few estuaries in NSW (eg. Hawkesbury, Clarence) and these may contribute most to the adult fishery in the entire State;

- episodic recruitment is a feature of NSW commercial fish in estuaries, even at estuary level -- recruitment can be very good across families or within species in one estuary and low in others (eg. Pollard 1992);
- there are consistent north-south differences in age structures of NSW estuarine fish in several families (p.c. #460 C. Gray).

| Table 1.3.2.5. Comparison of biomass estimates (grams metre ⁻²) from habitats within estuaries in the tropics and sub-tropics, using a variety of gears (see Appendix 4). | | | | | | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|---------------|------------------------------------------|---------------------------------|-------------------------------|-----------------|--------------|
| | open channels | sandy beaches | seagrass | mudflat adj. to mangrove fringe | small mangrove creeks/ inlets | mangrove forest | location |
| Blaber <i>et al.</i> (1989) | 7.1-16.1 | 5.0 | 0.5-1.8 | 70.6 | 8.2 | | Embley River |
| Robertson and Duke (1990a) | | | | | | 10.9 | Townsville |
| Beumer and Halliday (1994) | | | 0.83-1.64 (sparse); 1.25-2.85 (dense) | | | 2.01 | Tin Can Bay |
| Morton (1990) | | | | 2.9 | | 25.3 | Moreton Bay |
| Bell <i>et al.</i> (1984) | | | | | | 6.4 | Botany Bay |

The figures in Table 1.3.2.5 give some idea of the range of biomass estimates available for habitats within estuaries, but Blaber *et al.* (1989) caution that the differences (a factor of 70 in their study of mudflats vs seagrass) illustrate both;

- the difficulties in comparing across different gear types (beam trawl in seagrass vs stake net on mudflats), and
- the shoreward movement of large numbers of large taxa, such as rays, to feed.

Dr Malcolm Dunning (p.c. #210) has emphasised the importance of this movement in central Queensland, especially in regions of high tidal range, which represents a community of high biomass that resides always in a thin zone virtually at the edge of the tide.

1.3.3 The use of production figures in assessing the state of fisheries habitats

Specific studies of the status and change in fisheries production of estuaries and bays are rare over the period in which major habitat disturbances have occurred. Commercial

fisheries production figures are traditionally used for such comparisons (eg. Kearney 1996), but these are now known to have several sources of bias that must be addressed:

- *lack of data on angler effort and catch significantly under-estimates overall harvests*

A major problem in interrogating production figures in isolation is the lack of knowledge of harvest by anglers. A growing body of literature on recreational catches (SPCC 1981, Henry 1984, West 1993, Hancock ed. 1995) indicates that the harvest by anglers is at least as large as commercial production in some important estuaries and bays and that for several species anglers are now the principal harvesters (see below).

There is widespread belief that angling effort, efficiency and overall catch has expanded rapidly in the last 30 years, but there needs to be much more documentation of this perception (Hancock ed. 1995). For some highly valuable fisheries the environmental signals in CPUE figures are also clouded by persistent poaching that is not picked up by surveys of commercial and recreational harvests (eg. in the abalone fishery in Victoria).

- **changes in efficiency, markets and reporting**

The historical production figures also suffer from an inability to account for effort and changes in efficiency (eg. monofilament nets, electronic navigation and fish-finding devices) and changing market demands. Other perceptions of species shifts in catch may in fact reflect only changes in targeting, marketing and the reporting of mixed species - especially mis-reporting of minor species. For example, a widely reported species switch in the Moreton Bay prawn catch to include more *Metapenaeus bennettiae* (p.c. #290 N. Loneragan) may be due solely to improved species separation in catch reporting or to changes in discarding practices.

Over the history of most fisheries there have also been increasing legislative restrictions on gears, areas and times of fishing.

- **spatial resolution of logbooks, confidentiality and “nil” returns**

The primary goal of many logbook programs was for use in management, not research, and the resolution of reports are often not informative. For example, in Queensland there is a suite of resolution in the logbook system -- at the level of 30-60 mile grids in the gillnet fishery on east coast, but by riverine system in the Gulf of Carpentaria. This makes it hard to tie catches to particular habitats, or even river systems - but there is great promise in this regard in the use of satellite vessel

monitoring systems (VMS) for trawlers. These will enable construction of density contours of trawling effort, and will possibly be adopted by major prawn fisheries by 1999. There are widespread efforts at improving the collection of production information to aid R&D (eg. researchers at NSW FRI are now endeavouring to apply logbooks with daily records and gear discrimination).

For the coastal estuaries and lagoons there are also problems with the use of catch data from a fleet that is usually very small. Researchers cannot distinguish catches in some estuaries and bays because it would clearly identify an individual's activities. For example, Tunnel-netters who supply a large market are limited in number to 3 or 4 in the entire Moreton-Sandy Straits region and only 4 or 5 work Hervey Bay.

The Australian Seafood Industry Council argues that the effects of habitat degradation cannot be seen in shrinking production figures because the biomass is in fact smaller overall, yet by increased efficiency the commercial catch is maintained. For some species this in competition with a greater share being taken by anglers. They also warn that it is inappropriate and misleading to make the assumption that habitat decline and fisheries production decline should be related in a linear manner (p.c. #370 D. Leadbitter). The examples given in Boxes 1.3.3.1 and 1.3.3.2 show the complexity in interpretation of such correlations and emphasise the importance of "corporate memory".

Box 1.3.3.1 USE OF PRODUCTION FIGURES IN NSW ESTUARIES

Pease and Grinberg (1995) presented a review of all reported production figures for NSW fisheries in the period 1940-1992. These showed that the reported production of estuarine finfish species remained stable or generally increased through the report period.

- Flat-tail mullet production was the only species with a declining trend through most of the report period, but West (1993) has attributed to this changes in market value and targeting
- Mulloway, sand whiting (*Sillago ciliata*) and trumpeter whiting generally declined since the early 1980's
- eel and silver biddy production increased
- anecdotal reports suggest that commercial interest in sand whiting has increased due to their value, but there is no ability to calibrate such trends against changes in efficiency such as the change from yarn to nylon nets.

West and Gordon (1994) collated historical catch information for the commercial fishery and conducted roving creel surveys of the recreational fishery in the Richmond and Clarence Rivers of NSW. The average annual catch of fish within each of 4 decades since 1950 (not including prawns) was stable overall, but there had been declines in flat-tail mullet, dusky flathead and mulloway in both rivers, and yellowfin bream in the Richmond.

These comparisons do not account for fishing effort, or changes in gear efficiency. All of the major species in the production figures were known or suspected to move between estuaries which further complicates the interpretation of such broad historical comparisons. The declines in the commercial figures reported by West (1993) may be partly due to competition with anglers, as estimates of the ratios of angler: commercial catch in the Clarence were:

- 0.73:1 - 0.97:1 for yellowfin bream
- 0.64:1 - 1:1 for dusky flathead
- 0.27:1 - 0.45:1 for sand whiting
- 0.26:1 - 0.46:1 for luderick
- 0.5:1 - 1.5:1 for mulloway
- >1:1 - >2:1 for tailor.

These ratios also showed that anglers were the principal harvesters in the Richmond river of yellowfin bream (12:1 - 19:1) and dusky flathead (2.5:1 - 5:1). In contrast, sea mullet are caught almost exclusively by the commercial sector throughout their range in Australia.

The Clarence River is the most heavily flood mitigated system in NSW (see Chapter 2), yet there is no evidence of decline in commercial catch, and it is still the most productive estuary in the State. Mullet, bream, flathead and possibly whiting are moving amongst nearby estuaries and the Clarence catch possibly comprises 30-40% of immigrants, so it has not been possible to discern signals in production figures of the impact of floodgates in localised reaches.

(p.c. #540 R. West)

Box 1.3.3.2 SEAGRASS DIEBACK AND FISHERIES PRODUCTION IN VICTORIAN BAYS

Perhaps the best known attempts to highlight the effects of habitat alteration on bay fisheries have been those of MacDonald (1992). This work initiated an intense focus on seagrass-fisheries relationships - mostly funded by FRDC (eg. Jenkins *et al.* 1993d) -- and has culminated in the first paradigms regarding the limits to secondary production for any vegetated aquatic habitat in Australia (see section 1.4.4.1 and Edgar and Shaw 1995a,b,c).

The first step was analysis of an extensive dataset on commercial catch since 1914 and CPUE logs since 1973. The returns in 1914-1960 were monthly but changed after 1964/65 to daily catch logs, and again after 1973/74 to more detailed breakdown by gear. Inter-annual variability in recruitment across the Victorian Bays heavily influences the signal of seagrass loss, but the species-specific patterns were perceived to be:

- clear decline for six-spine leatherjacket attributable directly to seagrass loss since 1970
- low catches of King George Whiting (KGW) before 1960 were due to low popular opinion of them as table fish, then the fleet started to target this species and snapper as popularity grew
- barracouta catch declined sharply at same time as KGW went up, largely because of changing targets and fishing gear
- outside the bays a general "crash" in Barracouta has been unexplained, and may reflect large-scale oceanographic events. The catch was 3-4000 tonnes p.a. up to 1960's, started to decline in mid-late 1960's and was down by early 1970's to just 500 tonne p.a.
- *Heterozostera* dieback in Western Port Bay caused a different recent history in KGW catch. The Port Phillip Bay (PPB) catch stayed high, whereas Westernport declined
- the calamari squid catch declined too in both Bays, but angling probably plays a major, undocumented role in this change
- In mid-1980's the total catch in PPB escalated due to pilchard seining, from <250 t in 1970 to over 2000 t in 1990/91, which comprise 2/3 of all fish catch there now. Anchovies have been declining steadily while the pilchard catch has been going up - most sharply during 1975-92.
- decline in Aust. Salmon catch in PPB since 1950's and 1960's has been mainly because the number of traditional "shots" have been reduced due to placement of moorings, jetties etc, and loss of opportunities to catch schools.
- seagrass dieback in Corner Inlet was followed by decline in Rock Flathead catches -- rapid at first, then a recovery due probably to fleet behaviour and price rather than seagrass recovery (twice the price as other flathead)
- dieback of about 30 km² in the Geelong Arm of PPB coincided with a sharp decline in Rock Flathead catch between 1982-1990
- decline in Corner Inlet seagrass occurred from mid-late 70's through mid-80's, but there has been recovery since then (but not re-surveyed since 1990)
- coincidental, sharp decline in Flounder catch during 1960-1990 - but the accumulation in meshing areas of "Wire weed" (*Amphibolus* sp) may have affected catchability
- big change in netting practice occurred in Corner Inlet -- since 1989, haul-netters were allowed to use power-hauling to cope with currents and much bigger tidal amplitude (2-3m; cf Westernport 1.5-2m), and heavier leadlines not allowed in other embayments
- this has caused rise in vulnerability and in catch of the Blue Rock Whiting (*Haletta semifasciata* ; Odacidae)
- Snook and Longfin Pike decline in Corner Inlet is due to cessation of a specialist drift-gillnet fishery
- Sea Garfish in all bays have shown no declines (except wartime decrease), and are not thought to be critically dependent on seagrass in Victoria
- Yellow-Eye Mullet catches have been decline in since 1960's in Corner Inlet and Gippsland Lakes - almost certainly due to a lack of interest because of low price -- but catches are rising in PPB, because the proximity to market affords a sustainable prices-to-cost ratio
- YE mullet catches are also rising in Westernport, but probably due to "desperation" of local fishermen affected by KGW decline.

