# ISSUE 1:
# Natural Dynamics in Fisheries Habitats and Environmental Variability

## 1.1 Overview and FRDC role

### 1.1.1 The issues

The present suite of Australian fisheries habitats are shaped by combinations of major physical, climatic, geological, palaeohistorical and ecological forcing functions that must be considered in assessing habitat status and change -- particularly when assessing anthropogenic threats. The different combinations of these factors along the steep gradients that comprise the entire Australian coast will need a regional-scale focus in R&D investment in the "Ecosystem Protection" Program, as there may be relatively few generic applications of results across habitats. It may be profitable for the FRDC to follow the example set by the LWRRDC in identifying and mapping issues pertaining to important coastal and marine resources (see Anon. 1995e).

In this chapter we give a brief summary of the "natural dynamics" of fisheries habitats, with a focus on:

- effects of the environment on fisheries production
- the state of knowledge of fisheries-habitat links
- the state of knowledge of dynamics and ecological processes in major habitat types - saltmarsh, mangrove, seagrass, estuary, sandy beach, rocky coast, coral reef and continental shelf.

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

- most of the EEZ and many major fisheries are on the shelf and deeper waters. Nationally this is the main region of active expansion of the fishing industry into previously unfished areas and habitats to exploit new resources

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

The Cronulla workshop highlighted "natural dynamics" as the highest priority issue for FRDC investment, in terms of gaps in knowledge (Williams and Newton 1994), and this theme also prevailed in the workshop held by the Australian Society for Fish Biology in 1992 (see Hancock 1993). We come to the same conclusion in a strategic sense in this review, with the proviso that there are many well-known problems that require urgent conservation and rehabilitation in a tactical response (see later Chapters).

Knowledge of natural dynamics in both fisheries and habitats underpins any assessment of threats and methods for conservation or rehabilitation. In simple terms there needs to be an understanding of what habitats and links must be conserved and rehabilitated, why, and how to do it. Whilst many of the causes of disturbance are outside fisheries stakeholders control (see chapters 2 and 3) , and many gaps in basic knowledge are beyond FRDC's immediate interest, there is still a strong role for the FRDC in developing techniques, approaches, inventories and networks to study natural dynamics. The impetus to extend fisheries interests in such R&D is available now with national coastal initiatives and common interests with other R&D Corporations (see Chapter 2).

Strategic R&D is needed to help:

- distinguish anthropogenic disturbance from natural events and processes
- understand effects of the environment on fisheries production
- comprehensively study life-histories to determine "critical" habitats and habitat-links
- understand natural and threatening processes to develop techniques that address the cause of disturbances
- map with inventories the Australian aquatic ecosystems to enable regional planning and conservation of both biodiversity and fisheries production

- predict and assess impacts of new coastal developments, and offset them in "no nett habitat loss" policies
- design and implement monitoring programs in intertidal and subtidal habitats with appropriate "triggers" for management intervention
- monitor the performance of interventions in threatening processes

A theme of our review has been to search for existing knowledge or potential R&D opportunities for the FRDC that will have generic application across habitats and regions to address major threats. Instead we conclude that such intelligence is elusive -- there are a suite of interacting forces that define habitat types and their vulnerability to disturbance to such an extent that problems and solutions are often bay- or catchment-specific. Indeed, the major findings of comparative community studies in estuaries on both the east and west coasts have been that each one is different - with few overviews available to explain why (eg. Robertson in press).

In simple terms this means that there may be few opportunities for the FRDC to invest in R&D "case studies" of habitat dynamics that will have wide generic application - but there could be a leading role for the FRDC in investing in development of techniques and approaches for such study.

Seagrass-fisheries studies are a case in point, with natural divisions readily apparent between temperate (mostly species with long-term stability) and tropical (mostly dynamic, annual species), east (some relict populations in bays) and west coasts, and deep and shallow, bay and estuarine situations. The implications of seagrass dieback for fisheries and the possibilities for recovery and restoration vary accordingly and cannot be adequately predicted across all habitats from the work already invested in by the FRDC in localised geographic regions.

Seagrass and mangrove ecosystems are protected by Fisheries Acts in some States and have long been recognised as important fisheries habitats. It is not surprising therefore that the FRDC and fisheries agencies have previously led or supported much of the research into the dynamics and fisheries links with these habitats. Other habitats - most notably sandy shores, rocky and algal reefs and shelf megabenthos - have been studied much less, despite the important fisheries they support.

More recently, there has been a coordinated effort to better document, understand and integrate information on all these habitats, driven by biodiversity conservation goals under the "Ocean Rescue 2000" Program, its components such as NatMIS and IMCRA, and State of the Marine Environment Reporting (see below).

Our review has shown that these new initiatives offer convenient vehicles for extending fisheries R&D, yet there is a serious lack of integration of fisheries production data with them at all scales, which is :

- hampering an understanding of the natural dynamics and production potential for Australia's coastal fisheries
- hindering fisheries protection in regional planning initiatives by local governments and councils
- posing a threat of future conflict between fishing, mariculture and the proposed National System of Marine Protected Areas.

More surprising was the lack of interrogation of existing habitat inventories and fisheries production data in any regional overviews. The same fish and crustacean families figure throughout the nation in coastal fisheries (Table 1.3.2.1), yet there are remarkably few comparisons amongst estuaries within regions, amongst regions and between west and east coasts available to determine what are key features of coastal habitats governing production. The maturity of most catch and effort datasets now affords much opportunity for such informative comparisons that will help shape R&D questions.

The "Coastal Habitat Resource Information System (CHRIS)" (FRDC #95/167) being developed by QDPI is the first attempt we have seen to comprehensively integrate habitat and fisheries production information.

There is also a lack of basic life-history information for many fisheries - particularly early, post-larval stages during which recruitment to "critical" habitats may be occurring. Inferences about habitat usage have most commonly been made from community surveys along environmental gradients or amongst habitat types within single estuaries and bays. The information available from such studies is steadily improving with better refinement of sampling designs and less-selective gears. However, there is a clear need for better application and development of innovative biomarkers and stable isotopes to trace the trophodynamic links of fisheries with vegetated habitats that are not discernible to traditional surveys of distribution and abundance.

Hydrodynamic modelling and studies of pre-settlement behaviour and recruitment patterns have been used together recently to predict the location of recruitment "hotspots" that could determine "sources" and "sinks" at larger scales and allow for more specific habitat protection at smaller, bay or estuary scales. Key uncertainties lie more with the poor knowledge of larval and juvenile behaviour than physical processes.

We could find few generalisations about the nature of "critical habitats". Much of the earlier study of "estuarine dependence" has been more a matter of semantics than of providing predictive capacity for assessments of estuarine modification on fisheries. Australian nearshore species may best be characterised as using a "critical chain" of habitats in quick ontogenetic shifts that may include mainly shelter and shallow water at first. The few studies of shelf trawl species also show a shoreward decrease in average size that indicate shallower nurseries.

Key features of productive inshore nursery habitats include:

- shallows
- fine sediments
- turbid conditions
- variable salinities
- sheltered, low (wave and tide) energy waters
- vegetated habitats (seagrass, algae, mangroves)

There is also much regional variation in the importance of different habitat types as nurseries within species and genera. The suite of forcing functions we focus on in this review interact to produce a range of alternative sheltered habitats that is greatest in the tropics (due to the "estuarisation of the shelf") and least on high energy coasts of NSW, where submerged macrophytes and seagrass in estuaries are major recruitment sites. Generalisations about the nature of "critical" habitats must therefore be made carefully in the overall context of regional features.

The value of vegetated habitats for shelter and feeding is clear, but there still remain largely unresolved questions about the response of fish and prawn species to the loss or change in these habitats - do recruit densities rise in the remaining stands? Do "stands" and "fringes" serve equivalent fisheries functions? Will bare substrata be used by new recruits in the absence of any vegetated cover?

It is these questions that are most urgent, given the growing pressures of coastal development on freshwater macrophytes, seagrasses and mangroves throughout the nation. Despite this, the scientific community has not taken best advantage of unavoidable disturbance to learn about the response of fisheries to loss of vegetated habitats. Seagrass are probably the most threatened and vulnerable (see Chapter 2), whereas mangroves have been increasing in local abundance in some important areas.

There are many opportunities to fill these gaps in knowledge of life-histories and natural dynamics with R&D couched in "adaptive environmental assessment and management" frameworks, such as those being used in habitat rehabilitation studies in NSW (see Chapter 2). The basic provision of sheltered, shallow water (eg. through restoration of tidal access) may be the most fundamental pre-requisite of habitat rehabilitation and restoration of fisheries nursery function. If sedimentary profiles are right and seedbanks are nearby the restoration of tidal access alone in lower catchments will encourage recruitment of aquatic vegetation, prawns and fish.

Movement away from traditional, single-species stock assessments to more comprehensive, ecosystem-based fisheries management would also incorporate study of the ecological relationships and requirements of species in fishing zones.

This is a natural progression of one of the most important areas for future R&D -- the effects of the environment on fisheries. There is a basic need to develop a better understanding of the dynamics of recruitment and their environmental correlates to understand the potential variability in our fisheries.

For example, knowledge of the role of the Leeuwin Current has been a cornerstone in understanding variability in at least five of Western Australia's most important fisheries, rainfall variability explains much of the variation in production of banana prawns and barramundi, and zonal westerly winds drive profound changes in production in the area of the sub-tropical convergence. In contrast, there has been little consideration of the role of the East Australian Current in natural dynamics of coastal species in Qld and NSW.

Finally, knowledge of natural dynamics and connectivity of vegetated habitats - especially seagrass - could be much improved by better, question-driven monitoring with biomonitoring techniques (stress, productivity) that complement existing mapping and surveys of distribution. There are much wider "ecological services" afforded by coastal habitats, so there are clearly many common goals amongst fisheries, conservation and development interests in understanding, monitoring and maintaining them.

### 1.1.2 The literature

A detailed overview of all the major factors shaping our coastal habitats is beyond the scope of this review. In the sections following in this chapter we have given relevant detail on the natural dynamics and connectivity of key fisheries habitats, based largely on a review of world marine and coastal ecosystems by Alongi (1997). For these habitats:

- coastal freshwater
- saltmarsh
- mangroves
- seagrass
- estuaries
- sandy shores
- rocky coasts and reefs
- coral reefs
- continental shelves

We have summarised over 460 research papers on fisheries-habitat associations by State, location of study, habitat type, taxa, life-history stage and results or scope. These have been grouped into "inshore habitats" (seagrass, mangroves, estuaries) in Appendix 4, "rocky reefs and coasts" in Appendix 5 and "shelves" in Appendix 6.

The breakdown of literature in our entire bibliographic database is given in Tables 1.1.1 and 1.1.2 to allow a consideration of the gaps in coverage by habitat, subject and threat.