(p.c. #1060 M. McDonald)

1.3.4 Lack of knowledge of links between life-histories and habitats

General inferences about the processes linking fisheries to habitats can be made from studies of distribution and abundance, but their results must be complemented with detailed life-history information for the fished species to enable definition of “critical” habitats. The coastal Australian species generally have a three-phase ontogeny, involving pelagic larvae and pre-settlement juveniles, recruitment to shallow nearshore habitats and movement to deeper offshore habitats and spawning grounds.

On the west, south and east coasts there is also a common movement against the direction of prevailing currents to spawn. The migrations of Australian “salmon”, sea mullet and eastern king prawns are well known and followed in fishing activities, but the greater or lesser extent of movement by other species has never been fully documented. It is known that the Fraser Island area (eg. sea mullet, tailor), the location of bifurcation of the EAC in the Coral Sea (eg. black marlin) and the Albany area (Australian “salmon”, “herring” and pilchards) are common spawning grounds for some important species. However, these are almost always studied in isolation from each other in single-species stock assessments (eg. snapper FRDC #93/074, sea mullet FRDC#94/024) - integration of R&D on “assemblages” could be more profitable for pre-settlement and juvenile life-history stages.

Fisheries for species aggregated to spawn share the same key uncertainty - from which regions and habitats are the most recruits derived, and are these patterns consistent? Conventional tagging programs have proven to be of limited use in addressing this question, and should be augmented by recent innovations in use of otolith microchemistry, biological tags and other techniques.

Unfortunately, there is a surprising lack of basic life-history information for most of the major fishery species in Australia (with the exception of prawns), and a lack of sampling in alternative, non-estuarine habitats. There is consequently a paucity of information on “critical” habitat requirements and processes such as recruitment, post-recruitment mortality and competition, spawning, and species interactions.

The existing information does show that the nature and location of these habitats can vary significantly on a regional basis within a species range. Species with the most “flexible” life-histories would be expected to be most resilient to habitat disturbance.

In this regard it is important to note that:

- the downward trends in production of NSW fisheries in the period 1940-1992 (Pease and Grinberg 1995) were mainly associated with species thought not to have a dependence on nearshore or estuarine habitats. Long-term declines in rock lobster, ocean jackets, teraglin and sand flathead are unexplained, and after peaks in the 1970's and 1980's the production of school whiting, snapper and yellowtail kingfish have declined. Kearney (1996) notes that fishing pressure - not habitat destruction - is the likely cause for these declines, yet the life-histories of these species are poorly known. For example, we could not find a single study on any aspect of teraglin (*Atractoscion aequidens*) biology in Australia.
- the ubiquitous yellowfin bream and sea mullet on the east coast are found in almost all microhabitats and salinities in estuaries (eg. Pollard 1992). Their production may have been sustained by this "flexibility".

We had hoped to derive inferences about habitat requirements by summarising information from the individual "FinForms" used by BRS for assembly of "Australian Fisheries Resources" (Kailola *et al.* 1993). We obtained electronic copies of all the FinForms, but found there was insufficient information there to do this -- the life-history information reported was mainly growth, age, spawning seasonality and diet, and the species and fishery ranges were not very informative about the regional "grain" in fisheries production.

The knowledge-base is much more extensive for abalone, prawns and western rock lobster, but reviews are lacking (but see papers in Courtney and Cosgrove 1995).

This lack of information has hampered prediction and rehabilitation of effects of habitat disturbances, and is widespread for fish even amongst such major families as the sparids and sillaginids. For example, Hall (1984) reported that it was important to determine the timing and direction of movements through the Murray Mouth to enable the threats of mouth closure to be addressed by the most appropriate engineering solutions. However, at that time there was not even sufficient knowledge to assess whether major spawning of black bream, flounder and yellow-eye mullet was occurring at, outside or inside the mouth and mulloway were only suspected to spawn just outside.

The situation has not rapidly improved since then for these taxa, with reviews by West (1993) and Kerby and Brown (1994) outlining both the vintage (many pre-war) and

scarcity of definitive literature for major estuarine species. For example, in a review of studies of estuarine fish biology in New South Wales, West (1993) found no published papers for flathead, mulloway, tailor and luderick, sea mullet had no research attention since the 1950's, there had been no publications on bream for 45 years, and only a single publication on sand whiting since 1947.

Importance of nearshore resources

The importance of bays and estuaries as nursery sites is evident from the summary tables throughout this review, but lesser known is the general importance of nursery sites inshore of adult distributions of "deepwater" trawl species and the links between inshore resources and offshore food chains.

For example:

- tropical mangrove jack (*Lutjanus argentimaculatus*) and estuary cod (*Epinephelus coioides* and *E. malabaricus*) use fresh and brackish estuaries until they move offshore into the deep coral reef matrix of the GBR and mature (Sheaves 1995a);
- scarlet sea-perches (*L. malabaricus*, *L. erythropterus*) occur as juveniles in shallow bays before moving offshore on the central GBR (Ludescher 1997);
- several shark genera use shallow nurseries -- juvenile school sharks are probably not found anywhere outside the bays of the Bass Strait area (eg. Simpfendorfer and Milward 1993, Stevens FRDC #91/023) ;
- there are about 100 spp in the South East fishery, yet even basic life-history information is available for just a handful - there are "20 lost years" for orange roughy (see Caton *et al.* 1997 for reviews);
- for the SE fishery, the adults spawn on the shelf and slope, and juveniles recruit there, but by and large the larvae are found mainly between the coast and the mid-shelf - the inner half of the shelf is the most important larval habitat (p.c.# 1180 B.Bruce);
- however, morwong, trumpeter (*Latris lineata*) and *Arripis* larvae are way off the eastern Continental Shelf, 40-100 km offshore - some of these taxa have an extended pre-settlement phase (about 9 months for morwongs) ;
- Tasmanian jackass morwong and tiger flathead surveyed in waters 15m - 400 m deep show that their nurseries are in nearshore waters - blue grenadier nurseries are located right across the shelf from inshore shallows and bays to shelf break;
- Stevens *et al.* (1984) found marked increase in length with depth for *Caranx georgianus* and *Trachurus declivis* in the Great Australian Bight, but not for *Scomber* or *Sardinops*. *Scomber* were found in mainly 50-150m, *Sardinops* not greater than 100m deep.

The influence of inshore habitats is further extended offshore by movement of baitfish and other links, for example:

- Williams and Cappo (1990) documented a link, through baitfish life-histories, between mangroves and billfish grounds in the GBR Lagoon;
- tropical pre-settlement fish (including scombrids) are known to aggregate inshore before moving back offshore (see Thorrold 1993);
- this movement may be to take advantage of better food supply along plumes or the coastal boundary layer (Thorrold and McKinnon 1995);
- offshore advection of seagrass detritus after storms enriches pelagic food chains supporting the Tasmanian regions major predator - the blue grenadier (see Thresher *et al.* 1989, 1992);
- rafting of rocky shore drift algae along plumes, slicks and fronts are important pre-settlement habitat for many genera on the shelf (see Kingsford 1990 for review) - eg juvenile centrolophids (warehouse, blue-eye trevalla) are very poorly known, but have been found in association with floating drift algae and jellyfish.

Regional variation in life-histories

There are a variety of species that show flexibility in life-histories throughout their range. For example, Yellow-eye Mullet spawn in late autumn and early spring in southern WA to coincide with seasonal breaching of estuarine bars at that time -- whereas the same species spawns in summer on the NSW east coast; in January-April in the Coorong; and in autumn in Gulf St Vincent (Potter *et al.* 1990, Hall 1984).

There are also striking differences within genera and within species amongst regions. For example:

- most NSW studies have found newly-recruited yellowfin bream in seagrass beds or other submerged vegetation, yet Pollock and Williams (1983) found newly settled fish in turbid, mangrove-fringed areas in Moreton Bay
- studies on the central GBR indicate a shallow, inshore (<22m) distribution of juvenile *L. malabaricus* - but surveys by NTDFIP in the Arafura Sea found juveniles of *L. malabaricus* (6-7 cm) inshore and well offshore in deep water (>60m) with the adults (p.c.# 20 D.Ramm).

It is often difficult to tell from the literature how much of such regional life-history differences are due to a lack of sampling of the entire suite of possible recruitment sites in different studies. In Table 1.3.4.I we have given some examples of the striking differences

within genera, and amongst regions within species, which demonstrate the need for sampling of alternative habitats in life-history studies.

This realisation has occurred through the logical extension of research away from focus on single habitat types such as seagrass (see section 1.4.5.1 and West and King 1996). For example, Jenkins *et al.* (1996) found that juveniles of a number of important commercial species that had previously been found in seagrass were also present in some microhabitat types on shallow reefs. Significant shifts in juvenile habitat are now known to occur within the first few weeks and months after settlement from the pelagic environment. There is also poorly documented shift amongst habitat types during tidal cycles (see Laegdsgaard and Johnson 1995).

Table 1.3.4.1. Variation amongst species within genera, and within species amongst regions in requirements for nursery habitats.

| taxa | location | sediment, depth, vegetation | recruitment season | feeding habits | reference |
|-------------------------------|-----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|---------------------------------|---------------------------------------------------------------------------------|-----------------------------------------------|
| <i>Sillago analis</i> | Moreton Bay | muddy-sand <1m | | | Weng (1983) |
| <i>S. bassensis</i> | Cockburn Sound-Geographe Bay | <1.5 m bare sand, exposed | ? | | Hyndes, Potter and Lenanton (1996) |
| <i>S. bassensis flindersi</i> | Botany Bay | deep>4 m sandy sites | Aug | crustacea (75%) and polychaetes (14%) | Burchmore et al. (1988) |
| <i>S. burrus</i> | Cockburn Sound-Geographe Bay | <1.5 m bare sand; sheltered | Feb. | | Hyndes, Potter and Lenanton (1996) |
| <i>S. ciliata</i> | Botany Bay | shallow sandy beach <4 m and <i>Zostera</i> | Apr-June | polychaetes 61% and crustacea 37% ; ontogenetic shift away from small crustacea | Burchmore et al. (1988) |
| <i>S. ciliata</i> | Jervis Bay | sandy <1m | | | Jenkins et al. (1996) |
| <i>S. ciliata</i> | Moreton Bay | sandy <1m | | | Weng (1983) |
| <i>S. maculata</i> | Moreton Bay | muddy-sand to mud at 1-3m | | | Weng (1983) |
| <i>S. maculata maculata</i> | Botany Bay | shallow sandy beach <4 m and <i>Zostera</i> | Apr-Aug | crustacea (45%) and polychaetes (40%) | Burchmore et al. (1988) |
| <i>S. robusta</i> | Botany Bay | deep>4 m sandy sites | Aug | crustacea (48%) and polychaetes (39%) | Burchmore et al. (1988) |
| <i>S. robusta</i> | Cockburn Sound-Geographe Bay | ?deep >5 m | ? | | Hyndes, Potter and Lenanton (1996) |
| <i>S. schomburgkii</i> | Blackwood River estuary, WA marine embayments | | year-round | | Lenanton (1982) |
| <i>S. schomburgkii</i> | Cockburn Sound-Geographe Bay | <1.5 m bare sand, <i>Posidonia</i> (only 0.1%); sheltered | Feb. | | Hyndes, Potter and Lenanton (1996) |
| <i>S. vittata</i> | Cockburn Sound-Geographe Bay | <1.5 m bare sand, sheltered | Feb. | | Hyndes, Potter and Lenanton (1996) |
| <i>Sillaginodes punctata</i> | Cockburn Sound-Geographe Bay | <1.5 m bare sand, <i>Posidonia</i> (only 1.2%); sheltered | Nov. | | Hyndes, Potter and Lenanton (1996) |
| <i>S. punctata</i> | Barker Inlet | sheltered; intertidal (<i>Zostera muelleri</i>) | Jun-Jul; 70-80 d. larval life | | Connolly (1994a), Fowler and Short (1996) |
| <i>S. punctata</i> | Port Phillip Bay | sheltered: <i>Heterozostera</i> , but also reef-algal (fine <i>Gracilaria</i> or <i>Ceramium</i> ; not <i>Cystophora</i>) | Sept-Oct; 100-170 d larval life | benthic crustacea (84%), polychaetes (26%) | Jenkins et al. (1996), Edgar and Shaw (1995b) |
| <i>S. punctata</i> | Yorke Peninsula | shallow <i>Posidonia</i> , intertidal <i>Heterozostera</i> , <i>Zostera</i> ; reef-algal <i>Hormosira</i> | | | Jenkins et al. (1996) |

In the following boxes we have assembled notes on some major taxa to give insights into the variation and directions of R&D.

Box 1.3.4.2 KNOWLEDGE OF FISHERY-HABITAT ASSOCIATIONS - JUVENILE KING GEORGE WHITING

Juvenile King George Whiting show a clear change in habitat preference with growth:

- post-larval settlement is initially to seagrass - in Port Phillip Bay (PPB) they recruit even far inside the boundaries of thick beds and dense blades of *Heterozostera*
- young juveniles are eating meiofauna near seagrass (mainly harpacticoid copepods) in great amounts -- epibenthic harpacticoids are the key to habitat selection, and juveniles ($\leq 20\text{mm TL}$) prey on them to an almost obligate extent
- at one site larvae will settle on bare sand (Swan Bay) because nearby seagrass is very dense and produces a pool of very rich detritus and outstandingly rich meiofauna in the sand there -- in finer sediments with much detritus there are up to 100,000 harpacticoid copepods m^{-2} , whereas out in St Leonards there are almost no epibenthic copepods in the sand.
- there are also direct correlations between growth rates and feeding rates - both are higher in the finer grained/higher organic content sediments -- productivity is inversely related to the grain size of the sand. The food function of the seagrass beds is probably more important than the shelter function
- juveniles can settle on macroalgal -- provided they are in the right (shallow) depth. There are more settlers on the fine red algae and filamentous forms than the large thallose forms, however. These include *Gracilaria*, but not *Cystophora*, and also a kind of unknown finely branched 1mm diameter red alga, somewhat like *Ceramium* or *Polysiphonia*
- there are ontogenetic shifts with growth to unvegetated habitats and/or reef/algal habitats within the first six-months of life
- the settlement variability comes down to passive transport that brings them into an area, then choice of microhabitat occurs as the juveniles start to cue in about a month after settlement by seeking a food-rich area
- At Grassy Point in PPB there is consistently high settlement -- a "hotspot" like Towra Point in Botany Bay. Modelling (Jenkins and Black 1994) predicts an eddy around Grassy Point where juveniles will be aggregated. Wave heights are added onto the currents in the model, as the larvae are extremely vulnerable, and are re-dispersed or killed by high wave energy. The model can predict pattern of settlement with an $r^2 = 0.75$
- in SA older juveniles move intertidally, but younger juveniles are subtidal and occur in less than 2m depth -- unlike PPB the SA juveniles continue to be associated with seagrass rather than making an ontogenetic shift to bare mud and other unvegetated habitat
- in SA there are distinct recruitment hotspots (Barker Inlet is the most important site in the State) -- characteristic conditions are shelter, and almost intertidal/subtidal seagrass (*Zostera* and *Heterozostera*). The western sides of Gulfs have plenty of seagrass, yet not so much shelter, and therefore less recruits
- work in SA now will focus on spawning and advection models, larval condition indices as a means of predicting and testing recruitment patterns; in Vic. There is a proposal to test the predictive capacity of the advection models in Corner Inlet and Westernport.
- larvae are in top metre during day in PPB (wind driven) and then spread to deeper water during the night (tidally driven)

(p.c.#1680 G.Jenkins, p.c.#1520 A.J. Fowler, p.c. #970 M. Keough)

Box 1.3.4.3 KNOWLEDGE OF FISHERY-HABITAT ASSOCIATIONS - JUVENILE SNAPPER

Primary research on the NSW snapper fishery is to develop an age structure and recruitment and juvenile surveys are only secondary, in collaboration with QDPI (FRDC#93/074).

- West (1993) noted many fewer juveniles in the northern river samples compared with bays and estuaries of central and southern NSW, despite the proximity of a major fishery for them, but this can explained this in terms of a preference of juveniles for areas of lesser freshwater influence.
- north of Forster, Wallis Lake, until Moreton Bay there are no "fully" sheltered habitats, only creeks and rivers, but snapper do not like freshwater. Therefore, NSWFRRI have designed a fish trap to survey young-of-the-year snapper on the shelf grounds in this area
- surveys are in place off all ports within 4 slabs of coast roughly 100 km long : Tweed-Ballina, Coffs Harbour, Crowdy Head-Forster, Tuggerah Lakes-Sydney
- in good recruitment years, snapper "fill other habitats" - but there are certain habitats that always support juveniles even if recruitment bad
- therefore recruitment studies cannot adequately detect year class strength without sampling in appropriate strata, and to do this need random sampling in "preferred" and "other" microhabitats
- bycatch studies record juveniles down to at least 30 fathoms
- the FRI surveys therefore use the pro fleet to deploy traps in plots in a mixed design
- this equates to 50% random sampling (by specifying plotter coordinates where pros should deploy), and 50% "targeted" where pros are allowed to set on grounds where they know juvenile snapper occur
- there is also estuarine survey work in areas where they are known to occur (all work in Sydney and North)
- in NZ a factor of 12 in interannual variation in recruitment can be pinned down to water temperature. Therefore pros will be using PVC bottle with pinhole in traps to measure bottom water temperature and SST
- preliminary findings are that a 2° C change will double catch - it is not the warmth but the change that is important, and the mechanism is catchability not movement - the EAC sucks a colder water counter-current along inshore on very short time scales
- snapper juveniles are a bycatch issue --trawled vs trawlable and closed vs untrawled showed 8 fold difference in abundance between trawled and untrawled.

For the east coast adults it is known now that the oldest and older fish are all at the northern end of the range:

- off Fraser-Moreton there are many 5-10+ fish
- the age at maturity = 2-3+ but roe size and % roed increases with age/size and location northwards
- one model has the Mackay run as the parent stock for the entire east coast
- off the central NSW coast all snapper are <= 3-4 +
- the timing of spawning becomes later as with location south - off Fraser= May, Oct-Nov in Botany, January in Port Phillip Bay

Similar juvenile flexibility is seen in SA:

- 0+ fish mainly in northern top of Spencer Gulf -- a cyclonic gyre there concentrates eggs and larvae
- there is a big year class now (1991 spawning) and the juveniles of that year class were found over seagrass and all other habitats from deep to shallow.

(p.c. #470 D. Ferrell p.c.#1580 D. McGlennon)

Box 1.3.4.4 KNOWLEDGE OF FISHERY-HABITAT ASSOCIATIONS -- PRAWNS

Prawn life-histories show a profound influence of sediment type and grain size, and salinity tolerances, on adult distributions, and wide difference in use of aquatic vegetation as nurseries:

Tiger Prawns (*Penaeus semisulcatus*, *P. esculentus*) use intertidal, shallow seagrass or ephemeral algae (eg. *Caulerpa*) as nurseries. The adults prefer finer sediments with a large mud fraction.

- structure, rather than vegetation type is a major factor
- depth of seagrass is very important in defining critical prawn nursery habitat - a restricted band of shallow intertidal to just sub-tidal seagrass is most important
- *P. esculentus* does occur in seagrass on reef tops in Torres Straits
- *P. monodon* requires inshore muddy sediments and estuarine nurseries

Banana Prawns *Penaeus merguensis* have strong association with mangrove creeks and shallow muddy canals - the post-larvae extend to the very upper tidal limit at backs of forests, beyond the range of fish

- shallow mudflats near mangroves very important
- the juveniles dwell in creek margins during low tide and forest during high tide
- structure of mangrove pneumatophores are important shelter from predation

Sediment type may also be a limiting factor for *P. merguensis* - mangrove species type does not explain much variance. Rainfall has complex influence on emigration to fishing grounds.

In contrast there is no knowledge of habitat requirements for the Red-leg Bananas (*P. indicus*).

Red-Spot Kings (*Penaeus longistylus*) work off Townsville found juveniles on reef tops and adults on hard-coraline sand substrata.

Eastern Kings *Penaeus plebejus* are ATYPICAL. They are highly migratory -- departing NSW then moving north (>= 1000 km reported). Larvae reach nurseries in a short period - they require quartz/sandy sediments and do not like freshwater influence. The mouth of the Noosa River is a well-known nursery area. Although the species migrates, Rothlisberg *et al.* (1995) found evidence of small pockets of localised nearshore spawning within 2 km of the coastline near estuaries. Nearly 40% of tagged ones go south and mature females have been found as far south as Sydney -- this is within the proposed larval advective distance (200km) needed to supply Lakes Entrance -- long-distance larval dispersal from Qld to Victoria does not have to be invoked. This advection and dispersal does account for the occurrence of *P. plebejus* as far afield as New Zealand and Tasmania, but no systematic latitudinal sampling of the occurrence of spawning females or early larval stages has been undertaken.

Blue-Leg Kings (*Penaeus latisulcatus*) are found around river mouths as juveniles in the north. They prefer a hard-silica sand substratum. Nurseries are largely unknown in the north, but well known in the south and west:

The western kings in SA live 3-4 yrs and aggregate in NE parts of the Gulfs to spawn Oct-March

- larvae spend 42-48 days in the water column with wind-driven, northward larval transport
- Jan, Feb, March are main settlement times -- interannual variability and east/west side of Gulfs differences in settlement are driven by wind
- in Spencer Gulf, settlement generally higher on Western side of Gulf, but conversely, higher on Eastern side of Gulf in St Vincent
- approach is to find spawning aggregations and predict dispersal based on hydrodynamics, then test these predictions based on the distribution of settlers - but none of the 6 years recruitment data seem low enough to limit numbers of recruits going out into fishery
- post-larvae and juveniles are in unvegetated shallow, intertidal and sub-tidal (narrow belt) in WA estuaries -- inshore of the seagrass in the intertidal zones of the northern Gulfs in SA
- Port Wakefield at the very top of Gulf St Vincent is prime nursery - with consistently highest settlement per month
- organic content of sediments probably higher importance factor than grain size

Metapenaeus - inshore endeavours, school, and greasyback prawns

- are affiliated with freshwater inputs and very muddy sediments, also complete life cycles in shallower and lower salinity waters cf. *Penaeus*

(p.c. #140 A. Courtney, p.c. #80 N. Gribble, p.c. #1550 M. Kangas, p.c. # 290 N. Loneragan)

1.3.5 The concepts of “estuarine dependence”, “estuarine opportunism” and “critical habitats”

There has been a long history of recognition by the fishing industry that healthy estuaries are vital for sustaining production (eg. Anon. 1985a, Anon. 1992a, Leadbitter and Doohan 1992) and the research community has responded with a variety of studies (Quinn 1993) leading to some generalisations (Young and Glaister 1993) - yet definitive knowledge of “critical habitats” for conservation and restoration is not readily available (see papers in Hancock ed. 1993). The lack of this specific information needed for coastal management has been a source of criticism of Australian marine science, and attributed in part to pursuit of academically attractive small-scale experiments at the expense of basic inventories and life-history studies (Zann 1996).