Table 1.1.1. Breakdown of literature from the entire bibliography by number of papers containing specific information on natural dynamics and fisheries links.

| Habitat Type | Description, Natural Dynamics, Processes and Connectivity | Fisheries and Life-histories | Fisheries-Habitat Links and/or community surveys |
|---|---|---|---|
| Coastal Freshwater | 36 | 16 | 41 |
| Saltmarsh | 12 | 2 | 5 |
| Mangroves | 59 | 5 | 38 |
| Seagrass | 124 | 9 | 103 |
| Estuaries and Sheltered Bays | 78 | 92 | 124 |
| Sandy shores | 10 | 3 | 7 |
| Rocky coasts and Reefs | 58 | 17 | 79 |
| Coral Reefs | 55 | 16 | 54 |
| Continental Shelves | 64 | 74 | 67 |

Table 1.1.2. Breakdown of literature from the entire bibliography by number of papers containing specific information on natural dynamics and threats.

| Habitat Type | coastal freshw. | salt-marsh | mangroves | seagrass | estuaries and bays | sandy shores | rocky coasts | coral reefs | shelf |
|---|---|---|---|---|---|---|---|---|---|
| description, variation and dynamics | 30 | 10 | 42 | 105 | 70 | 8 | 57 | 49 | 54 |
| physical and biological connectivity | 6 | 2 | 17 | 19 | 8 | 2 | 1 | 6 | 10 |
| changes to drainage | 24 | 1 | 2 | 2 | 32 | | | | |
| modification of habitat | 23 | | 2 | 5 | 18 | 1 | | 1 | |
| nutrient inputs | 25 | | 7 | 15 | 78 | | 2 | 12 | 7 |
| contaminants | 28 | 5 | 7 | 9 | 124 | | 4 | 9 | 10 |
| introduced pests | 31 | | | | 52 | | 10 | 2 | |
| effects of harvesting | 3 | | | 2 | 64 | 2 | 12 | 24 | 76 |
| restoration and rehabilitation | 58 | | 2 | 10 | 30 | | 9 | | |

With such a diversity and broad range of studies we have not attempted to more thoroughly interrogate the common themes within them. However, several major features are outstanding for the “inshore habitats”:

- there is not a close relationship between the number of papers and the location of habitat problems, with the exception of southern WA - numbers of studies are summarised from Appendix 4 as follows:

| Location | Number of papers |
|---|---|
| Gulf of Carpentaria | 40 |
| north Qld | 25 |
| south-east Qld | 30 |
| NSW | 40 |
| Victoria | 30 |
| South Australia | 7 |
| Tasmania | 4 |
| southern WA | 56 |
| northern WA | 3 |
| Northern Territory | 4 |

- the majority of papers deal with pre-adult or adult fishes, crustaceans and molluscs, not critical early life-histories;
- there is a predominance of community studies describing patterns of distribution and abundance along gradients or amongst habitat types and seasons;
- studies of trophic links between fisheries and sources of primary or secondary production are rare;
- most studies are at small-medium spatial and temporal scales -- reviews and regional overviews are rare;
- studies of unvegetated habitats are rare, and there is poor knowledge of saltmarsh and sandy shores in particular ;
- it is difficult to tell from the available literature how much of the reported regional variations in habitat needs and life-histories are due simply to a lack of sampling of alternative habitats;
- long-term studies are rare and the consequences for fisheries of major loss or creation of coastal habitat are difficult to document; long-term changes (eg. in Port Phillip Bay fish fauna) can seldom be explained in the context of known threats.

These trends reflect the general history of Australian marine science - a review cited in Robertson (in press) found that only 18% of 368 papers dealt with system-level processes, such as physical and nutrient cycling and food chains, in Australian coasts and estuaries. Reviews by Fairweather and Quinn (1996) and Keough *et al.* (1990) have outlined the lack of research on hard and soft substrata, whilst Edyvane (in press) has maintained that there has been a general neglect of the south in R&D, and over-emphasis

on coral reef habitats. Hatcher *et al*. (1989) have reviewed the threats to tropical marine ecosystems and described how lack of knowledge of natural dynamics has hampered identification and prediction of human impacts.

The most common type of "fisheries habitat" literature we found were studies and inventories that documented the fish communities associated with single habitats in sheltered coasts, bays and estuaries. Comparisons with catch rates and patterns found elsewhere were often inappropriate because of differences in gear and sampling regimes, but strong differences were sometimes noted.

Until the late 1980's the majority of studies did not adequately address the importance of estuarine and nearshore nursery habitats because;

- they did not look at all habitats within estuaries and bays (open waters and unvegetated substrata were especially overlooked);
- sampling of different habitats was sometimes inadequate due to gear selection and vulnerability differences (Blaber and Brewer (p.c.# 280) recommend that such inventories should use a wide range of gear and a large range of mesh sizes if gillnetting);
- adjoining marine areas were not sampled.

Studies by Blaber *et al.* (1989), West and King (1996), Gray *et al.* (1996) and Vance *et al.* (1996a) have attempted to overcome these deficiencies. For habitats further offshore, Wassenberg *et al.* (1997) provide a clear demonstration of how inefficient prawn trawls are in comparison to fish trawls in assessing fish community structure.

This has been a particular problem in estuaries of the tropics and subtropics, which generally have more diverse fish faunas and habitats than their temperate counterparts. These include mangrove stands and fringes, seagrass beds, mudflats and open-water channels, as well as habitats that differ in tidal exposure, water depth, topographic complexity and sediment type.

A persistent feature of "seagrass versus bare" comparisons of fish distribution and abundance is the level of confounding with other factors:

- benthic productivity is ubiquitously high inside estuaries so "seagrass vs bare" differences may not be detectable or important there -- but this inference can not be translated to bay and coastal situations;

- "seagrass vs bare" comparisons are often confounded because the "bare" locations are directly influenced by the detrital pools created by adjacent seagrass (eg. Swan Bay - see Jenkins *et al.* 1993d);
- similarly, detrital pools and other influence of *Posidonia* may persist for several years, or perhaps more, after dieback events - so "before-after" comparisons of fisheries effects may not be significant at the short time scales of study;
- economically important species are extremely mobile amongst habitat sites, localities and regions.

The directions of shelf and coastal research have diverged in a manner that does not necessarily reflect the relative accessibility and cost of R&D in the different fishery assemblages. Shelf and sea-mount R&D in the South-East has attempted to comprehensively model the sources and potential for production with a focus on trophodynamic relationships and environmental forcing (eg. Koslow 1997, Young *et al.* 1996), whereas estuarine and bay studies have generally lingered on description of patterns of distribution of communities (eg. Pollard 1994a, Loneragan 1993). These differences are outlined in Table 1.4.5.1.

Knowledge of life-histories is even more loosely related to accessibility of fished taxa, and is closely tied to fishery value. For example, much of the literature on "bread and butter" species like mullet, bream and whiting is decades old and uninformative, whereas the activities of individual southern bluefin tuna on the high seas have been monitored in great detail. Early work on western rock lobster juveniles that invoked hypotheses of density-dependence, the potential for effects on ecosystems through predation on grazers, and other ecological concepts has not been carried forward. It is also somewhat ironic that the knowledge of biology and recruitment processes of some pests such as crown-of-thorns starfish and northern Pacific sea-stars far exceeds similar studies on fished species.

In Table 1.1.3 we have assembled key references that document well the major sources of variation in Australian fisheries communities. With the exception of a series of papers by Edgar and Shaw (1995a,b,c) and Andrew (1989,1993) there are few paradigms regarding biological sources of variation in key fisheries habitats that have been tested at regional scales in Australia.

This has been at least partly due to the fact that there exists so much natural variability at all scales. For example, many studies have shown that the distribution of estuarine faunas is structured by:

- distance from the mouth
- extent of tidal intrusion
- salinity and episodic floods
- position of the halocline (salt wedge)
- depth of the channel
- position and nature of vegetated habitats.

Table 1.1.3(a). Selected references documenting or invoking major sources of variation in fisheries-habitat links, by habitat type.

| | Habitat complexity and microhabitat type | Flood Pulse | Salinity | Turbidity | Depth | Sediment Type |
|---|---|---|---|---|---|---|
| *coastal freshwater* | Pusey *et al.* (1993, 1995) | Bayley (1991), Gehrke (1991), Swales (1994) | Russell and Garrett (1985), Griffin (in press) | Gehrke (1990) | | Lake (1990) |
| *estuaries* | Bell *et al.* (1984), Blaber *et al.* (1989), Connolly (1994a), Halliday and Young (1996), Laegdsgaard and Johnson (1995), Haywood *et al.* (1995), Morton (1990), Sheaves (1992), Humphries *et al.* (1992), | Glaister (1978a,b), Griffin (1987b), Staples (1986), Sumpton and Greenwood (1990), | Dall (1981), Geddes (1987), Hall (1984), Loneragan *et al.* (1989, 1990), Longmore *et al.* (1990), | Blaber *et al.* (1985), Cyrus (1992), Cyrus and Blaber (1992), | Loneragan *et al.* (1987), | Frusher *et al.* (1994) |
| *seagrass* | Bell and Westoby (1986a,b,c), Bell *et al.* (1987), Blaber *et al.* (1992b), Coles *et al.* (1993), Connolly (1994c), Edgar (1990b), Edgar and Shaw (1995a,b,c), Loneragan *et al.* (1994), Middleton *et al.* (1984), Vance *et al.* (1996b), Worthington *et al.* (1991), | | Vance *et al.* (1996b), | | Bell *et al.* (1992), Lee Long *et al.* (1996) | |
| *mangroves* | Vance *et al.* (1996a) | | | | | |
| *soft shores* | Ayvazian and Hyndes (1995), Lenanton *et al.* (1982), Lenanton and Caputi (1989), Robertson and Lenanton (1984) | | | | | |
| *rocky reef* | Andrew (1991, 1993b, 1994), Andrew and McDiarmid (1991), Barrett (1995), Connell and Jones (1991), Edgar *et al.* (in press), Fitzpatrick *et al.* (1989b), Howard (1989b), Jenkins *et al.* (1996), Jernakoff *et al.* (1993,1994), Jones (1988b, 1992), Jones and Andrew (1990), Lincoln-Smith *et al.* (1989), McGuiness (1990), Shepherd *et al.* (1992), Shepherd and Partington (1995), | | | | | |

| | Habitat complexity and microhabitat type | Flood Pulse | Salinity | Turbidity | Depth | Sediment Type |
|---|---|---|---|---|---|---|
| *coral reef* | reviews by Sale (1991), Doherty (1992), Jones (1988a,1990b), Williams and Russ (1994), | | | | Kramer *et al.* (1994), Newman and Williams (1996), Newman *et al.* (1997) | |
| *bay and shelf demersal* | Blaber *et al.* (1995), Hyndes *et al.* (1996), Jenkins *et al.* (in press, 1993b,c), Lenanton (1982), Shaw and Jenkins (1992), Vanderklift (1994), Warburton and Blaber (1992), Weng (1983,1990), | Staples *et al.* (1995), | | | Blaber *et al.* (1994), Harris and Poiner (1991), Parry *et al.* (1995), Koslow *et al.* (1994), Newton and Klaer (1991), Tilzey *et al.* (1990), | Gribble (1997), Somers (1994), Somers *et al.* (1987), Watson *et al.* (1990), Gray and Otway (1994), McLoughlin *et al.* (1988), Ramm *et al.* (1990), Ward and Rainer (1988) |
| *bay and shelf pelagic* | Kingsford (1988,1992a,1995), Kingsford and Choat (1989), Young *et al.* (1996), | Rissik and Suthers (in press), Suthers and Rissik (1992), Thorrold and McKinnon (1995) | | | Gray *et al.* (1992), May and Blaber (1989), Stevens *et al.* (1984), | |

Table 1.1.3(b). Selected references documenting or invoking major sources of variation in fisheries-habitat links, by habitat type.

| Habitat Type | latitudinal/longitudinal variation | Variation due to Tidal access | Seasonal variation | Climate/ Current Cycles |
|---|---|---|---|---|
| *coastal freshwater* | | | Bishop *et al.* (1995) | |
| *estuaries* | Robertson and Duke (1990a), Pollard (1992), Staples and Vance (1987), West and King (1996), | Davis (1988), Miskiewicz (1986), Morton *et al.* (1987), Morton (1989), Neira and Potter (1992a,1994), Pollard and Hannan (1994), Pollard (1994a), Potter *et al.* (1993), Potter and Hyndes (1994), Wolanski (1992), | Loneragan *et al.* (1986), Robertson and Duke (1990b), Gaughan *et al.* (1990), Vance *et al.* (1994), | |
| *seagrass* | Coles *et al.* (1987), Ferrell and Bell (1991), Gray (1991a), Gray *et al.* (1996), Worthington *et al.* (1992a), | Bell *et al.* (1988), McNeill *et al.* (1992), Steffe and Westoby (1992), | Ferrell *et al.* (1993), Halliday (1995), Vance *et al.* (1996b), | |
| *mangroves* | | | | |
| *soft shores* | | | | |
| *rocky reef* | Holbrook *et al.* (1994), Kingsford *et al.* (1991a), Lincoln-Smith *et al.* (1991), Schaap and Green (1988), Underwood *et al.* (1991), | | | Caputi *et al.* (1995a,b,1996), Lenanton *et al.* (1991), Pearce and Phillips (1988), Thresher (1992), Thresher *et al.* (1989), |
| *coral reef* | reviewed by Williams (1982,1983), Williams and Hatcher (1983), | Kingsford *et al.* (1991b), Leis (1994), Milicich (1994), | | |
| *bay and shelf demersal* | Gray and Otway (1994), Okera and Gunn (1986), | Rothlisberg *et al.* (1995), | | Joll (1994), Joll and Caputi (1995), |
| *bay and shelf pelagic* | Griffiths and Wadley (1986), Young *et al.* (1986), Gray (1993), | Jenkins and Black (1994), Bruce and Short (1992), Hoedt *et al.* (in press), | Jenkins (1986), Fletcher and Tregonning (1992), | Clementson *et al.* (1989), Harris (1987), Harris *et al.* (1988,1991), 1992), Jordan (1992), Jordan *et al.* (1995), Thresher (1994a), Young *et al.* (1993), Young and Lyne (1993), |

### 1.1.3 FRDC action

The key uncertainties for fisheries-habitat links in shallow coastal habitats are similar at both small, local scales and large, regional scales. These are:

- are many, smaller habitats more productive for fisheries than fewer, larger ones?;
- where are the most important "sources" and "sinks" of larval supply and recruitment to fisheries
- do important species distinguish amongst natural habitat types (eg. bare vs vegetated), and between natural and modified habitats?
- are "fringes" of vegetated habitat types more productive than "stands" in a fisheries sense?
- what are the pathways of energy transfer from altered and natural sources of primary production to fisheries in disturbed habitats?
- will important species readily use disturbed habitats as alternative recruitment sites?
- do recruit densities in "intact" habitat types increase as surrounding habitat is lost?
- can harvest refugia and marine protected areas serve to safeguard critical sources of population replenishment, and what characteristics must be incorporated in the management of such areas?

The answers to such questions have been addressed at various smaller scales (eg. amongst sites within estuaries), but seldom at the large, regional scale (eg. which threatened wetlands are the prime barramundi nurseries on the east coast? do marine harvest refugia help sustain surrounding fisheries production?).

Mapping of the most important fishing areas, nurseries, threats and habitats at scales useful for planning and management of coastal development is the obvious first step in:

- identifying fisheries-habitat links
- assessing the effects of environmental variability on fisheries and habitats
- designing question-driven, robust monitoring programs to help distinguish anthropogenic and natural change in habitats and fisheries production
- implementing "land-scape" and "sea-scape" scale programs to conserve, restore and enhance fisheries values.

The challenge for the FRDC is to obtain and extend this information in cooperation with the existing initiatives underway to map and monitor Australia's EEZ and coastal habitats. In some coastal regions, major advances could be made without new collection of field data - integration of the multitude of existing, but separate, fisheries and habitat databases

is both highly attractive and feasible, and several collaborators are available to bring this about (eg. NatMIS, IMCRA).

However, for most of the area of the EEZ the main problem is a major lack of reliable data to integrate. Only a very small proportion of the area of the EEZ that is subject to fishing and fishery exploration has been surveyed and mapped for even gross features of habitat. For example in the area beyond the continental shelf, seamounts as large as the largest terrestrial mountains are still being discovered (and often fished very soon after). The habitat inventory and description is extremely weak for areas deeper than about 20 m, and this is because of a lack of systematic observations. Fishery catch and effort information is the main data available for most of this area, and alone this is insufficient to address habitat issues.

Spatially-based management of coastal resources using “marine harvest refugia” and “marine protected areas” is both a popular and proven response to the demands for integrated planning and conservation. There are many opportunities for the FRDC to contribute to the knowledge-base needed to design, monitor and test the application of such management, from the viewpoint of sustaining fisheries production, and we believe it would also be prudent to closely follow the development of the National System of Marine Protected Areas (NRSMPA).

With appropriate R&D there are opportunities to develop a national system of marine harvest refugia within, or complementing, the NRSMPA. Without this intelligence, fisheries stakeholders - particularly those in the rock lobster and abalone fisheries operating in southern “nests of endemicity”-may be adversely affected by the declaration of the NRSMPA, which is primarily aimed at conservation of biodiversity. There is consequently an early need for the FRDC to identify investment opportunities to maximise the benefit - and help minimise the threat -- of the NRSMPA in sustaining fisheries production.

There is also much opportunity for the FRDC to encourage refinement of collection of fisheries-dependent (CPUE) and fisheries-independent data to be of better use in assessing fisheries-habitat links and change in coastal fisheries. This is a requirement of effective “Ecosystem-based Fisheries Management” (eg. see Edyvane 1993). For example, the resolution of some State CPUE databases does not allow identification of individual estuaries or bays in aggregation of data. Other, fishery-independent, survey and

monitoring programs could benefit from development of less-selective sampling gears and approaches.

Traditional surveys of distribution and abundance, and tagging programs, have been of limited use in inferring the nature and strength of association of fisheries-habitat links. There is a general need to supplement these techniques with new, innovative approaches in marine chemistry and hydrodynamic modelling. Techniques such as stable isotope tracers and otolith microchemistry studies can offer better insights into the major sources of recruits to some fisheries, while models of larval advection can help predict "sources" and "sinks" of recruitment (eg. Rothlisberg 1995).

Marine chemistry can also provide powerful biomonitors that identify the causes of dieback in seagrasses, rather than just the symptoms, as well as providing information on the neglected trophodynamic links between sources of primary and secondary production and fisheries.

The recommendations in Table 1.1.2 show that the scales of questions vary amongst habitat types and amongst threats and management requirements. We have attempted to rank them in decreasing order of national priority.

Table 1.1.4. Summary of major opportunities for FRDC investment in addressing R&D gaps in knowledge of "Natural Dynamics" -ranked in descending order of strategic priority.

| R&D Gaps | Main Habitats | Main Fisheries | Key reference | Initiatives |
|---|---|---|---|---|
| Large Fisheries Ecosystems -- where are they? -- need for inventories of existing information and integration with the IMCRA | entire coast and shelf | mainly reef, shelf and coastal fisheries | Chesson *et al.* (1995), Sherman (1991) | OR 2000 , IMCRA and NatMIS |
| The NRSMPA - an opportunity or threat for fisheries? Connectivity, species interactions and R&D opportunities for stock enhancement and marine harvest refugia | mainly temperate and sub-tropical | especially rocky reef species (see above) | Edyvane (1997), RAC (1993) | OR 2000 , IMCRA and NatMIS |
| Mapping of spatial and temporal extent of sub-tidal habitats -- critical gaps in coverage | seagrass, rocky reefs and macrobenthos | prawns, fish, rock lobster and abalone | Hamdorf and Kirkman (1995), Ortiz and Pollard (1995) | IMCRA (Thackway and Cresswell 1996) |
| Lack of integration of fisheries production figures in the context of primary production and habitat features -- regional overviews needed of critical areas of production and limiting factors | temperate, sub-tropical and tropical bays and estuaries | all estuarine and coastal species | Gwyther (1990), Pollard (1994a) | CHRIS (FRDC #95/167) |
| Need for development of innovative techniques to map and identify nursery habitats and partition major sources of recruits to spawning-run fisheries -- what are the priority areas and habitats for conservation? | Floodplain Lagoons; estuaries, bays | Barramundi; estuarine and coastal prawns and fish | Courtney *et al.* (1994), Thresher *et al.* (1994) | |
| A lack of basic life-history information and fisheries-habitat links - the timing, cues and access needs for recruitment and spawning - what are the critical factors? | Floodplain Lagoons; estuaries, bays | Catadromous and estuarine species | Neira and Potter (1992b), Potter *et al.* (1990) | |
| Refinement of knowledge of requirements of important species settling in estuarine aquatic vegetation (brackish-water macrophytes, seagrass, mangroves and algae) -- bed position, depth and morphological characteristics | estuaries (sub-tropics) and bays (temperate) | east coast estuarine fish and prawn, temperate bay finfish (see above) | Bell *et al.* (1988), Jenkins *et al.* (1993c), West and King (1996) | |
| Regional and local-scale variability in recruitment -- where are the major nursery areas, and can hydrodynamics be used to predict their location and "recruitment hotspots"? | vegetated habitats | finfish and crustacea settling in seagrass | Jenkins and Black (1994), Steffe and Westoby (1992), | |