The degree to which various inshore and marine fishes of the Indo-West Pacific may be dependent on estuaries, particularly as nurseries, has received much focus in the literature (eg. Blaber 1985, Blaber *et al.* 1989, West 1993, Lenanton and Hodgkin 1985, Lenanton and Potter 1987 and see Appendix 4). These and other studies have not produced an overriding conclusion, other than that most species spawn in the sea, and that in some regions estuaries are the only areas suitable as nurseries (this is more the case on the east coast, than for the north tropical coast in Australia).

Key attributes of suitable nursery habitats in the tropics are

- shallows
- turbid conditions
- variable salinities with periods of low salinity
- sheltered, low (wave and tide) energy waters
- muddy substrata that generally produce more benthic food sources

Such areas can extend out in whole seas (eg. Malaysia) in the tropics - hence the use of the term “estuarisation of the shelf” - that offer an abundance of alternative nursery sites for fished species.

There are not necessarily the same suite of attributes in temperate Australia, because there is a wholly different fish fauna that is biologically less diverse, and there is a vastly different balance of biological and physical forces. One of the major differences concerns the influence of lower temperatures on osmoregulatory performance. Maintenance of a narrow salinity/temperature balance is not so critical in the tropics, whereas salinity

change in temperate estuaries has far greater effects because of the limiting physiology of osmoregulation at lower temperatures (p.c.# 280 S.Blaber).

Tropical species can therefore cope well with estuarine salt wedges, whereas the wedge profoundly influences the distribution of temperate species (eg. see southern WA papers in Appendix 4). For example, Blaber (p.c.#280) found the giant trevally *Caranx ignobilis* and the big-eye trevally *C. sexfasciatus* in the tropical Kosi Bay estuary down to about 0.25 ppt - the bare minimum needed for kidney function -- but temperature has to be a optimum level (Whitfield et al. 1981). The same species are found in freshwaters of the north Queensland estuaries (p.c. V. McCristal), and there is an increasing awareness of the ability of our tropical serranids and lutjanids to persist in low salinities (eg. Sheaves 1996). In contrast, no temperate carangids enter freshwater, major movement away from freshets occurs in northern NSW estuaries (eg. Andrew et al. 1995) and there are few euryhaline species in the south (eg. black bream).

Surprisingly, we could not find any Australian literature using such a fundamental concept since Dall (1981a,b), but it fits well the conclusion that there is more plasticity in the life-histories of tropical species.

Several respondents in the interviews for this review had serious reservations about the prevailing, narrow use of the concept of “critical habitats” (p.c. # 720 D. Staples, p.c.#540 R. West). Instead, a “chain of habitats” concept is a useful one for Australian species and it is important to manage entire systems - not just focus on habitat subsets, such as seagrass. For example, yellowfin bream (*Acanthopagrus australis*) need recruitment sites in submerged vegetation (eg. freshwater macrophytes, *Ruppia*, seagrass, mangroves), but then move to and feed over beach sand and exposed rocky headlands through their life-history, before spawning in sand-bar zones at river mouths. A variety of tropical lutjanids and serranids are also known to recruit to nearshore habitats and remain there as pre-adults, but then move offshore for the remainder of their mature, spawning lives (eg. mangrove jack and estuary cod; Sheaves 1995a).

These associations between fisheries and habitat are explored further in the subsequent sections of this chapter.

The focus in the literature to date has been classification of fish species as “estuarine”, “estuarine opportunists”, “marine stragglers” and “marine” based on their occurrence in

estuaries and adjacent habitats (eg. Blaber *et al.* 1989, Lenanton and Potter 1987, Potter *et al.* 1990, West and King 1996).

For example, Lenanton and Potter (1987) concluded that virtually none of the commercially important marine species in WA could be considered entirely dependent on estuaries, and that these marine species would be best regarded as “estuarine opportunists” rather than “estuarine dependents”.

Lenanton and Potter (1987) calculated the total commercial catch of fish, molluscs and crustacea taken between 1976 and 1984 in open marine waters, marine embayments and estuaries in temperate WA from the Murchison River 27°S to 36°S and 124°E just east of Esperance according to five life-history categories. We have tabled examples of their classification in Table 1.3.5.1.

| Table 1.3.5.1. Classification of Western Australian commercial catch by life-history category - *top 8 groups selected from Table 2 in Lenanton and Potter (1987). β % of total fish catch. | | | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|-------------------------------|------------------------------------------|--------------------------------------|
| Estuarine | Semi-anadromous | Predominantly estuarine (M-E) | *Estuarine and inshore marine (M-E & IM) | *Marine (M) |
| <i>Acanthopagrus butcheri</i> | <i>Nematalosa vlaminghi</i> | <i>Mugil cephalus</i> | <i>Arripis truttaceus</i> | <i>Thunnus maccoyi</i> |
| | | | <i>A. georgianus</i> | <i>Sardinops neopilchardus</i> |
| | | | <i>Aldrichetta forsteri</i> | <i>Sardinella lemuru</i> |
| | | | <i>Cnidogobius macrocephalus</i> | <i>Furgaleus and Mustelus sharks</i> |
| | | | <i>Pagrus auratus</i> | <i>Carcharhinus sharks</i> |
| | | | <i>Hyperlophus vittatus</i> | <i>Glaucosoma hebraicum</i> |
| | | | <i>Sillago schomburgkii</i> | <i>Mustelus antarcticus</i> |
| | | | <i>Sillaginodes punctatus</i> | <i>Seriola hippos</i> |
| β 0.3 | 1.5 | 3.9 | 36.4 | 57.9 |

Catches in estuaries directly contributed 6.0% of total catch and 12.1% of all finfish.

The black bream (*Acanthopagrus butcheri*), river garfish and school prawns were the only species confined to estuaries and the Perth Herring (*N. vlaminghi*) is the only semi-anadromous species, passing upstream from the sea to breed in the upper estuary.

The weight of estuarine dependent fish species represents 20.3% of the total commercial fish catch -- mainly due to large catches of species which make use of both estuaries and

inshore marine environments. This is much lower than the estimates of Pollard (1981) for NSW, due mainly to the very large catches of rock lobster, tuna and pilchards. When tuna catches were very low, the weight of estuarine-dependent fish species represented 64.8% of the total finfish catch.

Lenanton and Potter (1987) then concluded that “estuarine dependent” was too definitive for describing the relationship between many marine species and estuarine habitats. They considered that these species would survive if estuaries were removed and proposed that the term “estuarine opportunist” is more appropriate than “estuarine-dependent”.

In south-western and southern Australia very few species have been considered to be estuarine dependent and sheltered marine embayments (eg. garfish, sand and king George whiting) or exposed sandy beaches (eg. yellow-eye mullet, *Aripis* spp, *Sillago bassensis*) provide alternative habitats (Lenanton 1982). Important exceptions are known to be Black Bream and school prawns (*Metapenaeus dalli*), which rely on low salinities for spawning cues. Lenanton (1977) suggested that the reddish carotenoid pigment of ovaries in black bream are adaptations to estuarine spawning to aid egg cell respiration in estuarine waters of low oxygen tension. Hall (1984) noted that the greenback flounder (*Rhombosolea tapirina*) in the Coorong also have this pigment, but there has been no further examination of this feature in life-histories. A number of studies in WA have concluded that Black Bream, Yellow-eye mullet and Sea Mullet have preferences for reduced salinities and/or features associated with riverine environments (Potter and Hyndes 1994).

Part of the problem with the deliberations on estuarine dependence concern the mixture of temporal and regional scales in the debate. From a palaeohistorical and evolutionary point of view, one leading authority concluded that “.....estuaries are transitory features in a geological sense and could not be depended upon as critical environments for the survival of marine species in coastal environments.....”. The rejoinder of Blaber et al. (1989) to this statement was that coral reefs are also transitory and estuarine species are no more dependent on a single estuary than coral reef fish are dependent on a single coral reef.

Blaber et al. (1989) demonstrated that, even if one excludes the truly estuarine gobies, gudgeons and other small taxa, at least one-third of the Embley River species are

estuarine-dependent-- including the economically attractive mullets, barramundi, queenfish and whiting.

Lenanton and Potter (1987) do acknowledge that if estuaries were removed overall numbers of fish might decline, and that growth rate of species (and hence production) is generally greater in estuaries than in alternative inshore marine nursery areas.

Therefore, we consider that for the purposes of assessing fisheries habitats (and not just life-histories and evolutionary patterns) the overall argument is a semantic one and the coastal fisheries in estuarine areas are, indeed, estuarine-dependent.

Such semantics can demean the importance of estuaries if the classifications are taken out of context, and may be misleading if alternative habitats have not been sampled.

For example, West (1993) classified yellowfin bream, mullet and tailor as “estuarine opportunists” in NSW, but to our knowledge newly-recruited yellowfin bream are most abundant in estuaries in NSW (see Pollard 1992) and very small mullet have not been caught outside them -- due to both the habitat preferences of the fish and a lack of alternative sheltered habitats.

Despite the lack of sampling there, it is unlikely that the exposed coastlines of NSW, Victoria, Tasmania and SA will prove to be suitable nursery habitats for the majority of economically important inshore fish species after they settle out from pelagic stages. Wave energies are high and the clear waters are generally deep close to shore. This is unlike the situation described by Lenanton (1982) for south-western WA where fringing limestone reefs offer sheltered nearshore habitats.

The definition we adopt here is adapted from Blaber *et al.* (1989) “ -- an ‘*estuarine dependent*’ species is defined as one for which estuaries, or similar habitats, are the principal environment for at least one part of the life cycle, and without which a viable population (fishery) would cease to exist”.

For these reasons we would classify Australian fisheries for the black bream, yellowfin bream, sea mullet, luderick, mullet, some flathead species, school prawns and perhaps tarwhine as “estuarine dependent” due to the lack of alternative habitats or for the purposes of sustaining commercial fisheries.

The lack of detailed early life-history information and comprehensive surveys of alternative, non-estuarine habitats prevents further useful speculation - especially for tropical species -- and there is also clear evidence that there are differences in habitat use at many levels, for example:

- a number of species that are either estuarine *sensu stricto* or as young juveniles prefer estuaries in temperate WA, also occur in marine environments further north in subtropical regions where there are no permanent estuaries (eg. tailor, yellow-tail trumpeter, western school prawn, western king prawn and blue manna (sand) crab
- estuarine dependence in sub-tropical and tropical faunas is not confined to particular families, or even genera. For examples, *Gerres filamentosus* and *Gerres oyena* are estuarine dependent, whereas *Gerres subfasciatus* is not (Blaber *et al.* 1989); *Sillago sihama* and *S. analis* are considered estuarine-dependent (Blaber *et al.* 1989), but *Sillago schomburgkii* and *S. bassensis* are not (see Table 1.3.4.1); *Acanthopagrus australis* can recruit in marine waters, but *A. butcheri* apparently requires low salinities to spawn
- there is even intraspecific variability within regions: yellowfin bream (*Acanthopagrus australis*) recruit to sub-tidal, vegetated habitats - exclusively in estuaries on the north coast of NSW, but also into sheltered bays on the central and south coast; barramundi recruit to both hypersaline and freshwater limits of the tide in the NT.

Widely cited, but rare, studies estimating the recurrent, annual monetary value of estuaries and seagrass beds include those of Pollard (1981), Blamey (1992) and Watson *et al.* (1993). The values are surprisingly high - more so when it is considered that they can be accrued indefinitely given adequate management.

1.4 An overview of processes, connectivity and production in the major fisheries habitats

In the following sections we provide the detailed context of habitat processes and links that must be considered in assessing threats and strategic R&D gaps. NOTE: The information given below on processes and connectivity in individual habitat types is not always fully referenced, because it comes mostly from an extensive review of the international literature by Alongi (1997). The sections on fishery-habitat links are focussed solely on Australian information and all citations are supplied.

1.4.1 Coastal freshwater

The areal expanse and persistence of coastal freshwater habitats are controlled by a variety of land-based, atmospheric and marine-related processes. With regard to tidal wetlands along Australia's coastlines, rainfall and evaporation rates are central to their existence. Indeed, it is generally recognised that the main driving force responsible for the existence and ecology of coastal freshwater systems is the "flood pulse" (Junk *et al.* 1989). A range of freshwater pulses (from short to long duration and predictable to unpredictable) regulates river-floodplain ecosystems (see Boon and Brock 1994).

Hence, the natural ecosystem dynamics of these systems are cued to freshwater inputs. In temperate Australia, rainfall is strongly seasonal in most areas, although droughts are common. Fish yields are closely linked to pulses of greater primary production as a result of the flood pulse events (Briggs *et al.* 1993). In temperate lotic systems, light and/or temperature variations as well as anthropogenic modifications may ameliorate the impact of flood pulses. In billabongs, for instance, seasonal growth and germination of plants and animals is timed not only to flood events but to species' sensitivity to a combination of high minimum and maximum temperatures (Britton and Brock 1994, Brock *et al.* 1994). Drought-resistant plants such as charophytes (eg. *Chara australis*) respond to water level changes by altering morphology and resource allocation (Casanova 1994). These habitats can be the source for rich invertebrate communities (crayfish, insects, gastropods, etc) that are in turn a food source for low diversity fish assemblages (Bunn and Boon 1993, Cheal *et al.* 1993, Merrick and Schmida 1984).

In the tropics, flood pulses are more intense as rainfall is greater closer to the equator and highly seasonal, large floods often follow cyclones or are associated with monsoonal rain depressions (Lough 1993). For instance, in the Pilbara region of Western Australia, coastal freshwater habitats are ephemeral due to low rates of precipitation ($< 200 \text{ mm yr}^{-1}$) -- rainfall is highly coincident with tropical cyclones originating in the Indian Ocean. Flash floods in low-lying salt pans result in algal blooms in coastal billabongs and streams and several species of birds and other fauna rely on the presence of these temporary habitats.

These areas quickly run dry however, so most freshwater and estuarine fauna either rely greatly on the presence of coastal fringes of mangroves in this dry coastal region, migrate, or die-off. In the humid tropics, such as in north Queensland, summer wet season precipitation is greater and somewhat more predictable, resulting in larger expanses and

persistence of coastal freshwater habitats -- wet season blooms of macrophytes and other algae are common (see Pajimans *et al.* 1985 for review). In these rivers, fish assemblages appear to be more species-rich than other tropical Australian rivers of equal size, attributable to greater habitat diversity and more constant and predictable freshwater flow (Pusey *et al.* 1995a,b).

In both temperate and tropical rivers, salinity gradients seaward determine the community composition of submerged vegetation, and fish and invertebrate communities. Some freshwater macrophytes such as *Vallisneria*, *Egeria densa* and *Ruppia* can survive in occasionally saline water and live in both freshwater and brackish-waters (0- 15 ppt). Others, such as the giant water-lily, *Nymphaea gigantea* are extremely eurytolerant.

Rainfall (or the lack of it) is therefore a prime driving force behind the dynamics of coastal freshwater systems, both tropical and temperate. A comprehensive analysis by Bayley (1991) suggests that the 'flood pulse advantage' (the amount by which fish yield per unit area is increased by flood pulses) is evident for both tropical and temperate fisheries, and that to mimic flood pulses would be of great benefit to restore fish communities depleted in degraded systems. Whether or not such an approach is workable in Australia is the subject of intense R&D at present (see series of papers in proceedings of "Environmental Flows Seminar" eg. Arthington and Pusey 1994), but the idea underscores the dominance of freshwater flow of the central mechanism driving coastal freshwater ecosystems.

Flood pulse events naturally carry over into the estuarine zone, delivering freshwater, sediments, nutrients and contaminants into the coastal zone. Such events are most dramatic in the wet tropics. The most extensive data for Australia is for the Great Barrier Reef region (see reviews of Wasson 1997, Rayment and Neil 1997). From the 18 largest rivers, it is estimated that from 7.4 to 28 million tonnes of sediment per annum is transported into the lagoon. In terms of nutrients, from 57 - 2065 tonnes of phosphorus and 1947-4258 tonnes of nitrogen are deposited into GBR waters per year. Upwelling and river discharge account nearly equally for at least 75-80% of total inputs.

Rivers with intense land use (mainly grazing, forestry, canelands) in their catchments discharge nearly four times more material than rivers associated with no or weak land use. The types of materials discharged include fertiliser and natural soil nutrients, pesticide residues, heavy metals, remobilised freshwater sediments, and eroded soil. Approximately 80,000 tonnes of fertiliser nitrogen and 17,000 tonnes of fertiliser P are discharged into

the GBR, mainly via soil erosion during the summer wet season. Terrestrial runoff is the largest source of sediment and nutrients from the continent to the coastal zone.

Variability in river discharge encompasses variability in temporal patterns of precipitation, from recurrent summer wet season flows in the wet tropics to irregular, episodic floods in the dry tropics. A good example of river export is the study by Mitchell *et al.* (1997) for the Herbert River catchment in north Queensland. Studying changes in river chemistry during a flood event following Cyclone Sadie in 1994, they calculated an export of at least 600 tonnes of N, 65 tonnes of P, and 100,000 tonnes of suspended sediment over this six and one-half day flood event. This underscores the importance of intense, short-term climatic events on the connections between continental and coastal ecosystems.

In most coastal regions, freshwater discharge into the coastal ocean is manifested as extensive river plumes. The extent to which the material exported by plumes into the coastal zone impacts on pelagic and benthic food webs, including fish communities, is poorly understood. It is known that phytoplankton blooms occur after post-flood events, but the fate of this photosynthate is not clear. Ichthyoplankton and larger zooplankton assemblages show temporally dynamic and taxon-specific responses to river plumes associated with the wet season and benthic responses are even less known.

In the central Great Barrier Reef lagoon, Thorrold and McKinnon (1995) found that both community structure and abundance of larval fish were greatly influenced by the presence of river plumes. Taxonomic affinities were similar between fauna sampled from the plume front and from coastal waters, and appeared to be driven by offshore movement of the plume translocating larvae offshore. This movement may explain the accumulation of fish larvae at the plume front that in turn may have affected larval recruitment and survival. It is not known whether these larvae are attracted and feed on the abundant phytoplankton and zooplankton at the plume front.

It should be pointed out that not all river plumes result in enhanced biological activity. For instance, phosphate levels are several times greater (50-100 Molar) off the Fitzroy and Brisbane Rivers, but turbidity suppresses algal blooms and, presumably, other biological activity. It is likely that the impact of freshwater flow into most coastal zone areas of Australia (including mangroves and salt marshes) is much more subtle than the dramatic impacts observed at river plume fronts in influencing rates of plant growth, altering

seasonal community composition of both plants and animals, and producing biogeochemical gradients and fluxes across the land-sea boundary. Needless to say, such subtle impacts have rarely been clearly demonstrated in Australia's coastal zones.

1.4.1.1 Fishery-habitat links

The importance to fisheries of environmental flows of freshwater is illustrated in section 2.3.

Submerged and emergent aquatic macrophytes are known to provide shelter and presumably the basis for food chains in coastal freshwaters, but there are very few publications outlining their role in coastal supporting fisheries. This neglect is surprising, given their abundance and the popular scientific view that carp (*Cyprinus carpio*) are destroying them (eg. in the Gippsland Lakes). Their role in the freshwater and "gradient" zones of estuaries is locally important as West (1993) found significant beds of *Vallisneria spiralis* (about 17km²) in the Clarence River Broadwater to be an important nursery for yellowfin bream. The introduced "Elodea" or "Grafton weed" *Egeria densa* was also found to shelter new recruits of yellowfin bream and Australian Bass (also see Gehrke and Harris 1996).

The role of the ubiquitous common rush *Phragmites australis* is unknown, but would presumably provide shelter, epiphytic algae for grazing by sea mullet and other herbivores and the detrital basis of food chains.

The role of riparian and aquatic vegetation is generally unknown but the use of stable isotope tracers has produced very promising results in assessing the lack of contribution of introduced weeds (see Bunn *et al.* 1997 in section 5.3.3).

Catadromous and anadromous coastal fishes (eg. bass and barramundi, eels) and crustacea are the most vulnerable species and the threats are outlined in subsequent chapters. For example, the barramundi is a cultural icon and is threatened by interruption of its life-history on the east coast - the juvenile habitats are described in box 1.4.1.1.

Box 1.4.1.1 A CASE STUDY OF THE COMPLEXITIES -- BARRAMUNDI LIFE-HISTORY

On a regional basis catchments with big floodplain reserves have bigger populations and better growth rates, but in the absence of freshwater swamps, juveniles will use saltmarsh swamps in the Gulf hinterland. In the NT they can spawn in a whole range of estuarine habitats but on the east coast sandbars at river mouths are important. The cause of decline of the east coast commercial harvest to about 118 tonnes has never been partitioned by habitat loss and fishing. Rainfall is a key determinant of year class strength in both the NT and Qld.

Key attributes of habitat links are:

- nursery habitat could best be characterised as tidal swamps at the upper reaches of the tidal range, where it meets freshwater, but also where there is no freshwater
- prime habitat in the NT are wetland areas where the tide just reaches in September, October and November? , but it is by no means clear that these are the only areas - eg Leanyer swamp backed by high country, and the wide Mary River floodplain with extinct chenier dune systems.
- the plant *Peplidium* may be a useful indicator of suitable habitat, and this could be surveyed aerially and mapped, but no definitive research yet
- in Qld they are opportunistic but freshwaters are prime habitat - eg some juveniles are found in the seagrass at the mouth of the Johnstone, but mostly upstream in the Booleroo Swamps. The upper freshwater reaches provide the prey, shelter and lack of predators comprising ideal nursery habitat. The larvae and postlarvae have positive, upstream-swimming behaviour when young and are well camouflaged
- there may be quick ontogenetic shifts in habitats in some systems. In Trinity Inlet surveys could not find size classes between 6-7 mm and 100 mm -- they must have been upstream.
- lower salinities may be spawning cues, but juveniles are tolerant of a range of salinity - at the mouth of the Norman River there are huge floodplains with small channels and open pools, which are all saline or hypersaline and barra juvenile use these
- sampling difficulties make it unknown to what extent mangroves are used by very young fish - development of an innovative juvenile "collector" by NTDPIF (FRDC#94/144) offers much potential
- there is a gap in knowledge about where they are immediately after hatching -- when there is no water in the swamps, or the tide is not high enough -- where are the larvae/juveniles ?
- larvae have been caught at the South Alligator Bridge 70 km inland
- key uncertainties concern the CUES that juveniles use to enter and leave nurseries to avoid being trapped in drying swamps

QDPI Northern Fisheries is also involved in an intensive mass-marking of restocked juveniles to develop guidelines on release strategies. By releasing 40-50 mm and 60-70mm fish they will be assessing the optimum size at which fingerlings should be restocked. By releasing in the upper freshwater, tidal, upper-tidal interface and swamps, they will also be able to assess both survival in different habitats and also infer paths of movement between habitats. They will monitor angler and pro. fishing catches as well as some sampling of their own, but the fish should reach the fishery mainly as 3+ yr olds in the summer of 1995/96.