| R&D Gaps | Main Habitats | Main Fisheries | Key reference | Initiatives |
|---|---|---|---|---|
| Development of biomarkers to trace nutrient exchange and trophic links with fisheries - how important are seagrass, saltmarsh and mangrove habitats? | Estuarine and bay | inshore prawns and fish | Hemminga and Mateo (1996), Loneragan *et al.* (in press), Thresher *et al.* (1992) | |
| Effects of the environment on fisheries - role of the EAC in east coast fisheries | estuarine and bay | coastal and estuarine (eg. Sea Mullet, Tailor, Y'fin Bream, estn King prawn) | West and King (1996) | |
| Effects of the environment on fisheries -- Climate cycles, zonal winds, larval supply and habitat change - need for development of recruitment indices appropriate for distinguishing the interactions | coastal reef and shelf | abalone, rock lobster, SE Trawl (eg. gemfish) | Caputi *et al.* (1995b), Thresher (1994a) | Petrusevics (FRDC# 93/050) |
| The role of freshwater flow in estuarine processes and fisheries production | see Chapter 2 | see Chapter 2 | see Chapter 2 | see Chapter 2 |
| What is the relative "fisheries value" of "fringes" versus "stands" in mangrove and seagrass habitats? | Temperate and sub-tropical seagrass (esp. WA) and mangroves (esp. Qld, NSW) | King George and Sand Whiting, Garfish, Calamari Squid, Y'fin Bream, Sea Mullet | Halliday and Young (1996), Vance *et al.* (1996a) | QDPI "no nett habitat loss" policy |
| Demography, life-history and environmental tolerances of seagrass- ecophysiology for an understanding of threats, fisheries role and restoration potential | all major genera of tropical and sub-tropical seagrasses | prawns, fish, Calamari squid and Portunid crabs | Dennison (1994), Lee Long and Coles (1997a), | CRC Reef Seagrass studies in GBRMP; Moreton Bay Wastewater Study |
| Ecological significance of shallow and deep tropical seagrasses on the east coast of Queensland | north-east Qld | finfish and prawn | Lee Long *et al.* (1996) | |
| The ecology of tidal flats and beaches is virtually unknown in Australia - how important as spawning and nursery areas? | Surf beaches and foreshores | finfish, western King prawns | Carrick (FRDC #91/3), Ayvazian and Hyndes (1995) | CSIRO (1994) |
| The prediction of effects of disturbances and appropriate management responses on rocky reefs -- a lack of knowledge of major processes, algal demography and primary and secondary productivity | temperate and sub-tropical, limestone and sandstone reefs | wstn, sthn ,estn, nthn rock lobster; abalone | Keough *et al.* (1990), Edgar *et al.* (in press) | |
| Fisheries-megabenthos interactions -- need for mapping of shelf habitats and identification of links between fisheries and habitats | see Chapter 4 | see Chapter 4 | see Chapter 4 | see Chapter 4; also Bax (FRDC#94/040) |

| R&D Gaps | Main Habitats | Main Fisheries | Key reference | Initiatives |
| --- | --- | --- | --- | --- |
| Lack of consideration of the linkages in processes between habitat types -- imbalance in study of different habitat types | sheltered bays and estuaries | finfish and prawn | West and King (1996) | |
| Sampling power, precision and bias -- a need for protocols in selection of gears for comparisons amongst different habitat types | estuary and bay aquatic vegetation | mangrove fishes | Halliday and Young (1996) | FRDC#94/042 |
| Which regional areas of saltmarsh are important nurseries? | Sub-tropical and tropical | Barramundi, Qld estuarine | Davis (1987), Griffin (in press) | FRDC#97/203 |

## 1.2 Major forcings shape habitat dynamics - currents, tides, geomorphology and climate

A brief summary is given here to outline the Australian physical context and the extremes and disturbances that characterise it. These patterns have made it inappropriate to adopt overseas knowledge to predict outcomes for some Australian problems (eg. eutrophication). They must also be considered by the FRDC in assessing the generic application of the results of future research here.

The natural forces that should be closely considered in assessing both threats and generic applications of R&D are :

- Currents - govern productivity; transport early life-history stages and adults; form slicks and surface habitat structure; seabed shear stress governs megabenthos distribution
- Tides -- determination of habitat type; access to habitats - transport and retention; flushing of pollutants; vulnerability to sea-level rise
- Wind and waves -- determination of habitat type; sedimentary processes; access to habitats - transport and retention; upwelling and local productivity; zonal wind shifts and climate cycles affect recruitment; cyclones and storm events modify habitats
- Geomorphology -- determination of habitat type; interaction with currents, tides and freshwater input; sediment type and size governs benthic productivity
- Climate, rainfall and riverine inputs -- ENSO events and climate cycles interact with currents and larval supply and survival; variability in rainfall governs estuarine and floodplain processes; heat and light govern primary production; cyclones destroy habitat
- Bioprovinces - palaeohistory has shaped communities; recruitment variability occurs in ecotones; vulnerability and sensitivity to threats governed by size of bioprovince; populations at edge of a species range most vulnerable; declaration of marine protected areas will affect harvesting activities.

For example, the NSW coast offers shelter from a heavy wave climate mainly in estuaries, coastal lagoons and a few bays interspersed along a cliff and sand dominated coast. Being microtidal these enclosed waters have very poor flushing, yet there are strong tidal currents at their narrow entrances. Consequently there are few alternative nursery sites for coastal fisheries in that State, but the poor flushing makes the enclosed waters particularly vulnerable

to eutrophication and sediment inputs. Southern WA is similar, but with shelter and nurseries outside estuaries provided by limestone and sandstone barrier reefs. In contrast the "estuarisation of the shelf" (Longhurst and Pauly 1987) in the tropical north of Qld, NT and WA offers many alternative nursery sites for finfish and crustacea along most of the coast with freshwater lagoons being the most vulnerable habitats.

*Surface Currents (see section 1.2.1)*

*Tides*

Tidal energy is perhaps the greatest forcing function in estuaries and enclosed bays (Williams 1985). It shapes the nature of fisheries habitats, access to them and flushing of pollutants, yet there have been very few overviews of the role of tides in these contexts.

The coastal patterns of tidal range are not simple, but in general terms the areas of maximum tidal range are in the arid tropics of North Western Australia, the wet-dry tropics around Darwin and the dry tropics of central Queensland. Most importantly, the major coastal settlements and major estuarine fisheries are located in micro-tidal or meso-tidal areas of the east coast.

Bucher and Saenger (1994) have provided the only overview of wetland habitats in the context of tidal range. The greater tide range coincides with a greater area per estuary of all wetland types except seagrass, for which there was insufficient information -- and possibly a negative relationship due to increased turbidity with larger tidal range (Table 1.2.1).

Table 1.2.1. Distribution of estuarine wetlands in tropical and subtropical Australia with extreme tide range. Adapted from Table 4. in Bucher and Saenger (1994).

| Extreme tide range (m) | Number of estuaries | Total Area ($km^2$) | Open water / intertidal flats - mean area ($km^2$) | Mangroves - mean area ($km^2$) | Saltmarsh/ clay pan - mean area ($km^2$) |
|---|---|---|---|---|---|
| 0.1 -2.0 | 16 | 211 | 13 | 1.4 | 0.76 |
| 2.1 - 4.0 | 191 | 6472 | 34 | 11 | 7.9 |
| 4.1 - 6.0 | 130 | 9397 | 72 | 15.4 | 39.7 |
| 6.1 - 8.0 | 170 | 11910 | 70 | 14.2 | 28 |
| 8.1 - 10.0 | 27 | 1544 | 57 | 9.9 | 29.6 |
| 10.1 - 12.0 | 29 | 3362 | 116 | 18 | 40.7 |
| 12.1 - 14.0 | 8 | 1470 | 184 | 42 | 36.5 |

*Access to habitats - transport and retention*

There have been few studies of pre-settlement movement of fish and prawns into estuaries and enclosed marine waters (eg. Miskiewicz 1992, Neira and Potter 1992b), but they generally show that tidal currents are very important in the role of transport and retention.

Eastern King Prawns show ontogenetic changes in vertical migration to allow "ratchetting" inshore and upstream into estuaries by flood tides (Rothlisberg *et al.* 1995), and the conservative longitudinal patterns of larval diversity and distribution upstream in Western Australian estuaries have been attributed to weak tidal movement (eg. Neira and Potter 1992a).

Once in nursery habitats juvenile prawns are known to be retained there by weak tidal flushing that causes "lateral trapping" of water in mangrove creeks (Wolanski 1992). The ebb and flood of tides causes exchange of material amongst intertidal and subtidal habitats as well as widespread movement of fauna.

Tides also interact with wind and waves to close and open sandbars at the entrance to many coastal lagoons, and to structure the position and depth of beach gutters and other formations.

*Flushing of pollutants*

Major sources of pollution from urban and industrial sources (eg. Homebush Bay and Hobsons Bay) occur in some enclosed marine waters and estuaries in areas with small tidal ranges. The delivery, deposition, processing and flushing out of sediments, contaminants and nutrients is governed by tidal regime and entrance dimensions. Although tidal currents at the entrances to enclosed waters can be very fast (eg. the entrance to Lake Macquarie) there is often extremely long residence time and severe dampening of tidal range (and hence poor flushing).

Residence time of water in Port Phillip Bay is in the order of one year, and the narrow entrance to Tuggerah Lakes dampens tidal range inside the mouth to the order of several centimetres only with a correspondingly low flushing rate.

*Vulnerability to sea-level rise*

The areas most vulnerable to sea level rise will be those with very low elevations and high tidal ranges, such as the major floodplains in the Northern Territory.

Whilst there is still widespread debate about the rate of past and future sea level rise, the saline intrusion occurring now on the Mary River floodplain shows the great rapidity of habitat change that could result from even small changes to tidal regime (see Chapter 2). In that case tidal energy is increasing -- with each tidal cycle the tidal prism is enlarged, erosion is increased and a larger head of water enters the system to further aggravate erosion and saline intrusion.

The changes to drainage channels with changes in tidal energy are one of the few habitat changes that can be modelled on physical laws to adequately predict human impacts.

Deepening of channels by dredging and coastal modifications of constricted bay and estuary entrances can quickly and profoundly alter the tidal regime inside, and even very small changes in amplitude can have an amplified and expanding effect on intertidal and non-tidal aquatic communities.

*Wind and Waves*

Wind and waves cause the turbulence without which there would be no life in the sea, and the progression of high and low pressure systems across the lower continent causes changes in water movement at variety of temporal scales. These changes are known to be consistent at a variety of temporal scales -- daily sea breezes, seasonal wind shifts, and perhaps long-term cycles in zonal winds.

The wave climate varies greatly around the Australian coast with the temperate and subtropical coasts being dominated by large swells and high wave energy. At least 82% of Austral shelves are dominated by storms (either cyclones or wind swell) (Harris 1996). In the absence of protective reefs (as in south-western Australia) the coastline is mainly long sandy beaches and rocky headlands and the only sheltered habitats are in bays, estuaries and gulfs. Coral reef communities are strongly structured by wave energy (Bradbury and Young 1981).

The sediment grain size and type on the coast is governed partly by wind-driven onshore and longshore transport. Shelf habitats are also influenced to various depths depending

on wave climate. A demarcation at about 30 metres depth between shallow planktivorous molluscs and deeper deposit feeders in the Gippsland region has been attributed to the influence of wave and wind climate (Poore 1982).

There is an important role of wave energy in the movement of materials and contaminants through sediments and porewaters and in the process of denitrification and eutrophication (eg. see Gabrielson and Lukatelich 1985).