Over 40 returns to date (Nov 1995) show they are surviving, but here is clear difference in growth rates due to food availability between tidal and freshwater. This will help assess rate and amount of stocking required, but there needs to be a hatchery code of practice to assure the gene pools are not declining.

(p.c. #1670 R.Griffin, p.c. # 1230 T. Davis, p.c. #70 J. Russell) and see Russell and Rimmer (1997)

1.4.2 Saltmarsh (and saltpan)

Like other intertidal habitats bordering both land and sea, salt marshes exchange biota, nutrients, and other dissolved and particulate materials and gases with adjacent ecosystems. The extent to which salt marshes interact with bordering habitats depends upon many factors, any combination of which can result in ecologically distinct marshes even within the same climatic region. Australian salt marshes have a reciprocal distribution to mangroves, occurring most extensively > 30°S latitude. However, this statement is only true if saltpans associated with marshes are excluded. Otherwise, Bucher and Saenger (1991, 1994) have shown that saltmarshes actually have more area than mangroves in northern Australia, and that most saltmarsh is in Qld, the NT and northern WA. Only the plant species richness increases in marshes in the south (Adam 1990).

Saltpans with fringing saltmarsh vegetation cover very large areas of northern Australian estuaries, and surveys have commenced to determine their role as prawn habitat (p.c. R.Connolly, Griffith University). Salt marshes have been subjected to human impact to a much greater extent than their mangrove counterparts along the more populated southern coast, but there is also concern about the loss of such habitats due to flooding by artificial damming in northern WA and by ponded pastures in central Queensland.

To a lesser extent than mangroves, salt marshes trap and bind sediments, and recycle organic matter and nutrients via detritus-based food chains that (in concert with high rates of plant productivity) are responsible for marshes being coastal habitats rich in animal life. Such richness is maintained by the complex physical and ecological connections marshes have with neighbouring terrestrial habitats, the coastal ocean and the atmosphere. Interrelated environmental factors influencing salt marsh vegetation include tidal inundation (both elevation and frequency), height of the freshwater table and proximity to freshwater, soil salinity, rainfall, evaporation, insolation, soil composition, drainage and aeration.

Salt marsh connections to the adjacent coastal ocean have been examined within the context of “outwelling”, that is, the export of nutrients or organic detritus from fertile estuarine areas to support productivity of offshore waters. Recent reviews indicate that while most salt marshes export some material, many others do not -- no data are available on outwelling from Australian marshes, despite their proximity to major nurseries. This is unfortunate because outwelling and other exchanges of material and

biota with adjacent coastal systems is a key ecological process that is both a reflection of, and a cause for, high estuarine productivity, including fish. The amount of material exchanged is influenced not only by rate of primary and secondary production, but also by physical characteristics, to the extent that each system is unique. These characteristics include:

- tidal range
- ratio of wetland to watershed area
- water circulation
- total wetland area
- frequency of storms and rainfall
- volume of water exchange.

Recent studies have indicated that the role of micro- and meso-scale hydrodynamics is crucial to material and biotic exchange processes in salt marsh systems (see Alongi 1997). Many hydrodynamic constraints can have ecological consequences. For instance, intricate and long creeks will result in weak dispersion at the upstream end and weak secondary flows compared to a short, single-branched waterway. This results in more trapping of materials upstream, lower dissolved oxygen, and more complete aggregation of detrital particles in the creek water. Further, these physico-chemical changes can alter the dynamics of lower trophic levels that support fisheries. For instance, bacterial numbers and productivity are closely regulated by:

- nutrient supply
- availability of substrata
- tides
- changes in climate (eg. temperature).

Bacterial densities and productivity are highest in tidal creeks and channels, declining seaward. Enhanced productivity is caused by higher nutrients and better substrata, temperature and less physical domination of food webs compared to those offshore.

In short, marshes are sites of high faunal richness and productivity because of their proximity to land and shallow seas where tidal energy is maximal. Marsh fauna and flora are closely dependent upon freshwater and land-derived nutrients and trace elements such as iron, manganese, and phosphorus as well as tidal water from which they take up dissolved nitrogen and carbon -- exposure to air maximises rates of nitrogen fixation, the

use of atmospheric N₂ by microbes to synthesise cellular (organic) nitrogen. Salt marshes are also somewhat dependent upon nitrate derived from precipitation.

A nitrogen budget of the Great Sippewissett Marsh in the north-eastern United States shows that nearly two-thirds of the marsh's nitrogen input is supplied via tidal exchange, with the next largest source being groundwater. Nitrogen fixation accounts for one-half the amount of nitrogen supplied from groundwater. Similarly, the largest loss of nitrogen was via tidal exchange with the next greatest loss to the atmosphere via denitrification -- the bacterial reduction of nitrate to gaseous nitrogen. Hence, from an energetic view, marshes and their biota are interlinked to land, sea, and atmosphere.

The strong connectivity of salt marshes to both land and sea also translates into a tight coupling of anthropogenic episodes occurring in adjacent habitats affecting marsh plants and biota. The major causes of marsh degradation both worldwide and in Australia are:

- alterations to land management practices in catchments
- regulation of freshwater input and tidal access (eg. by ponded pastures in Qld)
- direct habitat loss
- urbanisation
- exotic species (eg. *Spartina cord grass*).

There has been a lack of study of the role of Australian saltmarsh as fisheries habitats - insufficient to provide a separation section in the review. The few studies of fish penetrating extreme upper limits of tidal movement (Morton *et al.* 1987, 1988, Davis *et al.* 1988, Russell and Garrett 1985) have shown that fish do use such habitats directly, and may have an important role there as predators of mosquito larvae (Ritchie and Laidlaw-Bell 1994). In the tropics, ephemeral water bodies on saltpans are known to provide temporary habitat for barramundi juveniles, but studies are lacking. This use of flooded habitats may be relatively short before drying occurs, but there may be abundant food there at times due to the presence of insect larvae in high densities (eg. chironomids). More comprehensive knowledge of the use and role of this habitat type is needed urgently, and will be forthcoming for south east and central Queensland from the FRDC investment in projects 97/203 and 97/201 (see Appendix 3).

We found interesting speculation about the role of wind-blown (aeolian) transport of nutrients offshore from extensive saltpans in supporting the benthic production and tiger

prawn fishery of Exmouth Gulf (p.c. G. Brunskill AIMS). This is supported in principle by the work of Paling and McComb (1994).

1.4.3 Mangroves

Description

Mangroves comprise a unique and diverse forest and shrub ecosystem of the intertidal zone, bordering coastal margins and offshore islands of the tropical and warm temperate zones of Australia. Mangroves occur in most estuaries although their presence is more limited along the southern coastline and they are absent from Tasmania. The area of mangroves in Australia is around 8,200 km², and is the third largest in the world. Most are found in tropical parts, notably in Queensland and the NT (Table 1.4.3.1).

Estimated area (km²) of mangrove habitat in Australian states:

| | NSW | VIC | TAS | SA | WA | NT | QLD | Total |
|----------|-----|-----|-----|-----|------|------|------|-------|
| Mangrove | 107 | 41 | 0 | 111 | 1561 | 2952 | 3424 | 8195 |

Source: Saenger (1996)

Mangroves are an ecological assemblage of highly specialised plants that share characteristic adaptations of both physical shape and physiological function, allowing them to prosper in otherwise harsh environments of seawater salinity, regular inundation by water, often anoxic soils, and exposure to coastal storms. Such adaptations include: above-ground breathing roots; buttress and prop- root support structures; floating viviparous propagules; salt excretion from leaf pores and/or salt accumulation in senescent leaves; and a tolerance of high salt concentrations in their sap.

The stature of mangroves in Australia range from shrubby thickets of 1-2 metres, to closed forests up to 35 metres tall. The composition of mangrove plant communities vary considerably, but generally species numbers decrease markedly with increasing latitude south. On the east coast of Australia numbers drop from 37 taxa in the north of Queensland to 1 in Victoria, while numbers in WA decrease from 17 in the north, to 1 in the south of the State (Table 1.4.3.1).

Mangrove biodiversity

In total, there are 39 mangrove taxa in Australia, representing more than half those found in the world (Duke 1992). These belong to 19 plant families ranging from a ground fern, a palm, to shrubs and trees. Only one species, *Avicennia integra*, is endemic, and it is found in the NT only. Other species are more widely distributed, but all are essentially tropical in distribution with their greatest overlap in north-eastern Queensland.

This is in marked contrast with seagrasses that are roughly divided equally into tropical and temperate ranging species. The distribution of mangrove species is further influenced by climatic and physical conditions such that numbers notably decrease in more arid regions, and in estuarine systems with smaller catchment areas. The distributions of species are further characterised by two other criteria -- their range upriver and their zonation across the tidal profile.

Within a particular estuarine system, each species will have a distinct downstream and upstream limit related mostly to salinity and its marked seasonal fluctuations. Species are also distributed in distinct zonation patterns across the intertidal profile, based on several factors including: inundation frequency and depth, the shape and size of propagules, and the predation of propagules by crabs (Robertson 1991). In consideration of such variables, the distribution of an individual mangrove species might best be described in terms of its geographic location, estuary size, rainfall in the catchment, upriver range, and intertidal position (Table 1.4.3.2).

Structural diversity in mangrove habitat

Given the wide range of plant types that make up mangroves in Australia, there are significant differences in the structure of this intertidal habitat in different locations. Perhaps the most marked difference is between mangrove forests in southern Australia, dominated by *Avicennia marina*, and those in the north, dominated by *Rhizophora* species. Mature *Avicennia* forests, 2-20 m tall, are noticeably open and park-like in appearance without appreciable understorey structure except for dense mats of pencil-like pneumatophores (breathing roots), ~10cm high, and some scattered seedlings. In contrast, mature *Rhizophora* forests, 2-35 m tall, have a tangle of thick woody above-ground roots (prop roots), 1-2 m above the substratum, emerging from the lower stem particularly, but also from the upper branches.

Water flow is much more restricted through *Rhizophora* forests and their prop-roots are essential in stabilising sediments and protecting mature trees and their offspring from water erosion, particularly during periods of large floods and storm wave action. In tropical areas, *Rhizophora* tend to dominate the low intertidal zone and enclose most other species within the high- and mid-intertidal zones along the estuary from the mouth to varying distances upstream, depending on the freshwater catchment area and location.

Furthermore, other species in the tropics also have well-developed root structures -- notably *Sonneratia* sp. with pneumatophores commonly around 30cm, and *Bruguiera* and *Xylocarpus* spp with a variety of buttresses and thick knee-roots (Table 1.4.3.2). In both regions, there are also areas where mangroves form thickets of shorter shrubs with multi-branching further adding to the structural complexity and diversity of this habitat.

Dispersal and colonising ability

Mangroves are adapted to living in coastal waters with many species having large buoyant propagules, able to survive for sometime at sea where they are dispersed on surface water currents. They appear to have achieved this in a number of characteristic ways (Table 1.4.3.2) with vivipary mostly (eg. *Rhizophora*, *Bruguiera*, *Ceriops*, *Avicennia*), but also with enlarged seed capsules in *Nypa*, *Cynometra* and *Xylocarpus*. While a number of species have smaller seeds, it is generally thought that larger propagules assist long distance dispersal. This is supported by the occurrence of *Rhizophora* and *Avicennia* in pantropic distributions while most other species are more localised.

The rehabilitation potential and vulnerability to disturbance of mangrove species may also be ranked according to their position in the successional sequence of a mangrove community from its first establishment to maturity. Some pioneers include *Avicennia* and *Sonneratia*, and to some extent *Rhizophora*. Maturity in the successional sequence may be rarely achieved, however, since the intertidal zone is so changeable at the time-scales of tree growth and forest succession.

This concept of forest succession is discussed by Smith (1992), who also described the influence of crabs and molluscs that consume and damage mangrove propagules. The herbivorous activity and preferences of these fauna are considered sufficient to influence forest succession. Clearly, this occurrence will also affect the physical structure of mangrove stands (Robertson 1991).

Table 1.4.3.1. Mangrove distributions in Australia (Primary source: Duke 1992).

| Mangrove Species | SEast Aust | | South Aust | | | West Aust | | NT | North Aust | | NE Aust | |
|-----------------------------------|------------|----------|------------|----------|----|-----------|-----|----|-------------|----|-----------|----|
| | NSW | VIC E | TAS +BS | VIC W | SA | WA Sth | Nth | | QLD Gulf | TS | QLD NE | SE |
| <i>Avicennia integra</i> | | | | | | | | • | | | | |
| <i>Sonneratia X urama</i> | | | | | | | | - | | | | |
| <i>Acanthus ebracteatus</i> | | | | | | | | | | | • | |
| <i>Bruguiera cylindrica</i> | | | | | | | | | | | • | |
| <i>Diospyros littoralis</i> | | | | | | | | | | | • | |
| <i>Lumnitzera X rosea</i> | | | | | | | | | | | • | |
| <i>Heritiera littoralis</i> | | | | | | | | | | | • | |
| <i>Dolichandrone spathacea</i> | | | | | | | | | - | | • | |
| <i>Sonneratia X gulngai</i> | | | | | | | | | - | | • | |
| <i>Sonneratia caseolaris</i> | | | | | | | | | - | | • | |
| <i>Rhizophora mucronata</i> | | | | | | | | | - | | • | |
| <i>Cynometra iripa</i> | | | | | | | | | - | | • | |
| <i>Sonneratia lanceolata</i> | | | | | | | | • | | | • | |
| <i>Ceriops decandra</i> | | | | | | | | • | | | • | |
| <i>Bruguiera sexangula</i> | | | | | | | | • | | | • | |
| <i>Ceriops tagal</i> | | | | | | | | • | | | • | |
| <i>Rhizophora X lamarckii</i> | | | | | | | | • | | | • | |
| <i>Rhizophora apiculata</i> | | | | | | | | • | | | • | |
| <i>Nypa fruticans</i> | | | | | | | | • | • | | • | |
| <i>Lumnitzera littorea</i> | | | | | | | | • | • | - | • | |
| <i>Scyphiphora hydrophyllacea</i> | | | | | | | • | • | | | • | |
| <i>Acanthus ilicifolius</i> | | | | | | | | • | • | • | • | |
| <i>Camptostemon schultzei</i> | | | | | | | • | • | • | • | • | |
| <i>Bruguiera parviflora</i> | | | | | | | • | • | • | • | • | |
| <i>Sonneratia alba</i> | | | | | | | • | • | • | • | • | |

| Mangrove Species | SEast Aust | | TAS +BS | South Aust | | West Aust | | NT | North Aust | | NE Aust | |
|---------------------------------------------|------------|----------|------------|------------|----|-----------|-----|----|-------------|----|-----------|----|
| | NSW | VIC E | | VIC W | SA | WA Sth | Nth | | QLD Gulf | TS | QLD NE | SE |
| <i>Bruguiera exaristata</i> | | | | | | | • | • | • | • | • | - |
| <i>Pemphis acidula</i> | | | | | | | • | • | • | • | • | - |
| <i>Xylocarpus granatum</i> | | | | | | | • | • | • | • | • | - |
| <i>Xylocarpus mekongensis</i> | | | | | | | • | • | • | • | • | • |
| <i>Osbornia octodonta</i> | | | | | | | • | • | • | • | • | • |
| <i>Lumnitzera racemosa</i> | | | | | | | • | • | • | • | • | • |
| <i>Ceriops australis</i> | | | | | | | • | • | • | • | • | • |
| <i>Aegialitis annulata</i> | | | | | | • | • | • | • | • | • | • |
| <i>Rhizophora stylosa</i> | • | | | | | | • | • | • | • | • | • |
| <i>Bruguiera gymnorhiza</i> | • | | | | | | • | • | • | • | • | • |
| <i>Acrostichum speciosum</i> | • | | | | | | • | • | • | • | • | • |
| <i>Excoecaria agallocha</i> | • | | | | | | • | • | • | • | • | • |
| <i>Aegiceras corniculatum</i> | • | | | | | | • | • | • | • | • | • |
| <i>Avicennia marina</i> (all var.) | • | • | | • | • | • | • | • | • | • | • | • |
| <i>A. marina</i> var. <i>australasica</i> | + | + | | + | + | | | | | | | + |
| <i>A. marina</i> var. <i>eucalyptifolia</i> | | | | | | | + | + | + | + | + | |
| <i>A. marina</i> var. <i>marina</i> | | | | | | + | | | | | | |
| Sub-regions (& States) | 6 | 1 | 0 | 1 | 1 | 2 | 17 | 29 | 25 | 19 | 37 | 11 |
| Regions | 6 | | 1 | | | 17 | | 34 | | | 37 | |

Notes:

unlike seagrasses, all mangrove species are distributed through tropical north Australia

Table 1.4.3.2. Structure, morphology and phenology of mangrove (Primary source: Duke 1992)

| Species | Life Form | Canopy Position | Location Upriver | Location on Tidal Profile | Above-ground Roots | Dispersal. Agent | Fruiting Season | Substrate |
|----------------------------------------------------|------------|-----------------|------------------|---------------------------|----------------------|------------------|-----------------|-----------|
| <i>Acanthus ebracteatus</i> | Herb | Under | I | M-H | none | Seed | Jan-Feb | M,S |
| <i>Acanthus ilicifolius</i> | Herb | Under | I-U | M-H | none | Seed | Jan-Feb | M,S |
| <i>Nypa fruticans</i> | Palm | Canopy | U | L-M-H | none | Seed | Feb-Mar | M,S |
| <i>Avicennia integra</i> | Tree | Canopy | I | L | P/phores Sml Prop | Crypto Vivipar. | Dec-Jan | M |
| <i>Avicennia marina</i> var. <i>australasica</i> | Tree/Shrub | Canopy | D-I | L-M-H | P/phores | Crypto Vivipar. | Apr-Jun | M,S |
| <i>Avicennia marina</i> var. <i>eucalyptifolia</i> | Tree/Shrub | Canopy | D-I | L-M-H | P/phores | Crypto Vivipar. | Mar-Apr | M,S |
| <i>Avicennia marina</i> var. <i>marina</i> | Tree/Shrub | Canopy | D-I | L-M-H | P/phores | Crypto Vivipar. | Mar-Nov | M,S |
| <i>Dolichandrone spathacea</i> | Tree | Canopy | U | M | none | Seed | Nov | M |
| <i>Camptostemon schultzei</i> | Tree | Canopy | D-I | L-M | none | Crypto Vivipar. | Mar-Apr | M |
| <i>Cynometra iripa</i> | Shrub | Under | I-U | H | none | Seed | Dec-Feb | M |
| <i>Lumnitzera littorea</i> | Tree/Shrub | Canopy | I | M | Sml Knee | Crypto Vivipar. | Feb-Mar | M |
| <i>Lumnitzera racemosa</i> | Tree/Shrub | Canopy | D | M-H | Sml Knee | Crypto Vivipar. | Feb-Mar | M,S |
| <i>Lumnitzera X rosea</i> | Shrub | Canopy | I | H | Sml Knee | Crypto Vivipar. | Feb-Mar | M |
| <i>Diospyros littoralis</i> | Tree | Canopy | I-U | M-H | none | Seed | Sept | M |
| <i>Excoecaria agallocha</i> | Tree | Canopy | D-I-U | M-H | Knees | Seed | Jan-Feb | M,S |
| <i>Pemphis acidula</i> | Shrub | Canopy | D | H | none | Seed | Dec | S,G |
| <i>Xylocarpus granatum</i> | Tree | Canopy | I | M-H | Buttress | Seed | Jun-Sept | M,S |
| <i>Xylocarpus mekongensis</i> | Tree | Canopy | I | M-H | P/phores | Seed | Dec-Feb | M,S |
| <i>Aegiceras corniculatum</i> | Shrub | Canopy | I-U | L | none | Crypto Vivipar. | Jan-Mar | M,S,G |
| <i>Osbornia octodonta</i> | Shrub | Canopy | D | M-H | none | Seed | Feb-Mar | S |
| <i>Aegialitis annulata</i> | Shrub | Under | D | M-H | none | Crypto Vivipar. | Feb | M,S,G |
| <i>Acrostichum speciosum</i> | Fern | Under | I | H | none | Spores | all year | M |
| <i>Heritiera littoralis</i> | Tree | Canopy | I | H | Buttress | Seed | Sep-Dec | M |
| <i>Sonneratia alba</i> | Tree | Canopy | D | L | P/phores | Seed | Jan | M |
| <i>Sonneratia caseolaris</i> | Tree | Canopy | U | L | P/phores | Seed | Jun-Jul | M |
| <i>Sonneratia X gulngai</i> | Tree | Canopy | I | L-M | P/phores | Seed | Mar, Aug | M |
| <i>Sonneratia lanceolata</i> | Tree | Canopy | U | L | P/phores | Seed | Dec | M |

| Species | Life Form | Canopy Position | Location Upriver | Location on Tidal Profile | Above-ground Roots | Dispersal. Agent | Fruiting Season | Substrate |
|-----------------------------------|------------|-----------------|------------------|---------------------------|--------------------|------------------|-----------------|-----------|
| <i>Sonneratia X urama</i> | Tree | Canopy | I | L-M | P/phores | Seed | Dec-Jan | M |
| <i>Bruguiera cylindrica</i> | Tree | Canopy | D-I | M | Knees | Vivipar. | Nov | M |
| <i>Bruguiera exaristata</i> | Tree | Canopy | I-U | H | Knees | Vivipar. | Feb-Mar | M |
| <i>Bruguiera gymnorhiza</i> | Tree | Canopy | D-I | M-H | Knees | Vivipar. | Jan-Feb | M,S |
| <i>Bruguiera parviflora</i> | Tree | Canopy | D-I | M | Knees | Vivipar. | Jan-Feb | M |
| <i>Bruguiera sexangula</i> | Tree | Canopy | I-U | M-H | Knees | Vivipar. | Aug-Sep | M |
| <i>Ceriops australis</i> | Tree/Shrub | Canopy | D-I | H | Buttress | Vivipar. | Dec-Feb | M |
| <i>Ceriops decandra</i> | Shrub | Under | I | M-H | Buttress | Vivipar. | Dec | M |
| <i>Ceriops tagal</i> | Tree/Shrub | Canopy | D-I | M-H | Buttress | Vivipar. | Mar-May | M |
| <i>Rhizophora apiculata</i> | Tree | Canopy | I | M | Props | Vivipar. | Feb | M |
| <i>Rhizophora X lamarckii</i> | Tree | Canopy | D-I | M | Props | Vivipar. | Jan-Mar | M |
| <i>Rhizophora mucronata</i> | Tree | Canopy | I-U | L-M | Props | Vivipar. | Jan-Mar | M |
| <i>Rhizophora stylosa</i> | Tree | Canopy | D-L | L-M | Props | Vivipar. | Jan-Feb | M,S,R |
| <i>Scyphiphora hydrophyllacea</i> | Shrub | Under | I | H | none | Seed | Feb-Mar | M,S |

NOTES: Upriver: D=downstream; I=intermediate; U=upstream
Tidal (above MSL): L=low intertidal; M=medium intertidal; H=high intertidal
Substrate: M=Mud; S= Sandy; G=Gravel; R=Rocky

Processes and connectivity

The connections of mangrove forests to other habitats is better understood than for salt marshes, despite the fact that there are slightly more salt marshes in Australia (13, 595 km²) than mangroves (11,500 km²). Essentially, the same suite of factors that determine the extent of exchange between marshes and adjacent ecosystems also operate for mangroves, with the prime exception of the role of leaf-burying mangrove crabs in processing and exporting carbon (see Alongi 1989, 1990a,b,c, Alongi *et al.* 1989, Alongi and Christoffersen 1992, Alongi 1997, Daniel and Robertson 1990, Robertson 1986).