The burial of metals has been documented in coring, but resuspension occurs in extreme storm events and continuous flux of buried contaminants across the sediment/water interface occurs through mechanical pumping of pore waters by wave motion and complex physico-chemical means.

*Wind-driven access to habitats - transport and retention*

From the prevalence of correlations between fish movement patterns and seasonal shifts in direction of longshore water flow it would appear that wind-driven surface currents provide both “cues and clues” for migration to spawning areas as well as subsequent transport of pre-settlement stages back to nursery areas.

There are also a wide variety of wind-driven surface features that act to attract or passively aggregate and transport pelagic stages and their prey (see Kingsford 1990 for review). These include the phenomena of Ekman drift and Langmuir cells, as well as wind-rows of drift algae and flotsam that provide food and shelter for pre-settlement stages -- or act to transport them across boundary currents towards shore.

The western rock lobster fishery, for example, relies partly on onshore transport of puerulus across the Leeuwin Current by westerly winds after a very long offshore larval phase (eg. Caputi *et al.* 1995b).

Seasonal wind shifts also determine the cycles of erosion and deposition along beaches that determine the closure of entrances of lagoons and estuaries and the beach formations on exposed coasts. For example, the interplay of high winter tides and strong winds scours a channel at the Murray Mouth and may transport sand offshore. Closure is most likely in summer when winds bring a net onshore and longshore movement of sand.

*Wind-driven upwelling and local productivity*

Despite the poleward flow of our major western boundary currents, there are areas of wind-induced upwelling along the Australian coast and these will become better known with further investigation. Upwelling in the region of rich rock lobster reefs of the South East of SA is caused by a shift in wind strength and direction from the south-westerly quarter during March-November to the south-easterly quarter in November-March. The SE Wind drives a nett offshore movement of surface waters which is compensated by upwelling of deeper colder water, relatively rich in nitrate. This causes summer stratification of the water column there (Lewis 1986).

Another type of upwelling occurs through the GBR matrix with the cross-shelf intrusion of cool nitrate rich waters during summer (Furnas 1996).

Less well-known are wind-driven upwelling "cells" on the western end of Kangaroo Island and the foot of Eyre Peninsula in South Australia which have been found recently in surveys of pilchards (Hoedt *et al* in press). There may be upwelling off Albany and Fremantle also. There is a seasonal fishery for *Sardinella lemuru* off Fremantle and this species is closely associated with upwelling in Indonesia.

*Zonal wind shifts and climate cycles*

Westerly wind field shifts have been associated with a number of oceanographic processes and hypotheses regarding fisheries production (eg. Thresher 1994a, Harris *et al.* 1992). The best known example is for on the fishery for jack mackerel off Tasmania (see Box 1.2.1).

Unpublished studies also indicate a recent, major phase shift in the westerly wind field off the south-west coast of Australia that may have caused changes in flow across the Great Australian Bight (p.c. P. Petrusevics). Such a shift caused profound changes in the South African rock lobster fishery.

A number of hypotheses can be invoked for the mechanisms behind correlations between zonal wind shifts and recruitment to fisheries. For example, offshore winds may force abalone larvae away from coastal nurseries; decreased turbulence influences larval survival through lower encounter rates with prey; changes in water column mixing and productivity enhance gemfish larval survival.

*Cyclones and storm events*

These natural, catastrophic disturbances can alter the wave climate so much that sub-tidal habitats, such as coral reefs, kelp and seagrass beds, can be uprooted over very large areas (eg. Preen *et al.* 1995).

In March 1985 cyclone Sandy swept along the western shore of the Gulf of Carpentaria destroying about 180 $km^2$ or 18-20% of seagrass beds. Comparisons of intact and damaged seagrass beds showed that a large proportion of endeavour (*Metapenaeus endeavouri*) and tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) were replaced by blue-leg king prawns (*P. latisulcatus*). In later years the commercial catches of tiger prawns declined offshore from the damaged areas (see Poiner *et al.* 1993b).

Storm surges of several metres can temporarily alter the tidal prism and inundate freshwater wetlands with saline intrusions, whilst water-column productivity offshore can be enhanced from sediment resuspension during such events (eg. Furnas 1996).

Although studies are lacking, fish larvae are also known to be very vulnerable to wave energy, and the success of recruitment of King George Whiting larvae in Port Phillip Bay is partly explained by wave climate in models (Jenkins and Black 1994).

*Geomorphology*

Understanding the patterns and processes in coastal fisheries production requires an acknowledgment of the different sediment regimes and coastal landforms that comprise the Australian EEZ. Geomorphology is not static -- natural erosion and accretion are occurring quite rapidly in some habitats. Australia's coastal fisheries are conducted in barrier lagoons (eg. sthn NSW lakes), Victorian "sunklands" (eg. Port Phillip Bay), Drowned Valleys (eg. Hawkesbury River) and on a predominantly narrow shelf.

The mainland part of the Australian EEZ is characterised by a relatively narrow continental shelf in the temperate and sub-tropical regions and a wide shallow shelf in the north-west and Timor and Arafura seas.

The rate of natural change in geomorphology varies around the coast. Roy (1984) proposed that estuaries along the east coast resulted from two processes. Valleys were drowned during the last sea-level rise about 6,000 - 7,000 years ago and then aged

through infilling by fluvial sands from erosion in the catchments and through longshore and upstream drift of marine sands from ocean deposits.

For example, the upper Richmond and Clarence rivers of northern NSW are drowned valleys, with the lower floodplains as "infilled barrier estuaries" formed by deposition of fluvial sediments behind barriers of marine sands (West 1993). Large, shallow "cut-off arms" are a feature of some coastal rivers in SE Australia, such as Lake Wooloweyah and the Broadwater on the Clarence River, while large shallow basins are present in major estuaries of south-western Australia, such as Wilson Inlet and the Peel-Harvey estuaries. Both features support productive commercial and recreational fisheries.

The most important implications of this geomorphology are:

- the ease with which seemingly small manipulations of the entrance channels can cause cascading changes to the flushing regime and tidal movement upstream;
- the long residence time of water in the basins
- the shelter from wave energies and dampening of tidal energies.

These make such estuaries habitable for submerged and emergent aquatic vegetation but also very vulnerable to anthropogenic influences (see Chapter 2). There is also a trend for mangrove colonisation and accretion of sediment as infilling occurs. This may explain the recorded increase in spatial extent of mangrove stands in some NSW estuaries, such as the Hunter River.

Sediment type is a major determinant of habitat type and fisheries production. In general terms the finer sediments have higher rates of benthic primary and secondary production with more benthic infauna available as food for fish. The dominance on tropical shelves of fine, terrigenous sediments inshore has produced an "estuarisation of the shelf" that offers alternative nursery habitats outside estuaries in turbid coastal waters that offer shelter and enhanced food supplies.

Previous analysis of large-scale patterns of teleost distribution have shown clear faunistic boundaries at 132°E (Sainsbury 1987, Ramm *et al.* 1990) in the north. Ramm *et al.* (1990) attributed these differences to a suite of factors, including sediment and substratum type, fluvial or oceanic influences, and fishing history. Ramm *et al.* (1990) and Blaber *et al.* (1994b) indicated that future investigations should target sediment and substrata types as influential factors in distribution of demersal fish in the north. The percentage of mud in

sediments of the western Gulf of Carpentaria have been shown to shape prawn abundance at large scales (Somers 1994), and sediment type governs prawn distribution in the Great Barrier Reef Marine Park (Gribble 1997).

*Bedrock structures temperate reef faunas*

There are few discussions of the importance of regional geomorphology in structuring reef faunas (eg. Underwood *et al.* 1991), but the type of rock forming the substrata must have an important role in determining both population densities and interactions amongst fished species. For example, Lewis (1986) considered that a primary determinant of southern rock lobster (*Jasus edwardsii*) abundance in South Australia was the nature of the reefs affording them shelter. The greater abundance of rock lobsters in the south east of SA was attributed to the presence of abundant crevices ("dens") in the bryozoal limestone overlain by calcarenite -- in contrast to the smaller populations in the granitic rocks of the West Coast.

*ENSO Events and climate cycles*

It is already clear that ENSO events have major effects on the strength and southward penetration of our major currents, with both the EAC and the Leeuwin Currents being stronger during La Nina years.

With the advent of the debate concerning global climate change there has been renewed focus on the relationships between climate and fisheries (eg. Walker *et al.* 1989). The association between ENSO events and flow patterns of Leeuwin and Eastern Australian Current have been documented only in the past decade, and even more recent is the hypothesis that zonal wind shifts and climate cycles may be determining production of some Australian fisheries at large scales (Thresher 1994a, and see 1.2.1 below). In this regard Australia has lagged behind northern hemisphere research, partly because of the lack of reliable catch and effort data in long time series, but also because of the rarity of long-term research programs at appropriate scales.

*Variability in rainfall - drought and flood*

The role of environmental flows of freshwater in estuarine processes is examined closely in Chapter 2. In general terms the major features of Australian rainfall are :

- its variability - causes a need for Australia to impound for storage more than 12 times as much water per capita than the US and Europe;

- the importance of "events" - floods, droughts and fire - that often closely follow one another ;
- its restricted distribution that enforces overlap of fishing and agricultural uses of floodplains - the SOER concluded that there was a positive, linear correlation between land degradation and rainfall.

Construction of sediment and nutrient budgets for tropical catchments has determined an overriding influence of episodic floods in delivering the bulk of terrigenous inputs to coastal zones (Furnas *et al*. 1997, Mitchell and Furnas 1997).

Fundamental links between fisheries and variability in river flow has been acknowledged in development of the "flood-pulse" concept (Junk *et al.* 1989) in freshwater, but wider influence includes formation of coastal boundary layer and estuarine plumes, and access of anadromous fish to habitats.

*Heat and light*

Sea-surface and air temperatures are also fundamental to physical, chemical and metabolic processes. As such, they shape the pathways and rates of energy flow and the degradation of pollutants. Associated with regular seasonal changes in temperature are changes in primary and secondary production, and habitual ontogenetic, foraging and spawning migrations of many fished species.

Superimposed on these regular variations are infrequent extremes of temperature in heating or cooling events. These can cause significant disturbances to habitats under certain combinations of tide and water flow, and have been implicated in widespread seagrass dieback (p.c.#1530 S. Seddon) and coral bleaching -- particularly during low tides and at the edges of species' ranges and thermal tolerances.

Evaporation at the heads of enclosed gulfs (eg. Spencer Gulf) or semi-enclosed seas (Great Australian Bight) in arid areas comprising most of south-western and western Australia form "inverse estuaries" with associated haloclinic currents that are major forcing functions.

### 1.2.1 Effects of the environment on fisheries

*Summary*

The are major effects of the environment on fisheries at all scales from:

- local fish kills due to anoxia in coastal wetlands and estuaries (eg. Longmore *et al.* 1990);
- natural epidemics of disease (eg. pilchards, see chapter 5; ciguatera poisoning - see Bagnis1994) and "natural pests" (eg. corallivorous starfish and snails ; Ayling 1996);
- inter-annual changes in recruitment and spawning due to rainfall and other environmental factors (eg. Francis *et al*. 1997);
- episodic loss of habitat due to extraordinary natural disturbances (eg. cyclones destroy nurseries in seagrass);
- inter-decadal "regime shifts" and changes to recruitment in entire ocean basins.

The changes at larger scales are sometimes notoriously difficult to separate from effects of fishing on the environment (see chapter 4 and Drinkwater and Myers 1987). For the "gadoid outburst" in the North Sea, prevailing explanations concern both the cycling of the Greenland High Pressure system and an effect of trawling -- similar species shifts between anchovies and sardines overseas are difficult to explain given that they are both heavily fished.

Following international debates over the roles of environment and fishing (eg. the Thompson-Burkenroad debate over dwindling halibut stocks) some authors have questioned the worth of intensively pursuing the environmental correlates with recruitment, in a fisheries management sense, given that;

- there is rarely a single factor producing the correlations and there is often autocorrelation in some environmental data (eg. sea temperature)
- the mechanisms are rarely explained by such correlations
- only hindcasting is possible - we cannot precisely predict the suite of environmental factors at scales useful to management
- R&D funds may be better spent on pre-season recruitment surveys or other fishery independent surveys with better forecasting power

However, we conclude that there is a basic need to develop a better understanding of the dynamics of recruitment and their environmental correlates to understand the potential variability in our fisheries.

For example, knowledge of the role of the Leeuwin Current has been a cornerstone in understanding variability in at least five of Western Australia's most important fisheries (eg. see Lenanton *et al.* 1991, Caputi *et al.* 1996) :

- western rock lobster - interannual variation in puerulus recruitment is correlated with an ENSO-related atmospheric pressure signal, and with sea-level off Fremantle explaining recruitment; positive relationship between westerly winds and Leeuwin current strength are involved;
- Australian "salmon" and "herring" --- a 50 yr dataset for salmon shows 4-fold variation in catch that peaks approximately every 14 years; juvenile recruitment is negatively related to El Nino - westerly wind strength may govern eastward transport to nurseries;
- Shark Bay scallops;
- pilchards and "whitebait" - strong eastward advection of pilchard eggs in La Nina years for pilchards.

In contrast, the role of the East Australian Current (EAC) has been seriously neglected in R&D on coastal species on the east coast of Australia. The northern spawning migrations to the Fraser Island area and southern larval dispersal of species such as Eastern King Prawns, Tailor and Sea Mullet are well known, and all species (with the exception of mulloway and bass) tagged in southern and northern NSW estuaries are recaptured after movement to the north (West 1993) - as far as Moreton Bay or other Queensland waters -- yet we could find no consideration of the EAC in influencing their populations.

It is now known that ENSO events have major effects on the strength and southward penetration of our major currents, with both the EAC and the Leeuwin Current being stronger during La Nina years. This intelligence has been used to forecast catches of western rock lobster (see Box 1.4.7.1) and also to detect the role of climate cycles in fisheries.

Zonal Westerly Winds (ZWW) are now known to have profound influence on primary and secondary production in the south-east region, and there is growing evidence of their importance elsewhere:

- in transport of fish larvae across the Great Australian Bight (Petrusevics FRDC# 93/050);

- governing recruitment of eastern rock lobsters, east coast abalone and gemfish (Thresher 1994a);
- enhancing influx of King George whiting larvae into Port Bay Phillip Bay (Jenkins *et al.* 1993c);
- causing shifts of baitfish prey concentrations away from the coast that result in penguin starvation and fishery failure (p.c. #1570 F. Hoedt).

There is general agreement that 20 year datasets on recruitment and environment are marginally short to detect relationships of the sort that we have discussed here. The Australian R&D in this area falls roughly into 4 categories:

- fishery independent recruitment surveys - eg rock lobster puerulus collection; arripids in SA (>14 yrs data) and WA; snapper and estuarine species in NSW (FRDC#94/042);
- use of CPUE figures and length frequency - eg gemfish;
- hindcasting of recruitment from validated age structures - eg black bream in the Gippsland Lakes, coral trout on the GBR;
- a mixture of two or more of these approaches - eg banana prawns in the Gulf of Carpentaria, barramundi in the NT.

The effect of rainfall on banana prawn recruitment is one of the earliest examples of use of environmental data in fisheries production models (eg. Staples *et al.* 1995) and this approach has been extended to barramundi models in the NT and Queensland. However, the relationship varies considerably amongst catchments, there are rainfall thresholds above which the relationship is reversed and there is a need to refine knowledge of the mechanisms behind the response in recruitment. For example, Hinchinbrook channel contains the largest areas of mangroves on the east coast and receives high rainfall, yet the adjacent banana prawn fishery in Rockingham Bay is small.

A growing body of literature documents the relationship between freshwater flow and estuarine fisheries production elsewhere (eg. mulloway and black bream at the Murray Mouth, school prawns in the Clarence). The roles of "environmental flows" of freshwater in lower catchments are discussed in detail in section 1.4.5.1 and chapter 2, and are now being recognised by the LWRRDC in new initiatives (p.c. S.Bunn).

We anticipate that there will be a growing demand for R&D in these areas as long-term collection of catch data reaches a critical mass of information in all States, and more

fishery-independent surveys are initiated. For example, 50 yr datasets on CPUE are now assembled for NSW (Pease and Grinberg 1995), the first 8 years of the Queensland logbook program have been summarised (Williams 1997) and the South Australian "GARFIS" database has entered its 14th year.

For other species the datasets are shorter (eg. the "salmon" and "herring" in SA; 14 yrs at the time of writing) and are dominated by the leverage of one or more outliers of strong recruitment. Long-term, spatially replicated recruitment surveys throughout the range of nursery habitats (good and bad) are needed to detect outstanding recruitment events (eg. NSW snapper FRDC#93/074). It is also desirable that a suite of environmental variables are studied in concert with the recruitment indices (FRDC#93/050).

*Surface currents are of profound importance*

The autumn currents around the mainland portion of the Australian EEZ are shown in Figure 1.2.1 constructed by G. Cresswell of CSIRO. Of major note for fisheries production, larval advection, and biogeographic barriers, are the East Australian Current and its associated eddies, the Flinders and Zeehan Currents, the Sub-Tropical Convergence and the Leeuwin and Capes Currents.

There is a growing body of evidence indicating that the life-histories and fisheries production of major finfish, crustaceans and molluscs are driven by these currents. There has been informative analysis of the role of the Leeuwin Current in WA fisheries production, yet the relationships between the EAC and the aquatic flora, fauna and fisheries of the mainland east coast have been neglected. Some of these associations and their implications are discussed in later chapters.

Despite their importance, circulation patterns are largely unknown for the large areas of the Arafura and Timor Seas and the North West Shelf. A major project under way now will integrate historical ship-borne and remote sensing data to help model and map the local and basin-scale circulation of the EEZ ("Oceans EEZ" Craig 1995).

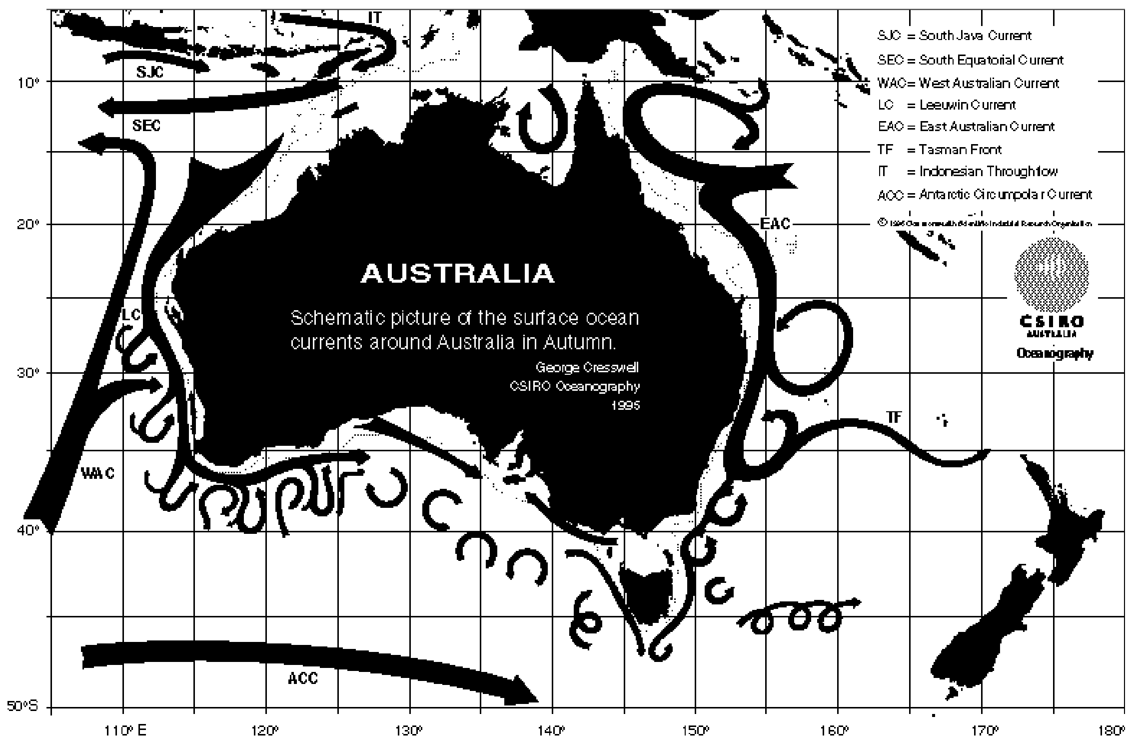


Figure 1.2.1. Schematic diagram of the surface currents of Australia

*Low ocean productivity*

Most of the oceans around Australia are sub-tropical and nutrient poor, with low biomass, limited by Nitrogen (Walker *et al.* 1989). South of Australia the sub-tropical convergence provides higher productivity. Local areas of high water column productivity are associated with physical mechanisms (eg. wind-forced upwelling; the interaction of currents; mesoscale eddies; shelf waves interacting with topography) which bring nitrate into near-surface waters.

In the Indian Ocean, there is an anomaly, in that there is no equator-ward eastern boundary current. Instead there is a poleward flow of warm oligotrophic water along the WA coast (the Leeuwin Current).

As a result, the rich upwellings and highly productive fisheries observed along the west coasts of other continents are lacking (eg. the Benguela Current off western Africa and the Humboldt Current off Peru).

*Bays and estuaries more productive*

These factors have fostered development of coastal fisheries in close association with all the major bays, inlets and estuaries where vegetated habitats and riverine flows provide enhanced primary productivity. Even in these areas phytoplankton production is relatively low, with 111 g C $m^{-2}$ $yr^{-1}$ in Port Phillip Bay and 235-435 g C $m^{-2}$ $yr^{-1}$ in the Humboldt and Benguela areas (Gwyther 1990). The fisheries production from our coastal estuaries and lagoons can be very high relative to the shelf waters - up to 3300 kg $m^{-2}$ $yr^{-1}$ (Pollard 1994a).