Tidal movement of water plays a major role in the structure and function of mangrove ecosystems, often driving biogeochemical and trophic processes. Water circulation is very different between waterways and within the forests themselves. Strong tidal flows occur in creeks and other mangrove waterways due to the tidal prism caused by the surrounding forests. This leads to a strong dispersion at the downstream end of creeks, which helps to flush material out to sea. In contrast, there is weak dispersion and trapping of materials (often for several weeks) resulting in low oxygen concentrations and low pH in creek waters (Ridd *et al.* 1990).

The presence of forested areas and frictional forces lead to tidal current asymmetry, with ebb currents being much greater than those in flood, and maintains deep, scoured channels. The high tree density leads to high friction, retards flow, and results in trapping of water within forests. The complex topography of mangrove forests can also lead to secondary currents and small-scale tidal fronts which in turn lead to aggregation of floating mangrove detritus in long lines and enhancement of export from the forests (Wolanski and Ridd 1986). Biogenic structures provide pathways of water and material exchange between forests and creeks.

Mangrove creek and adjacent coastal waters form a “coastal boundary layer”, a highly turbid water body that mixes slowly with offshore waters. This boundary layer inhibits mixing of water and associated materials, to the extent that there is often longshore transport, but not across-shelf transport, of mangrove-derived materials. Globally, export of organic carbon from mangroves varies with latitude, not only from more luxuriant and productive forests closer to the equator, but with greater rainfall. The role of climate plays a strong role in the tropics where litterfall partly relates to precipitation and frequency of cyclones.

The role of climate and water circulation on the extent of exchange between mangroves and coastal waters is best seen in the nitrogen budget constructed for the mangrove ecosystem of Missionary Bay, on the northern end of Hinchinbrook Island in north Queensland. More than 80% of nitrogen input into the mangroves comes via tidal exchange, with the rest via microbial nitrogen fixation. Similarly, nearly 99% of the nitrogen output occurs by way of tidal exchange -- the remaining losses escape to the atmosphere via bacterial denitrification.

In terms of carbon, there appears to be less dramatic exchange between mangroves and coastal waters. Of a total living mangrove biomass of 190,000 kg C ha⁻¹, only 2% is lost via tidal exchange, mostly in the form of refractory particles and larger pieces of roots, leaves, flowering parts, bark, wood, and propagules.

Surprisingly, this outwelled material is of limited importance in the coastal zone. Little material (relative to total tree production and standing biomass) is exported from the mangroves. What does get exported generally does not get transported more than a few kilometres from the mangrove estuaries. This carbon has a significant impact on sedimentary nutrient cycles, but does not translate into a significant dietary subsidy for fish and prawns and other coastal macro-organisms, despite the fact that juveniles of some penaeid prawns feed on mangrove detritus or on meiofauna that is mangrove dependent. Some fishes are clearly mangrove-dependent (eg. Blaber *et al.* 1989), but it is unknown to what extent this dependence relates to nutrient cycling and other ecological connections between mangroves and coastal waters.

Leaf-burying mangrove crabs of the family Sesamididae are thought to provide a pivotal link between mangrove primary production and coastal food chains, but studies are lacking (Robertson 1986, Robertson 1991). For example, recruitment of larval fish into mangrove waterways peaks in the Townsville region during mid-summer (Robertson and Duke 1990b) in coincidence with the outflow of crab zoeae, but there is a lack of study of the role of the crab larvae in the diets of the fish. Studies in progress of lutjanid and serranid diets in Townsville mangroves show a striking predominance of adult sesamid crabs in the diet of mangrove jack, estuary cod and other major angling species (p.c. M. Sheaves JCUNQ).

There have been some comparative studies of adjacent fish communities in mangroves and adjacent seagrass (eg. Robertson and Duke 1987, Laegdsgaard and Johnson 1995,

Blaber *et al.* 1995b), but the extent of material links between mangroves and adjacent seagrass beds and saltmarshes is unknown in Australia. Without this information it is not possible to predict the effects of habitat disturbances such as runnelling for mosquito control (see section 2.2)

There is some evidence of close fish community structure and material links between seagrass and adjacent mangroves, for example, in Calancan Bay in the Philippines (Fortes 1994). In Calancan Bay, detritus is exchanged between mangroves and seagrass beds. Mangrove detritus is imported into the seagrass beds, at a rate equivalent to 18% of net seagrass production. Seagrasses, in turn, export detritus to the mangroves, equal to 7% of production. There is also a high overlap between mangroves and seagrass beds in the similarity of fish (30%), crustacean (51%), and epiphytic algal (32%) communities, implying close trophic links between these adjacent systems.

The Gazi Bay ecosystem in southern Kenya is another good example of a tropical ecosystem that shows a broad interdependence among seagrass beds, marshes, mangroves and adjacent coral reefs (Hemminga *et al.* 1994, Kitheka 1996). Gazi Bay is a semi-enclosed shallow embayment 10 km² in area. Mangrove forests, an additional 5 km² in area, line the bay. Stable isotope analyses indicate that mangrove-derived particulate organic matter is exported to the adjacent subtidal seabed. The signature of this material decreases rapidly with distance from the shore, indicating that the seagrass beds most proximate to the mangroves receive the most material. Moreover, changes in the isotope composition of seagrass parallel the inputs of mangrove material suggesting that the mangrove carbon is assimilated by the seagrass.

This transport of material is not unidirectional -- on flood tides, the flux reverses with some seagrass-derived carbon flowing back into the forest. The exchange of materials is driven by tidal currents which, in concert with onshore winds and longshore currents, promotes the trapping of brackish, turbid water inundating the mangroves and seagrass beds, but not the coral reefs offshore. The connection between mangrove and seagrasses widens through tides and river plumes in the wet season. The seagrass beds and coral reefs are weakly linked, mostly by tidal currents.

Such a linkage between mangroves and adjacent systems likely occurs along some coastal areas in tropical Australia, but comprehensive information does not exist. However, a promising start has been made in the northern prawn fishery (eg. Loneragan *et al.* in

press). How, or to what extent, organisms of commercial importance rely on such proximate habitats for sustenance and growth is not known, but is of crucial importance.

1.4.3.1 Fishery-habitat links

Major reviews of the relationships between fishes and crustaceans and mangroves have been given by Robertson and Alongi (1996) and Robertson and Blaber (1992). We have assembled the relevant literature by habitat type, including mangroves, in Appendix 4.

A synthesis of those studies features:

- the importance of shelter -- eg. banana prawns extend right through to back of *Rhizophora*, *Ceriops*, and *Avicennia* where predator numbers are very low, but shallows are critical and they are not restricted to the forested areas. Laegdsgaard and Johnson (1995) compared mangroves, mud flats and seagrass nursery areas (53 spp) in SE Qld -- mangroves were the key as the fish will recruit elsewhere, but they do not survive or grow as well due to better food supply. For this reason yellowfin bream recruit to seagrass, then move into mangroves.
- the importance of infauna and epiphytic algae on roots as food supply - eg in Tin Can Bay Flathead eat *Crangon* clicking shrimp, yellowfin Bream eat *Sesarma* crabs, sea mullet eat epiphytic algae. Mud Crabs eat the gastropod *Telescopium* in NT. Gulf banana prawns eat amphipods and copepods in the mangroves. Recent studies in SE Qld show that juvenile whiting, and other commercial species, have an obligate dependence on meiobenthos (p.c.# 910 P. Laegdsgaard).
- temporal and spatial variation in mangrove use as fisheries habitats at all scales - eg. long-term sampling of "fringes" on St Helena and Green Islands in Moreton Bay showed variability amongst sites within locations and the community changed quickly by both seasons and amongst years. Many more fish penetrated the fringe during darkness and new moon catches were significantly higher. Sediment types were important. More squid and *Sillago ciliata* use mangroves in carbonate sediment areas, which have clearer water. "Mud vs carbonate" differences were significant despite similar tree densities and canopy. There is poor application of tropical mangrove knowledge to the sub-tropics because the pneumatophores in the tropics are long (*Rhizophora*) and very short in the subtropics (*Avicennia*). Tides and sediments are also different.
- lack of regional comparisons and a predominance of fish community studies within single estuaries (but see Robertson and Duke 1990a, Staples et al. 1995) - eg there

are consistent, unexplained differences amongst river systems in NT mud crab production, but this has not been specifically studied in terms of differences in habitats, or in larval supply, recruitment or mortality.

- few studies comparing a range of adjacent habitats (but see Blaber *et al.* 1995b, Laegdsgaard and Johnson 1995).
- a focus on mangrove channels where sampling is easiest (but see Vance *et al.* 1996a, Sheaves 1992).
- a lack of development of more comprehensive sampling methods (but see Halliday and Young 1996, Sheaves 1995b).
- a lack of comparative biomass and secondary production data for different mangrove microhabitats and locations.
- a lack of monitoring of the fisheries performance of mangrove rehabilitation (see section 2.2.8).

Key uncertainties concern:

- the trophic links and exchange of material amongst saltmarsh, mangroves and seagrass (see above) - stable isotope studies are needed to augment inferences made from surveys in each habitat type.
- the relative importance to fisheries of “fringes” vs “stands” of mangroves in local fisheries production -- mangrove fringes are more readily penetrated by fish and crustaceans during tidal cycles, and there is mounting speculation that fringes, not stands, are most important for feeding and shelter (p.c.#220 I. Halliday). This could have implications for the replacement of many small areas of mangrove by single, large stands (naturally, or in rehabilitation projects).
- lack of understanding of patterns of microhabitat use and dependence on different, adjacent habitat types during tidal ebb and flood - habitat fragmentation and destruction of adjacent habitats (eg. seagrass dieback just offshore from mangroves) may expose entire mangrove fringe faunas to predation on each ebb tide if they cannot shelter in adjacent microhabitats (p.c.#920 I.Tibbetts).
- the implications for fisheries of fragmentation of mangrove habitats.

Other priorities we have identified for mangrove conservation and restoration are:

- refine maps of mangrove areas - Australia-wide and systematic;