The contribution of saltmarsh, mangrove, benthic microalgae, seagrass and brackish-water vegetation to production in these coastal waters is well recognised but poorly documented (see below), and there are no regional comparisons of sources and status of primary production in our major bays and estuaries.

*The East Australian Current*

The EAC will probably prove to be of fundamental importance in the spawning, dispersion and recruitment of many NSW coastal fish and crustacean species (eg. Miskiewicz 1987), yet there have been few studies of this role. There has been study of the phytoplankton communities and mesopelagic fish and crustacean communities of the EAC itself (eg. Griffiths and Wadley 1986, Jeffrey and Hallegraeff 1987), a major research emphasis in the Tasmanian shelf region (eg. Young *et al.* 1996), but no studies of its relationships with Qld, NSW and Victorian coastal fisheries of the mainland.

*Subtropical Convergence and the South East region -*
*Australia's most important shelf fisheries*

Between Wollongong and the south-eastern tip of Tasmania are located our most productive demersal and pelagic shelf fisheries for a wide variety of demersal and pelagic species. Research underway now aims to comprehensively describe the trophodynamic and hydrodynamic processes supporting these fisheries (eg. Koslow 1997, FRDC#94/040).

Off eastern Tasmania, warm, nutrient-poor EAC water (>16°C) meets cooler nutrient-rich subantarctic water <14 °C (SAW) creating the subtropical convergence (STC) >14°C to <16°C. The latitudinal position of this varies both seasonally and between years, as the EAC extends southward in summer and retreats again in winter. Overlying the seasonal signal are interannual fluctuations relating to the influence of both ENSO and the strength of the prevailing westerly winds (Young *et al.* 1996).

Located south of Australia, the subtropical convergence is a large-scale oceanic front dividing subtropical waters from the nutrient-rich, sub-Antarctic water mass. There are spring and autumn blooms in phytoplankton in the southeast, due to a weak temperate seasonal cycle. This is induced by seasonal variations in frontal location, winter mixing, and mesoscale frontal excursions. The fisheries implications are illustrated in Box 1.2.1.

**BOX 1.2.1 ZONAL WINDS AND JACK MACKEREL CATCHES**

A 40-day oscillation in the ZWW, driven by latitudinal changes in the position of the subtropical high pressure cells over south-eastern Australia, interacts with ocean circulation and water column stability to alter primary and secondary production. This complex phenomenon causes vast changes in the vulnerability of jack mackerel to purse-seining, and to the spawning behaviour of this species in the following manner.

- nitrate concentrations are strongly correlated with temperature in these waters. High ZWW stress causes advection of colder, nutrient-rich subantarctic water up the eastern side of Tasmania and reduces water column stability
- the result is periodic overturn of the water column and increased new production.
- spring blooms tend to be later, but stronger, as a result of periodic mixing and restratification.
- reduced ZWW stress (under the influence of high pressure) leads to incursions of subtropical water, increased water column stability and reduced biological production.
- in calm years spring blooms tend to be earlier, but weaker, because of the reduced nitrate availability
- changes in the strength of the 40-day oscillation cause changes in the dominant zooplankton populations: from salps in windy periods, through a mixture of krill and salps in normal years, to copepods in calm periods
- reduced nutrient availability in warm years leads to reduced new production and a drastic reduction in the biomass of larger zooplankton, especially krill
- in summer, jack mackerel feed on krill in coastal waters. If krill are rare and do not swarm in sufficient numbers, the jack mackerel do not school in commercial quantities and the fishery fails.

These events have occurred at about 10-year intervals during anti-ENSO events. This is a very clear example of climate-induced, “bottom up” control of the distribution of a commercial fish stock (Harris *et al*. 1991,1992).

*The Western Australian coast and Great Australian Bight - a linkage of flows*

Overlap in the beginnings and ends of the Leeuwin and Zeehan Currents and seasonal wind-driven surface flow provide a vehicle for transport of larval and post-larval stages eastward and southward -- across the entire southern coast from Albany spawning areas to western Victoria in the case of Australian “salmon” and “herring” (*Arripis* spp).

*The Leeuwin and Capes Currents*

At least three sets of surface currents move up or down the southern half of Western Australia’s coast at various times of the year (Anon., 1981). Meanders and eddies of the northward flowing West Australian current flow southward from latitude 30° S and wind-driven southward and northward currents occur in summer and winter respectively under the influence of prevailing winds.

The Leeuwin Current is warm (2°C above local waters), low salinity water of tropical origin. During autumn and winter it flows around the south-west corner at Cape Leeuwin and into the Great Australian Bight (GAB). Between April and July it forms a water mass some 20 km wide that may flow at nearly 4 km $h^{-1}$ (2 knots). The strict signature of the water mass truncates off Esperance, but there is a continuation of flow eastward across the GAB and into Bass Strait and down the west coast of Tasmania (the Zeehan Current). This flow eastward is partly due to a density gradient caused by evaporation at the Head of the Bight and westerly wind fields (p.c. G. Cresswell, P.Petrusevics FRDC#93/050).

In late spring and early summer as the northward winds strengthen, the Leeuwin Current tends to weaken and moves a little offshore in the area between Cape Leeuwin and Cape Naturaliste, to be replaced by a cooler northward flow along the coast. This has been defined as the "*Capes Current*".

It is quite narrow, about 20km or so, and flows from approximately October to March. It produces an annual temperature range of only 3 degrees in this area, whereas off Perth there is an annual range of about 7 degrees (Pearce *et al.* 1996).

It is possible that the Capes Current might bring some upwelled water from the Albany area (G. Cresswell pers. comm.), but its most obvious effect is to produce strong cross-shelf change from temperate to sub-tropical fisheries habitats in the vicinity of Perth (see 1.2.3).

*Zeehan Current*

Zeehan Current flows off and along the shelf, but there is also another one on the shelf. In winter the Zeehan is recognisable flowing northward about halfway up the East Coast of Tasmania, but it is then pushed south by the EAC.

*The Flinders Current*

The seasonal migration from north to south of the subtropical high pressure zone results in nett surface water flow from east to west during summer (the Flinders Current) and from west to east for the remainder of the year. This westward flow occurs at the same time as westerly movements within several important fisheries such as southern rock lobster, but there has been no study of its role in assisting such migration.

### 1.2.2 The nature of disturbance

Despite the obvious loss of many habitats the R&D to date can make only highly uncertain predictions about the effects on fisheries of change or partial loss of habitat. This is partly because there are two main types of disturbance to benthic communities (and aquatic vegetation) with much different outcomes and recovery paths. These were summarised by Dayton *et al.* (1995) as:

- Type 1 disturbance- death of some residents leaving a patch at least in part bounded by survivors. Recovery will often be from the margins, emphasising the local community. Succession by vegetative growth, asexual budding, settlement from fast-growing opportunistic species which will often disappear, short-lived larvae/propagules from adjacent areas, long-lived larvae/propagules from distant slow-growing species and immigration of motile adults.
- Type 2 disturbance - larger scale disturbance resulting in patches isolated from existing assemblages. Recovery will be much slower and will emphasise opportunistic fast-growing species, long-lived larvae/propagules from distant slow growing species, asexual reproduction and immigration. Sediment encroachment is relatively common and long-lasting.

Notable examples where fisheries impacts are difficult to discern because of an “intermediate” level of disturbance include seagrass dieback (see Chapter 2), coral reef destruction by cyclones and small-scale clearing of mangroves.

### 1.2.3 Fisheries ecosystem management, bioregionalisations and the National Representative System of Marine Protected Areas

The emergence of spatially-based management of coastal resources using “marine harvest refugia” (Dugan and Davis 1993, Pollard 1993b) and “marine protected areas” is both a popular and proven response to various demands for integrated planning and conservation (see Sherman 1991, 1994). The single biggest marine and coastal initiative of this decade has been the “Ocean Rescue 2000” program focussed around development of a National System of Marine Protected Areas (NRSMPA) by the year 2000.

Tests of the utility of marine harvest refugia in conserving and sustaining fish stocks are rare in Australia (but see Ayling *et al.* 1992 and section 4.9) and best demonstrated overseas for rocky or coral reef habitats (eg. see Ault *et al.* 1997, Ballantine 1997, Russ

and Alcala 1994, 1996a,b). With appropriate R&D there are opportunities to develop a national system of marine harvest refugia within, or complementing, the NRSMPA. Fisheries stakeholders - particularly those in the rock lobster and abalone fisheries operating in southern “nests of endemicity” (Edyvane 1995b, 1996b)-may be affected by the declaration of the NRSMPA, which is primarily aimed at conservation of biodiversity. There is consequently an early need for the FRDC to identify investment opportunities to maximise the benefit - and help minimise the threat to fisheries -- of the NRSMPA in sustaining fisheries production.

In specific fisheries terms, marine harvest refugia would, ideally, protect “sources” of recruitment, not just “sinks”, and be designed at such a scale and spread of locations that :

- export of juveniles or adults would supplement production in surrounding, fished, areas
- genetic diversity and integrity of unfished age and size structures would be conserved and maintained.

Specific Australian studies are lacking in this regard (but see McNeill and Fairweather 1993) although much marine research has relevance (eg. Jones 1997) - especially the “effects of fishing” experiments outlined in section 4.9.

However, the philosophy behind the NRSMPA is much more complex than simple stock conservation, and reflects more the public good, the conservation of biodiversity, and the general principle that extractive activities may have some effects on ecosystems. The principles adopted in selecting the NRSMPA may include:

- *representation* - each biogeographic region must be represented
- *replication* - multiple areas of each biogeographic region must be protected
- *sustainability* - single reserves are unlikely to be self-sustaining, given the wide larval dispersal and “connectivity” in marine ecosystems, so networks of areas are desirable.

Ballantine (1997) reviews and broadens these principles with particular reference to their role in ecosystem management and as a complementary measure to traditional, data-based, stock-specific fisheries management. These “no take” areas are seen as insurance - an approach which assumes uncertainty, ignores detailed causation and concentrates on preventing damage without specific prediction. This review was based on two decades of experience with marine reserves in New Zealand, and the author reported growing public support but scepticism amongst fisheries scientists and managers.

In Australia, Fisheries Ecosystem Management (FEM) is a framework for incorporating the principles and policies of ecologically sustainable development into fisheries management. There has been slow progress since the proposal of an FEM process in 1992 (see Chesson *et al.* 1995 and Staples 1997 for review). Originally it was proposed to report and assess FEM at existing jurisdictional units in fishery management. Most recently the process had modified a proforma to collect information at a more holistic, ecosystem level, and six provisional Large Marine Ecosystems (LMEs) were defined by a Delphic approach. These were broadly similar to the CONCOM biogeographical regions if the small coastal regions were amalgamated with large adjacent oceanic zones (Chesson *et al.* 1995). These 6 LMEs were provisional for the purposes of developing a proforma for FEM reporting, but their credibility must be low now, in view of the poor reception of the CONCOM precedent and the rapid development of IMCRA (see below).

Ultimately the LMEs must be based on IMCRA and the lack of any regionalisation or more holistic treatment of Australia's fisheries seriously hampers strategic interpretation of patterns and processes in fisheries production and threats to production.

Comprehensive overviews of the Australian EEZ are lacking, and the current OR2000 bioregionalisation process (IMCRA and CTC) will provide a foundation to enable:

- an understanding of the relationship between the physical and palaeohistorical factors that determine the type and productivity of benthic and vegetated habitats supporting fisheries,
- a powerful means of monitoring natural dynamics
- an assessment of the regional threats and opportunities for fisheries habitats and R&D.

Previous attempts at biogeographical regionalisations were useful for some biogeographic, taxonomic and evolutionary studies, but were not pitched at the right scale, detail or information content for management of marine resources and environments. There was a severe lack of information on the characteristics and boundaries of regions, and the lack of metadata and documentation behind the CONCOM/IUCN regionalisation made it untrustworthy.

A key feature of the philosophy of fisheries ecosystem management concerns monitoring change and assessing and identifying anthropogenic disturbances. There has been recent focus on developing appropriate environmental indicators for biodiversity and ecosystem

"health" (see Anon 1996a, Anon. Unpublished, Bengston 1985, Deegan *et al*. 1997), and for "sustainability" of fisheries (see Staples 1997).

*What is IMCRA?*

The philosophy behind IMCRA lies in the existence of a hierarchy of coastal systems. This breaks downward from the bioregions (zoogeographic provinces) to ecosystems-communities and habitats (biocoenoses and biotopes), to the species level and ultimately metapopulation or genetic levels. In order to safeguard fished populations, there must be a good knowledge of all the levels above, but the logical starting point is the bioregionalisation, to enable a start on reducing problems to compartments. The implications of different human activities will be different in different bioregions, and these differences are magnified downward through the classification to habitats and populations.

The IMCRA aims to characterise the spatial organisation of natural systems (both processes and patterns) as a fundamental building block for further zonations, for Marine and Estuarine Protected Areas (MEPAs) and for decision-support systems (see Box 1.2.3). The projects are moving towards a concept of a series of layers for bioregionalisation, so that the various products can be tailored to the client needs.

The primary clients are DEST and OR2000 and their needs are capability to:

- identify gaps in current system of Marine and Estuarine Protected Areas
- identify representative ecosystem areas, so as to spot sites of key conservation significance (this includes assessment of threats);
- select potential reserve areas;
- assess feasibility of these potential reserve areas and negotiate declaration of those areas with fishermen and other stakeholders;
- establish and manage a National Representative System of Marine Protected Areas.

The Commonwealth Trust Consortium are working on IMCRA mostly at "Province" level, and the State IMCRA teams at sub-provincial level -- non-coincident boundaries will arise and be accounted for in integration of the two. There are two main approaches:

- a "bottom-up" numerically-derived regionalisation using physical and biological data whereby rules and data blend in the model to provide a regionalisation ;
- a "top-down" Biological Attributes Method is also employed whereby perceived patterns are mapped and aggregated under a philosophy that they are produced by fundamental processes -- this one is typically referred to as a "Delphic Approach".

Ultimately there will be a blend of these approaches, as both generate useful hypotheses.

There are two important contexts that shape faunal distributions

- biological controls, or the "Hutchinsonian leash" - eg. Salinity and Temperature tolerances, the position of the permanent thermocline, surface and sub-surface currents, shore sediment facies zone below which only storm waves influence; and
- evolutionary history - palaeogeography determines the chance of an organism occurring at a particular location.

Historical events drive the province level regionalisation and produce "centres of endemism", then these are maintained by physical barriers, currents and other forcing boundaries. Fore example, because the WA shelf is wider than that of the east coast the influence of the Leeuwin Current causes a much wider zone of overlap of tropical and temperate species. There is a "wedging effect" with a cross-shelf change in the ratio of tropical : temperate species and a longshore change too in the vicinity of Perth.

Component 3 of the CTC regionalisation focuses on fish because there is a national coverage of datasets and readily available information, they are surrogates for ecosystems, and there is a need for an ecological basis for regionalisation. It covers the estuarine, coastal, shelf and shelf-pelagic fish fauna at Province Level, with a recognition that marine conservation should be addressed at the biocoenoses level.

The approach was to hold "BIOTAX'96" -- a workshop of the top 10 Australian fish taxonomists and museum staff. They evaluated 1000 species and then focussed on 600 high priority species using strictly defined criteria for ranking and grouping "reliability" under the RAP (Rapid Assessment Phylogenetic approach). This included "Group richness" and "Range Scales", for example ranked highly useful were:

- "High Richness Groups" (>= 10 spp) with very narrow ranges (eg. *Urolophus* and *Heteroclinus*);
- "Low/Medium Richness" (<=9 spp) almost all very restricted in range (eg. *Sillago, Ammotretis*).

Major findings were:

- diversity is highest in the tropics, but endemicity is highest in the temperate zones, and there is much more sub-provincial structure for the endemic species;

- there are some huge ecotones on either side of the continent, with very strong boundary zones at Cape York, Fraser Island and on the SW Western Australian coast. Narrower boundary zones exist in central NSW, Western Victoria, the SE of SA, the Esperance area, Shark Bay and the Pilbara;
- there is a notable proximity of boundary zootones with the ends and starts of currents -- eg. the saline and hot water in the Head of the Bight near the Esperance zootone;
- the estuarine species had very similar boundaries to the coastal ones, but with much flatter diversity.

A spin-off from analyses have been advance in innovation in interpolation. For example, temperature depends on depth and latitude (mainly), and sediments are largely a function of waves, slope, tides, bottom depth in a multi-dimensional space. Dr Vince Lyne has plotted all these different data in multi-dimensional parameter space to assess gaps in coverage. This method has the great advantage of identifying in parameter space where the knowledge gaps are -- for example at 100-120 m at 20 degrees South. These *knowledge gaps* do not necessarily correspond directly with the spatial nature of *sampling gaps*.

Obtaining a good understanding of boundaries of the zootones will be an essential monitoring tool for climate change and other long-term cycling in the environment. For example, in the last 5 yrs there has been a major shift southward in the warm temperate reef fish *Parma microlepis* and *Chromis hypselepis*, associated with the appearance in the south of the "urchin barrens" habitat (see chapter 4). A major concern for biodiversity conservation is that many temperate species will have no southward opportunity for retreat in the face of ocean warming. The unexplained disappearance of *Macrocystis* kelps in Tasmania may be the result of a major shift in coastal conditions (Rees 1996).

The position of a fishery within a species range will also have a profound influence on recruitment and variability in production. For example, in SA there are striking changes in the distribution of mangroves, seagrasses, macroalgal communities and fish communities from the east to the west of the State. Mangroves, blue crabs (*Portunus pelagicus*), razor fish (*Pinna bicolor*), and trumpeters (*Pelates*) occur in Streaky Bay and Ceduna -- yet none occur in nearby Venus or Bairds Bays at almost equivalent latitudes (p.c. #710 A. Caton). Several major species in both Gulfs in SA are also relicts of a Tethyan sub-tropical fauna. Associated with these features are major fluctuations in recruitment of fished species - eg the Streaky Bay blue crab fishery fails intermittently, and yellowfin whiting (*Sillago schomburgkii*) and snapper have extremely erratic recruitment (p.c.#1560 K.Jones).

Greenlip abalone have declined overall in Victoria, but they are on the western edge of their distribution there, and therefore effects of fishing cannot be distinguished.

**BOX 1.2.3. IMCRA AND MANAGEMENT OF COASTAL HABITATS - THE WA APPROACH**

The fundamental priority and approach for the EPA in WA is protection of primary producers, but with a recognition that there is a natural capacity for assimilation of pollutants. The key issue is to protect seagrass meadows and benthic algae, then separate out their different forms on the basis of vulnerability and recovery potential. When assessing threats there is a need to focus on the habitat *attributes* and the *pathways* of assimilation and energy flow (eg. eutrophication causes shading by water column phytoplankton and epiphytes).

WA' s Strategic Objectives are to :

- implement a State system of marine reserves
- adhere to the principles of ESD

Detailed objectives are **derived** from the WA State Conservation Strategy

- to maintain biodiversity
- to maintain ecosystem integrity
- to maintain ESD of renewable and non-renewable resources
- They are being **achieved** through **regulation** and **reservation**. Once in place the options for management and generic information requirements are determined:
- comprehensive description of environment
- natural variability
- status and trends
- establish linkages (including with human activities)
- implement management and good monitoring
- implement remedial management strategies

These are not immediately available for the whole State, so a **Simple Risk Assessment** for 10 or so regions all around WA is conducted:

- What are the **values** (intrinsic, cultural, uses)
- What are the **current** and **future threats** (people, waste)
- What is the **vulnerability** and potential for irreversible impacts?

Overall requirements are:

1) a **philosophical basis** to the management processes
   - whereby ecological values have higher preference than “cultural and usage” values
   - in which ecological requirements and values are non-negotiable vs economic considerations
2) Management Units should be based on **Ecological Boundaries**
3) There is the problem of Creep, whereby technocrats are continually being asked to redefine targets (eg. P, N going into Albany harbours) when the question really should be “**what are the levels of acceptable change**”?
4) **biomonitors** should be used to define change (Nitrogen is the limiting factor)
   In the case of N, use of standards in water quality (N levels) data are questionable, because WA can allow increase in nutrient concentrations in water, but cannot allow increases in phytoplankton, epiphytes and consequent light attenuation that causes seagrass dieback. Therefore we have to try and compress the time scale between cause and effect, then monitor key indicators of pathway between N and seagrass loss
5) We must **Define Environmental Quality Objectives** so that biomonitoring responses can be assessed and compliance tested. Research must be targeted to outline the pathways and links between the environmental quality objectives and the loadings of Nitrogen.

(p.c.#1400 C.Simpson)

Although seagrass and mangroves are protected under Fisheries Acts in some States other government departments govern threatening structures or processes. For example, in NSW, CALM and NPWS often have responsibility for fisheries habitat, not the Dept of Fisheries. Therefore a major weakness is that MEPAs are declared by those agencies but not monitored due to lack of intent, funds or expertise, and therefore there is no "adaptive management" to tailor their size to natural dynamics or interaction with fisheries. Monitoring costs are high -- a repeat of the 1991 grey nurse baseline survey at Seal Rocks would cost about $1000 per shark sighted (p.c. #1330 A. Smith, D. Pollard).

The regions identified by IMCRA Version 2.0 (Thackway and Cresswell 1996) are described in Table 1.2.3.1 and examples of their attributes are given for 3 bioregions in Table 1.2.3.2. Notable features of the attributes and classification are:

- the absence of information on fisheries - eg. no mention is made of the significance of rock lobster catch in the Abrolhos (Table 1.2.3.2), yet wildlife values appear
- the inconsistency in use of physical and biological information as attributes amongst States
- the great depth and scope of information on marine habitats incorporated in the process
- the southern "nests of endemicity" in abalone and rock lobster fishing areas.